CHAPTER 3

Principles for Maintaining and Restoring Natural Diversity

Introduction

An effective naturalization plan is based on the application of principles for maintaining natural diversity in a managed landscape. Diversity, as used here, is not the diversity of a zoo, but is diversity as seen in natural communities and ecosystems. The aim is not to plant as many different kinds of trees as possible on a particular site, but to restore a natural community on a site with as full a complement of native species as possible. Restoration of a natural plant community provides a variety of habitats valuable to a variety of animals. These principles are not prescriptive; they are designed to help people think about the use of a particular parcel of land. Application of the principles will enable managers of golf courses, parks, recreation areas, farms, schools, and other parcels of land to increase the diversity of plants and animals on their land. If applied widely within a region, these principles can result in a new landscape mosaic that increases overall naturalness and regional diversity of native plant and animal species. Restoring many small areas to natural communities contributes to increased individual, population, and community diversity.

Thorne (1993) offers that “the fundamental goal of ecological design should be to maintain ecological integrity, also referred to as ecological health. Ecological integrity is characterized by (1) natural levels of plant (primary) productivity, (2) a high level of native biological diversity, (3) natural (usually very low) rates of soil erosion and nutrient loss, and (4) clean water and healthy aquatic communities.”

Maintaining and restoring natural diversity to our increasingly fragmented landscape is our challenge. Thorne (1993) states “the landscape is a particularly useful unit for understanding broad-scale issues of ecological integrity. Landscapes typically include a mixture of both human and natural features and contain numerous interacting ecosystems, such as forests, fields, waterways, and human settlements. By understanding the nature of interactions across landscapes, it is possible to address systemic ecological issues over the long term.” A number of studies address this issue. For example, as forests in the northeastern United States were converted to farmland in the late 1800s and early 1900s, the number of species of migratory songbirds using these areas declined. But, as small forest patches were reestablished in the latter half of this century, the number of bird species increased. A study of small urban and suburban forest preserves of less than 247 acres suggests that populations of many species may not be self-sustaining in a small preserve, but are instead an important part of a larger, regional population (Askins and Philbrick 1987). The study illustrates that diversity can increase in an area even when the creation of a large preserve is not possible. When created, small preserves can play an important role in restoring our natural heritage without diminishing the intended human use of the land. To preserve the regional diversity of native plants and animals, it is important to restore many small sites.

Small areas will not satisfy all the needs of all species that occur within a region. Robinson et al. (1995) pointed out that many neotropical migrants are declining. Declines are attributed to the loss of breeding, wintering, and migration stopover habitats. Forest fragmentation appears to be a major cause. Nesting success is reduced below replace-
ment levels in some fragmented landscapes. Brood parasitism by brown-headed cowbirds increased with fragmentation in nine midwestern study areas. In landscapes with less than 55 percent forest cover, most wood thrush nests were parasitized. In heavily forested landscapes, nest parasitism by cowbirds was not significant. Robinson et al. (1995) suggest that “conservation strategies should consider preservation and restoration of large, unfragmented ‘core’ areas in each region.”

By analyzing specific characteristics of an individual area and consulting the lists of native plants for that ecological community, the landscaper can determine the types of plants that will best survive and prosper at a specific site. In restoring native plant communities, the landscaper provides an opportunity for the animal species associated with those communities to find suitable shelter, food, and areas for raising young. Although only a few species may be present on any given restored site, the total of all restored sites will preserve a large number of species and create diversity within a region.

This chapter provides principles, guidelines, and design suggestions for increasing and maintaining a diversity of plants and animals on parcels of managed land. Each parcel, whether a golf course, school, yard, farm, park, or unused corporate land, can play an important role in maintaining regional diversity. The principles and designs suggested in this chapter can be used to increase species diversity, increase the populations of particular species, and assist in restoration of specific ecosystems. These principles can be applied during the establishment of a new managed area or on an area currently in use.

What Is Diversity?

Biological diversity, or biodiversity, refers to the variety of life in all its forms and levels of organization (Hunter 1990). Deliberations on biological diversity include discussions of genetic diversity of individuals within a species, diversity of populations, diversity of communities, and diversity of ecosystems and regional vegetation types called biomes. This chapter discusses four levels of biological organization: individuals, populations, communities, and ecosystems.

Scientists identify all individual plants or animals by a two-part scientific name. The first word is the genus to which the species belongs and the second word is the specific epithet, or species name. Each species is adapted to survive in a certain range of conditions. All individuals of a species differ slightly from one another in their abilities to adjust and respond to a particular range of environmental conditions. These slight differences represent diversity within the species. Since all environments are continually changing, this diversity is important in the long-term survival of species.

A population is defined as a group of individuals of a single species that interact, interbreed, and live in a given area. The individuals in a population are genetically diverse, and a viable population has sufficient genetic diversity to withstand changes in the environment. All environments change. In genetically diverse populations, some individuals may die as a result of changes, but many survive and the population survives. Usually a large population contains more genetic diversity than a small population and thus has a better chance of surviving environmental change. Density, or the number of organisms per unit area, is one measure used by scientists to characterize a population.

An ecological community is an interrelated assemblage of plants and animals associated with the abiotic or physical environment. A community type repeats itself, with variations, under similar conditions across the local landscape (or within an ecoregion). Through time, species within a community have developed complex relationships and interactions. Competition among similar species for scarce food supplies is a common occurrence in communities. Predation of one species upon another affects the number of different kinds of species in a community. Studies of competition, predation, decomposition, and many other relationships among species within communities suggest that preservation of a single species isolated from its community is difficult, and often impossible. Because of the many varied relationships, interactions, and requirements of species, studies of the needs of a given species are often incomplete and are always time consuming to conduct. Although autecological studies (studies of individual species' needs) may be very successful in preserving a species, time and financial constraints make such studies of all species within a community impractical. An effective and less expensive means of preserving a species is usually through preserving or restoring its natural community. Restoration of
natural communities does not require knowledge of all requirements of all species.

An ecosystem is a complex system of biotic and abiotic components and relationships. It includes not only the plant and animal communities, but also the microorganisms, climate, sunlight, water, and soil that interact with communities and with each other. Nutrients, water, and energy cycle through the system. Animals use other animals or plants as food. Slightly different soils, slopes, and many other factors make for subtle differences in each locale or habitat within a given ecosystem. An ecosystem usually contains, or can include, many different ecological communities and may cover a large area.

The place that a plant or animal lives is its habitat. Plants and animals of a given species have specific requirements which must be met in order to survive. Each site or parcel of landscape has characteristic soil, exposure, moisture, and temperature ranges which meet the requirements of a given assemblage of plants. Each community of plants provides habitat for a particular group of animals. Each has different requirements for soil type and moisture. It is better to restore or preserve an upland site or a wetland site than attempt to artificially recreate such a site where it did not exist.

The intricate interdependencies of living things dictate that restoration and conservation efforts be focused on the habitat and community levels. The north-facing and south-facing slopes of a hill in the eastern deciduous forest provide different habitats and thus different communities of plants and animals. These differences result from different amounts of direct sunlight that fall on the hillsides which, in turn, affect the moisture and temperature regimes in the soil. These two communities in the same ecosystem are different.

Since the 1800s, ecologists have attempted to define criteria that determine the numbers and kinds of organisms that live in any given ecosystem. In one woodland ecosystem in England, scientists have attempted to list all species of plants and animals. This effort has taken several years, does not include microorganisms, and is not complete (Hunter 1990). Because ecosystems are so complex and are continually changing, ecologists frequently study a particular group of organisms such as rodents, birds, trees, or grasses, or an individual species. From these studies they attempt to develop general rules of ecosystem function or preservation.

Scientists measure and evaluate biological diversity in several ways. One concept of diversity is the number of different types or species of organisms within an ecosystem or over a defined parcel of landscape. In order to compare different sites and different studies, ecologists have developed ways to measure diversity. One of the simplest measures of diversity is the number of species that dwell in a habitat. The number of species is referred to as species richness. Habitats with more species are considered more diverse. But simple numbers of species often do not tell the entire story of diversity. A forest with 90 percent of one tree species and 5 percent each of two other species is different from a community containing the same three tree species but at densities of 25, 35, and 40 percent. Each forest has the same richness with three species of trees, but the forest with the more even distribution is considered more diverse. The distribution of abundance among different species or the relative abundance of species is referred to as evenness. Forests with high evenness are considered more diverse than forests with low evenness. Ecologists have developed several different equations combining richness and evenness to measure diversity. In these equations, richness or number of species is a more important factor than evenness. Frequently, ecologists use only the number of species, or richness, when studying an area.

Diversity can be increased to very high levels. But diversity is not our only goal. We would like also to maintain or restore the natural communities that occurred in a region. Restoration of natural communities is suggested for two main reasons. First, by using plants that originally occurred in an area, the manager will also be more likely to attract and reestablish native animals within the area. Trees, for example, attract fewer bird species when planted in areas in which they are not native. Exotic pine trees in France (Constant et al. 1973) and Australia (Disney and Stokes 1976) contain fewer species of birds than are found in pine plantations in their native countries. Eucalyptus trees are not native to California, Sardinia, or Chile (Smith 1974) and plantations in these areas contain few bird species. Eucalyptus trees, however, support a diverse community of birds in their native Australia.
The implications of these studies are clear. Native populations of plants will maximize the diversity of native animal species. A second reason to restore natural communities is that current scientific methods do not provide the means to understand all relationships and individual species' requirements necessary to create a community. Diversity may be increased without understanding all the reasons for that increase. Restoration of a natural community should include as many of the components of the community as possible, to ensure that the requirements of individual species are met.

Principles of Diversity

Landscape restoration is based on an understanding of how ecosystems work. Studies of species' requirements, maintenance of natural areas and biological diversity, island biogeography, landscape ecology, and ecosystems have led to the recognition of specific principles that can be applied to managed parcels of land to maintain and restore natural diversity.

Ecology is the study of how organisms interact with each other and with their environment. Ecologists are often satisfied with general explanations of why certain things happen. However, managers of golf courses, recreation areas, or parks want to predict the outcome of a particular action under specified conditions. Because of the complex relationships within an ecosystem, the predictive powers of ecology are limited. But some ecological principles are understood well enough to be applied, resulting in increased diversity. Application of these principles will increase the diversity on small tracts of land and at the same time increase the aesthetic value and preserve the functionality of the tract.

"The key to planning the management for all species of wildlife is to know the species' habitat requirements and provide a variety of habitat components in a desirable combination that will meet the needs of as many species as possible" (Schneegas 1975). To increase the diversity of native plants requires the evaluation of existing site conditions and the application of ecological and horticultural principles in using native plants. Most plants, being rooted in the soil, are totally dependent on the site conditions. For animals, we may analyze why certain species or combinations of species are found in certain places, and recreate the conditions specifically related to those species. Alternatively, we may recreate the native plant community and rely upon immigration of animal species (Figure. 3.1). Animals require food, shelter from predators and the weather, and breeding habitats to ensure the best chances of securing mates, nesting, and raising young. The challenge with managed areas is to restore or retain sufficient characteristics of the natural community to maintain a high diversity of plants and animals and at the same time allow human use of the area.

The principles outlined in this book are to some degree hierarchical and overlapping. For example, the theoretical best restoration of a disturbed site is a large, circular (maximize interior, minimize edge)
that can be applied to maintain and enhance the biodiversity of an ecosystem. Understanding the interactions among species and the processes that affect their distributions is crucial for effective management. The principles outlined in this book provide a framework for understanding and applying ecological concepts to real-world situations.

Figure 3.2: Theoretical effects of fragmentation on species on a parcel of land. Numbers of species are for illustrative purposes only. The total number of individuals within each species will also diminish as the degree of fragmentation increases. The number of species that can be preserved depends on the size of the fragment and the number of species that can survive in that size. If the site is to have a variety of uses, then perhaps the original community and its species cannot be restored.

Some of the principles have a threshold of applicability. If a 500-acre forest exists, most species that normally inhabit a forest, including some that inhabit deep forest, will be found in this area. If half of that 500 acres were changed to native grasslands, both the forest species and grassland species would be found on that same 500 acres. The forest acreage is reduced to below the size and shape that will support the entire complement of forest species, then a reduction in the number of species occurs as the parcel is further subdivided (Figure 3.2). Knowing the limitations of when and how the principles are applied requires some understanding of natural communities. Discussion with ecologists, botanists, and zoologists familiar with the local communities may aid in determining which principles to use in any given area.

Beginning in the late 1800s, scientists noted that islands contain fewer species than continental land areas of equal size. In 1967, MacArthur and Wilson formally developed the theory of island biogeography. Much of today’s landscape is divided into island-like habitat patches that are decreasing in size, becoming more isolated, and disappearing. Habitat patches display some similarities with islands. Which species can reach a patch? How diverse is each patch? What is the relationship between patch size and its diversity? These are concepts that have analogous island concepts.

Scientists continue to debate specifics of the theory of island biogeography and other ecological concepts, but a few principles for explaining diversity have emerged: smaller islands contain fewer species; islands further from the mainland contain fewer species; boundaries (edges) between different vegetation types contain more species of both plants and animals; more extinctions of species occur in smaller areas; and reductions in the pool of species for immigration will reduce the number of species and the relative abundance of species in a community. Although many authors apply the theory of island biogeography to the design of natural reserves in order to maintain plant or animal communities, there is no agreement on all management strategies.

Golf courses, recreation areas, farms, schools, and parks may be managed to increase diversity by applying ecological principles. The following is a synopsis of ecological principles that represent current scientific thinking on how diversity is maintained, and suggestions for applying these principles to preserve, recreate, or restore natural areas. We have divided the principles into those relating to the spatial aspects of ecosystems on the landscape (Table 3.1) and those relating to the community or biological aspects of ecosystems (Table 3.2). These principles summarize concepts and ideas derived from scientific studies. A more detailed discussion of each spatial and community principle comprises the remainder of this chapter. The reader may elect to skip the detailed discussions of the principles that follow or read about the principles that are of particular interest.
Table 3.1. Spatial Principles and Guidelines

- Large areas of natural communities sustain more species than small areas—Preserve as many large natural communities as possible in single tracts for each ecosystem or increase the size of existing patches to the minimum size needed to sustain viable wildlife populations.
- Many small patches of natural communities in an area will help sustain regional diversity—Where there is no opportunity to preserve, increase, or create large natural community patches, increase the number of small community patches.
- The shape of a natural community patch is as important as the size—Modify or design the shape of natural community patches to create more interior habitat. If space is limited, a circular area will maximize interior habitat.
- Fragmentation of habitats, communities, and ecosystems reduces diversity—Avoid fragmentation of large patches of natural vegetation. Even a narrow access road through a forest can be a barrier to movement of small organisms, eliminate interior habitat, and introduce unwanted species.
- Isolated patches of natural communities sustain fewer species than closely associated patches—Minimize the isolation of patches. Corridors and an increased number of patches can prevent isolation.
- Species diversity in patches of natural communities connected by corridors is greater than that of disconnected patches—Maintain or develop many corridors of similar vegetation to connect isolated patches of the same or similar community types. Opportunities exist along roadways, rivers and streams, urban ravines, fencerows, hedgerows, railroad rights-of-way, to name a few. Wider corridors provide more wildlife benefits and protect water quality better than narrower ones. Breaks in the corridor should be avoided.
- A heterogeneous mosaic of natural community types sustains more species and is more likely to support rare species than a single homogeneous community—On large parcels, mosaics of natural communities should be restored as the diversity of the landscape allows. Smaller parcels should be evaluated within a regional context with the goal of developing such mosaics on the landscape.
- Ecotones between natural communities are natural and support a variety of species from both communities and species specific to the ecotone—Ecotones (transition zones between communities) should be allowed to naturally develop between adjacent communities. The amount of area in ecotones can be increased by increasing the interspersal of community types on a given parcel, but this should not be done at the expense of reducing interior habitat.

Table 3.2. Community Principles and Guidelines

- Full restoration of native plant communities sustains diverse wildlife populations—The more fully restored natural community has a higher diversity. This means introducing as many components of the natural community as possible.
- An increase in the structural diversity of vegetation increases species diversity—The vegetational structure of a community can be enhanced by restoring tree, shrub, and herbaceous layers that are reduced or lacking. Dead logs and litter should also be left.
- A high diversity of plant species assures a year-round food supply for the greatest diversity of wildlife—Introduce as many species known to be part of the natural community as possible. Also retain dead, standing, and fallen trees as they provide important nesting sites for many cavity nesting species and a source of food for other species.
- Species survival depends on maintaining minimum population levels—Different species will have different minimum population requirements. The minimum population in a particular parcel will depend upon factors listed above, such as how connected patches are.
- Low intensity land management sustains more species and costs less than high intensity management—The maintenance costs and environmental impacts associated with landscape management can often be reduced by reducing management intensity. Management intensity can be reduced by converting areas to native vegetation adapted to site conditions. Natural forest, grassland, and wetland communities are low intensity landscapes.

Spatial Principles

The landscape matrix of fields, wetlands, urban areas, and other areas of habitat includes a mosaic of patches, corridors, and networks (called a matrix). This matrix of patches provides internal and external connectivity across many landscapes. Controlling for the connectedness of communities, the larger the area that is isolated and not connected with the landscape matrix, the less restored natural communities can contribute to species diversity in the United States. On the other hand, if the matrix of habitat patches regenerates to a similar level, the species diversity through natural processes is high. Regeneration is the result of natural processes, including the dispersal of seeds and the natural succession of species. The matrix of patches and corridors can regenerate with the same rate as the natural habitat, or it may require human intervention. Succession is the transformation of one type of vegetation into another, and how fast it happens varies greatly. Restoration can aid in the transformation of one type of vegetation into another, and how fast it happens varies greatly. Restoration can aid in the transformation of one type of vegetation into another, and how fast it happens varies greatly. Restoration can aid in the transformation of one type of vegetation into another, and how fast it happens varies greatly. Restoration can aid in the transformation of one type of vegetation into another, and how fast it happens varies greatly. Restoration can aid in the transformation of one type of vegetation into another, and how fast it happens varies greatly.
Spatial Principles

The landscape is a mosaic of land uses, such as fields, wetlands, woods, and asphalt. Patches are areas of habitat different from the surrounding area (called a matrix). The study of natural patches provides insight into the ecological mechanisms controlling which species inhabit them. Remnants are isolated patches of persistent, regenerated, or restored native ecosystems. In many areas of the United States, previously disturbed patches may regenerate to the original ecosystem. This regeneration is the regrowth of a natural community through natural succession. The ability of a patch to regenerate will depend on its size, degree of isolation, and how severely it has been disturbed. Restoration can recreate natural ecosystems in areas where regeneration is not possible. Additionally, restoration can reestablish ecosystems more rapidly than regeneration. Principles of restoration and succession are discussed in Chapter 4.

Principle One—Large areas of natural communities sustain more species than small areas

Species richness within communities follows a consistent pattern of an increasing number of species with increasing size of the area. One method of showing the relationship between number of species and area size is the species-area curve. Scientists plot the number of species on one axis of a graph and the area on the other axis. The number of species in any given ecosystem will increase rapidly as the tract size increases up to a certain point, and then increases less rapidly (Dunn and Loeble, 1988). The species-area curve is different for different vegetation types and for their associated animals. A first estimation of the number of species expected in an area of a certain size can come from studies of species-area curves. To achieve maximum diversity for different types of organisms in different regions, areas of different minimum sizes are required, as illustrated by the species-area curves in Figure 3.3.

The optimum method to maintain maximum diversity is to preserve many large areas. The larger the area, the more species preserved. Very large areas ensure the preservation of rare species and large predators. Predators such as hawks and owls require larger patches for survival than do songbirds.

Different geographic regions exhibit different numbers of total species on the same size area. Climate is one of the most important factors affecting geographic variability in species richness. Benign climates have greater species richness than harsh climates (Figure 3.4). Stable climates have a larger number of species than variable climates (Currie 1991). To protect all or most of the species representative of a particular community or habitat, an area of minimum size must be established. The minimum size area may be different in different ecosystems and the total number of species that can be expected will differ in different areas of the country.

To preserve all species in a forest, large tracts must be preserved. Forest interior species will not occur in small forests. Freemark and Merriam (1986) concluded that large tracts of forest are needed to provide habitat for forest interior birds. Bird species richness increases significantly through a forest island size of approximately sixty acres and is likely to continue increasing significantly at forest sizes greater than sixty acres. Forest interior bird species began appearing in two acre forests (Galli et al. 1976). The interior structure of grassland can be achieved in a smaller area than is required for the establishment of a forest interior. A smaller area can thus provide sufficient habitat for grassland interior birds.
Principle Two—Many small patches of natural communities in an area will help sustain regional diversity

The scientific literature contains many articles debating whether a single large or several small preserves of equivalent total area will contain more species. No clear, general answer on either theoretical or empirical grounds has emerged. Even though it is desirable to preserve large areas, fragmentation of natural communities and the mounting pressures from expanding human populations preclude the establishment of large tracts of natural communities in many areas. When preservation of large areas is not possible, the next best option is to preserve many small areas.

The number of species in any area is determined chiefly by the number of different habitats (Forman and Godron 1986). Increasing the size of an area increases subtle habitat differences. Differences in soil, slope, moisture, and associated species affect the composition of the community. Even if sites are randomly chosen, rather than selected to maximize diversity, it is likely that groups of separate sites will encompass various habitats. Each small area will, because of the subtle habitat differences, contain different species. Any single small area may not contain as many species as a large tract, but the total number of species from all smaller tracts may equal or exceed the number of species in a single large tract. When making comparisons, only native species should be counted. Small reserves may contain a higher percentage of exotic species.

By maintaining several similar patches, the likelihood of all individuals of a species being destroyed is reduced. Random events such as epidemics, parasitic infections, or fires may exterminate a species in a patch. If one large patch containing all the individuals of the species is lost, the species will become extinct. But if several small patches contain the species, it is unlikely that an epidemic or fire will spread to all patches, so some individuals will survive. The last population of Heath Hens was found on an island. A large fire and an epidemic among the hens occurred. These combined natural disasters exterminated this last population (Hunter 1990). Had there been populations on other islands or tracts of mainland, some probably would have survived and could have functioned as a source of immigrants for reestablishing the population on the devastated island.

At any moment several small patches may contain different species due to local extinctions. If the region as a whole is made up of many different patches, then each of the small reserves may support a different group of species and the total number of species conserved might exceed that in a large reserve containing a single or few habitat types. Additionally, the different patches serve as a source of species to emigrate to new patches. Studies summarized by Simberloff and Abele (1982) indicate that for plants in England, birds and mammals on mountaintops in the American Great Basin, and lizard species in Australia, several small re-
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Principle Four—Fragmentation of habitats, communities, and ecosystems reduces diversity

Fragmentation can be viewed in several ways. Morrison, et al. (1992) define it as the increase in isolation and decrease in size of resource patches. For the purposes of this book we define fragmentation as the process of altering the landscape, eventually leading to the creation of isolated remnants of natural communities that had once covered the entire landscape. Fragmentation ranges from put-

Principle Three—The shape of a natural community patch is as important as the size

Patches of natural habitat occur in many shapes. Depending on the patch, the shape may affect its utility in preserving and creating diversity. Long, thin reserves are optimal for catching immigrants, and functioning as corridors to help direct emigrants to suitable larger reserves; but they do not allow development of distinct interior habitats. A circle is the shape with the least edge per unit area. Use a circular area if space is limited and interior habitat is desired.

Most natural areas are surrounded by human activity that can affect the natural area. Human activities produce disturbances that reduce the number of species. The further the natural area is from human activities, the less likely it is that the system will experience a reduction in the number of species. The edge of a natural area is impacted by surrounding human activities. Oblong or irregularly shaped patches contain a larger portion of edge than round patches or squares with the same total area (Figure 3.5). Thus round areas have a larger area that experiences less disturbance and will be more likely to have a higher species richness.

When habitat with a distinct interior is to be preserved or created, the optimal shape to use is a circle. If paths are to be created in a natural area, they should be placed as near to the edge of the patch as possible and still allow people using the path to experience the natural communities. Placing paths close to the edge of the natural area leaves a larger central area with less disturbance.

Figure 3.5. The shape of the patch dictates the amount of edge and interior (Temple 1986).
ting a road through a forest to the elimination of a forest. For the purposes of emphasis and explanation we have specifically chosen to separate the closely related concepts of isolation, corridor development, and size, shape, and number of patches from the overall concept of fragmentation.

Much research has focused on fragments and their relationship to islands, and the application of island biogeographic theory to fragments. Porosity—the measure of density of patches—decreases as fragmentation increases. This means the distance from one patch to another increases. Reduction of species richness within fragments is a generally accepted phenomenon. Agricultural or urban landscapes that surround native habitat patches are radically but not totally different from the native habitat. Some of the native plants and animals still exist in the agricultural or urban landscape, yet the diversity is greatly decreased and they exist isolated from a natural community.

Long-term fragmentation of natural landscapes has been documented in Wisconsin from 1831 to 1950 and in England between 1759 and 1978 (Shafer 1990). A commonly accepted theory is that habitat loss through fragmentation is the leading cause of species extinctions (Norton 1986). As the remaining patches of natural habitat become smaller and smaller, the diversity of animals and plants decreases (Figure 3.6). Fragmentation of natural communities is occurring on every continent. In some parts of the world, few fragments of natural areas remain. The pattern of decreasing size and increasing modification of fragments is similar on every continent except Antarctica.

Ecological communities and habitats are lost as a result of fragmentation. Fragmentation may result in the complete loss of some habitats and their associated species. The small patches that result from fragmentation may not contain a minimum viable population of a species (i.e., the number of individuals of a given species sufficient to sustain the population). If individuals cannot move from patch to patch and breed with individuals from other patches, genetic diversity, which is necessary for the long-term survival of a species is maintained. If individuals cannot move among patches, the population may be reduced below the minimum size needed to preserve the population or the genetic diversity may be lowered to a harmful level. As fragmentation progresses, the patches of original habitat become further apart. The increasing distance between similar patches decreases the likelihood that species can migrate among patches. As species are exterminated within a given patch, new individuals cannot immigrate and diversity is decreased.

Rare species and species with patchy distributions are more susceptible to extinction as a result of habitat loss through fragmentation than are common species with an even distribution. As populations in habitat patches are exterminated, the likelihood of extermination of other populations dependent on that species increases.

Effects of fragmentation can be reduced by maintaining or establishing corridors to connect patches. From earlier discussions of eastern woodlots, we have seen that the effects of fragmentation can be reversed as patches of woods are reestablished in farmlands. If large tracts of natural communities exist, every effort should be made to prevent fragmentation. Paths, service corridors, rights-of-way,
and roads should be placed on the margins of natural areas. Buildings and areas used by humans should be clustered near the edges of natural communities.

Principle Five—Isolated patches of natural communities sustain fewer species than closely associated patches

Insularization is the process by which fragments of the original ecosystem become more and more isolated from one another thus becoming more like islands. Insularization can decrease or even stop colonization of patches from outside areas. The patches become too far apart to allow individuals to move from one patch to another. Random events such as epidemics may cause the death of all individuals in a patch. Without the possibility of immigration, the diversity is thus permanently reduced. Insularization can remove resources that species in the reserve depend on for survival (Wilcox 1980). As the patches become so small that species requirements are not met, extinction occurs. Extinction of a species in turn affects other species and may result in a further decrease in species richness (Balser et al. 1981).

In the book *Wildlife—Habitat Relationships* (Morrison et al. 1992), the authors state that “over time, individuals in local patches or groups of patches might become extinct from chance variations in survivorship and recruitment or from catastrophic or systematic declines in the resource base.” Figure 3.7 (a-f) is taken from Morrison as an example of this point.

Patch size and degree of isolation affect both the species composition of bird communities (Butcher et al. 1981, Whitcomb et al. 1981) and the local abundance of birds (Lynch and Whigham 1984). Patch size, acreage of nearby forests, and the distance to extensive forest tracts affect the number of bird species (Opdam et al. 1985). In Maryland, forest fragments of at least three acres will permit most forest interior bird species to breed if the tract is near enough to a larger forest fragment to allow recruitment of individuals (Whitcomb 1977, Whitcomb et al. 1977). Although patches this small might not ensure survival of forest interior bird species over long periods of time (Whitcomb et al. 1981), they do contribute to genetic diversity, reduce the effects of random events, and allow more individuals to produce young each year.

Morrison et al. (1992) states that “connectivity of patches and permeability of edges vary according to a species’ body size, habitat specificity, and area of home range. What acts as habitat entirely suitable in type and amount for sustaining a small-bodied, habitat-specific species such as the red tree vole (*Arborimus longicaudus*), a specialist on Douglas-fir, also might act, at a much wider scale, merely as a dispersal steppingstone for a larger-bodied, less habitat-specific species such as the mountain lion (*Felix concolor.*))

Columbian ground squirrels may move between habitat patches, but they do not colonize some new patches because emigrants only settle near other squirrels of the same species rather than in all vacant patches. Movement into a new patch is related to distance from a source of squirrels, but not to the size of the patch (Weddell 1991). Thus, for some mammal species, location of patches near colonizing sources is important for establishing new populations. Isolation will reduce colonization in these species.

If large tracts of land must be subdivided or fragmented, the resulting smaller areas should be kept close together or connected by corridors to prevent isolation.

Principle Six—Species diversity in patches of natural communities connected by corridors is greater than that of disconnected patches

Corridors are narrow strips of habitat that allow movement between patches of similar habitat (Figure 3.8). The concept of corridors resulted from studies of species on islands, peninsulas, and mainland fragments. Mainland fragments typically contain more species than islands of the same size. Yet peninsulas or islands that are part of an island group, with some islands near the mainland, have more species than isolated islands. As species become extinct in fragments, corridors allow new species to move into the fragments. Since random events commonly cause local extinctions, corridors are important in maintenance of diversity.

Even small corridors may be effective in providing a path for movement of small mammals, amphibians, and reptiles that travel on the ground and have limited mobility. Some exterminations are inevitable in small reserves or islands. Coloniz-
Figure 3.7 (a-f). Schematic representation of landscape dynamics of patch colonization and occupancy (Morrison et al. 1992).

3.7a. Occurrence of ten patches of old-growth forest within a watershed.

- Old growth forest
- Species present

10 patches
7 occupied (70%)

3.7b. Occurrence of old-growth obligate vertebrate in seven of the ten patches.

- Old growth forest
- Species present
- Clearcut

10 patches
7 occupied (70%)

3.7c. Selection of three patches for clear-cut timber harvesting.
3.7d. Immediate result of harvest disturbance: loss of the species in three patches.

3.7e. Later loss of the species in a distant, isolated, smaller forest patch (faunal relaxation).

3.7f. Still later loss of the species in a larger forest patch recently isolated.
Corridors facilitate movement between patches and broaden the area of contact for species moving across a landscape.

Figure 3.8. Corridors facilitate movement between patches and broaden the area of contact for species moving across a landscape.

In addition to providing a means to reestablish populations that have been exterminated in a patch, corridors facilitate genetic exchange among small populations. Such exchange is important in maintaining the viability of small populations. The literature includes many articles discussing minimum population size necessary to ensure that a species does not become extinct. Many events can cause drastic reductions in population size. Reduced populations typically exhibit a loss in the genetic variability of the species. Reduced genetic variability may endanger populations because the reduced genetic diversity lowers the chances that at least some individuals in a population will be genetically equipped to endure changes in the environment. The population may thus be reduced further, and lose more genetic variability. As the population becomes smaller, inbreeding occurs, further impairing the ability of the species to survive. Inbreeding of closely related individuals increases the probability that harmful genetic traits will be expressed in their offspring. Movement of individuals...
among patches reduces inbreeding. Many animals disperse long distances from their parents before they themselves begin breeding. Corridors increase movement of adults among patches and dispersal of young. Both increase genetic diversity.

Abandoned ravines in urban settings, riparian (river edge) areas, utility rights-of-way, roadways, railroad rights-of-way, hedgerows, and fence lines may function as corridors. For some species it is not important that corridors be of the same vegetation type as the natural areas they connect, but only that they be different from the surrounding croplands or urban areas (Merriam 1984). In designing corridors, connections to existing corridors as well as patches should be incorporated into the design of a site. In urban areas habitat islands are often small, isolated from natural habitats, experience much disturbance, and thus experience high extinction rates (Davis and Glick 1978). It is important to create corridors that connect with existing corridors and patches to insure their maximum effectiveness.

In arid regions, areas along rivers (riparian habitats) frequently contain trees not found in adjacent grasslands or deserts. Riparian woodlands maintained along streams in arid regions function as corridors for movement. However, as pointed out by Simberloff et al. (1992) some communities, riparian communities, are very threatened and could be protected independent of their value as corridors.

Forested riparian corridors are also important in cultural and urban settings. For example, in the prairie landscape of Kentucky’s Bluegrass region several species of salamanders and mammals occur along the “mainland” wooded corridor of the Kentucky River. Bryan (1991) found smoky shrews (Sorex fumeus) only in the deep forest litter of the wooded ravines of the river valley.

Forested corridors are often important resting and feeding areas for migrating birds (Sprunt 1975). They help maintain suitable water temperatures for aquatic life, improve water quality, and preserve aquatic integrity. Forested areas along streams should be reserved during development of golf courses and other managed areas. To protect water quality, filter strips bordering streams in flat terrains should be at least twenty-five feet wide and include two feet in width for each one percent of slope (Trimble 1959). In municipal settings the filter strip should be doubled in width (Trimble and Sartz 1957). Filter strips for wildlife may need to be even wider. Stauffer and Best (1980) studied riparian communities of breeding birds in the Central Plains and found that for wooded study plots to contain the maximum diversity of twenty species, a minimum width of 660 feet was needed. A strip 297 feet wide had only thirteen of the twenty species and strips less than twenty-three feet wide contained seven of the twenty.

Two characteristics of corridors—breaks and nodes—have significant implications in increasing and maintaining diversity (Figure 3.9). Breaks in corridors are long or short areas in which the corridor community is interrupted by the surrounding habitat. Corridors of trees and shrubs around agricultural fields are often interrupted in areas where gates or connections between fields occur. Animal movement along corridors may be reduced or eliminated by such breaks (Forman and Godron 1986). If breaks are necessary, they should be as small as possible. Corridor breaks as small as 50-100 meters may be significant to birds, bats, and other small mammals. Exposure to predation may be a primary reason for avoidance of such openings.

Nodes are areas in which the corridors are wider. Nodes often occur at the junction of two corridors or, in the case of riparian corridors, in the inside of river bends. Increases in species diversity are documented for nodes along fence rows although the nodes show relatively small increases in width compared to the corridor (Forman and Godron 1986).

Opportunities for corridors along roads are often excellent. A slightly wider right-of-way to accommodate native grasses, shrubs, and trees creates an effective corridor. Areas around buildings can serve as screening as well as corridors.

**Principle Seven—A heterogenous mosaic of natural community types sustains more species and is more likely to support rare species than a single homogenous community**

Sampon and Knopf (1982), in discussing forest management, stressed that managers should strive for a diversity of ecological communities not maximum diversity within one community. Maximum diversity means conserving the greatest number of species possible on one tract of land. Preserving a diversity of ecological communities means preserving many different habitat types on many
different tracts of land. Each tract will contain slightly different environmental factors and thus slightly different communities of plants and animals. Each individual tract may not represent its highest potential diversity, yet a diverse array of species associated with each tract will be preserved. Preserving many tracts of land in many different locations takes advantage of slightly different habitats at each location. Specialized habitats that occur on only a few locations are thus more likely to be preserved and rare species that are found in only these habitats will survive.

In nature, many communities form a natural mosaic of small patches over the landscape. Using the earlier example of north- and south-facing slope communities, we saw this natural mosaic effect. Several distinct communities and habitats may occur in an area of hills with north-facing slopes, south-facing slopes, and wet areas such as springs, seeps, and streams at the bases of the slopes. Disturbed areas and old fields form other patches. Each species has very specific requirements that are satisfied in a particular habitat. The goal should be to preserve different habitats rather than attempt to create a habitat that does not naturally occur in an area. Restoration of an existing south-facing slope community would be easier than attempting to create a north-facing slope community in an area that does not possess the appropriate exposure to sunlight, soils, or hydrology. Restoration of the community that originally occurred in an area will more likely be successful, will require less management, and will exhibit more long-term viability. By analyzing an area and restoring the natural communities as much as possible, we will restore the natural mosaic of communities.

**Principle Eight—Ecotones between natural communities are natural and support a variety of species from both communities and species specific to the ecotone**

Ecotones are the transition zones or boundaries between two habitats, community types, or ecological systems. The boundary may be between a hay field and a forest or between a natural grassland and a forest (see Figure 3.10). Typically the edges of the two ecosystems are not distinct lines, but the transition from one ecosystem to another occurs over some area. This area of transition is called an ecotone. An ecotone may be as abrupt as the edge between a lake and the forest on its shore. Larger ecotones exist in the transition from forest type to
Principles for Maintaining and Restoring Natural Diversity

Figure 3.10. The ecotone between two natural forest communities will include species from both and species that occur only in the ecotone.

Community Principles

Principle One—Full restoration of native plant communities sustains diverse wildlife populations

The physical conditions of a particular site determine what community of plants will survive for the long term without special care. When confronted with a previously farmed or otherwise disturbed area, it may be difficult to determine the vegetation history of the site. The soil series on a site is one of the best clues to the original vegetation. The techniques described in Chapter 5 can be used to analyze the site. Restoring the fullest possible complement of those plant species that would most likely have originally occupied an area, while retaining the characteristics of the site needed to
maintain its human uses, results in an increase in native animals (Figure. 3.12).

Principle Two—An increase in the structural diversity of vegetation increases species diversity

Physiognomy, or vegetation structure, is important since it affects the variety of habitats available for animals and plants. A forest with a shrub understory has more structure and more habitat types than one without a shrub layer. Most species are habitat specific. Some ecosystems naturally have a lower diversity of habitats and species than others. Birds that inhabit grasslands are usually quite characteristic of, and restricted to, the grassland vegetation type. Both diversity and density of bird species are low in grasslands compared to other habitats (Cody 1985a).

When migratory birds return to the forests of the eastern United States to breed, they frequently return to the same area year after year. They need food sources, perches from which they sing to attract mates, and nest sites, all of which are affected by vegetation structure. Components of the vegetation that correlate with song posts and nest sites include canopy tree volume, tree cover, tree height and size, number of trees, ground cover, and number and type of shrubs (Clark et al. 1983). This and similar studies in other forested communities suggest that the natural association of trees, shrubs, and ground cover is needed to attract and maintain a diverse bird population in eastern forests. Manicured forests with a diminished shrub layer and reduced ground cover and litter will attract fewer birds and provide less protective cover for small mammals, reptiles, insects, and amphibians. One study found that the development of a good ground cover resulted in the addition of one or two bird species; a shrub layer added one to four species. A tree layer added approximately twelve species, with the addition of three more species as the trees developed (Wilson 1974).

In the Northern Great Plains, the reduced number of sparrows on reclaimed mine spoils was shown to be related to the loss of sagebrush habitat. Sparrows used the sagebrush as singing posts, for nesting, and for perches from which to feed on grass seeds. A second factor associated with the abundance of sparrows was the presence of litter (Schaed et al. 1983). Litter should be left in place in both forest and shrub communities. Preserving or establishing shrubs along roads, as screening around maintenance buildings, and between fairways can increase the populations of sparrows in mixed grass prairie regions.

In shelterbelts in the Great Plains, multiple rows of trees and shrubs provide more structure than single rows. They provide more winter cover and, therefore, more bird species than single row shelterbelts (Schroeder 1986). Multirow shelterbelts also provide cover for deer and other mammals. The most effective configuration of plants in shelterbelts is tall trees in the middle rows and lower shrubs in the outer rows of the belt. Maximum species richness occurred in shelterbelts of eight or more rows and ninety or more feet in width. In the Central Plains of Iowa, Stauffer and Best (1980) showed that vertical stratification of vegetation, sapling and tree species richness, and sapling and tree size all correlated positively with bird species richness. In this same study it was shown that removal of the shrub and sapling layer adversely affected eleven species and benefited four species. Maximum numbers of bird species occur
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when three distance layers exist:

herbaceous, shrub, and trees over

ty-five feet tall (MacArthur

and MacArthur 1961).

Although small mammal

populations increase in response

to seed production in arid areas

and after forest clearing, vegeta-

tion cover is the single most im-

portant factor affecting small

mammal species richness in fence

rows of the eastern United States

(Asher and Thomas 1985). Struc-

ture is also critical to the small

mammal community. The bio-

mass and diversity of mice, voles,

and shrews are related to the lower

strata of vegetation and the depth

and friability of the litter and soil

humus layers (Bryan pers. com.).

Vegetation structure is in-

creased by establishing several

layers of vegetation including herbs, shrubs, un-

derstory trees, and canopy trees. Litter and dead

logs also increase structure and should not be

removed. Horizontal logs retain leaves and build litter

layers which enhance habitat for small mammals,

amphibians, and reptiles.

Principle Three—A high diversity of plant

pecies assures a year-round food supply for

the greatest diversity of wildlife

Seeds are energy rich and are frequently used by

animals as food. Management of areas should include

a system to allow seed production. This is especially

ture for arid areas and grasslands.

Grassland environments exhibit large, unpredict-

able changes from year to year (Collins and Glenn

1991). A high degree of annual fluctuation in tem-

perature and precipitation occurs with no apparent

trend. The amount and timing of precipitation deter-

mine the production of seed crops upon which grass-

land birds depend. Thus, it is not surprising that

grassland birds are opportunistic. Unlike birds of the

eastern forests, they do not return to the same site each

year for nesting, but instead seek the most suitable site

for reproduction each year. Establishment of natural

vegetation will provide song posts, food supplies,

cover, and nesting materials and sites. Since the

essentials for survival and reproduction exist at these

sites, they will be selected by birds. Grassland birds

often feed on seeds and insects. Management of

grassland should include allowing grasses to produce

seeds. The grass stems should be left standing to

provide perches from which the birds hunt for insects.

Increases in small mammal populations are often

related to increased supplies of food such as seeds. In

arid regions, small mammal population increases are

correlated with increased seed production. Forest

clearings or disturbed areas exhibit an increase in deer

mice resulting from increased supplies of seeds and

insects (Ahlgren 1966). Butterflies, especially their

caterpillars, can have very specific food require-

ments. This requires the planting of particular plant

pecies if those butterflies are desired or considered

part of the particular community being restored. Ber-

ries, nuts, nectar, leaves, and twigs may all be used as

food sources. Some species feed on different food

sources during different times of the year. A diversity

of plants assures a year-round supply of food for
different species.

Principle Four—Species survival depends

upon maintaining minimum population levels

The size of a reserve affects the number of

ividuals of any species that can live in that reserve.

ery individual of a population requires a certain

ount of space. The amount of space is dependent
upon food sources and preferences, species interactions, and reproductive needs. Additionally, a minimum number of individuals of a given species is necessary to maintain genetic diversity and long-term survival of the species.

Much research has focused on the minimum population size needed to prevent a species from becoming extinct. One definition of a minimum viable population is the smallest isolated population having a 99 percent chance of persisting for 100 years in spite of random effects. Random effects include demographic, environmental, and genetic events and natural catastrophes (Shafer 1990). The minimum viable population size thus obviously varies among species.

Early suggestions stressed the need for a large population of between 50 and 500 animals to maintain sufficient within-population variation to prevent negative genetic effects. However, since not all individuals in a population are part of the mating system, more than 50 to 500 individuals may be needed (Boecklen and Simberloff 1986). Recent papers have focused on the subdivision of populations as a means of maintaining genetic diversity rather than trying to determine the minimum population size. This recalls the idea of many small reserves linked by corridors to allow for migration among populations.

In nature, plants frequently exist in small populations. Higher plants, being rooted to one spot, are often highly site-specific. The most favorable sites are a few environmentally heterogeneous reserves of sufficient size to minimize edge effects. Some plants have the ability to propagate asexually. The majority of higher plants are bisexual. Asexual reproduction and bisexuality implies that minimum population sizes for maintenance of genetic diversity can be half those of populations requiring two individuals to reproduce (Ashton 1988). For these reasons plants often need less space than animals to support a viable population.

Principle Five—Low intensity land management sustains more species and costs less than high intensity management

Managed areas in the United States receive a range of treatments, but are often kept neat and tidy. Leaves, dead limbs, fallen trees and limbs, and debris are immediately removed. Grass is mowed on all accessible spots. The resulting communities lack diversity of habitats, do not exhibit complex vegetation structure, and contain reduced food supplies. Diversity of plants and animals is reduced. Reduced management and maintenance provide the opportunity for increased diversity. Dead leaves, twigs, and other debris are a food source for insects which are an important food source for small mammals and birds. Dead limbs provide nest cavities and harbor insects as food supplies for birds. Mature grass provides seed supplies and a more complex vegetation structure. Decreased management intensity increases complex structure of the environment and food supplies, and costs less than intensive management.

Stauffer and Best (1980), in a study of breeding birds of the Central Plains, found that snags (dead, standing trees) were more important than live trees or dead limbs as nesting sites for the ten bird species requiring cavities for nests. Snags or fallen logs also provide food and shelter for many bird species. Mammals, amphibians, and reptiles may also use cavities in snags and logs for shelter. In addition to providing food and shelter, dead logs and snags function in nutrient and energy recycling. Larger species such as the pileated woodpecker can use only trees of a certain minimum size, but small species can use large or small snags. Hunter (1990) suggests that a minimum size of snag to provide for larger species is a thirty foot tall snag with a diameter of twenty inches. Additionally, snags should be distributed throughout the forest since birds establish territories and cannot be crowded into small, localized areas. Explicit equations have been developed to estimate numbers of snags needed to support the maximum number of some woodpeckers. But the aetiology of all cavity nesting woodpeckers, much less all species, is too poorly understood to allow the determination of precise numbers of snags needed. Foresters and wildlife managers have generally recommended two to four snags per acre. For North American species, this is supported by some empirical data (Hunter 1990).

Conclusion

Forests in Massachusetts represent a transition zone between the hardwood forests of northern New England and the oak–hickory forests of southern New England. Studies of thirty-two woodlands
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resulting communities not exhibit complex stain reduced food sup-
id animals is reduced. maintenance provide (diversity. Dead leaves, food source for insects source for small mam-
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y of all cavity nesting l species, is too poorly termination of precise Foresters and wildlife commended two to four merican species, this is tal data (Hunter 1990).

ranging in size from 2 to 170 acres showed that the size of the woodland was the primary influence on diversity. Forests with manicured understories were not included in the study. The number of species of birds rapidly increased as the size of the woodlots increased from two to sixty-two acres, but increased more slowly thereafter. At sixty-two acres, 75 percent of the bird species were present. Management conclusions from this study include the following (Tilghman 1987):

- establish or maintain woodlands greater than sixty-two acres;
- maintain natural vegetation in the shrub layer;
- include a variety of microhabitats such as small scattered openings;
- create some form of water in, or adjacent to, the woods;
- include patches of conifers or wetland;
- eliminate buildings adjacent to the woods; and,
- limit the number of trails.

Similar recommendations exist for prairie communities (Verner 1975):

- preserve as large an area as possible;
- provide a heterogeneous mosaic of grasses and forb rather than a uniform stand of either;
- provide cattails of intermediate stem den-
sity, rather than bulrushes, for nesting;
- increase the structural complexity of the vegetation by increasing the vertical profile and increasing the percent vegetation cover and total volume of vegetation;
- make every effort to avoid single species plant communities or at least to reduce monocultures to small, intermingled patches;
- provide song posts;
- provide nest cavities; and,
- allow enough vegetation to provide cover for nests.

The studies cited above support the principles outlined in this chapter and the idea that restored or existing natural areas should be allowed to remain in their natural state. Grasses should not be mowed. Limbs, dead trees, litter, and debris should be left in place to produce a varied array of habitats.

The principles in this chapter will not all be used on any one site. However, for each site the use of even one or two of the principles will increase diversity. During development of a site, the cre-ative incorporation of these principles, when approp-riate, will increase diversity.