COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY • COLLEGE OF AGRICULTURE

# *Landscape Ecology and* Ecosystems Management

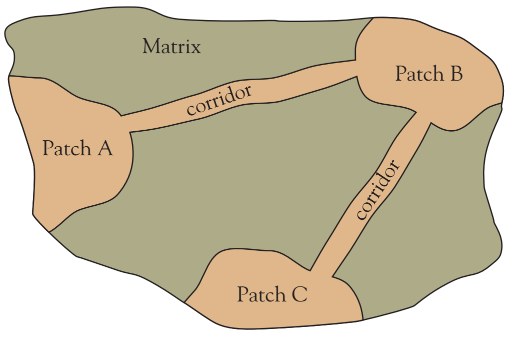
*Thomas G. Barnes, Extension Wildlife Specialist*

This publication introduces the concepts and principles of landscape ecology for managing wildlife and other natural resources. It is intended to raise public awareness and give an overview of a new philosophy and method for managing natural resources at the landscape level.

A landscape is a heterogenous area composed of a cluster of interacting ecosystems that are repeated in various sizes, shapes, and spatial relationships throughout the landscape. Landscapes have different land forms, vegetation types, and land uses. Another way of looking at a landscape is as a mosaic of habitat patches across which organisms move, settle, reproduce, and eventually die and return to the soil. The best way to envision a landscape is to look at the land from an aerial perspective or to examine aerial photographs to see how a particular piece of land fits into the larger picture.

Landscape ecology is the study of structure, function, and change in a heterogenous land area composed of interacting ecosystems. It is an interdisciplinary science dealing with the interrelationship between human society and our living space. Landscape ecology is a relatively new science, although Europeans have been using its principles much longer than Americans. We can learn a great deal from examining how the Europeans have taken an almost completely human-dominated landscape and attempted to restore ecological functions to its systems.

*Figure 1. Landscapes consist of the matrix (the dominant feature), patches, and corridors that connect the patches.*




*This publication is intended to be a companion to FOR-75, "An Ecosystems Approach to Natural Resources Management."*

## Principles of Landscape Ecology

To understand landscape ecology, we have to focus on some of its important principles: landscape composition, structure, function, and change.

- Composition involves the genetic makeup of populations, identity and abundance of species in the ecosystem, and the different types of communities present.
- Structure involves the variety of habitat patches or ecosystems and their patterns—the size and arrangement of patches, stands, or ecosystems—including the sequence of pools in a stream, snags and downed logs in a forest, and vertical layering of vegetation.
- Function involves climatic, geological, hydrological, ecological, and evolutionary processes such as seed dispersion or gene flow.
- Change involves the continual state of flux present in ecosystems.

A landscape consists of three main components: a matrix, patches, and corridors (Figure 1). If we understand these components and their interrelationships, we can make better management decisions at the landscape level.

## Matrix

The matrix, the dominant component in the landscape, is the most extensive and connected landscape type, and it plays the dominant role in landscape functioning. If we try to manage a habitat without considering the matrix, we will likely fail to provide what wildlife need in that area.

For instance, if your goal is to enhance the number of different species in a 40-acre forest patch surrounded by soybean fields, you will not create wildlife openings in the forest. That is, you will not want to create more edge (the outer zone of a patch that differs from its interior) because in an agricultural matrix, any type of opening will create more and smaller forested patches in that area, further reducing the amount of interior habitat available to the wildlife that need it.

The characteristics of matrix structure are the density of the patches (porosity), boundary shape, networks, and heterogeneity. If an area has been broken up but the patches are fairly close together, the patches are still dense enough to be useful for animal movement. However, if you open up a large forested area by creating small openings, the patches may not be dense enough to sustain certain kinds of animals, and you could have a problem with predation on other wildlife by raccoons, opossums, black rat snakes, or blue jays. A reduction in density might also increase nest parasitism by brown-headed cowbirds on neotropical migrant songbirds. We can illustrate how lack of density can create problems with brown-headed cowbirds. Some parts of eastern Kentucky do not have a large problem with brown-headed cowbirds because the matrix there is forested land. However, these birds pose a potential problem in other areas of eastern Kentucky where the matrix has been highly fragmented by coal mining, agriculture, and urban development (Figure 2).

Boundary shape also has implications for neotropical migrant birds and edge species of wildlife. The more uneven the boundary, the more edge. Within matrix areas, networks connect habitats of different size and shape, creating what is called heterogeneity within the landscape. These different habitat patches usually are replicated throughout the matrix.

For example, the forests of eastern Kentucky vary by slope, landscape position, and soil type. Ridgetop forests are dominated by pine and oaks, cove sites are mixed hardwood stands, south- and west-facing slopes are oak-hickory forest, etc. If a chance event like a tornado were to occur, it might tear up one or two areas, but it would not wipe out all habitat for a species because the same habitat type is replicated several times in an area. The overall damage to wildlife would not be as great because that type of habitat would still be close by.

### *Context vs. Content*

When natural resources are managed at the landscape level, context—where the biological element is placed in the landscape—is just as important as content. In other words, you must consider the surrounding matrix when attempting to conserve an area for its unique ecological attributes. Thus, if the land is being set aside to preserve rare plants (such as wildflowers in a glade) or animals (such as bats in a cave), the content—or community—we are interested in is affected by the context of the environment if the surrounding landscape is altered.

It is well documented that adjacent habitats affect each other through changes in microclimates and the transfer of nutrients, materials, or seeds, etc. between communities. These changes ultimately affect ecological processes such as gene flow and species composition in each community. For example, breaking up the forest or creating openings in the forest matrix creates smaller forest patches, with the matrix becoming open land (Figure 3). Thus, fragmentation of forest patches results in drier microclimates, which:

- alter species composition and favor exotic, invasive species
- increase the susceptibility of windthrow of existing trees
- exacerbate a loss of forest interior wildlife species (like neotropical migrant songbirds)
- reduce the genetic diversity of the remaining populations, and
- allow for the invasion of exotic, weedy species.

Ultimately, small preserves that are set aside for their content may fail unless people intervene with intensive management, which is expensive and time consuming. To refer again to the example of the glade, opening the surrounding forest habitat increases the kinds and numbers of exotic plant species that overcome the rare plants unless intensive, site-specific management like herbicide treatment, hand pulling, etc. is implemented.

Similarly, fragmenting the forest surrounding a cave could alter the cave's microclimate; certainly, nonpoint source pollution would alter its climate and make the cave unsuitable for bats or other unique organisms like blind cavefish.

## Patches

Patches are nonlinear surface areas that differ in vegetation and landscape from their surroundings. They are units of land or habitat that are heterogeneous when compared to the whole. They include four different types: disturbance, remnant, environmental resource, and introduced.

- Disturbance patches are either natural or artificial. They result from various activities, including agriculture, forestry, urbanization, and weather (i.e., tornados, hurricanes, ice storms, etc.). If left alone, a disturbance patch will eventually change until it combines with the matrix.
- Remnant patches result when humans alter the landscape in an area and then leave parcels of the old habitat behind. Remnant patches are generally more ecologically stable and persist longer than disturbance patches.
- Environmental resource patches occur because of an environmental condition such as a wetland or cliff line.

*Figure 2. Eastern Kentucky forest matrix has been fragmented by mining, agriculture, and human habitation.*

*Figure 3. Notice how the forested matrix has begun to be converted to an "open lands" matrix.*

- Introduced patches are ones in which people have brought in nonnative plants or animals or rearranged native species. Animals moving from one area to another can also bring in these nonnative elements.

### *Patches as Islands*

Several aspects of patches are important from an ecological perspective and affect landscape-level management decisions. The approach used most often in analyzing patch habitats is to think of them as islands. Much of the current thinking about landscape patch management has its roots in the theory of island biogeography. This theory was developed in 1967 by MacArthur and Wilson to explain the patterns of species diversity on oceanic islands. It has also proven useful and applicable to a variety of ecological situations because an island is simply defined as a patch or parcel of favorable habitat surrounded by unfavorable habitat. Just as wildlife disperse to oceanic islands, terrestrial wildlife and plants move between habitat islands. MacArthur and Wilson's theory suggests that various dispersal events could therefore be predicted.

A key concept in MacArthur and Wilson's theory is that an equilibrium point exists in a population between the rate that new species come in and the rate that previously existing species become extinct. Once this point is reached, the island's populations of species are then maintained at this equilibrium diversity. Island populations, then, have a tendency to "seek out" this equilibrium.

Island size and relative isolation (distance to the mainland) affect both these rates and their equilibrium point. Relatively isolated and small fragments offer the lowest equilibrium species diversity, while nearby large islands offer the highest. Thus, from a habitat standpoint, the first important concept is patch size, which determines how much energy can be stored in that patch as well as the number of species that can reside there. A larger patch can normally support a larger number of species and a greater variety of habitat types (Figure 4).

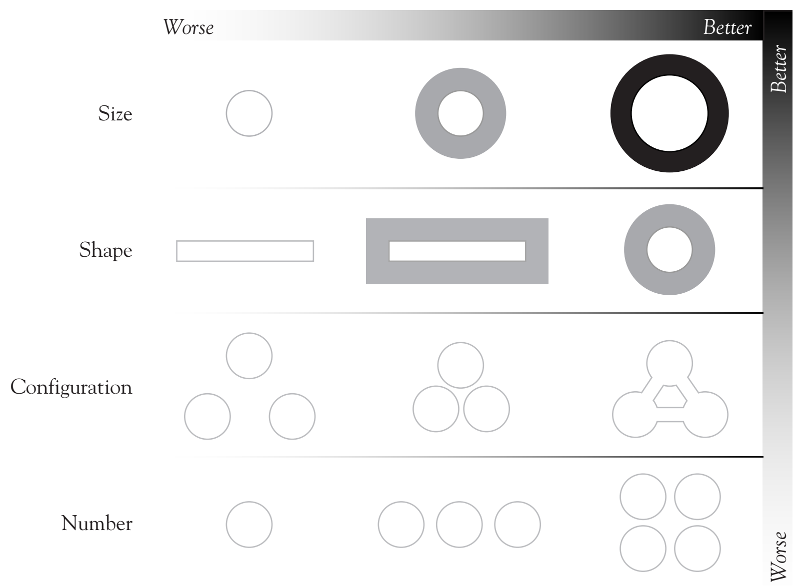



*Figure 4. The size, shape, configuration, and number of patches all affect the amount of interior habitat in the patch. Small, single, rectangular patches provide the last amount of interior habitat, and large circular patches provide the most interior habitat.*

### *Patch Size and Edge Effect*

A concept getting closer consideration these days is the relationship between habitat patch size and the edge effect. In 1933, in *Game Management*, Aldo Leopold wrote that creating edge and maximizing the amount of interspersion, or the juxtaposition, of habitats was beneficial for wildlife. Held as dogma by wildlife biologists until recently, this philosophy is unfortunately the most overused concept Leopold discussed. He stated that increasing the edge increases the number of wildlife species in an area. However, if we look at things from a landscape perspective, edge is the one habitat not in short supply. Although edge is good for certain species, particularly generalist or game species, it favors those species over interior species, or species that require specific habitat types.

Unfortunately, fragmented habitats with a large percentage of edge can become an ecological trap. These islands of habitat may look good for some species of birds to build their nests in, but they also attract a wide host of nest predators, including raccoons, skunks, opossums, blue jays, and rat snakes. These animals decrease the nesting success of any birds in that area. For instance, in a recent study, scientists compared nesting success of loggerhead shrikes in fencerow habitat versus those in more contiguous forested habitat. In fencerow habitats, the bird's nesting success dropped almost to the point that they could not replace themselves due to nest predation.

Additionally, patch size has implications for neotropical migrant songbirds if the surrounding matrix is good habitat for brown-headed cowbirds. If present in the matrix (and they will be present in an agricultural matrix), cowbirds will lay their eggs in the nests of neotropical migrant birds. The neotropicals cannot recognize the cowbirds' eggs, and they end up raising cowbirds rather than their own species.

It is important to keep patches in the landscape as large as possible because the habitat in shortest supply in the landscape is contiguous forest or grassland. An important consideration from a landscape perspective is how to maximize patch size and minimize the edge effect because nest parasitism begins to drop off significantly at 50 yards from a forest edge. Therefore, anything more than 50 yards into a patch could be considered interior habitat.

So, in a patch 100 yards across, how much would be interior habitat? None would be interior habitat because if you go 50 yards in on each side, there is nothing left. In general, as patches get larger, there is more interior habitat. And if a patch is large enough, there is significantly more interior habitat. But how big should habitat patches be to minimize the influence of exotic or edge species? This requirement varies by species; nest parasitism by cowbirds, for example, may extend up to 900 yards into the forest interior. There are no definitive guidelines except "the bigger, the better."

Furthermore, patch shape and configuration also influence how large the patches need to be. Scientists estimate that if we are to maintain minimum viable populations for many neotropical migrants, the minimum patch size should be 10,000 acres.

Patch shape is also important. A circular patch minimizes the amount of edge compared to a thin, rectangular strip patch, which has only a narrow band of interior habitat. If the strip is narrow enough, there is no interior habitat for interior species, and ultimately the diversity in the strip would be low.

There are also functional ramifications related to edges and patch size. In general, the higher the interior-to-edge ratio, the less patch border you have, which decreases the amount of interaction with the surrounding matrix. A higher interior-to-edge ratio also:

- decreases the probability of barriers that could limit the movement of organisms
- decreases the probability of habitat diversity within the patch, which would not necessarily be harmful because it would be natural, not artificial, diversity
- decreases the importance of corridors for species movement, as they are able to move more freely throughout the matrix
- increases species diversity and the total number of animals within the patch.

A low interior-to-edge ratio would do exactly the opposite.

*Habitat Fragmentation*

One of the issues related to patch size is habitat fragmentation. Fragmentation is a process that occurs along a continuum (Figure 5) in which a particular area is initially all one habitat type (a forest, for example) and is eventually decreased until only isolated patches remain. It results in habitat loss and discontinuity and eventually leads to habitat isolation. Fragmentation ranges from creation of small disturbance patches to widespread habitat loss and insularization.

There are two components to fragmentation: 1) a decrease in the amount of interior habitat and 2) a decrease in the connectivity between those habitat patches. As an example, suppose we started out with all forestland; then, three farmers move in and farm their small areas. As time passes, development creeps in, and the farms expand their agricultural base, resulting in larger gaps between habitat patches. At this point, the landscape is moving from a forest matrix to an agricultural matrix. In the beginning, there is still connectivity between forest patches even though it is narrow. At the endpoint of the continuum, there is a totally different type of habitat. From the wildlife standpoint, many of the original species would have two options: move to another area, or perish.

At the present time, forested wildlife habitat in the landscape often occurs in patches within an agricultural landscape matrix. Managing wildlife at the landscape level is an attempt to unite habitat patches (through the use of corridors, specifically riparian forests or fencerow habitats) to allow native biodiversity to flourish across the complete range of environmental gradients or between ecosystems. Viewed in another context, we do not necessarily have to connect habitat fragments, but rather direct our management to allow for the natural dispersal of wildlife.

Species can move across land more easily than across water. However, fragmentation in terrestrial systems creates something similar enough to the island effect that predictions can be made based on island biogeographic principles. How easily organisms can move across the landscape is determined by the density of the landscape. Thus, a high density of patches would tend to be similar to a large number of stepping-stones that organisms could use as cover as they go from one patch to another.

As noted earlier, the number of species that reside in a patch increases as the size of a patch increases. However, patches are not a random sample or a subset of the landscape. As a general rule, when you fragment the habitat, you section off one particular type of habitat (Figure 6). Thus, if you are going to fragment a habitat patch, you need to look at the habitat types within both the patch and the matrix and attempt to maintain each patch type.

Habitat fragmentation can be viewed as either a positive or negative feature in the landscape. It can have positive effects by increasing habitat diversity, creating beneficial juxtaposition of habitats, and, as Leopold said, increasing edge, which favors generalist wildlife species like white-tailed deer, raccoon, opossum, northern bobwhite quail, etc.

Fragmentation can be viewed as negative when:

- there is a loss of habitat,
- smaller habitat patches are created that lead to local extinctions or isolation,
- habitats are no longer connected, particularly if the fragmentation is caused by a nonforestry activity such as urbanization, and
- the amount of edge is increased because fragmented habitat is harmful to interior species like bobolinks, wood thrushes, etc.

### *Fragmentation and Nonnative Species*

As habitats are fragmented into smaller pieces, one final negative impact occurs: the invasion of nonnative or exotic organisms. Current estimates indicate that more than 25 percent of the flora in the United States is exotic. The history and folly of premeditated and accidental introduction of exotic plants and animals are well documented.

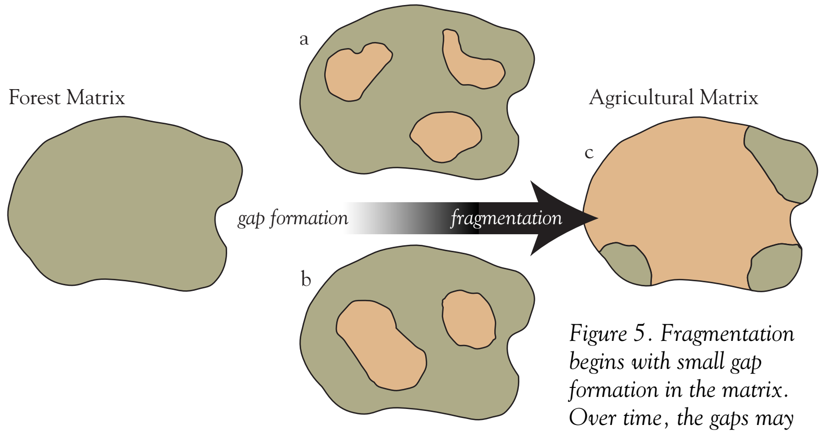
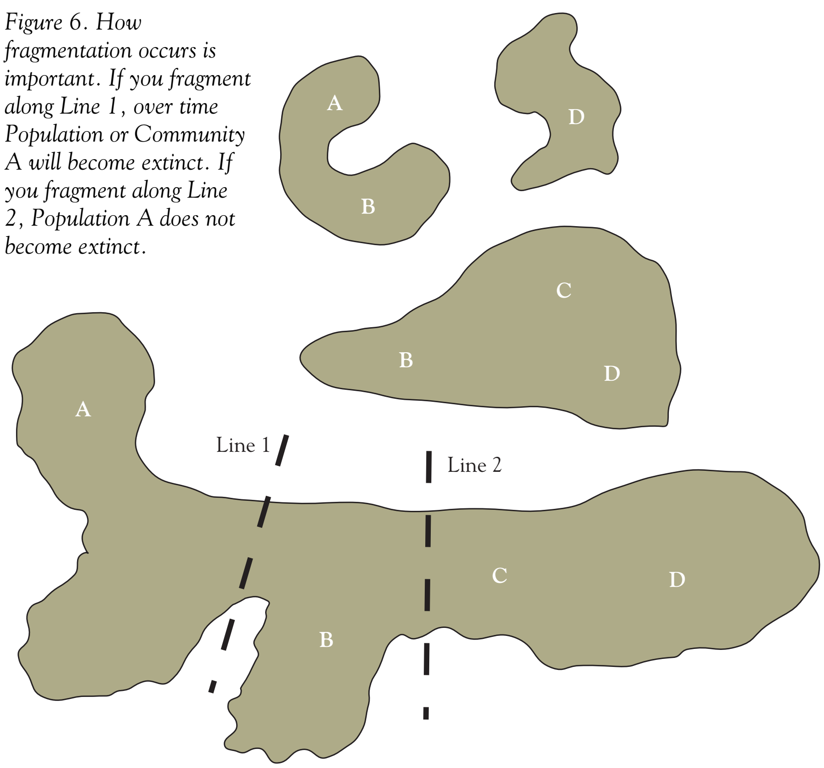



*Figure 5. Fragmentation begins with small gap formation in the matrix. Over time, the gaps may get larger, resulting in a shift in the matrix.*

These alien species, particularly those introduced by humans into environments they would not have reached through normal dispersal methods, have transformed, and are continuing to transform, entire ecosystems. For example, the American chestnut once accounted for one-quarter of the standing timber volume in the eastern deciduous forest. Today this species is reduced to sprouts and a few adults that were not destroyed by the introduced chestnut blight. This invasion by an alien species has dramatically altered the composition, structure, and functioning of this ecosystem.

*Figure 6. How fragmentation occurs is important. If you fragment along Line 1, over time Population or Community A will become extinct. If you fragment along Line 2, Population A does not become extinct.*



It has been estimated that exotic animals and plants harm or threaten resources in at least 109 national parks. An introduced tree, the Australian tree, has infested more than eight million acres of native sawgrass prairies in Everglades National Park. In addition to causing loss of habitat for wading birds and increased drying of the marsh, this pest is particularly intrusive. It does not respond to burning or herbicide treatment and may increase as a consequence of these eradication methods. The Loxahatchee National Wildlife Refuge is spending at least $75,000 a year in an attempt to control the invading tree.

In addition to completely altering ecosystem structure and composition, exotics cause other problems. In native ecosystems, a species is kept in check by ecosystem control like competition for food, space, or water; pathogens that cause disease; or predators. When a new species is introduced into an ecosystem, those same control mechanisms usually are not present. What usually happens is that its population blossoms without any natural controls. Exotics have also been known to hybridize with related native species, resulting in a lack of genetic fitness for the native population. Introduced predators may cause a decline in native prey species because the "naive" native prey have not become adapted throughout time to deal with the new predator.

Introduced species may also bring new diseases into an ecosystem that native species are not adapted to combating. Finally, an introduced species may adversely affect the workings of human communities by disrupting businesses, hastening the decline of an important food or recreation resource, or affecting water quality.

## Corridors

The final landscape component is the corridor, the strip of land that differs from the matrix on either side. Corridors are areas that link patches together, serving as highways or conduits for organisms to transfer or move from patch to patch. Corridors are a unique mixture of environmental and biotic attributes from the surrounding matrix and patches. They have origins and types similar to those of patches: there are disturbance, remnant, environmental resource, and planted corridors. There are also stream corridors such as the path followed by a river or stream and the strips of streamside vegetation so important to migrating wildlife.

Different types of corridors foster different species. Corridors function in several ways to provide habitat for various species, especially the smaller ones like chipmunks. Line or narrow strip corridors are mainly dominated by edge species, whereas wider strip corridors, which may have mostly interior species, function for better movement of animals.

Corridors can serve as a conduit for movement or act as a barrier or filter (which may serve as a barrier to gene flow). For example, roads can serve as an almost complete barrier to amphibian movement, ultimately isolating individual populations.

### *Corridor Structure and Function*

Corridor structure and function depend on a variety of different factors, including degree of curvilinearity, breaks, narrows, nodes, and connectivity.

- Curvilinearity, or the twisting and winding of the corridor, has functional ramifications related to edge. A higher degree of curvilinearity increases edge.
- Breaks occur where the matrix divides up a continuous corridor. They may not affect movement for some species, but for others—particularly plant species—they may stop the flow of species, genes, and energy through that system.
- Narrows, caused when some of the corridors narrow down, keep some species from moving through the restricted area.
- Nodes are corridor intersections, where, according to studies from England, numerous interior species are sometimes found.
- Connectivity of corridors should be maintained—that is, they should be kept continuous and unbroken.

### *Corridor Drawbacks*

Corridors also have some drawbacks. They encourage predators to alter their search patterns, resulting in increased predation on native wildlife species. Small animals that use a path as a corridor for travel will be more susceptible to reduction by predation. Consider how the eastern diamondbacked rattlesnake likes to lie next to a hiking path to get sun. Additionally, think of the humans using that footpath. The humans would probably destroy every rattlesnake they encountered, ultimately leading to fewer rattlesnakes.

Another drawback is that some corridors, like roads or railroad rights-of-way, can be a conduit for the invasion of exotic organisms or diseases and pathogens.

Here is a landscape-level example: If you have corridors connecting two patches that have nest predators such as raccoons and opossums, the predators will move along these corridors in order to have cover. By their movement patterns, they are going to increase their predation on birds in that new area. The area can become very hazardous for many types of wildlife, particularly turkeys.

Current research findings in the southeastern states on turkey predation occurring along riparian habitats indicate that the narrow corridors of suitable habitat allow predators like the raccoon searching for turkey hens and nests to find and eat their prey more easily. The proximate cause of death is predation, but the ultimate problem is a lack of suitable corridor width (habitat) that would make it more difficult for predators to search the appropriate habitat.

The message is simple: the wider we make these corridors, the better, because doing so will decrease the chance of predators finding their prey (Figure 7). These wide strips may need to be several miles across for some bigger species like black bear, but only a few yards wide for smaller species. Any time a corridor is 100 yards wide, the habitat's interior characteristics change, and nest predation drops off significantly thereafter.

*Figure 7. Corridors need to be wide enough to provide more positive benefits for wildlife. This narrow riparian corridor probably produces more negative impact on wildlife.*

## Landscape Change

Landscapes change, even though we tend to manage land with the idea that it will always be in some static community. But we all recognize that ecological communities are dynamic, ever-changing entities. For instance, when a tree falls, it creates a gap in the landscape matrix. This gap will eventually change and once again become part of the matrix.

When you create a change, you have to consider the impact it will cause on the landscape, not just for the present moment but also for 50 to 100 years in the future. For example, if you clearcut 10 of 100 acres at five-year intervals, over the next 20 to 30 years all those clearcuts and the resulting forest will end up at the pole stage (small trees that are the size of poles) at one time. From a biological diversity standpoint, the pole stage is the least conducive for promoting biological diversity. Therefore, it is vitally important to project the effects of management prescriptions well into the future.

Another force that alters ecosystems is the movement of plants by seeds. For example, anemochores are seeds that are blown with the wind, like maple seeds. If we cut a forest down and create a gap, this change allows the wind to move through, spreading these seeds over greater distances and affecting forest community structure. It has been hypothesized that many of the unique forest types in the Cumberland Plateau are being replaced by red maple. Could this be a result of previous harvesting strategies? Similarly, if you impact the hydrology of wetland or riparian systems, you would affect the hydrochores (seeds moved by water), and any management technique that affects wildlife would affect plants that are spread by zoochores (berries). The result of these activities could be good or bad, depending on whether it is a species that you want to spread.

## Metapopulation Dynamics

Finally, one of the aspects of landscape ecology that ecologists have only recently explored is metapopulation. A metapopulation is a network of semi-isolated populations with some level of regular or intermittent migration and gene flow among them. In simpler terms, it is a population of populations.

In metapopulation dynamics, individual populations may go extinct, but then they can be recolonized from other populations (Figure 8). If we drive these individual populations down to low enough numbers and do not get movement between populations, serious genetic problems may develop for maintaining the species. Even a small amount of movement between populations will keep the genetic situation somewhat stable.

### *Source and Sink Patches*

If there is no movement, those populations will probably go extinct, depending on whether they exhibit a source or sink patch of a metapopulation. Source patches will always stay in a particular locale and contribute individuals to all the other patches in the landscape. Sink patches allow populations or individuals to become extinct because they do not contain conducive habitat for the species to exist. For example, many times with territorial wildlife species a source patch of habitat or population will be full or at carrying capacity.

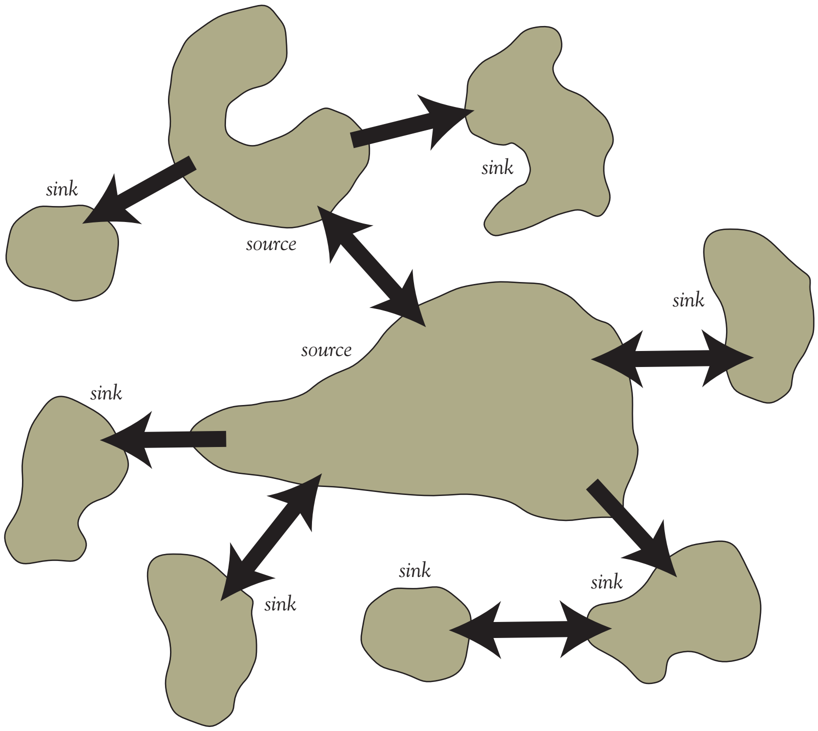



*Figure 8. A metapopulation is a population of source and sink populations.*

Thus, some animals move to the sink patch. Even though it may not be the best habitat for some species, birds, for instance, may be able to nest and be successful there.

Another advantage of the sink population is that if some catastrophic event occurs in one sink patch resulting in the extinction of its members, another patch could help to repopulate it. Thus, the sink patches help to stabilize the population over time. What happens in one patch is asynchronous to what happens in the rest of the patches.

Another important attribute about metapopulations is that in some cases they may actually buffer the species from extinction because of the relative isolation and protection of the source and sink patches. For example, if a disease in one patch wipes out all the individuals there, despite the connectivity between the patches, there is no way the disease could spread to all the populations. Therefore, the concept of metapopulations plays a very important role in the management of wildlife today.

An example will serve to illustrate the importance of understanding metapopulations when managing wildlife at the landscape level. Northern bobwhite quail exist in a series of metapopulations. Today, they live in fragments of habitats with some movement by animals between the fragments. Sometimes that movement is very poor. In the winters of 1976 and 1977 in Kentucky, very cold weather occurred along with abundant snow and ice. Unfortunately, some of the patches of quail totally lost their populations. Over time, even with poor movement, those patches have become repopulated, although it has taken 20 years for some local populations to recover. In other cases, significant habitat alteration occurred that prevented quail from repopulating some areas, and these populations became extinct. In these cases, metapopulations allowed the species to survive and ultimately recover small populations throughout its range.

An important point concerning metapopulations has to do with the time scale used in making management decisions. Many times biologists make decisions based on what the population level is at the present time. With metapopulation dynamics, however, you have to consider extinction and indications of the area's total potential. As in the case of the quail, it has taken 20 years to restore some local populations, but many have still not recovered and may never recover due to continued habitat degradation.

### *Appropriate Management*

Understanding metapopulation dynamics can lead to appropriate management at the landscape level. As we transform large expanses of relatively uniform habitat patches in the landscape matrix, physical changes occur that create the island effect in the resulting fragments. Such changes include:

- a decrease in size of the patches
- an increase in the proportion of edge, and
- changes in patch microclimate, including increased sunlight, greater temperature fluctuations, and greater exposure to wind.

These effects can mean:

- local extinctions of organisms
- reduced dispersal and recolonization of habitat patches
- invasion of exotic or nonnative species
- increased nest parasitism or predation on birds, and
- a reduction in the diversity of forest interior wildlife species.

Although metapopulation dynamics and the concepts of landscape ecology are complex and difficult for the general public to understand, we must make the effort to understand these concepts because of their importance in determining decisions about landscape-level and wildlife management.