Chapter 2. A Practical Framework for Making Local Habitat Protection Decisions

Citizens often voice their intent to preserve environmental values as communities develop and grow. However, these intentions are frequently difficult to realize, in part because achieving environmental protection may pose challenging compromises among needs to preserve the environment, to invigorate the economy, and to protect private property rights. Rising to these challenges requires a scientifically sound, utilitarian approach to protection, an approach that is legally and politically tenable. This report describes practical methods for protecting wildlife habitat. These methods can be applied broadly across a range of landscape types and a variety of political jurisdictions in response to many types of development.

The usefulness of the methods described in this handbook depends on a few key concepts and assumptions about the ways that people and wildlife share the land. In the first part of this chapter, we outline these assumptions and concepts. In particular, we make three points.

- We develop the idea that there are two fundamentally different categories of human effects on wildlife, categories that operate at different scales in the environment.
- We discuss how these different categories of impact require different approaches to management.
- We show that the opportunities for success in managing human impacts on wildlife depend on the current state of land development in the area of interest (i.e., the extent to which the area is rural or urban in character).

Later in the chapter, we use this framework to offer practical guidance for what to do on the ground to protect wildlife populations and habitats.

DEFINITIONS

Communicating ideas about human impacts on wildlife habitat requires us to think clearly about ecological concepts, ideas that may not be familiar to all readers. Such thinking requires a clear vocabulary. Several biological terms will be used frequently in this chapter. These are defined in Table 2-1 (page 6).

SCALE, HUMAN IMPACTS, AND WILDLIFE PROTECTION

Equipped with these definitions, we begin with the idea that residential development influences wildlife at two fundamentally different scales—the broad "landscape" scale and the more focussed "site" scale. At the landscape scale, development influences the distribution, survival, and persistence of wildlife populations and communities. At the site scale, development influences the behavior, survival, and reproduction of individual animals. Effects at the landscape scale can be mitigated by landscape management; effects of development at the site scale can be mitigated using site management. These two key concepts of scale are illustrated in Table 2-2 (page 6).

Scale, in turn, determines the usefulness of actions chosen to modify the impacts of development. To illustrate this idea, it might be useful to think of a rural landscape, a large area that is predominantly undeveloped, but that contains a few spatially separate subdivisions. The impacts of people within those subdivisions occur at fine scales. At these scales, we will refer to human impacts on wildlife as "site

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Ferrets have declined with the loss of prairie habitat and the extensive killing of prairie dogs.

Table 2-1. Definitions of Ecological Terms

- **Landscape** is a large land area (i.e., multiple square miles) that contains habitat for wildlife. A watershed offers an excellent example of what we mean by a landscape. Within a landscape there are usually different types of vegetation arranged in a mosaic, much like a patchwork quilt.
- **Patch** of habitat is what you would think it is—a spatially separate instance of a given type of habitat. For example, a stand of aspens surrounded by conifers is a habitat patch for some species of cavity-nesting birds.
- **Vegetation type** is a classification given to plants that are found in the same place on a landscape. For example, stands of trees that are predominantly aspen would be classified as the aspen vegetation type, while areas that are covered with grasses and no trees would be classified as the grassland vegetation type. Different wildlife species have different affinities for vegetation types.
- **Population** is a group of individuals of the same wildlife species that reside in areas small enough that members of the group are reasonably likely to breed with one another. Thus, a herd of mule deer that uses a creek drainage in the Colorado mountains is, most likely, a single population. However, herds of deer that use drainage separated by peaks are likely to be distinct populations.
- **Community** is a group of different wildlife species that are linked by ecological processes (e.g., predation, pollination, competition) at a given location. Often, communities are associated with a particular type of vegetation. Thus, the aspen wildlife community refers to all of the wildlife species (birds, mammals, amphibians, reptiles) that live in stands of aspen.
- **Biodiversity** is the variety of all lifeforms considered at all levels of organization, from the genetic level through the species and higher levels of taxonomic organization, and including the variety of habitats and ecosystems.
- **Fragmentation** is the breaking up of continuous areas of habitat into smaller parcels. For example, a forest becomes fragmented when sections are cleared for agriculture or when trees are cleared to build roads.
- **Habitat** consists of the physical features (e.g., topography, aspect, stream flow) and biological characteristics (e.g., vegetative cover, other animal species) needed to provide food and shelter for wildlife.
- **Species diversity** is the number of different species of wildlife, or species richness, and their relative abundance in a given location. As species die out in that location, species diversity declines.
- **Scale** is the relative size of an area of interest. If we focus on relatively small areas (say, the area around a house or a single subdivision), our focus is *fine scale.* If we pay attention to much a larger area (i.e., a county or watershed), we are looking at *coarse scales.*

effects." Such effects include the influences of dwellings, roads, and human behavior on the behavior, reproduction, and survival of individual animals. Examples of site effects include avoidance of structures and roads by wildlife, changes in mortality rates (e.g., highway deaths or cats preying on songbirds), and increases in human/wildlife conflict (e.g., bears picking through trash cans). Taken together, these site effects

Table 2-2. The Landscape Scale and the Site Scale

Scale of Effects of Development	Examples of Effects of Development	Type of Protection	Examples of Protection Tools
Landscape Scale	Conversion of habitat patches to residential development. Fragmentation of habitat patches by roads.	Landscape Management	Zoning Clustering Transportation planning Transfer of development rights Conservation easements
Site Scale	Increased predation by domestic pets. Increased disturbance from human activity. Reduced cover of native vegetation.	Site Management	Control of pets Buffer requirements Maintenance of native plants in landscaping Sensitive lands overlays

produce what we will call a "disturbance zone" around a house or a subdivision. (See Figure 2-1.)

We define a "disturbance zone" as the area surrounding a house, road, or a subdivision in which

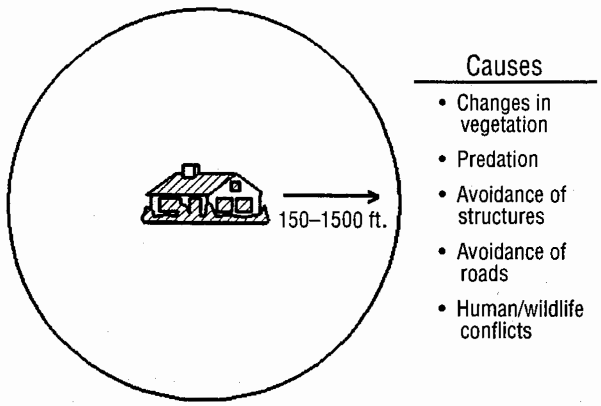


Figure 2-1. Disturbance Zone

the value of habitat for wildlife is meaningfully reduced by human activity and/or structures. A meaningful reduction in value occurs whenever an area is avoided by native wildlife or when the ability of individual animals to survive and/or reproduce declines in the area.

Although site effects of a given development are important at that location, such effects are not the only way that development influences wildlife. At larger scales, such as a valley containing several subdivisions, site effects accumulate and disturbance zones add together to cause what we will call "landscape effects." Landscape effects cause changes in the behavior, reproduction, and survival of populations, which, in turn, influence the composition and persistence of communities of wildlife. Landscape effects include reductions in habitat area (which results in diminished animal numbers) and increases in habitat isolation (which constrains the movement of animals among patches of habitat or seasonal ranges).

Differentiating between the scales of human effects is important because scale determines the kinds of approaches a community can use to manage the ways that development influences wildlife.

At the scale of a specific subdivision, site effects can be mitigated by "site management," which includes all of the actions that can be taken by people to moderate their effects on the behavior and survival of individual wildlife. Examples of such management include buffering of roads and structures, avoiding critical habitat by site design, management of vegetation, and control of pets. The primary goal of site management is to reduce the size of the zone of disturbance.

In contrast to site management, the goal of landscape management is to reduce harmful effects of increases in the density and distribution of the human population on populations and communities of wildlife, as opposed to individual animals. In general, this means managing the type and intensity of development and its spatial location in a broader area (e.g., a county or a basin as opposed to a subdivision). In so doing it is possible to maintain the variety and extent of valuable habitats and to preserve opportunities for animal movement among those habitats by using techniques that steer development away from areas that have high value for wildlife and towards areas that have low value.

THE RURAL-URBAN CONTINUUM

The opportunity to use site-level and landscape management depends on the history of development in a given area. We can think of the extent of development as a continuum extending from relatively undeveloped, rural areas to areas that are predominantly urban (Figure 2-2). The emphasis in a plan for wildlife protection depends on the position of an area of interest along this continuum. Landscape management may be most effective in rural areas, whereas site management is likely to be most effective in urban areas.

At the rural end of the development gradient, there is large opportunity for landscape-level management, simply because there is abundant wildlife habitat. As a result, it is possible to plan for development by identifying the areas of high wildlife value and encouraging development elsewhere. Because undeveloped areas predominate the landscape, the fragmentation of the landscape by new development still leaves large undisturbed areas. This means that there is ample opportunity for movement of wildlife among habitat patches. County governments and private landowners will have primary responsibility for protection programs in rural areas.

In contrast, municipal governments play a much more important role in habitat protection in urban areas. Because much of the landscape has been fragmented by development, opportunities for effective landscape management are not as great as in rural areas. Thus, site-level management becomes much more important at the urban end of the gradient.

This rural-urban continuum is useful for organizing our thinking about protecting habitat, but it should not be used as a fixed recipe for management. All areas contain some blend of the attributes described above, and, as a result, all habitat protection programs should contain elements of landscape-level and site-level management. In the following sections, we offer some general guidelines for managing people and development to achieve habitat protection.

GETTING THE JOB DONE

A conservation plan contains an analysis of priorities for the protection of wildlife, plants, and natural communities. Such plans also describe the specific actions to be taken to achieve that protection (Beatley 1994). The two fundamental questions of wildlife conservation planning are:

- What areas of a landscape should be protected to preserve wildlife populations?
- What should we do now and in the future to protect those areas?

In the following sections, we assemble what we believe to be the most important findings of the science of conservation biology to provide some rules of thumb for conservation planning. First, we describe some "operational principles" for working with scientists to design effective, practical conservation plans. Subsequently, we review "biological principles" for managing human density at the landscape scale. We then turn to what is known about the biological basis for managing effects of development at the site scale. We will briefly describe how to apply each principle, and then we will review current scientific understanding to offer a rational basis for applying it.

SEVEN OPERATIONAL PRINCIPLES FOR HABITAT PROTECTION

Conservation planning requires combining scientific knowledge with techniques of planning, law, and politics to develop a strategy for protecting wildlife, plants, and natural communities. Here we describe some operational considerations for achieving effective conservation planning. We emphasize from the outset that conservation planning needs to be a collaborative and flexible process. It should be collaborative by involving a broad range of expertise and viewpoints, and it should be flexible in drawing on a variety of actions for implementation. Those actions should be chosen with regard to local values, capabilities, and preferences while also respecting regional, state, and national needs for conservation.

Collaboration is the very essence of conservation planning. A diversity of expertise and viewpoints is needed simply because conservation plans deal with unusually complicated problems—the interaction of human and natural systems with all their attendant political, biological, and cultural complexity. It is, therefore, not surprising that success depends on people with different backgrounds working together successfully. The following groups have played an important role in conservation planning efforts in the past and will continue to do so in the future.

- Citizens, including landowners, developers, and environmental advocates, who communicate goals as well as needs and preferences for implementation
- Ecologists, who identify areas for protection based on biological attributes that provide a rational basis for regulation and investment
- Attorneys, who develop regulations and standards for wildlife protection
- Land trust representatives, who mobilize private resources for protection efforts
- Planners, who integrate priorities for wildlife with other needs of community, such as housing, transportation, recreation, infrastructure, and services
- Decision makers, who approve plans that achieve community goals in an equitable way

Table 2-3 summarizes some principles that will enhance the collaborative approach to conservation planning. In particular, we describe how citizens and planners can interact effectively with ecologists in developing practical and scientifically sound approaches to habitat and species protection.

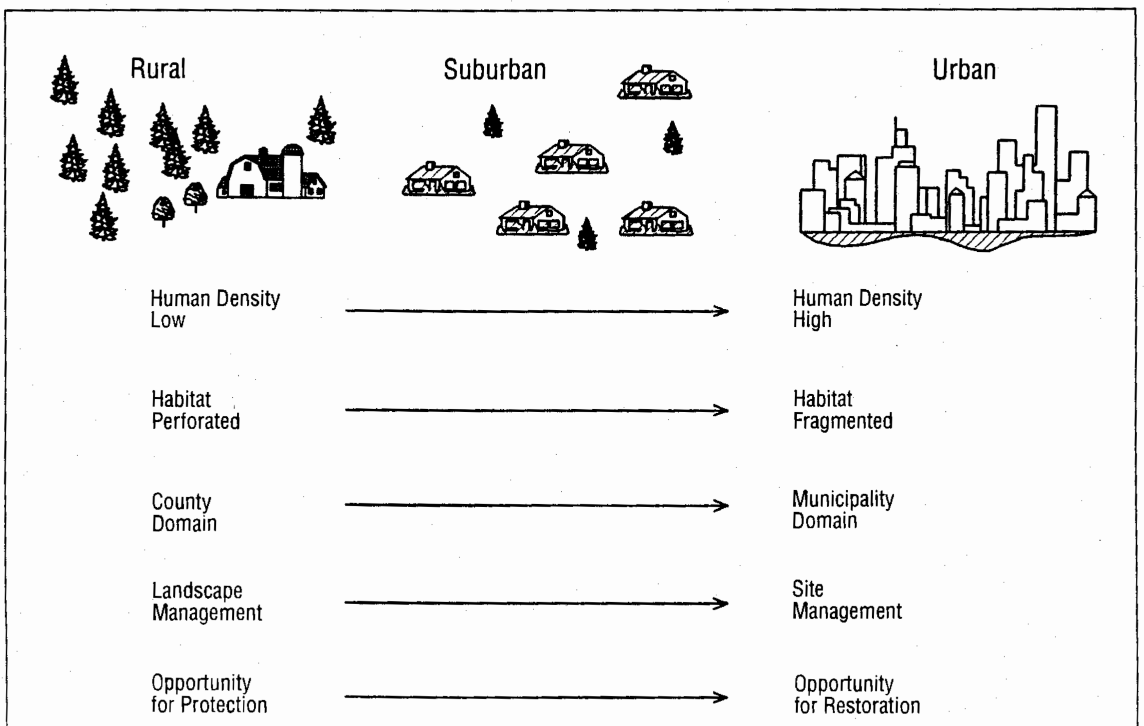


Figure 2-2. The Rural-Urban Continuum

Table 2-3. Seven Operational Principles of Habitat Protection

Principle 1	Be willing to use rules of thumb based on scientific findings that may someday prove to be false.
Principle 2	Understand that complex environmental problems do not have a single, scientific solution founded on "truth."
Principle 3	Begin all conservation plans with clearly stated, specific goals for wildlife protection.
Principle 4	Insist that the analysis used for setting conservation priorities can be understood by everyone who is affected by it.
Principle 5	Realize that all models are wrong, but some are useful.
Principle 6	Make plans adaptive by evaluating the consequences of actions. Learn by doing.
Principle 7	Seize opportunities to enhance wildlife habitat by intelligent design of developments.

Principle 1. Be Willing to Use Rules of Thumb and "Truths" That May Someday Prove to Be False.

It is not uncommon to hear ecologists express concern that the current state of knowledge is inadequate to make recommendations for managing complex ecological systems, particularly human systems. Of course, knowledge is imperfect—any science has some uncertainties, and ecology is no exception. But at any given time in the maturation of a science, there is a prevailing wisdom or opinion that is useful at that time. You should insist that such wisdom is used to support current decisions, while appreciating that scientific understanding will be revised as knowledge improves. Thus, the ecological principles of habitat protection that we offer below are our best effort to assemble current scientific knowledge relevant to conservation planning. Apply the principles we offer with confidence until someone offers you something better.

Principle 2. Understand That Complex Environmental Problems Do Not Have a Single, Scientific Solution Founded on "Truth."

This is a corollary to the first operational principle above. Deciding what areas of landscapes should be protected for wildlife is a highly complex environmental problem, and, if you expect an ecologist to deliver a crisp solution similar to a specific flow rate of water in a pipe delivered from a reservoir, you are bound to be disappointed. There are many examples in the physical sciences where precisely stated problems can be solved unambiguously, but ambiguity is inherent in most ecological problems.

However, such uncertainty is permissible in most applications. For example, it is usually the case that the standards of "proof" legally required to support regulations with science are often not as rigorous as the standards that scientists apply to themselves. That is, in a court of law, it may be sufficient to simply present a reasonable, credible argument based on a range of scientific interpretations. It is often unnecessary to state a precise, mathematically expressed level of confidence in that interpretation.

The main point here is that conservation plans can be developed using a variety of approaches to analyze the problem of what to protect, a variety of data relevant to that problem, and a range of scientific viewpoints defining its solution. The data, analysis, and viewpoints that are most appropriate for a given conservation plan depend on two things: (1) the goals of the plan, and (2) the ability of an ecologist to make his or her approach to the plan understandable and credible to the people who will be affected by it.

Principle 3. Begin All Conservation Plans with Clearly Stated, Specific Goals for Wildlife Protection.

It follows that one of the more important steps in developing a conservation plan is establishing clear and specific goals. The operative words here are clear and specific. As an example of a goal that lacks these operative features, consider the following:

> Land uses should be designed to be harmonious with wildlife habitat in the county.

This goal sounds laudable, but it is so broad that no one could disagree with it. From a legal point of view, it is so vague that it may even be unenforceable. For example, it is arguable that downtown Denver is "harmonious habitat" for Peregrine falcons because it offers nesting habitat and plenty of pigeons. Because goals are needed to choose an appropriate analytical approach for setting conservation priorities, goals that are excessively broad, like this one, make all approaches equally worthwhile.

In contrast, consider the following:

> The county will strive to ensure the persistence of populations of all of the native vertebrates in the county. We will do this by preserving habitats sufficient to support viable populations of all species and by preserving the ecological processes needed to support those species. In addition, the county will minimize human impacts that harm the abundance and distribution of sensitive and economically important species, including native ungulates, sport fish, and watchable wildlife.

The second goal gives us something concrete to talk about—it specifies what we are trying to achieve by identifying three crucial elements: (1) a focus on habitat, (2) an identification of the species we are concerned about (native vertebrates), and (3) a criterion for success (viability). These three elements should be found in all goals for conservation plans.

Principle 4. Insist that the Analysis Used for Setting Conservation Priorities Can Be Understood by Everyone Who Is Affected by Decisions Based on that Analysis.

This is the "emperor must wear clothes" principle. "State of the art science," which is thought to be technically elegant by ecologists but which is opaque to citizens, should be dispensed with in favor of science that can be understood and believed by the people who will use it. This is a controversial statement, but we are convinced of its wisdom. The reason is that, in a democracy, all government decisions must be explainable to be credible. If a planner must support decisions with the technical blessing of an ecologist, that planner is not likely to be credible with the citizens he or she serves. We contend that it is part of our culture to be skeptical of highly technical or obtuse analyses, particularly when they affect our lives. Conservation biology is not rocket science, and if the analysis offered up by an ecologist is not clear to you, ask that it be made clear.

Principle 5. Realize that All Models Are Wrong, but Some Are Useful.

Setting conservation priorities will almost always involve some sort of an ecological model. It is important to understand that the predictions of all models are wrong simply because a model, by definition, is an abstraction of the real world. A corollary to this idea is the statement of Mark Twain that "prediction is difficult, particularly when it involves the future." The important point is that the value and utility of an ecological model should be measured in terms of your ability to use that model to make a better decision or to communicate the basis for that decision. The success of a model should not be measured against some absolute standard of accuracy because *all* models make inaccurate predictions.

Principle 6. Make Plans Adaptive by Evaluating the Consequences of Actions. Learn by Doing.

It has been said that the planning process is analogous to the scientific method. This analogy holds true if we evaluate how plans are implemented and then use what we learn from those evaluations as input to the next planning cycle, as illustrated in Figure 2-3. Using management actions to learn about the workings of ecological systems is known as "adaptive management" (Walters 1986; Walters and Holling 1990). Ecologists can be a tremendous resource in designing adaptive management plans because human actions disturb natural systems, and ecologists are trained to understand the effects of such disturbance in a rigorous way. For example, there are many unanswered questions about the effects of people on wildlife habitat that could be answered by managing development at the site or the landscape scale. How does housing density affect wildlife communities? What kind of setback from riparian areas is best for maintaining diversity of riparian species? How does infrastructure affect the movement of animals across landscapes? What is the impact of trail use on the nesting success of forest birds? If we commit ourselves in planning efforts to answering just one or two unanswered questions like these, we constantly improve our ability to develop and implement strategies and tactics for conservation.

Principle 7. Seize Opportunities to Enhance Wildlife Habitat by Intelligent Design of Developments.

The very notion of habitat "protection"—of locking up nature in order to save it—runs contrary to the idea

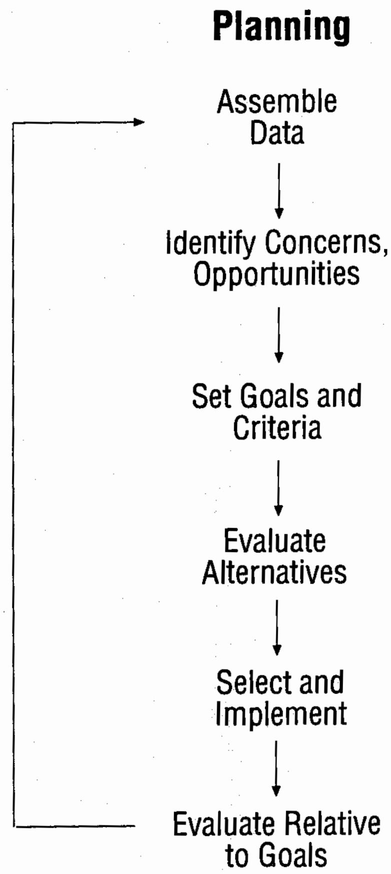


Figure 2-3. The Planning Process

that human systems can interact with natural ones in a favorable way and plan landscapes that enhance environmental values like wildlife habitat. An emerging view among contemporary ecologists is that we must manage the relationships between man and nature so as to achieve specific objectives for natural systems (Botkin 1990; Pickett et al. 1992; Jordon 1994; Turner 1994; Kane 1994). We urge you to reject the notion that all human actions degrade natural environments—the challenge we face is discovering a way that the human population can live in harmony with natural systems. If we take the view that all human actions lead to disharmony, we have admitted defeat in this fundamentally important endeavor.

For example, development can be used as a tool to enhance wildlife habitat in agricultural counties like those along the eastern edge of the Rocky Mountains. These counties contain substantial land committed to irrigated agriculture that is being developed as subdivisions. Before they were plowed, these lands contained very small streams that are now absent from the landscape as a result of cultivation. Intelligent design can restore these streams and perhaps create associated wetlands. Doing so can enhance wildlife habitat by rejuvenating a riparian zone. If such restoration is done in an intelligent, deliberate way over large areas, the streams and vegetation that emerge can create a network of corridors that offer habitat values at site and landscape scales.

SEVEN BIOLOGICAL PRINCIPLES FOR HABITAT PROTECTION AT THE LANDSCAPE SCALE

One thrust of the seven operational principles listed above is that effective conservation planning requires us to apply current knowledge to the design of protection strategies while knowing full well that such knowledge may be imperfect. The next step is to outline what we believe are the findings of conservation biology—or "biological principles"—that are most relevant to habitat protection in rapidly developing areas. We first address principles that apply to landscape management, and we then offer principles for site management. The seven key biological principles applicable at the landscape scale are summarized in Table 2-4.

Table 2-4. Seven Biological Principles for Habitat Protection at the Landscape Scales

Principle 1	Maintain large, intact patches of native vegetation by preventing fragmentation of those patches by development.
Principle 2	Establish priorities for species protection and protect habitats that constrain the distribution and abundance of those species.
Principle 3	Protect rare landscape elements. Guide development toward areas of landscape containing "common" features.
Principle 4	Maintain connections among wildlife habitats by identifying and protecting corridors for movement.
Principle 5	Maintain significant ecological processes in protected areas.
Principle 6	Contribute to the regional persistence of rare species by protecting some of their habitat locally.
Principle 7	Balance the opportunity for recreation by the public with the habitat needs of wildlife.

Principle 1. Maintain Large, Intact Patches of Native Vegetation by Preventing Fragmentation of those Patches by Development.

Action Needed to Implement Principle 1

Vegetation should be mapped across the landscape to identify natural areas that are not currently fragmented by roads or residential development. If all other values of habitat are equal, larger patches of habitat should be protected in preference to smaller ones. Try to strive to minimize development within these areas and avoid fragmenting them with roads.

Scientific Rationale for Principle 1

Large intact patches of native vegetation are valuable for wildlife because such patches support large, persistent populations and provide habitat for a greater diversity of species than small patches do. Here, we review the relationships between patch area and wildlife abundance, persistence, and diversity.

Effects of patch area on wildlife abundance. The primary reason to preserve large, intact patches of habitat is that long-term trends in population size of wildlife species are directly related to the area of habitat available to them (Harris 1984; Hoover and Wils 1984). Many wildlife species are territorial and "defend their space" against members of the same species. As a result of this defense, the number of individuals using a given patch is limited by the average territory size. For other species, abundance is ultimately controlled by the resources available in the patch—such as the amount of food or the number of nest sites (Sinclair 1989). It is often a safe prediction that the number of individuals of a given species within a patch of habitat will increase in direct relation to the area of the patch.

The characteristics of individual wildlife species determine the way that habitat area and quality affect the abundance of that species. The most obvious influence of species characteristics on animal abundance is body size—an acre of willows will support far more mice than moose (Peters 1983; Pennycuick 1992). This occurs because territory size increases as body size increases and because large animals require more food than small ones do. Hence, they require a greater area of habitat to meet their nutritional requirements. As a result, the number of animals per unit area increases as animal size declines, but this relationship is not directly proportionate to size.

The effect of habitat area on animal abundance is also influenced by the feeding habitats of wildlife. For example, predators require much more area than herbivores do, and, as a result, a given habitat patch will support far fewer predators, like bear or mountain lion or bald eagles, than herbivores, like mule deer or prairie dogs (Colinvaux 1978). Why this is true is easy to see by example. If a mountain lion eats 100 deer in a year, then a single lion must range over an area that supports more than 100 deer.

The abundance and diversity of wildlife in a habitat patch are also influenced by the types of patches that surround it and the land uses that occur in them. Of particular concern are so-called "edge effects" that occur in a zone of influence centered on the boundary between two patches. Historically, many wildlife biologists sought to maximize "edge" between two contrasting and adjacent habitat patches in the belief that this enhanced the landscape for wildlife. This was based on Aldo Leopold's (1933) "law of interspersion," which stated that the density of wildlife species requiring two or more habitat types is proportional to the amount of edge between or among those habitat types.

Luther Goldman, U.S. Fish & Wildlife Service

Collision with urban power lines is endangering the whooping crane.

Within the past 20 years, however, a number of ecologists have suggested potentially detrimental effects of such practices for some species, based on a number of studies conducted primarily in the eastern U.S. and focusing on songbirds (Gates and Gysel 1978; Whitcomb et al. 1981; Lynch and Whigham 1984). These investigators and others have suggested that some species require large, intact forest patches, and that such patches have become increasingly rare as wildlife habitat has been converted to urban or agricultural uses. Such conversions may be responsible for the decline of some species, notably migratory songbirds (Hagan and Johnston 1992).

Gates and Gysel (1978) referred to decreased nesting success near edges as the "ecological trap hypothesis." According to this hypothesis, birds that nest near edges suffer high rates of nest loss due to predation (Whitcomb et al. 1981; Yahner and Wright 1985; Andren and Angelstam 1988) or parasitism (Brittingham and Temple 1983). Based on a review of such studies, Paton (1994) surmised that these detrimental effects are most acute within 150 feet of the edge of a patch. Thus, the effective area of a habitat patch may be substantially less than the apparent area for species that are sensitive to edge effects.

Adjacent patches need not be large for edge effects to occur. For example, Small and Hunter (1988) documented higher predation rates for birds nesting in forested patches near roads or power line corridors. Roads also disrupt or prevent wildlife movement, act as conduits for exotic species and predators, and serve as sources of pollution and habitat disturbance such as fire (Schonewald-Cox and Buechner 1990; Bennett 1991).

Effects of patch area on species persistence. The reason that the effect of habitat area on animal abundance is so important is because, in the long term, the *persistence* of populations depends on population size. A persistent population is one that does not go extinct, and *persistence time* is the average time that a species is likely to exist before the species becomes extinct from the local area. Many studies have shown that the best predictor of persistence time is population size—large populations are much more likely to persist for a long time than are small populations (Wilcox and Murphy 1985; Wilcove et al. 1986; Simberloff 1988; Pimm and Gilpin 1989; Pimm et al. 1988; Ryan and Siegfried 1993; Fahrig and Merriam 1994).

This is the case for several reasons. First, small populations are more susceptible to "bad luck" in births and deaths (Raup 1991; Lande 1993; Caughley 1994). To illustrate the effects of such luck, think of an imaginary population that is regulated by the flips of a coin. Each year you flip the coin once for each animal in the population—heads it lives, tails it dies. If there are only 10 animals in the population, a run of bad luck could easily drive the population to extinction within a few years. On the other hand, if there are 1,000 animals in the population, the chance of getting enough tails to kill them all off is almost nil.

Another source of bad luck is the environment itself (Goodman 1987; Lande 1993). For instance, mortality rates for wildlife tend to increase dramatically during very harsh winters. Large populations are able to bounce back after such mortality, but small ones often cannot.

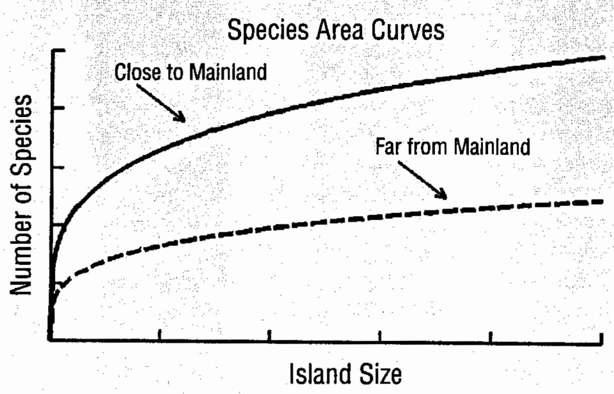
Finally, population size is important to persistence as a result of genetic effects (Lande and Barrowclough 1987; Lande 1988). Small populations tend to become *inbred* as a result of mating among close relatives. Inbreeding allows deleterious genes to accumulate in the population. This accumulation of "bad genes" diminishes reproductive success and survival, which makes it more likely that the population will decline to extinction (Beardmore 1983; Charlesworth and Charlesworth 1987; Pimm and Gilpin 1989; Hass 1989).

So, persistence of populations declines as abundance declines, but persistence is not directly proportionate to abundance. Populations that reach a level of abundance where chance extinction is highly improbable are said to be *viable populations* (Boyce 1992; Remmert 1993). For a population to be viable, it must have an adequate amount of habitat, because as we described above, abundance is roughly proportionate to habitat area. So, reductions in habitat area resulting from development can be reasonably assumed to reduce the average persistence time of populations and to reduce their viability (Ryan and Siegfried 1993; Fahrig and Merriam 1994).

Effects of patch area on species diversity. Large intact patches of habitat tend to support a greater diversity of species than small, fragmented patches do. Many ideas on habitat fragmentation and species diversity can be traced to studies of species diversity on islands. During the 1960s, Robert MacArthur and Edward O. Wilson (1967) developed and tested a theory predicting why islands contained different numbers of species. Their work and work of others has generally shown that species diversity increased asymptotically with island area (Deshaye and Morisset 1989; Gilpin and Diamond 1980; Seagle 1986; Simberloff and Abele 1982). (See Figure 2-4.) In addition to island area, an important influence on species diversity was distance to the mainland or other large land mass. All other things being equal, islands that were a long way from a continent tended to have fewer species than those that were close to continents (MacArthur 1972).

The relationship between island size and diversity is known as a *species area curve*. In addition to real islands (that is, land surrounded by water), species area curves have been documented for many "island-like" patches of habitat (e.g., mountain tops surrounded by lowlands) (Harris 1984; Brown 1971). (See Figure 2-5.) The generality of this relationship is believed to result from the balance between immigration rates (the number of species arriving at an "island" per unit time) and extinction rates (the number of species going extinct) (MacArthur 1972). As island areas decline, persistence time declines and extinction rates increase. As distance from other land masses or other sources of immigrants increase, colonization rates (the rates at which animals from other areas find their way to the island) decline. The number of species found on an island is the number present when extinction rates and colonization rates are equal.Thus, based on this theory and many subsequent empirical studies, it is reasonable to predict that large intact patches of habitat are likely

Figure 2-4. Island Size and Species Diversity



to support a larger number of species than small patches will.

Summary. The value of protecting large, intact habitat patches of habitat is supported by many studies documenting that the area of a habitat patch exerts a strong influence on wildlife population size. Population size, in turn, influences the persistence time of populations such that populations with large habitat patches tend to persist longer than those that make a living in small ones. Finally, species diversity tends to increase asymptotically with increased patch area.

Principle 2. Establish Priorities for Species Protection and Protect Habitats that Promote the Distribution and Abundance of those Species.

Action Required to Implement Principle 2

Applying ranking systems to identify species that will receive priority for protection and for investment in conservation. Learn about the habitat requirements for those species and devise protection and management plans to ensure that habitat requirements are met.

Scientific Rationale for Principle 2

Principle 2 is based on the frequent observation that a relatively small number of features of habitat are likely to be particularly important in determining the survival and reproduction of individual species. For example, Abert's squirrels require mature ponderosa pine for nesting, willow flycatchers require dense shrubs in riparian areas, and bighorn sheep require meadows in close proximity to rocky outcrops. Principle 2 can be thought of as the "devil is in the details" rule—managing to ensure persistence of species requires a detailed understanding of their life histories and habitat requirements. It is unreasonable to expect that such understanding could be accrued for all of the wildlife species in a given location. Consequently, it is important to "narrow the field" by setting some priorities for protection.

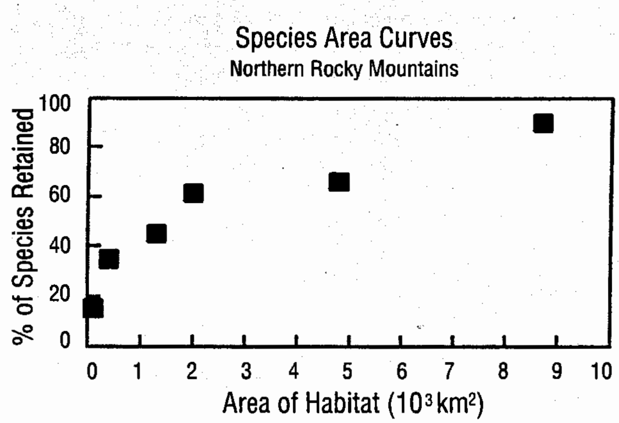
There are a variety of systems for such prioritization. Some emphasize the need to preserve a wide variety of species, while others focus on threats to persistence, the economic and aesthetic value of the wildlife, or other factors (Milsap et al. 1990; Master 1991; Given and Norton 1993; Gross et al. 1995). These systems can be used in combination with an understanding of local values to select a set of species that will receive particular attention in conservation efforts.

Principle 3. Protect Rare Landscape Elements. Guide Development Toward Areas with More Common Landscape Elements.

Actions Required to Implement Principle 3:

Principle 3 requires an inventory of wildlife habitats and vegetation within the landscape of interest. Such inventories can be used to identify landscapes, such as wetlands, riparian zones, cliffs, or old growth forest, that are uncommon or are necessary to support rare or threatened species. Development can be encouraged in other areas with a more predominant vegetation type.

Figure 2-5. Rocky Mountain Species Area Curve



Scientific Rationale for Principle 3:

Implementing Principle 3 is fundamentally important to all wildlife protection efforts because the diversity of wildlife species found on a landscape depends on the diversity of habitats available to them (Forman and Godron 1981; Marcot and Meretsky 1983; Fox 1983; Forman 1995). Habitat diversity in turn, can be markedly reduced if "uncommon" parts or features of habitats are lost.

To illustrate why habitat diversity is so important, think of a richly sewn patchwork quilt of many colors and fabrics and compare it to a simple wool blanket. The patchwork quilt has much greater diversity in its pattern than the blanket does. Just like the quilt, most landscapes contain several different habitat types juxtaposed in complex patterns—sagebrush is interspersed with grassland and riparian zones, stands of aspens are mixed with oakbrush, conifer forests are dotted with meadows. Increased mingling of different patches of vegetation creates a greater variety of "places to live" for wildlife species (Forman 1995).

This is the case because dissimilar habitats provide for the nutritional and reproductive requirements of different species. Whenever those dissimilar types occur together on the landscape, a greater variety of species can make a living there. The best example of this variety is seen in riparian zones, where water and land come together. This coming together allows for a much greater variety of species than would be found on land or in water alone.

This is important because habitat types are almost never distributed equally across a landscape. Some are rare, and some are common. It follows that rare habitats can contribute a disproportionate share of the diversity of wildlife that are found in a given place. For example, imagine that a hypothetical landscape is 95 percent grassland and 5 percent riparian. There are 200 species on the entire landscape, 100 of them depend on the riparian zone. Loss of 5 percent of the habitat area can lead to a 50 percent decline in species if that loss comes from the riparian zone. Thus, if these rare elements of landscapes are converted to human uses, particularly to residential development, a precipitous decline in wildlife diversity may follow. In contrast, wildlife diversity may be relatively insensitive to development that occurs in the more common habitat types. This creates opportunity for compromise in planning for development. The needs of people can be accommodated alongside the needs of wildlife if people are willing to adjust their distribution to avoid habitats for wildlife that are in short supply on the landscape.

Principle 4. Maintain Connections among Wildlife Habitats by Identifying and Protecting Corridors for Movement.

Action Required to Implement Principle 4

Whenever possible, map routes of movement among seasonal ranges of important wildlife species. In addition, try to identify small patches of vegetation that provide "stepping stones" among large, core patches described above. Protect these movement routes and stepping stones.

Scientific Rationale for Principle 4

We acknowledge from the outset that the importance of corridors in achieving habitat protection is scientifically controversial (Simberloff 1988; Hobbs 1992; Mann and Plummer 1995). In addition to creating the beneficial affects described below, some researchers conclude that connections among habitat areas could promote the transmission of disease and could concentrate animals within a given space, making them more vulnerable to predators. However, our view is that protecting corridors probably does no harm (but see Hess 1994) and is likely to offer substantial benefits to wildlife for the reasons described below.

Corridors are areas of the landscape that are more likely to be used for movement among habitat patches than other areas (Forman 1995). When we think about protecting corridors, there are two ways we can approach the problem. First, we can determine and map the routes that are used by wildlife to move among habitats by simply observing such movements with radiotelemetry or other techniques. Such routes are what most people think of when they talk about movement corridors.

Although that approach provides an intuitive way to identify corridors, it is very expensive. As a result, it tends to be used only for a few economically important species like elk or moose. What can be done to identify corridors for the many other species of wildlife?

One possibility is to identify stepping stones among major habitat types (Figure 2-6). In many cases, there are small patches of vegetation that tend to bridge the gaps between large ones in the same way that rocks in a stream bridge the gap between its banks. Most geographic information systems include analytical tools that can help identify these patches. In the absence of empirical studies of animal movements, we must simply presume that protecting these patches will facilitate movement among large, intact habitat patches. By making this presumption, we can protect corridors

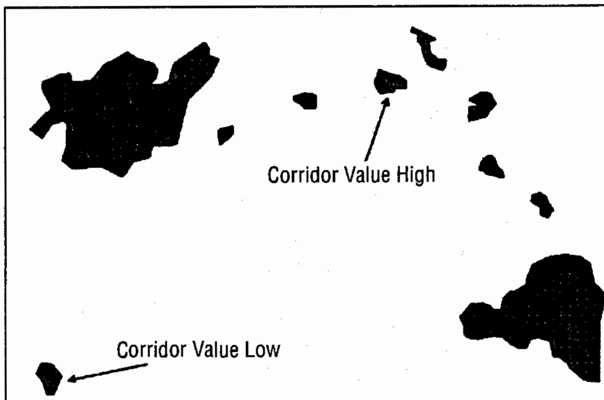


Figure 2-6. Stepping Stones

for entire communities of species using those patches.

Corridors are important because, by definition, they are areas of the landscape that facilitate movement among populations. Such movement is valuable for three reasons.

First, many species must move among seasonal ranges in order to meet their requirements for food and cover at different times of the year (Edwards and Ritcey 1956; Taber and Dasmann 1957; Herbert 1973; Risenhoover and Bailey 1985; Wilcove 1985; Shaw and Carter 1990; Kozakiewicz 1993; Boyce 1991). Eliminating movement routes for these migratory species can prevent them from meeting their seasonal needs for feeding and/or reproduction. For example, deer and elk typically use high-elevation ranges during the summer and lowlands in the winter. Often, migration occurs along drainage corridors connecting these areas. If migration routes among seasonal ranges are cut off, large areas of habitat can be rendered inaccessible. Such reductions in habitat area will compel reductions in population size as described above.

Second, populations that are connected to each other by the process of dispersal are more likely to persist than isolated populations (Wiens 1990; Stacey and Taper 1992; Wissel et al. 1993; Verboom et al. 1993). Successful dispersal among populations enhances persistence because a large population can "rescue" a small one from extinction by providing a source of immigrants—like "reinforcements" to an imperiled garrison. If immigrants arrive in a small population that is on the verge of extinction, they can help the imperilled population recover from a run of bad luck to achieve viable size.

Third, successful dispersal among populations prevents inbreeding and helps to maintain genetic variability within populations (Simberloff 1988; Lande and Barrowclough 1987). Such variability is associated with enhanced vigor, survival, and reproduction (Deforge et al. 1979; Beardmore 1983; Sausman 1984; Charlesworth and Charlesworth 1987; Hass 1989).

In contrast, blocking corridors or allowing development in locations that isolate wildlife populations can:

- reduce the area of habitat available to species;
- increase the likelihood of population extinction by reducing immigration; and
- exacerbate genetic problems that result from inbreeding

Principle 5. Maintain Significant Ecological Processes such as Fires and Floods in Protected Areas.

Action Needed to Implement Principle 5

Many natural ecological processes are necessary to maintain plant and animal communities within the landscape. Examples of ecological processes include periodic fires, floods, and distribution of habitat materials thrown by the wind. Local communities should consult with private and public land managers and ecologists to identify which ecological processes are most important to the community's priority wildlife species, and to ensure that those processes are sustained.

Scientific Rationale for Principle 5

Habitat protection has traditionally been viewed as an essentially passive process (Botkin 1990). In this process, we prevent development or resource extraction from an area of land. Preventing development, by itself, is thought to be sufficient to sustain the value of habitat. We have assumed that, if we leave nature alone, we will protect wildlife and its habitat. This intuitively appealing approach has been

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Supression of fire is a main factor endangering the hairy rattleweed, a perennial legume.

strongly challenged in recent years because ecologists have realized that "disturbance" of landscapes by events like fire, grazing, and flood is fundamentally important to maintain the plants and animals native to those landscapes (Pickett and Thompson 1978; Pickett et al. 1992). Thus, "leaving nature alone" will often fail to protect habitat if sources of disturbance are not maintained.

For example, the Colorado Division of Wildlife recently studied historical changes in the structure of a riparian landscape along the North Platte river. The area was purchased to protect wildlife habitat during the 1920s. The division mapped and analyzed the spatial distribution of patches of cottonwood forest using aerial photographs taken in 1937 and 1990. During that time interval, there were many impoundments built along the river, and the division's analysis showed that the cottonwood community that was ostensibly protected by a conservation purchase was in fact being lost because of the absence of annual flooding. Although conservationists bought the parcel, they ignored the process, and as a result lost much of the conservation value of the area. This work reveals that all facets of the landscapes are embedded in a larger context and the processes that operate in that larger context are critical to conservation.

There are many other examples. Periodic burning and grazing is needed to maintain native species in tallgrass prairie, and ground fires are needed to ensure regeneration of oak forests. In the absence of these sources of disturbance, wildlife habitat can be lost through natural processes of succession no matter how well it is "protected" from human use.

Maintaining appropriate levels of disturbance will frequently require active management of the land rather than passive protection. Often, it is necessary to substitute management actions for natural disturbance events. For example, prescribed burns might take the place of uncontrolled natural fires, logging might be used to simulate natural canopy gaps, livestock could serve as a surrogate for absent native herbivores, and releases of water from impoundments can be timed to mimic natural runoff.

As an example of active management to preserve disturbance, we now consider how intelligent planning for development can actually enhance the persistence of threatened species relative to passive protection alone. Consider the first Habitat Conservation Plan developed as part of the implementation of the Endangered Species Act in San Bruno Mountain, California during the 1970s. Habitat Conservation Plans are what they sound like—comprehensive plans for the conservation of habitat for threatened or endangered species. They allow for development in the habitats of such species, provided that active measures are taken to preserve and enhance habitat adequate to ensure viable populations of the species in questions. In the San Bruno Mountain case, habitat for the endangered mission blue butterfly was threatened by proposed development. However, it was also threatened by loss of habitat due to natural processes occurring in the absence of development. The mission blue butterfly is dependent on a species of flower only found in the native grassland, which was rapidly being converted to non-native species. Maintenance of native plants in the area required active management, which required steady funding. By implementing a conservation plan, developers provided the funding for management and restoration required to maintain the butterfly's habitat. In return, they were allowed to develop areas of habitat that would have been off limits if a conservation plan had not been put into place. Habitat Conservation Plans are discussed in much more detail in Chapter 6 and Appendix B.

Principle 6. Contribute to the Regional Persistence of Rare Species by Protecting Some of their Habitat Locally.

Action Needed to Implement Principle 6

Map wildlife habitat at state or regional scales and identify habitats that are rare or are home to sensitive wildlife species. Protect and manage some of those rare habitats in local conservation plans, especially if the local area contains a large proportion of the total habitat in the region. In other words, local communities need to think regionally and act locally.

Scientific Rationale for Principle 6

John Wesley Powell, a geologist who explored the American West following the Civil War, argued many years ago that the political boundaries of the West should respect the important environmental boundaries—particularly the limits of watersheds. Unfortunately for conservation, his arguments were never implemented, and, as a result, the existing political boundaries can cause serious gaps in species protection. This is because habitats and populations that are abundant within a political jurisdiction may be regionally rare, while regionally abundant species may be rare locally. In either case, knowledge of the status of species beyond the political boundaries is a prerequisite for intelligent conservation planning at the local level. Without looking beyond the political boundaries of municipalities or counties, it is possible that effort will be wasted in protecting species that are regionally abundant or that opportunities will be forgone to protect species that are regionally rare.

Principle 7. Balance the Opportunity for Public Recreation with the Habitat Needs of Wildlife.

Action Needed to Implement Principle 7

Ensure that some protected areas remain in private ownership not open to the public in order to reduce intensity of use by recreationists. Regulate recreational use of protected habitat on public land to minimize impacts on sensitive species.

Scientific Rationale for Principle 7

There is some evidence that human recreational activity can disturb wildlife populations to the extent that they will fail to thrive in heavily used areas. It follows that a comprehensive conservation plan would be wise to include some protected areas where recreational use can be limited to levels that are appropriate for wildlife protection.

FIVE BIOLOGICAL PRINCIPLES FOR HABITAT PROTECTION AT THE SITE SCALE

The smaller scale of wildlife habitat protection is the site scale. For our purposes, the site scale ranges from individual lots and neighborhoods to entire residential or commercial developments. We focus on species and habitat threatened by human activities. Again, the relevant question is How do we maintain the integrity of wildlife habitat to the greatest extent possible in the immediate vicinity of areas developed for human use? Thus, the overall goal is to sustain wildlife populations and in so doing to enhance the quality of the present and future human environment.

Although ecological investigations about wildlife are legion, relatively few studies have been conducted specifically in an urbanizing context. As a result, we must often extrapolate from studies conducted in nonurban settings and apply the results to areas where people live. Many investigations of the impacts of human activity on wildlife have focused on game animals, and we must thus cautiously extrapolate results to nongame species. Finally, most wildlife studies are of relatively short duration—three years or less. It is quite possible that the full effects of urbanization on wildlife may not become apparent for longer periods of time (Aldrich and Coffin 1980). For example, researchers in San Diego found that the number of years since canyons were isolated from larger tracts by residential development was an important factor in predicting extinction rates for bird species found there (Soule et al. 1988; Soule et al. 1992).

With these caveats in mind, our goal is to recommend ways to achieve a reasonable balance between the needs of people living in a community and the needs of wildlife—based on ecological principles and the best scientific information available. Where information is not available, we advocate a conservative approach in the hope of keeping options open. It is easier to retain habitat and protect species now than it is to replace them once they are gone.

Table 2-5 summarizes a number of fundamental principles for the conservation of wildlife at the site scale. These principles are by no means exhaustive and can be modified or built upon as information from relevant ecological studies accumulates.

Principle 1. Maintain Buffers Between Areas Dominated by Human Activities and Core Areas of Wildlife Habitat.

Action Required to Implement Principle 1

Designate habitat patches as core areas on the basis of their importance to wildlife. Relegate human activities to one or more buffer zones surrounding a core area, with more intense activities restricted to more distant zones. Visual buffers, such as a row of trees or shrubs, may also prove effective in mitigating human disturbance. If people must pass through the core area on foot or bicycle, limit them to a well-defined trail.

Table 2-5. Five Biological Principles for Wildlife Conservation at the Site Scale

Principle 1	Maintain buffers between areas dominated by human activities and core areas of wildlife habitat.
Principle 2	Facilitate wildlife movement across areas dominated by human activities.
Principle 3	Minimize human contact with large native predators.
Principle 4	Control numbers of midsize predators, such as some pets and other species associated with human-dominated areas.
Principle 5	Mimic features of the natural local landscape in developed areas.

Scientific Rationale for Principle 1

Human activities in or near wildlife habitat may cause some animals to alter their activity and feeding patterns. Although such alterations may seem relatively harmless at the time to the casual observer, they may have serious consequences for the animal. For example, stress that results from human disturbance may lead to increased susceptibility to disease, reduced reproductive output in some species, or abandonment of the area temporarily or permanently.

In order to mitigate the effects of human activity, we must first have an appreciation for the range of potential impacts on wildlife. Flushing distance (i.e., the distance from disturbance at which an animal flees) depends on the type of disturbance and the species. Information on flushing distances is available for a number of species, and these data may provide some guidelines regarding appropriate buffer sizes.

Effects of traffic on wildlife. Some wildlife species appear to alter their habitat use as a result of traffic, associated noise, or a combination of the two (Singer 1978; Rost and Bailey 1979; van der Zande et al. 1980; Reijnen et al. 1987). In the foothills of the Canadian Rockies, for instance, habitat use by elk is strongly related to the proximity of roads. Elk used grassy areas near roads only in the early morning and late evening, when traffic volume is lower. They are, however, found in similar areas when there is a visual buffer between the grassy area and the road (Morgantini and Hudson 1989).

Distance from roads and traffic intensity on the roads influence the response of some species (MacArthur et al. 1982). In the Netherlands, breeding grassland bird densities were diminished for up to 1.2 miles from a busy highway, while a quiet rural road had similar effects on birds only within 0.3 miles (van der Zande et al. 1980). Some studies show that disturbance in open terrain, such as traffic or noise, may be more severe than in woodlands for birds as well as some other animals (van der Zande et al. 1980; Gabrielson and Smith 1995).

Effects of hikers on wildlife. It is possible that people walking along a road or trail have an even greater effect on wildlife activity patterns than vehicular traffic. This is because people on foot pass through an area much more slowly (Gabrielson and Smith 1995). Deer and elk, for example, have been known to alter habitat use as a response to hikers on trails (Rost and Bailey 1979). Still, if people must pass through a core habitat area, it is probably preferable to have them walking on a well-defined path. People following a well-used trail become predictable, as does motorized traffic on busy roads. The activities are channeled or constrained to occur in the same place, and often at certain times of the day. Some wildlife species appear to habituate to predictable human activity if the disturbances are perceived as non-threatening (MacArthur et al. 1982). For wildlife, habituation is defined as the gradual disappearance of behavioral or physiological responses to repeated stimulation. Habituation is unlikely when disturbance occurs at irregular times and places. For this reason, humans moving unpredictably through an area seem to provoke a stronger response than does motorized traffic on roads or people on trails (Gabrielson and Smith 1995).

Physiological responses of wildlife to stress. When surprised or threatened, wildlife react in a number of ways, occasionally "playing possum" or assuming a defensive posture, but more often fleeing. Active responses to human disturbance are typified by the animal's running or taking flight in order to escape. This sort of response is associated with a number of profound physiological adjustments, such as increased heart and respiration rates, elevated blood sugar, increased blood flow, and increased body temperature—in other words, stress (Gabrielson and Smith 1995). Energy costs associated with an active response to human disturbance may have serious consequences for animals. This is especially true during critical times of the year, such as the postnatal period for mammals or the breeding period for birds, when an animal's energy reserves are already depleted and further stress may result in diminished reproductive output. For birds, disturbance may result in slower growth or premature fledgling for nestlings, and in nest evacuation or abandonment by the parents. Even if the parents eventually return to the nest, the eggs or young may be lost to predators in their absence.

Core area/buffer concept. What might be done to mitigate the effects of vehicular and pedestrian traffic? One approach involves the use of buffer zones, which are analogous to minimum impact areas at the landscape scale. One of the first expressions of this concept in a conservation context focused on old-growth ecosystems in the Pacific Northwest and involved "multiple-use modules" (Harris 1984). The basic idea was to establish a core area of sensitive habitat surrounded by buffer zones, with human use of increasing intensity permitted in the buffers as one moved away from the core (Harris 1984; Noss and Harris 1986). The notion of the core/buffer concept could also be applied in a suburban or rural setting. (See Figure 2-7.)

The first step is to identify sensitive or important habitat. Top priority should be assigned to habitat for threatened or endangered species, species that are particularly sensitive to human activity, habitat that is regionally unique, and areas that support large numbers of native species. Consideration should also be given to habitat that is rare locally or may have

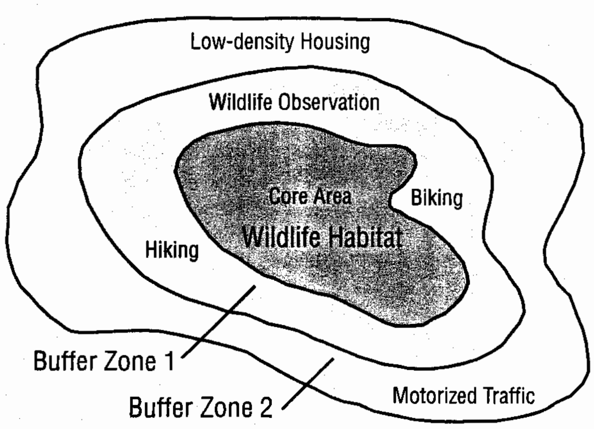

Figure 2-7. The Core/Buffer Concept

educational value, such as wetlands, riparian areas, large meadows, or woodlots. Roads and motorized traffic should be disallowed in the core area, but could occur in one or more of the buffers. Ideally, nonmotorized traffic and hikers would also be relegated to a buffer zone. The next best option is to limit this type of activity to the periphery of the core area. If hikers or bikers must be allowed to pass through a core habitat area, it would be best to limit their activities to marked trails. This might be accomplished by constructing short, natural-looking fences (split-rail, perhaps) along the trail that would direct the flow of human traffic, maintain a rustic visual impression, but still permit wildlife movement. In this way, wildlife may habituate to human intrusion by making its location predictable, with the added benefit of reducing "braided" trail systems. A braided trail system is one in which the hiker has different options for side trails that eventually rejoin the main trail—but result in disturbances over a wider area.

Alternative or complementary approaches to spatial buffers include visual barriers and temporal buffers. Visual barriers might take the form of a row of trees or shrubs along a road or hiking trail. Again, such barriers appear to be effective for some large mammals in mitigating human disturbance (Morgantini and Hudson 1980). Visual barriers can also serve the dual purpose of keeping people on designated trails. Temporal buffers would simply involve the limitation or exclusion of human activity in or near sensitive areas during critical times of the year, such as the nesting period in birds or the immediate postnatal period in mammals (Gabrielson and Smith 1995). Although these are perhaps the most critical times for some species, disturbance at other times of the year may also have important consequences. For example, winter is a time of food limitation for many species, a time when energy budgets are already strained (Hobbs 1989).

How far from a core area should a road or hiking trail be? The answer depends on which species are likely to be found there or which species are the targets of conservation efforts. For a few species, rough guidelines are available in the form of reported "flushing" distances (i.e., the distance from a disturbance at which an animal flees to a new location). (See Table 2-6.) This distance is variable, and depends upon a number of factors, including the nature of the disturbance, the individual animal, the degree to which it has been habituated to the disturbance, the habitat type, and the season. A distance of approximately 600 feet is recommended for mule deer to avoid most flight (Freddy et al. 1986; Ward et al. 1980), while distance reported for elk range from 50 to 1,300 feet (Schultz and Bailey 1978; Cassirer et al. 1992), depending on the type of disturbance and prior habituation.

Some researchers have recommended distances from 250 to 1,000 feet in order to avoid 90 percent of flushing in reaction to a person on foot for a variety of wintering grassland raptor species, including the American Kestrel, Merlin, Prairie Falcon, Rough-legged Hawk, Ferruginous Hawk, and Golden Eagle (Holmes et al. 1993). The mean flush distance for wintering adult Bald Eagles along the Nooksack River was 650 feet in response to pedestrians (Stalmaster and Newman 1978).

When relevant estimates of flushing distances are available, we advocate a conservative approach in determining buffer sizes because no study can exhaustively account for the many factors involved in determining the distance at which an animal flushes. An example of a conservative approach for establishing setback distances for colonial water birds involves using the mean flushing distance, plus one-half the mean, plus 130 feet as the width of a buffer zone (Rodgers and Smith 1995). In some cases, the flushing distance can be affected by the amount of cover in the area. If more cover is available around the animal, it may feel less threatened by a given disturbance or may need to move a shorter distance in order to feel safe. There is an

Table 2-6. Approximate Average Flushing Distances Based on Published Studies			
Species	**Disturbance Factor**	**Flushing Distance (in feet)**	**Source**
Double-crested cormorant	People walking directly toward nest	92	Rodgers and Smith 1995
Great blue heron	"	105	"
Black-crowned night heron	"	98	"
American kestrel	Person walking toward perched bird in winter	144	Holmes et. al. 1993
Merlin	"	250	"
Prairie falcon	"	300	"
Rough-legged hawk	"	580	"
Ferruginous hawk	"	207	"
Golden eagle	"	738	"
Bald eagle	Person walking during breeding season	1562	Fraser et. al. 1985
Bald eagle	Land activity near roost	820	Stalmaster 1980
Mule deer	Person walking in winter	656	Freddy *et al.* 1986
Mule deer	Person walking in winter	282	Ward *et al.* 1980
Elk	Person walking in winter	282	Schultz and Bailey 1978
Elk	Cross country skiers in low use area	1312	Cassirer *et al.* 1992
Elk	Cross country skiers in high use area	29	"

Source: Miller 1995

urgent need for information covering a wider variety of situations for more species and in more settings.

Principle 2. Facilitate Wildlife Movement Across Areas Dominated by Human Activities.

Action Required to Implement Principle 2

Provide for parcels of open space that are as large and continuous as possible within the constraints of site-scale planning. Maintain connectivity between these parcels. Locate roads and recreational trails away from natural travel corridors used by wildlife, such as riparian areas. Provide alternatives to crossing busy roads, such as underpasses, especially during road construction. Minimize fencing types that inhibit the movement of wildlife species that are likely to occur in the area. Minimize the visual contrast between human-dominated areas, including individual lots, and less disturbed terrain in the surrounding area.

Scientific Rationale for Principle 2

As mentioned earlier, the probability of extinction is inversely proportional to population size. That principle is just as true at the site scale as at the landscape scale. This suggests that local extinction—especially in an urban area that is highly fragmented and permeated by relatively intense human activity—is best avoided by maintaining large parcels of open space because larger areas generally support more individuals of a given species. The success of this strategy is enhanced if the parcels are contiguous or nearly so. For habitat patches that are not connected, corridors may facilitate dispersal as well as daily and seasonal movements (Soule 1991a; Noss 1993).

Although the corridor concept has been incorporated into many management plans, probably due to its intuitive appeal, the utility of corridors has been the subject of much debate (Simberloff and Cox 1987; Noss 1987). Much has been written on the topic, but overall there is little evidence, pro or con. A few studies indicate that some species seem to prefer corridors when they are available (Wegner and Merriam 1979; Dmowski and Kozakiewicz 1990; Merriam and Lonoue 1990), and there is an accumulation of observational data suggesting that animals use corridors (Bennett 1990; Saunders and Hobbs 1991). Experimental studies and manipulations are a prerequisite for more conclusive evidence, and such studies are both difficult and expensive to conduct. Still, it is likely that corridors increase the probability of movement between larger areas and may be especially important for species that are sensitive to barriers in an urban context. There is little doubt that it is more cost-effective to maintain existing connections than to recreate them (Hobbs 1992). Corridors should be considered in the context of local and regional conservation strategies and options (Simberloff et al. 1992), as well as site context and the ecology of target species, including home range, dispersal abilities, social structure, and foraging patterns (Lindenmayer and Nix 1993).

Roads as barriers to wildlife movement. The term "corridor" has also been applied to underpasses and tunnels connecting habitat on either side of a busy road or highway (Simberloff et al. 1992). Road kills of animals by vehicles are the most obvious impact on wildlife. Lalo (1987) estimated that 1 million vertebrates per day are killed on roads in the U.S. Populations of

James C. Leupold, U.S. Fish & Wildlife Service

Road kills and free-ranging dogs have added to the mortality of the deer population.

most small vertebrates tend to recovery rather rapidly from such losses (Bennett 1991), but the impact on populations of larger animals or rare species may be substantial. In Florida, for example, road kill is the leading source of mortality for all remaining large mammals except the white-tailed deer, including most of the large endangered species (Harris and Gallagher 1989). Roads also serve as barriers to dispersal for a variety of animals that are reluctant to cross them (Oxley et al. 1974; Wilkins 1982; Swihart and Slade 1984; Brody and Pelton 1989). One researcher asserts that roads may be "the single most destructive element of the habitat fragmentation process" (Noss 1993, 60).

There have been a number of attempts to reduce road kill and facilitate animal movement across roads, and these efforts have met with mixed success. Methods involving reflectors, fences, one-way gates, and wildlife crossing signs have for the most part been relatively unsuccessful (Forman 1995). Tunnels or underpasses, on the other hand, have been proven effective for a variety of species (Reed et al 1975; Singer et al 1985; Langton 1989; Mansergh and Scotts 1989). For existing roads, retrofitting underpasses is often prohibitively expensive. The opportunity to incorporate underpasses or tunnels into the construction of new roads is much more cost-effective and should be a consideration (Soule 1991b). One approach is to identify at least two species from the local or regional pool: the largest animal expected to use the underpass and the species for whom the road is likely to be the greatest barrier. Then design the structure with them in mind (Forman 1995). The assumption is that success for these two species should translate into success for a variety of other animals.

Fences as barriers to wildlife movement. In addition to roads, fences also inhibit movement for some species, and both barriers tend to increase with residential development. Fences that restrict movement are desirable in some instances, such as pet control. When privacy or aesthetics are the issue, however, barrier effects can be reduced by minimizing fencing, or at least fence types that are unfriendly to wildlife. Chain link fences, for example, would prevent movement by many mammal species, whereas split rail fences may not. Another alternative involves the use of fence substitutes, or "living" fences (e.g., shrubs), that serve some of the functions of fences but still allow wildlife to move through them. Furthermore, dense clumps of shrubs, perhaps in combination with a row of trees, may also provide nest sites, food, or cover for wildlife while serving as a visual screen or barrier to movement of humans. Back lot lines are commonly the least manicured area on a lot and, as a result, are likely to support native plants and animals while maintaining connectivity in a suburban neighborhood (Forman 1995).

Principle 3. Minimize Human Contact with Large Native Predators.

Action Required to Implement Principle 3

Prevent wildlife from associating food with humans by exercising tight control over potential sources of nourishment, such as garbage or food for domestic animals. Prevent pets from roaming freely in areas known to be inhabited by large predators (e.g., black bear, mountain lions, alligators).

Scientific Rationale for Principle 3

Perhaps nowhere is the need to minimize human contact with animals greater than with predators, particularly large predators. When people choose to live in close proximity to these species, there are attendant risks and responsibilities. The risk is that they may come into contact with a large predator, potentially resulting in harm or death. Our responsibility involves minimizing opportunities for predators to be rewarded by coming into contact with us. We have proven ourselves extremely efficient at eliminating these animals when we choose (Lopez 1978; but see Wilkinson 1995) but much less capable of coexistence.

To understand the basis for this conflict, imagine a pyramid with the various levels occupied by organisms that feed on the same general type of food (i.e., a trophic pyramid) (Elton 1927). The bottom tier is occupied by the most numerous organisms, such as plants. The next level is occupied by herbivores (species that eat plants and are therefore less numerous because it takes many plants to sustain an herbivore over its lifetime). Carnivores occupy the highest levels, with smaller carnivores consuming smaller herbivores, and larger predators feeding on herbivores in addition to preying upon some of the smaller carnivores. Again, there are necessarily fewer animals at the top of the pyramid because it takes a number of prey to support one predator.

This metaphor is admittedly oversimplified but is meant to illustrate two points. First, large predators exert a certain measure of control over the lower levels, at least in some cases. Second, a consequence of being at the top of the trophic pyramid is that, in a sense, it places these animals in direct competition and conflict with the most prolific consumer of all—man.

Habituation of predators to human food sources. For many predator species, habituation to people and their activities is not desirable. When large predators learn to associate humans or their residences with food, it probably means trouble for the humans and almost certainly eventual death for the animal. As we encroach upon the habitat of these species, we must make every effort to exert tight control over potential food sources. Garbage is irresistible to many large predators and other wildlife, and should be secured in animal-proof containers. The same can be said of food for domestic animals, barbeque grills, and compost piles. Wildlife need to associate either people or their environs with food only once. Once learned, the association is virtually indelible and will determine the animal's behavior.

The role of large predators in maintaining prey populations. Although top predators have often been persecuted as a result of negative impacts on their prey, they actually may play a role in maintaining populations of some species. As mentioned above, it has been suggested that large predators exert considerable control on populations of smaller predators (Soule et al. 1988; Harris 1989). In the absence of large predators, smaller predators may experience population explosions, in some instances increasing by several orders of magnitude (Terborgh and Winter 1980; Emmons 1984). This phenomenon has been termed "mesopredator release" (Soule et al. 1988). As the density of mesopredators increases, so does their impact on their prey—birds, nestlings, small mammals, amphibians, and reptiles. This may in turn affect other species, such as birds of prey, that rely upon the same prey base (George 1974).

Mesopredator release is difficult to prove, but there is a growing body of evidence supporting this phenomenon. Soule et al. (1988) provide both statistical and circumstantial evidence that the disappearance of coyotes from habitat islands in San Diego resulted in increases in smaller predators, such as gray foxes and domestic cats, which in turn increased predation pressure on birds. On Barro Colorado Island in Panama, an increase in the number of smaller predators appeared to be related to the extinction of the puma (Glanz 1982). Lindstrom et al. (1994) reported that red foxes in Sweden played a key role in suppressing a number of species of small game. Numbers of red fox have increased because forest clear-cutting created high-quality habitat for this midsized predator while humans have eliminated its natural enemies, such as wolves. In Spain, Palomares et al. (1995) report that Iberian lynx appear to control mongooses, resulting in increased densities of the latter's staple prey, the European rabbit. Pet owners especially should note that smaller predators sometimes function as prey items for larger carnivores. Domestic pets should not be allowed to roam freely in areas likely to be inhabited by large predators.

Principle 4. Control Numbers of Midsize Predators, such as Pets and Other Species Associated with Human-Dominated Areas.

Action Required to Implement Principle 4

Prevent domestic pets, especially dogs and cats, from roaming freely. As an alternative, provide designated areas where people can exercise or "run" their pets. Control potential food sources, such as garbage, for small to midsize predators that thrive in human-dominated environments.

Scientific Rationale for Principle 4:

In human-dominated environments, small to midsize predators often exist at high densities. For domestic pets, such as dogs and cats, the reason is obvious. Some wild animals, such as raccoons and striped skunks, also reach much higher densities in urban as opposed to rural areas (Hoffman and Gottschang 1977; Rosatte et al. 1991).

Impacts of midsize predators on other species. These species prey upon small mammals, amphibians, reptiles, and songbirds, including eggs and nestlings (Churcher and Lawton 1987; Harris and Silva-Lopez 1992). The mortality attributed to these predators is staggering. Churcher and Lawton (1989) estimate that domestic cats in Britain kill nearly 70 million birds and small mammals per year. An illustrative example is provided by Stallcup (1991), who suggests that with 55 million cats in the U.S. (a conservative estimate of the Pet Food Institute) and excluding 20 percent that are old or do not leave the house, and assuming that 1 in 10 cats eats a songbird per day, the daily death toll would be 4.4 million birds. Even if these estimates are off by an order of magnitude, the impacts are substantial. Human-dominated areas are degraded by the reduction or elimination of songbirds and other desirable species. Animals that nest on or near the ground may be particularly vulnerable (Emlen 1974; Guthrie 1974; Weber 1975; Vale and Vale 1976).

Supplemental food sources. In addition to pets being kept by people, there are two basic reasons that feral cats and dogs, as well as other species, such as raccoons, reach such high densities in urban areas. First, there is a variety of structures to serve as shelter for these species, such as abandoned buildings, the crawlspace of a house, sewers, etc. Second, there is an abundance of feeding opportunities (Hoffman and Gottschang 1977; Haspel and Calhoon 1989). A primary source of supplemental food is garbage. One study showed that an urban neighborhood with poorly contained refuse supported nearly twice the number of free-ranging cats compared to an area where most refuse containers were covered (Calhoon and Haspel 1989). It follows that one simple step which homeowners can

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Urban conversion of coastal habitat puts humans in close contact with dangerous predators, such as the American crocodile.

take in an effort to maintain lower densities of wild or semiwild predators is to secure their garbage and food for pets.

Prevent pets from roaming freely. The death rates of small animals mentioned above were caused not only by wild species but also by domestic pets. How is it possible that well-fed pets could be responsible for exacting such a heavy toll? Laboratory studies indicate that, at least for cats, hunger and hunting are controlled by separate areas of the brain (Polsley 1975; Adamec 1976). In other words, some species continue to kill after their hunger has been satiated. This tendency may serve a purpose in the wild, where feeding opportunities are limited and prey capture is difficult (Adamec 1976), but it also enables well-fed pets to be very efficient predators. Furthermore, as Soule et al. (1988) have pointed out, animals that receive supplemental food from people can continue to take wildlife long after the prey base can no longer sustain a predator that relies on wildlife alone for food.

Principle 5. Mimic Features of the Local Natural Landscape in Developed Areas.

Action Required to Implement Principle 5

Retain as much predevelopment, high-quality habitat as possible, including some large patches. Keep levels of disturbance to trees, the understory, and other structural features to a minimum during construction. Design house lots in a fashion consistent with local natural habitats (e.g., by using native vegetation). Enhance the habitat value of degraded predevelopment landscapes with selective plantings.

Scientific Rationale for Principle 5

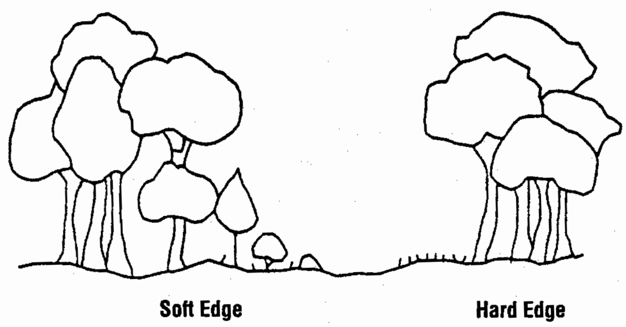
The most effective way to maintain the quality of habitat during residential or commercial development—and thereby enable native species to continue to persist after its completion—is to minimize habitat alteration during construction. Urban areas that have been designed with little regard for wildlife generally reflect this lack of planning in the assemblages of animals that live there. These faunas typically consist of species that are omnipresent in human-dominated environments and often become pests, including, for example, non-native birds, such as the House Sparrow, European Starling, and Rock Dove. With some planning and attention to landscaping, the presence of more desirable species can be maintained or increased.

Rather than design a new and artificial landscape, one should attempt to blend human developments in with the natural landscape. If the landscape was already highly degraded before development, with careful planning it may be possible to enhance its habitat value for some species. This is particularly true for a variety of bird species as well as some small mammals. In human-dominated areas, vegetation is a critical component of wildlife habitat, providing both food and cover. Fortunately, it is an element that can often be managed relatively easily.

Maintaining or enhancing habitat quality by managing vegetation. Most studies of the relationship between vegetation and wildlife conducted in an urban or suburban context have focused on birds. Adams (1994) suggested that the key to maintaining a diverse assemblage of birds in such areas is to have several layers of vegetation, such as ground covers, shrubs, and trees. (This idea has its genesis in the work of an eminent ecologist, the late Robert MacArthur, who quantified the relationship between increases in bird species diversity concurrent with vertical layering in vegetation, called foliage height diversity, over a range of habitats (MacArthur et al. 1961).) Some subsequent studies seemed to confirm this relationship (Karr and Roth 1971; Wilson 1974), while others asserted that the horizontal patchiness of vegetation was a better predictor of bird species diversity than was vertical layering (Roth 1976).

Generally, these relationships were explained in terms of food limitation and competition; more foliage means more food and more foraging sites (MacArthur et al. 1962). As an alternative explanation, Martin (1988) asserted that greater densities of plants provide a greater number of nesting sites and reduce the risk of predation. Finally,

Figure 2-8. "Soft" vs. "Hard" Edges



Source: L. W. Adams, *Urban Wildlife Habitats—A Landscaped Perspective* (Minneapois: University of Minnesota Press, 1994), 108.

there is evidence to support the notion that, in addition to plant diversity, the composition of the vegetation is also important (James and Wamer 1982; Rice et al. 1983; Anderson et al. 1983), and this may be related to the food resources that different species of plants provide (Rotenberry 1985). It seems likely that all of these factors—vertical and horizontal plant diversity, as well as plant composition—play important roles in determining which species are found in human-dominated areas.

Many studies have shown that bird assemblages in urban areas are characterized by fewer species but higher overall densities (Batten 1972; Geis 1974; Aldrich and Coffin 1980). These groups tend to be dominated by ground-foraging seed eaters and omnivores that nest on tree branches or buildings (Emlen 1974; DeGraaf and Wentworth 1981; Beissinger and Osborne 1982). Species that feed on insects, including those that winter in the tropics but breed in North America (e.g., Warbling Vireo, Common Yellowthroat, Black-headed Grosbeak), as well as birds that nest on the ground (e.g., Rufoussided Towhee), in shrubs (e.g., Yellow-breasted Chat, Veery), or in tree cavities (e.g., Downy Woodpecker) are either absent or occur at very low densities in urban areas (DeGraaf and Wentworth 1981). Suburban areas have a relatively greater diversity of birds, although the same species that dominate urban sites are still abundant in many suburbs. What features might account for these differences?

A number of researchers have suggested that the diversity of native bird species in urban areas depends on the amount of native vegetation that is present (Geis 1974; Mills et al. 1989; Sears and Anderson 1991). Urban areas are generally associated with fewer trees, shrubs, and areas of weedy growth than are suburbs (DeGraaf 1987). Thus, species that are able to use buildings and tree branches for nest sites are at an advantage in urban areas but are still able to benefit from this ability in suburban areas. The presence of bluegrass lawns provides feeding opportunities to ground-gleaning omnivores in both environments, and non-native ornamental trees and shrubs provide alternate sources of food for seed-eaters and omnivores but often have few insects (Beissinger and Osborne 1982). One explanation for this relationship, at least for birds that feed on invertebrates, is based on evidence that native vegetation may be associated with a greater number of insect species (Southwood 1961). DeGraaf (1987) further asserts that planted trees and shrubs, no matter how mature, do not suffice as breeding habitat for insectivorous songbirds, at least in the northeastern U.S.

Through planning and active management of vegetation, the possibility of retaining or enhancing predevelopment faunas is increased greatly. For instance, Goldstein et al. (1986) compiled a list of bird species that respond positively to the presence of predevelopment habitat features in suburban areas. The retention of fields and patches of trees and shrubs during development offer the best prospects for enhancing suburban bird assemblages (DeGraaf 1986). Where plantings are necessary, native trees and shrubs that provide cover, persistent fruits, seeds, and secure nesting sites offer good alternatives to non-native ornamentals (DeGraaf 1987). State wildlife agencies as well as local natural resources departments are good sources of information on locally occurring wildlife species and habitat-enhancing trees or shrubs.

Aside from arboreal mammals, such as squirrels, birds are probably more closely associated with vegetation structure than are mammals (D.M. Armstrong, personal communication). Still, concentrated areas of trees and shrubs, as well as weedy areas potentially serve as cover for many small mammals and are preferable to scattered trees and mowed lawns.

Minimizing edge effects. When we address edge effects at the local scale, we are usually referring to situations in which two fairly sizeable habitat patches meet, such as a residential area and a large field or woodlot. It makes little sense to attempt to minimize edge effects on a small individual house lot because, there, vegetation generally exists in strips or clumps rather than in large patches.

In our discussion of landscape-scale techniques, we have described a variety of edge effects and enumerated some potential consequences of edge for wildlife. There are several ways to minimize edge effects at the local scale. Habitat fragmentation may be reduced by consolidating artificial edges (Miller 1995). For example, instead of locating a trail through the middle of an intact habitat patch, place it alongside a road or along the perimeter of a subdivision. In addition to consolidating artificial edges, attempt to mimic naturally occurring edges. "Soft" edges (e.g., a variety of smaller shrubs that grade into larger shrubs and small trees at the edge of a wooded patch) provide more wildlife habitat than an abrupt or geometrically straight "hard" edge. Furthermore, soft edges are more aesthetically pleasing and require less effort to maintain.