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CHAPTER 11

Indirect Effects of Recreation on Wildlife

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Most of this book focuses on direct impacts to wildlife that result from contact with people. The purpose of our chapter is to provide a broad overview of the indirect influences that recreation has on wildlife. Recreational activities can change the habitat of an animal. This, in turn, affects the behavior, survival. reproduction, and distribution of individuals. Although more difficult to isolate and study, these indirect impacts may be as serious and long-lasting as direct impacts for many species.

Recreational Influences

Virtually all types of recreation alter some characteristics of soil, vegetation, or aquatic systems. By directly impacting these components, people affect an animal's food supply and availability as well as shelter, or living space. In turn, impacts on food and living space influence behavior, survival, reproduction, and/or distribution. These relationships (Fig. 11.1) provide the structure with which our chapter describes research on (1) recreational impacts to soil, vegetation, and aquatic systems, (2) the effects of these habitat changes on animals, and (3) the effects of recreation on wildlife in situations where habitat change appears to be the primary mechanism of impact.

Recreational Impact on Animal Habitats

Though a wide variety of outdoor recreational pursuits impact soil. vegetation, and aquatic systems, we will not distinguish between the effects of different forms of recreation except in the few cases where impacts are caused only by a particular sport or related business. The significance and magnitude of any effect are related to the extensiveness, intensity, and timing of the activity. The vulnerability and rarity of the habitat, and its importance to wildlife, should also be considered.

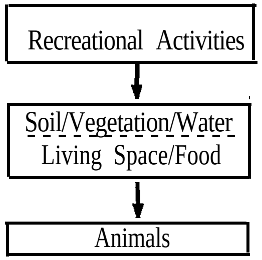

Figure 11.1 Simple conceptual model of the indirect effects of recreation on animals.

Numerous studies have documented the effects of recreation on vegetation and soils. Most of these studies report results of human trampling caused by hiking, camping, fishing, and nature study. Significantly fewer studies report the consequences of horse and bicycle riding or that of off-road vehicles and snowmobiles. Useful reviews of this literature include Liddle (1975), Manning (1979), Cole (1987), Hammitt and Cole (1987), and Kuss et al. (1990).

Impacts on soil include loss of surface organic horizons (Burden and Randerson 1972). compaction of mineral soil (Iverson et al. 1981), reductions in macro and total porosity (Monti and Mackintosh 1979), reductions in infiltration rates (James et al. 1979), and increases in soil erosion (Wilshire et al. 1978). Localized changes in soil chemistry have also been reported, but the precise changes noted have been inconsistent (Chappell et al. 1971; Cole 1982; Stohlgren and Parsons 1986). Other impacts include both reductions and increases in soil moisture (Settergren and Cole 1970; Blom 1976) and increases in the diurnal and, perhaps, seasonal range of soil temperature (Liddle and Moore 1974).

These changes in soil characteristics adversely affect the germination, establishment, growth, and reproduction of plants. Compaction reduces the heterogeneity of soil surfaces and, therefore, the density of favorable germination sites (Harper et al. 1965). Compaction increases the mechanical resistance of the soil to root penetration and can reduce the emergence of seedlings. Reduced macroporosity can result in oxygen shortages and less water being available to plants. These physical changes, along with reductions in organic matter and changes in soil microbiota, can seriously disrupt ecosystem processes (e.g., decomposition). They can impede soil-plant-animal interactions (e.g., nutrient cycling), causing decreased primary productivity.

The most obvious direct impacts on vegetation come from the crushing, bruising, shearing, and uprooting of vegetation that often accompanies recreational use. Various changes in individual plant characteristics occur, including reductions in plant height, stem length, leaf area, flower and seed pro-

duction, and carbohydrate reserves (Liddle 1975; Hartley 1976). Plants are often killed outright. Those that survive typically are not as vigorous and reproduce less successfully. Consequently, recreation areas characteristically have vegetation that is less abundant (reduced density and cover), of a reduced stature, and with a different species composition from undisturbed areas (Cole 1982; Luckenbach and Bury 1983; Cole 1993).

Species composition and vegetation structure change because species and growth forms differ in their ability to tolerate recreational disturbance (Dale and Weaver 1974; Cole 1982). They vary in their ability to resist being damaged, in their ability to recover from damage, and in their ability to flourish in the soil and microclimatic conditions that occur on disturbed sites. Some of the characteristics that individually, or in combination, make plants tolerant of recreational disturbance include: (1) being either very small or very large; (2) growing flat along the ground or in dense tufts; (3) having leaves that are tough and/or flexible; (4) having growth points at or below the ground surface; (5) having a rapid growth rate; (6) producing numerous seeds; and (7) being an annual (Frenkel 1970; Kuss 1986; Cole 1993). Composition also changes due to propagules of exotic species carried into the area by recreationists. Such species are often well-adapted to periodic disturbance.

Vegetation cover can also be reduced and species composition altered by intensive grazing of meadows where camping trips are supported by horses and other pack animals (Cole 1987). This can reduce the availability of forage that is important to indigenous herbivores.

Generally, species richness and diversity declined where recreational impact was pronounced (Young 1978; Cole 1993); however, diversity may be greatest at low to moderate levels of disturbance (Liddle 1975; Slatter 1978). The complexity of vertical structure of vegetation may respond in a similar manner. The vulnerability of vegetation of moderate height means that heavily used recreation areas often lose intermediate vegetation layers, even if it is possible to maintain an overstory and some resistant groundcover. Tree saplings and pole-sized trees are also thinned out, both purposely by management and by recreationists (Bratton et al. 1982). Low levels of disturbance, however, may result in increases in the complexity of both vertical structure and the spatial pattern of vegetation, for example, by creating canopy openings and areas of nutrient enrichment (Dale and Weaver 1974).

The implications of recreational impacts on vegetation, then, vary with intensity of disturbance. With few exceptions, the abundance and total biomass of vegetation will decline as disturbance increases. However, habitat diversity can increase at low to moderate levels of disturbance due to increases in vertical stratification, spatial heterogeneity, and even species richness.

Aboveground dead vegetation, from standing dead trees to fallen logs and brush piles, tends to decline in recreation areas. It can be pulverized underfoot, collected as firewood, or cleared out either for aesthetic reasons or to reduce fire hazard. Loss of downed woody material can adversely affect water and nutrient conservation on the site, as well as biological activity (Maser et al. 1988).

Snow-based recreation can also affect soils and vegetation. The most pronounced impacts are those associated with ski-resort development, which can involve substantial tree felling and ground-surface leveling, in addition to facility construction. Such developments can fragment and reduce the availability of critical habitat. Of the more extensive activities, the impacts of snowmobiling appear most pronounced. Snowmobiling damages shrubs and saplings (Neumann and Merriam 1972), reduces vegetative standing crop, and changes species composition (Keddy et al. 1979).

Water is impacted by both water-based recreational activities, such as motorboating and canoeing, and by land-based activities, such as fishing, hiking, and off-road vehicle travel. Trampling and other recreational impacts to the shoreline can alter flow regimes and eliminate the protective cover afforded by overhanging banks. It can result in increased sedimentation and turbidity caused by runoff across denuded surfaces. Loss of vegetation can reduce organic matter input to water bodies. Streambeds and lake bottoms can be disturbed by vehicular travel and also by wading.

Motorboating and shore-based activities can alter the chemical qualities of water. Outboard motors discharge oil and gasoline. These certainly contribute to chemical changes, though the effects on aquatic organisms are, as yet, poorly understood (Jackivicz and Kuzminski 1973). Shore-based activities can contribute nutrient influxes, such as the exceptionally high level of phosphorus recorded at a semi-wilderness lake in Canada that had experienced a 20-fold increase in recreational use (Dickman and Dorais 1977).

Aquatic plants can also be altered by recreational use. It is sometimes a result of direct mechanical disturbance by boats, but more often due to nutrient influxes. For example, in King's Canyon National Park, California, Taylor and Erman (1979, 1980) found that heavily used lakes had less nitrate, more iron, and more aquatic plants than lightly used lakes. They postulate that many years of heavy camping contributed trace elements, such as iron, that had restricted plant growth in the past. Heightened plant growth would have increased nitrogen uptake, decreasing nitrate levels. They also found more abundant insects, aquatic worms, and clams on the bottoms of the heavily used lakes. Chemical changes, along with biological and physical changes (such as increased turbidity), can have ripple effects throughout the entire aquatic community. This may include increases or decreases in productivity and nutrient cycling.

Eeffcts of Habitat Change on Animals

Recreation impacts discussed in the preceding section influence important characteristics of animal habitats (Table 11.1), in turn affecting the quality and quantity of food and living space of animals (Fig. 11.1). The type of recreation activity, its location and areal extent, the severity or magnitude of impact, and its timing (interval, frequency, and predictability) all shape the "habitat template" (Southwood 1977) and an animal's subsequent response (Knight and Cole 1991). The following discussion focuses on selected examples that illustrate how habitat characteristics sensitive to recreational activities affect the behavior, distribution, survivorship, and reproductive ability of individual animals. Over a longer time period, impacts also occur to the population, community, and ecosystem; these are discussed at the end of this section.

FOOD

Habitat changes that alter the type, distribution, and food amount available will impact animals, whether in water or on land. For example, in soil, any activity that removes or reduces the overlying organic layers, or organic material

Table 11.1

Primary Recreational Impacts on Animal Habitat
Soil characteristics
Loss of surface organic horizons
Reduced soil porosity
Altered soil chemistry
Altered soil moisture and temperature
Altered soil microbiota
Vegetation characteristics
Reduced plant density/cover
Altered species composition
Altered vertical structure
Altered spatial pattern
Altered individual plant characteristics
Aquatic system characteristics
Altered bank/shoreline characteristics
Altered bed/bottom characteristics
Altered flow regimes
Increased sedimentation/turbidity
Altered organic matter content
Altered water chemistry

within the soil, reduces a primary food source for many species. Seastedt (1984) found that about 95% of the 300,000 microarthropods living in one square meter of soil in northern coniferous and deciduous forests were mites and collembolans (organisms feeding exclusively on decaying organic matter). Recreation disturbances that remove this organic matter remove the food source for these primary decomposers in temperate climate ecosystems (Seastedt 1984).

Different plant species present different types of food (including leaves, flowers, fruit, and seeds) at different times of the year. They also exhibit different chemical and morphological defenses and attractants. Each of these features significantly impacts food availability. For example, Holmes and Robinson (1984) found that all 10 of the foliage-gleaning birds in a New Hampshire forest foraged preferentially on yellow birch trees. They avoided beech and sugar maple. Differences in tree preferences were partly attributable to differences in insect abundance among the three trees. Yellow birch had a higher density of all arthropods and lepidopteran larvae. Recreation that changes plant species composition will very likely change availability of food for animals.

Disturbances created by recreation also favor the germination, establishment, and growth ofexotic annual plant species (Mack 1986), substantially altering food availability within a habitat. In Manitoba, Canada, for example, Wilson and Belcher (1989) found that exotic grasslands with a high proportion of exotic Eurasian grasses had a significantly different resident bird community than native grasslands. Differences in resident birds were attributable to differences in food supply and habitat structure.

For many streams, allochthonous organic input from riparian vegetation is a primary source of food and nutrients for the entire aquatic ecosystem (Gregory et al. 1991). For example, Fisher and Likens (1973) showed that 98% of the organic matter in Bear Brook, New Hampshire, came from the surrounding forest. The quantity of riparian vegetation entering a stream strongly affects the invertebrate community. For example, biomass of shredders feeding on vascular plant tissues typically reaches a maximum at the time of greatest litter availability (Cummins et al. 1989). Consequently, recreation that alters natural litter input to streams may substantially change the animal community.

In addition, recreational activities that reduce riparian vegetation will increase soil erosion; resulting sedimentation can cover and kill the aufwuchs community of periphyton, bacteria, and fungi on the surface of rocks (Cordone and Kelly 1961; Murphy et al. 1981). These are an important food source for arthropods, many amphibians, and fish. Sedimentation also increases the turbidity of water; this caused up to a 50% reduction in bluegill feeding rates

(Gardner 1981). Both the concentration of suspended sediments and the duration they are in the water will have a large impact on aquatic ecosystems (Newcombe and MacDonald 199 1).

LIVING SPACE

Changes in habitat that alter living space, whether for breeding, feeding, or any other use, will have a large impact on wildlife communities. In soil, for example, many organisms live in the pore spaces between mineral particles, and require pores of sufficient size to survive and reproduce. Soil compaction reduces the size of pore spaces, altering the soil fauna. Wallwork (1970) found that collembolan species were restricted to certain soil types based on the size of available pores; smaller species were found in compacted soil in comparatively smaller pore spaces than the larger species. In addition, pore size can become so minimal that water completely fills the pore space, reducing oxygen levels sufficiently to inhibit aerobic metabolism. This causes a shift in composition toward anaerobic species (Paul and Clark 1989). Recreation that compacts soil is, therefore, likely to cause dramatic shifts in the distribution and species composition of the soil fauna.

Organic matter lying on the soil's surface provides a variety of microhabitats for vertebrate and invertebrate animals. In general, the greater the variety of habitats, the greater the variety of soil organisms. For example, Anderson (1978) found a strong, positive correlation between microhabitat diversity related to organic matter and mite species diversity. Recreational activities that remove organic layers from the soil will remove these microhabitats and their associated animal communities.

The physiognomy, density, and spatial pattern of plants strongly affect the living space of terrestrial animals. Numerous studies have shown the influence of vegetation physiognomy on birds (Holmes et al. 1986), small mammals (Harney and Dueser 1987), and insects (Lawton 1983). For example, plants with greater structural diversity offer insects a greater variety of microclimates, oviposition sites, predator refugia, overwintering sites, and food sources than plants of simpler structure (Strong et al. 1984). Well-known relationships also exist between the vertical distribution of vegetation, or "foliage height diversity," and the distribution of birds within a habitat. Stauffer and Best (1980) studiedmicrohabitat selection of 41 birds nesting in riparian vegetation in Iowa. Based on regression of bird counts to microhabitat variables, Stauffer and Best predicted that removing woody vegetation would eliminate 32 of the bird species, while reducing woody vegetation to narrow strips along stream margins would eliminate six species and decrease the abundance of 16 others.

Plant density and other attributes of a habitat closely related to plant density.

such as canopy cover, basal area of trees, shrub density, and fruit or cone density, can affect animal distribution. Lundquist and Mariani (1991) found that chestnut-backed chickadees and Vaux's swifts were "strongly (positively) correlated with density of total live trees" in the Cascade Range of southern Washington. Lundquist and Mariani attributed these correlations to a greater number of either insects or cones for the chickadees, and a greater abundance of nesting sites and insects for the swifts. For some species, plant density provides protection from predators; Dwernychuk and Boag (1972) found an inverse correlation between egg loss in artificial nests in relation to the quantity of plant cover.

Spatial pattern of plants is an important component of the living space of animals. Increasing the heterogeneity or patchiness of vegetation traditionally was considered "good" for animal habitat because it increased the proportion of "edge." Although increasing heterogeneity benefits some species, notably game species, several studies have recently shown the importance of contiguous, undisturbed habitat for many native species. For example, Robinson (1988) found that increasing habitat heterogeneity caused local reproductive failure of rare, endemic bird species. The causes were heightened competition for food between edge and endemic species, elevated brood parasitism, and higher nest predation. Recreational pursuits impacting the spatial pattern of plants may strongly affect animal assemblages.

Riparian vegetation greatly determines the living space of aquatic organisms. Riparian vegetation and overhanging banks provide protective cover for many fish and salamanders (Hawkins et al. 1983). By shading the water, streamside vegetation controls water temperature and solar radiation; this, in turn, directly governs primary and secondary productivity. For example, heavily shaded stream reaches have lower densities and relative abundances of herbivores than comparable stream reaches with open riparian canopies (Hawkins and Sedell 1981). In addition, woody debris that falls into streams provides important habitat for invertebrates and fish as well as retention of organic material (Harmon et al. 1986; Gregory et al. 1991). Speaker et al. (1988), for example, found that woody debris dams were the most efficient structures for retaining leaves, and that stream reaches in Oregon with debris dams retained four times more organic matter than reaches without debris dams.

Water flow regime (e.g., velocity, turbulence, and temporal pattern), strongly influences the behavior and metabolism of all major groups of aquatic organisms. Statnzer et al. (1988) found that mean water velocity and complex hydraulic characteristics were major factors in the distribution of microorganisms, macroinvertebrates, and fish within a stream reach. In addition, the size, surface area, texture, heterogeneity, and stability of substrate particles affect the living space of aquatic organisms (Minshall 1984) by pro-

viding, for example, attachment and oviposition sites. Malmqvist and Otto (1987) experimentally altered substrate stability, causing changes in macroinvertebrate composition and densities. Recreation activities that alter flow regime or substrate size wi!! therefore have a large impact on the aquatic organisms within a stream.

Long Term Effects of Habitat Change

When food or living space are altered, short-term effects on the behavior, survival, reproduction, and distribution of individual animals will likely cause long-term reactions throughout an animal community. These "trophic cascades" generally occur because habitat alterations either allow a variety of parasites, pathogens, and competitors into an area; or, they eliminate native species, often with long-term effects on the remaining species. For example, recreational activities that create clearings in forest provide favorable habitat for species such as the brown-headed cowbird that requires open foraging areas. Brown-headed cowbirds are nest parasites, laying their eggs in the nests of other birds. Several studies have shown decreases in the abundance of native birds caused by brown-headed cowbirds (e.g., Brittingham and Temple 1983).

Aquatic ecosystems may show time lags regarding the influence of recreational activities. For example, reducing streamside vegetation could cause increased erosion after substantial rainfall. Pollutants produced by recreational activities (e.g., gasoline and oil leaked by off-road vehicles) or sewage effluent may take considerable time to flow into groundwater or be flushed from the soil surface to streams or lakes. Aquatic systems also demonstrate that impacts to one species may ripple widely throughout the aquatic community (Power et al. 1988), even extending to terrestrial species. Spencer et al. (1991) showed how inadvertent introduction of opossum shrimp to Flathead Lake, Montana, caused the decline of zooplankton populations. This contributed to the collapse of kokanee salmon, an important food source for bald eagles and many other terrestrial vertebrates. Fall concentrations of feeding eagles dropped precipitously a few years after shrimp introduction.

If recreation affects the density or distribution of species that functionally dominate a community or ecosystem, resulting impacts will be especially severe. For example, Brown and Heske (1990) showed that experimental removal of kangaroo rats caused Chihuahuan desert shrub habitat to be converted into arid grassland. Similarly, beaver have been shown to dramatically alter the hydrology, biogeochemistry, and productivity of forest streams (Naiman et al. 1986). Consequently, activities that adversely impact species like the kangaroo rat and beaver can be expected to dramatically alter the present vegetation and animal community.

Indirect Impacts on Animals

In contrast to the sizeable literature of direct effects on wildlife, very few studies have documented impacts resulting from habitat changes induced by recreational activities. Accordingly, our review is based on limited empirical data.

Several studies have documented declines in numbers of a wide variety of soil invertebrates in trampled places (Chappell et al. 1971; Duffey 1975). One study found decreases in soil mites on footpaths, while springtails were most abundant in moderately trampled soils (Newton and Thomas 1979). Declines were caused, to some extent, by direct impact to soil invertebrates, but alteration of living spaces and food sources was important as well (Bayfield 1979).

Several studies have reported indirect effects of off-road vehicles (ORVs) on animal populations. In the Algodones Dunes, California, control plots had 1.8 times the number of lizard species, 3.5 times the number of individual lizards, and 5.9 times the lizard biomass of ORV-impacted areas. Controls also had 1.5 times the number of mammal species, 5.1 times the number of individual mammals, and 2.2 times the mammal biomass of ORV-impacted areas (Luckenbach and Bury 1983). In addition, control plots had 40 times the shrub volume of ORV-impacted areas, and cover and volume of perennial vegetation were both positively correlated with the number of individuals and number of species of lizards and mammals. This suggests that at least some of the decline in animal populations was indirectly the result of vegetation damage, although the precise causal mechanisms remain unknown.

Several studies compared animal populations in campgrounds to those in adjacent undisturbed areas to ascertain the effects of campground development on animals. Blakesley and Reese (1988) found seven bird species to be positively associated with campgrounds and another seven species to be associated with noncampgrounds. Changes in both food sources and living space provided likely explanations for differential species responses. Those species associated with the campgrounds nested in trees. Most of the noncampground associates, in contrast, nested on the ground, in shrubs, or in small trees, where disturbance was more severe. Ground foragers attracted to human food sources (such as the American robin) were associated with campgrounds, while ground foragers wary of humans (such as the fox sparrow) were associated with noncampgrounds. Mixed hardwood campgrounds in Wisconsin had a greater density of birds than adjacent noncampground forests (Guth 1978). They had slightly greater species richness, but less equitability. Moreover, a greater proportion of campground species were widespread species, in contrast to the number of rare forest species that were found only away from campgrounds.

Small mammal populations were significantly greater in campgrounds at

Canyonlands and Arches National Parks, Utah, than in adjacent controls (Clevenger and Workman 1977). The authors attribute this to increased food supplies due to camping use. In campgrounds at Yosemite National Park, California, “the animal populations studied display the full range of direct vs. secondary (indirect) and positive vs. negative visitor impacts” (Foin et al. 1977). Deer mouse populations responded positively to human use of campgrounds, while montane vole populations were unrelated to the distribution of human use. Some bird species, such as the junco, were negatively impacted both directly and indirectly. They nested and foraged on the ground and were influenced directly by human disturbance and indirectly through vegetation removal.

In sum, the indirect effects of recreation on animal populations are likely to be substantial, but there is little rigorous documentation of these impacts. Recreational activities clearly have substantial and generally adverse influences on terrestrial vegetation and soil, and on aquatic systems. Since these provide living space, shelter, and food for wildlife, animals are affected by these changes. For invertebrates, amphibians, reptiles, small birds, small mammals, and many fish, these indirect effects are likely to be more substantial than direct impacts of recreationists.

Management Options for Coexistence

Indirect impacts differ from direct impacts in two ways: (1) Indirect impacts are inevitable, occurring wherever and whenever recreational use occurs; and (2) they generally occur over long periods of time, with effects that are long-lasting and that may take place only after a time lag. Consequently, the timing of activities has less influence on indirect than on direct impacts.

These differences suggest that the appropriateness of various management strategies will vary given the nature of the activity. In particular, strategies that restrict the amount, type, and spatial distribution of use, as well as those that enhance site durability, seem well-suited for managing indirect impacts. Strategies that emphasize visitor education and temporal restrictions, while worthwhile in some situations, are less effective on indirect impacts than on direct ones.

Restrictions on Amount of Use

The severity of most recreational impacts on animal habitat is influenced by the amount of use that occurs. Since impact levels generally increase as use levels increase, indirect influences on wildlife could be limited by controlling the amount of recreation allowed. Numerous studies show, however, that the relationship between amount of use and amount of impact is highly curvilinear; as use levels increase, additional use has less and less effect on amount of impact (refer to Cole 1987 and Kuss et al. 1990 for reviews). This suggests that limiting recreation is effective in reducing indirect impacts only when usage can be virtually eliminated.

Restrictions on Type of Use

The nature and severity of recreational impacts are influenced by the type of recreational activities involved. Limiting or prohibiting particularly destructive types of use is an approach with considerable promise. This approach is most commonly used to manage motorized recreational activities, which are generally much more disruptive than nonmotorized activities. Motorized use is often prohibited in an area of concern (a campground or a nesting area); or, it is restricted to particular trails or locations while nonmotorized use is allowed anywhere. This latter strategy (zoning), where certain uses are allowed only in certain places, is a common means ofavoiding extensive impact caused by particularly destructive pursuits. Other examples include creating nature preserves that allow nonconsumptive uses while prohibiting consumptive activities.

Restrictions on the Spatial Distribution of Use

Because impact is almost synonymous with use, impacts can be reduced by limiting the spatial extent of use. This confinement strategy is one of the most commonly employed techniques in recreation management. Visitors are required to stay on trails, keep out of meadows, and camp only in designated campsites. Motor vehicles are required to stay on trails and in designated "sacrifice areas." Recreational use can also be concentrated more subtly by developing small high-use areas that provide for visitor needs, such as water and picnic facilities (Usher et al. 1974). Other examples include providing a ramp for launching boats or a raised boardwalk for viewing birds. The zoning strategy described as a restriction on type of activity also involves restricting use spatially.

The effectiveness of this approach can be amplified by confining use to sites that are particularly durable and able to withstand repeated disturbance, and by keeping use away from habitat that is rare or critical to animals. To illustrate, trails and campgrounds might be situated away from critical strips of riparian vegetation, while periodic opportunities for visitors to access the watercourses they find so attractive are maintained.

The success of attempts to employ spatial control as a management technique can be greatly increased through thoughtful site design. A good design will meet the needs and aspirations of recreationists, while minimizing both the extent and severity of impact. Activity zones can be interspersed with buffer zones and truly undisturbed zones (McEwen and Tocher 1976) to provide for the needs of a variety of animal species. Barriers, signs, and attention to the attractiveness and location of trails and facilities can all be used to minimize the proportion of an area that is frequently disturbed (Hammitt and Cole 1987).

Enhancing Site Durability

Maintenance and hardening of recreation sites can also reduce impact to animal habitats. Sites may need to be hardened, for example, to avoid increasing sediment inputs to streams. At off-road vehicle areas in California, debris basins have been built to trap sediment eroded from the area (Smith 1980). Active intervention may be necessary to maintain a diverse vertical structure and appropriate spatial pattern for vegetation in frequently disturbed places such as campgrounds (Blakesley and Reese 1988). In some cases, active rehabilitation must be engaged to restore the habitat requirements of animal species. This "hands-on" approach has costs as well as benefits, which must be carefully considered.

Knowledge Gaps

The preceding review should make it clear that animals are impacted by recreational disturbance of habitat. Two important questions remain, however: how significant are these impacts to wildlife populations and communities, and which habitat disturbances are most damaging to wildlife? Answers to these questions will require research designs radically different than the short-term correlational analyses that characterized previous research on indirect impacts.

Clearly, individual animals and localized populations can be impacted indirectly by recreation; but are these impacts significant when considered from the perspective of a larger spatial scale? Significant impacts might be those that are both extensive and severe, those that affect rare or important habitat, and those that affect rare, threatened, or keystone species. For example, impacts to small aquatic ecosystems might be more significant than those to large terrestrial ecosystems because more of the ecosystem is altered. Off-road vehicle impacts on dunes occupied by a rare herpetofauna might be more significant than camping impacts on forests occupied by a relatively common avifauna. Other examples of significant impacts include those that are long-lasting and those that impact populations and communities rather than just the behavior of individuals.

Research on these questions should begin by developing criteria for evaluating the significance of different impacts. It might proceed by identifying species, communities, and habitats that are particularly important or rare. Specific studies of the impacts of recreation on these species and habitats could then be conducted, including an assessment of the proportion of animals and habitat being affected. These studies should be long-term and attempt to identify changes at the population and community levels. Long-term changes at these higher levels of the biological hierarchy are particularly important because they incorporate a broad range of ecosystem interactions and processes. For such studies, research designs must be capable of providing the large spatial and long temporal perspectives that are needed.

Understanding the importance of various habitat disturbances will depend on a better understanding of (1) cause-and-effect relationships and (2) the importance of individual factors that influence the severity of impact. To unravel cause-and-effect, studies need to adopt experimental designs (Gutzwiller 1991), in contrast to the correlational analyses commonly used because of their relative ease. For specific disturbances, it is necessary to conduct experiments that separate effects on food sources from effects on living space.

An in-depth discussion of the factors that influence the severity of impact is beyond the scope of this review. A general treatment of the subject is presented in Chapter 5. Characteristics of the recreational disturbance (frequency, type of activity, timing, location, etc.), vulnerability of the habitat, and vulnerability of the animals all determine the impact of any recreational activity. Factorial research designs are capable of contributing to our knowledge about the importance of individual factors. For example, recreation areas with similar environments but different use levels can be compared to assess the relationship between amount of use and amount of impact. Alternatively, similar amounts of recreational use can be studied in different habitats to assess variation in the vulnerability of those habitats. Since it is often virtually impossible to control all these variables in the real world, the alternative is simuIation of recreational disturbance under controlled experimental situations. Cole and Baytield (1993) describe a simple experimental procedure for assessing the effects of both amount of trampling and vegetation vulnerability on vegetation impact. This approach could be extended to the secondary effects of vegetation change on animals.

The indirect impacts of recreation on wildlife are clearly substantial but even more poorly understood than the direct impacts. Reasons for this lack of understanding include the difficulty of unraveling cause-and-effect and the lack of interest in those animals most affected in indirect ways. Nevertheless, these less conspicuous species are important, and indirect impacts are extensive. So, we need to better understand recreational impacts resulting from habitat change and to find improved means of minimizing these impacts.

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