Natural Resources and Environmental Issues

Volume 0 *Wilderness Areas: Their Impact* Article 6

1990

Impacts of recreation on biodiversity in wilderness

David N. Cole
Intermountain Forest and Range Experiment Station, USDA, Forest Service, Missoula, Montana

Richard L. Knight
Department of Fishery and Wildlife Biology, Colorado State University, Ft. Collins

IMPACTS OF RECREATION ON BIODIVERSITY IN WILDERNESS

David N. Cole
Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, Montana

Richard L. Knight
Department of Fishery and Wildlife Biology, Colorado State University, Ft. Collins, Colorado

ABSTRACT: We discuss seven recreational impacts on biodiversity in wilderness areas. These include: 1) construction of trails, 2) trampling of vegetation and soils on trails and campsites, 3) collection and burning of wood in campfires, 4) water pollution associated with camping activities, 5) unintentional harassment of animals, 6) hunting, fishing, and associated management programs, and 7) grazing by recreational packstock. All of these activities can be considered detrimental because they alter the natural processes and functions of ecosystems. The activities which have caused the greatest impact on diversity at a regional scale are fishing, hunting, and associated management practices. None of these perturbations, however, have been studied in sufficient detail to assess their long-term impact.

Since passage of the Wilderness Act in 1964, the National Wilderness Preservation System has increased to its current size of 91.5 million acres. The intent of the Act is that each wilderness area should retain "its primeval character and influence" and should be "protected and managed so as to preserve its natural conditions." Protecting and managing this large acreage is a challenge, particularly given chronic understaffing and underfunding. One of the primary challenges is protecting wilderness resources from the throngs of recreational users drawn to wilderness. Enjoyment of wilderness and the recreational opportunities it provides is an important purpose of wilderness designation. But recreation is only one of many wilderness values and it should not be allowed to greatly compromise the nature preservation goals of wilderness.

Concern for the preservation of biodiversity parallels those concerns that led to passage of the Wilderness Act and subsequent wilderness legislation. Succinct definitions of biodiversity are hard to come by. The basic concern is that the diversity of life on Earth is being reduced, at a variety of spatial and temporal scales, and that we should do what we can to preserve this diversity. While the objectives of preserving biodiversity and preserving wilderness do not coincide precisely, they clearly overlap. Therefore, it seems worthwhile to look at how recreational use of wilderness affects biodiversity. Recreation is both a threat to wilderness and a value of wilderness. What is the relationship between recreational use of wilderness and biodiversity?

WHAT IS BIODIVERSITY?

For such an intuitively appealing concept, biodiversity defies simple definitions. Most definitions deal with the diversity of entities, at some level of the biological hierarchy, within some variably-sized space. Noss and Harris

(1986) suggest that we be concerned with diversity at the following levels: genes and gene complexes, individual organisms (genotypes and phenotypes), demes/populations, races/-subspecies, species, guilds, communities, ecosystems, landscapes, biogeographic provinces/biomes, and the biosphere. The diversity of any of these can be considered at various spatial scales. For example, the diversity of species in a localized area, such as a forest stand, might be very different from the diversity of species across a landscape or across a region. A perturbation that reduces diversity at the stand level, but not in the region, is not as significant as one that reduces diversity across the entire region. Some have also expanded the concept of biodiversity beyond biological entities to include diversity of process, structure, and function.

The concept is further complicated by the various connotations that accompany the word diversity. Traditionally, diversity has been represented by both richness and equitability or dominance. Richness refers to the number of different entities, the number of species in a community, for example. Equitability is also relevant because diversity declines as dominance by one or a few entities increases. A forest stand in which there are three tree species, one of which is dominant, is less diverse than a stand in which all three species codominate. Beyond these traditional concerns for richness and equitability, many have suggested that the goal of preservation should be to maintain characteristic "native diversity" rather than to maximize richness or equitability (Noss and Harris 1986).

IMPACTS OF RECREATIONAL USE

In the rest of this paper we will discuss recreational impacts on wilderness, and examples of the influence of recreational use on diversity--at several levels of the biological hierarchy and at several spatial scales. This discussion will be, of necessity, highly selective and largely anecdotal. Definite studies are largely lacking. We will conclude with an attempt to suggest the situations where recreational use poses the most serious threat to the biodiversity of wilderness areas.

Seven types of recreational impact are common and potentially significant in wilderness.

1. Construction of trails. Trails are constructed and maintained to provide access to the wilderness. In addition to the trampling impacts associated with trail travel (see below), trail construction can alter the local microclimate and topography dramatically. Moisture conditions are changed, where drainage systems are intercepted and through removal of trees and brush. Tree and brush removal also increases direct precipitation and light intensities and decreases evapotranspiration rates (Dale and Weaver 1974). Common topoedaphic changes along trails include superimposing a flat surface on a steep slope, depositing debris below the trail, creating or removing bare rock faces, and creating a trail tread of imported material (e.g. gravel)(Cole 1981). Generally, these changes are confined to narrow trail corridors several meters wide.

Trails may also impact species composition and interactions by creating edge. The increased vegetation heterogeneity associated with edges usually results in an increase in species diversity and density (reviewed by Reese and Rati 1988; but see Lovejoy et al. 1986). Although this increased diversity has traditionally been viewed as favorable by natural resource managers (Leopold 1933), it has recently been perceived in a negative light. This is because edge species may result in declines of habitat-interior species through predation, competition, or parasitism (reviewed in Lynch 1987). The placement of a right-of-way (e.g., trail) through a habitat creates corridors that are long and narrow and which are maintained to keep vegetation out. The edges that are formed are often abrupt and uniform so do not necessarily mimic naturally-created edges. Chasko and Gates (1982) studied bird populations in transmission-line corridors which

bisected an oak-hickory forest. They noted an increase in grassland and mixed-habitat species inhabiting the corridor as well as higher levels of nest predation and cowbird (*Molothrus ater*) parasitism. Although not documented, the impact of trails in wilderness may have a detrimental effect on some species.

2. Trampling of vegetation and soils on trails and campsites. Where people and livestock walk, trampling removes and abrades vegetation and organic matter and compacts mineral soils. The result is loss of vegetation, change in understory species composition, and exposure of compacted mineral soils. Most of this impact is localized, being confined to the immediate vicinity of trails and campsites. In a portion of the Eagle Cap Wilderness, Oregon, Cole (1981) estimated that no more than 0.5% of the area had been altered by the trampling of trails and campsites.

3. Collection and burning of wood in campfires. Around popular camping areas, collection of wood for fires leaves large areas stripped of all woody fuels. Campers also remove brush and lower limbs, and fell standing trees (Bratton et al. 1982). This has wide-ranging effects, from increasing erosion potential (by removing large decaying wood that creates check dams) to loss of habitat for animals. The area affected is even smaller than that affected by trampling, however.

4. Water pollution associated with camping activities. Camping activities can pollute aquatic ecosystems, although neither the prevalence nor severity of this problem is known. Taylor and Erman (1979) report changes in basic lake ecology in Kings Canyon National Park, California, that they attribute to the cumulative effects of many years of shoreline camping and pollution. They found that heavily-used lakes had more rooted aquatic plants, more bethic macroinvertebrates, more dissolved iron, and less dissolved nitrate than lightly-used lakes. They hypothesized that recreational use increased trace elements, such as iron, that formerly limited plant growth. Growth of plants and macroinvertebrates was stimulated by these higher elemental concentrations and this increased growth depleted available nitrates.

Impacts to aquatic systems could be more widespread than those to terrestrial systems, because water moves. Again, we simply do not know much about either severity or prevalence.

5. Unintentional harassment of animals. Another poorly-understood impact is unintentional harassment of animals. Harassment results when visitors intrude into animal habitat and disturb them. Camping at a desert waterhole, for example, can keep animals from using the water. Rock climbing can disturb raptor nesting sites. Entry into grizzly bear habitat can displace bears or, where bears habituate to humans, lead to encounters that eventually result in destruction of the bear. As with water pollution, these impacts can be widespread because animals are mobile. Impacts can be felt far beyond the local area where the impact originally occurred.

6. Hunting, fishing, and associated management programs. Non-native fish have been planted in wilderness and the ranges of game fishes have been artificially expanded (Behnke and Zarn 1976). For example, since the 1800s, approximately 67 fish species have been successfully introduced into the Colorado River Basin, raising the total number of fish species to over 100 (Carlson and Muth 1989). This has resulted in impacts on native fish populations and has added another trophic level to certain aquatic systems. Hybridization has occurred, altering gene complexes and the purity of races (Behnke 1979, Ryman and Utter 1987, Trotter 1987). Exotics have contributed to the demise of 12 of 24 extinct fishes in North America (Williams and Nowak 1986). Angling has additional impacts on the structure of fish populations.

In wilderness, management of game animals has involved fewer introductions and range extensions than management of fisheries.

Hunting, however, has had important effects on animal behavior, population structure, and species distributions. Geist et al. (1985) make the intriguing point that for certain species, such as bighorn sheep, hunting and hiking are incompatible. Hunting makes sheep wary of approaching humans, so they are readily displaced by hikers even outside the hunting season.

7. Grazing by recreational packstock. A final set of impacts is common wherever grazing by recreational stock is permitted. Again, even descriptive data on the significance and prevalence of impact is minimal. Grazing can reduce vegetative cover and change species composition, because some species are better adapted morphologically to withstand grazing and trampling and because certain species are grazed preferentially. Heavy grazing can make a meadow susceptible to invasion by alien species. Many of the grazing areas in the Bob Marshall Wilderness, Montana, for example, are now dominated by the aggressive alien grass *Poa pratensis* (Kentucky bluegrass), a degraded state from which they are unlikely to change (Johnson 1982). In the Eagle Cap Wilderness, Cole (1981) estimated that the portion of the wilderness disturbed by packstock grazing was several times the portion disturbed by trampling on trails and campsites.

IMPACTS ON BIODIVERSITY

Now we will discuss some examples of how recreational use of wilderness affects diversity at several levels of the biological hierarchy. Data are minimal at best and most examples will refer more to richness than to equitability. The best examples of impact below the species level (genes, populations, and races) are those resulting from hunting, fishing, and associated management practices. Introductions and translocations of game fish and wildlife have resulted in the loss of genetically distinctive races and subspecies. This loss has reduced genetic diversity at both local and regional scales. For example, the Colorado River cutthroat trout (*Salmo clarki pleuriticus*) is a geographical race that had been isolated to the upper Colorado River basin. Historically, it was the only trout that occurred in all of the famous Colorado trout streams. The stocking of nonnative fishes, such as brown (*Salmo trutta*) and rainbow (*S. gairdneri*) trout, resulted in hybridization between native cutthroat and these nonnative species. Unlike most hybrids, the hybrid of cutthroat and rainbow trout was fertile and could reproduce. Once hybridization began, it spread rapidly. These introductions of nonnative trout, therefore, resulted in the virtual elimination of pure Colorado River cutthroat trout throughout its range (Behnke and Benson 1980).

Although genetic diversity has tended to decrease as a result of recreation, there are certain examples of increases in behavioral and phenotypic diversity within species. The different behaviors associated with hunted and non-hunted wildlife populations provides a good example of increased behavioral diversity. For example, behavioral responses of bighorn sheep (*Ovis canadensis*) to humans differ between areas where they are hunted and where they are protected (King and Workman 1986). Likewise, bald eagles (*Haliaeetus leucocephalus*) showed differences in behavior to a canoe on two rivers less than 50 km apart but which had different levels of boating activity (Knight and Knight 1984). The removal of large dominant males from a hunted population can result in such behavioral changes as abnormal exertion by young males during the rut and even decreased female reproductive success (Hutchins and Geist 1987). Animal harassment and even the unintentional feeding of animals, from grizzly bears to squirrels, changes the behavior of some individuals, increasing behavioral diversity.

The phenotypic diversity of vegetation can be increased by trampling. Small, prostrate plants are better able to survive trampling than large, erect plants. Certain species have enough phenotypic plasticity to exist and reproduce as short, prostrate plants when subjected to frequent

bisected an oak-hickory forest. They noted an increase in grassland and mixed-habitat species inhabiting the corridor as well as higher levels of nest predation and cowbird (*Molothrus ater*) parasitism. Although not documented, the impact of trails in wilderness may have a detrimental effect on some species.

2. Trampling of vegetation and soils on trails and campsites. Where people and livestock walk, trampling removes and abrades vegetation and organic matter and compacts mineral soils. The result is loss of vegetation, change in understory species composition, and exposure of compacted mineral soils. Most of this impact is localized, being confined to the immediate vicinity of trails and campsites. In a portion of the Eagle Cap Wilderness, Oregon, Cole (1981) estimated that no more than 0.5% of the area had been altered by the trampling of trails and campsites.

3. Collection and burning of wood in campfires. Around popular camping areas, collection of wood for fires leaves large areas stripped of all woody fuels. Campers also remove brush and lower limbs, and fell standing trees (Bratton et al. 1982). This has wide-ranging effects, from increasing erosion potential (by removing large decaying wood that creates check dams) to loss of habitat for animals. The area affected is even smaller than that affected by trampling, however.

4. Water pollution associated with camping activities. Camping activities can pollute aquatic ecosystems, although neither the prevalence nor severity of this problem is known. Taylor and Erman (1979) report changes in basic lake ecology in Kings Canyon National Park, California, that they attribute to the cumulative effects of many years of shoreline camping and pollution. They found that heavily-used lakes had more rooted aquatic plants, more bethic macroinvertebrates, more dissolved iron, and less dissolved nitrate than lightly-used lakes. They hypothesized that recreational use increased trace elements, such as iron, that formerly limited plant growth. Growth of plants and macroinvertebrates was stimulated by these higher elemental concentrations and this increased growth depleted available nitrates.

Impacts to aquatic systems could be more widespread than those to terrestrial systems, because water moves. Again, we simply do not know much about either severity or prevalence.

5. Unintentional harassment of animals. Another poorly-understood impact is unintentional harassment of animals. Harassment results when visitors intrude into animal habitat and disturb them. Camping at a desert waterhole, for example, can keep animals from using the water. Rock climbing can disturb raptor nesting sites. Entry into grizzly bear habitat can displace bears or, where bears habituate to humans, lead to encounters that eventually result in destruction of the bear. As with water pollution, these impacts can be widespread because animals are mobile. Impacts can be felt far beyond the local area where the impact originally occurred.

6. Hunting, fishing, and associated management programs. Non-native fish have been planted in wilderness and the ranges of game fishes have been artificially expanded (Behnke and Zarn 1976). For example, since the 1800s, approximately 67 fish species have been successfully introduced into the Colorado River Basin, raising the total number of fish species to over 100 (Carlson and Muth 1989). This has resulted in impacts on native fish populations and has added another trophic level to certain aquatic systems. Hybridization has occurred, altering gene complexes and the purity of races (Behnke 1979, Ryman and Utter 1987, Trotter 1987). Exotics have contributed to the demise of 12 of 24 extinct fishes in North America (Williams and Nowak 1986). Angling has additional impacts on the structure of fish populations.

In wilderness, management of game animals has involved fewer introductions and range extensions than management of fisheries.

Hunting, however, has had important effects on animal behavior, population structure, and species distributions. Geist et al. (1985) make the intriguing point that for certain species, such as bighorn sheep, hunting and hiking are incompatible. Hunting makes sheep wary of approaching humans, so they are readily displaced by hikers even outside the hunting season.

7. Grazing by recreational packstock. A final set of impacts is common wherever grazing by recreational stock is permitted. Again, even descriptive data on the significance and prevalence of impact is minimal. Grazing can reduce vegetative cover and change species composition, because some species are better adapted morphologically to withstand grazing and trampling and because certain species are grazed preferentially. Heavy grazing can make a meadow susceptible to invasion by alien species. Many of the grazing areas in the Bob Marshall Wilderness, Montana, for example, are now dominated by the aggressive alien grass *Poa pratensis* (Kentucky bluegrass), a degraded state from which they are unlikely to change (Johnson 1982). In the Eagle Cap Wilderness, Cole (1981) estimated that the portion of the wilderness disturbed by packstock grazing was several times the portion disturbed by trampling on trails and campsites.

IMPACTS ON BIODIVERSITY

Now we will discuss some examples of how recreational use of wilderness affects diversity at several levels of the biological hierarchy. Data are minimal at best and most examples will refer more to richness than to equitability. The best examples of impact below the species level (genes, populations, and races) are those resulting from hunting, fishing, and associated management practices. Introductions and translocations of game fish and wildlife have resulted in the loss of genetically distinctive races and subspecies. This loss has reduced genetic diversity at both local and regional scales. For example, the Colorado River cutthroat trout (*Salmo clarki pleuriticus*) is a geographical race that had been isolated to the upper Colorado River basin. Historically, it was the only trout that occurred in all of the famous Colorado trout streams. The stocking of nonnative fishes, such as brown (*Salmo trutta*) and rainbow (*S. gairdneri*) trout, resulted in hybridization between native cutthroat and these nonnative species. Unlike most hybrids, the hybrid of cutthroat and rainbow trout was fertile and could reproduce. Once hybridization began, it spread rapidly. These introductions of nonnative trout, therefore, resulted in the virtual elimination of pure Colorado River cutthroat trout throughout its range (Behnke and Benson 1980).

Although genetic diversity has tended to decrease as a result of recreation, there are certain examples of increases in behavioral and phenotypic diversity within species. The different behaviors associated with hunted and non-hunted wildlife populations provides a good example of increased behavioral diversity. For example, behavioral responses of bighorn sheep (*Ovis canadensis*) to humans differ between areas where they are hunted and where they are protected (King and Workman 1986). Likewise, bald eagles (*Haliaeetus leucocephalus*) showed differences in behavior to a canoe on two rivers less than 50 km apart but which had different levels of boating activity (Knight and Knight 1984). The removal of large dominant males from a hunted population can result in such behavioral changes as abnormal exertion by young males during the rut and even decreased female reproductive success (Hutchins and Geist 1987). Animal harassment and even the unintentional feeding of animals, from grizzly bears to squirrels, changes the behavior of some individuals, increasing behavioral diversity.

The phenotypic diversity of vegetation can be increased by trampling. Small, prostrate plants are better able to survive trampling than large, erect plants. Certain species have enough phenotypic plasticity to exist and reproduce as short, prostrate plants when subjected to frequent

trampling, although they are typically erect when not subjected to trampling. This phenomenon has been most completely documented for species that grow in lawns (Warwick and Briggs 1979), but is likely to occur in wilderness settings as well.

Recreational impacts on the species diversity of local communities — Whittaker's (1960) alpha diversity — are complex. The general pattern suggested is that of increasing species richness to be maximized at intermediate levels of disturbance conforms to theories advanced by Grime (1973) and Connell (1978). For example, some grazing by packstock is likely to produce small disturbed spots that can be colonized by weedy invaders without the loss of any original natives. With heavy grazing, however, fragile and palatable species are likely to disappear, reducing richness. Most places that experience substantial recreation use show declines in species diversity, however. For example, Cole (1985) studied the effects of controlled levels of trampling on six vegetation types in western Montana. On average, the number of species was reduced by 25% and 50% after 75 and 400 walks, respectively. The removal of downed woody materials and brush from large areas around campsites, to build fires, is likely to decrease the diversity of insects, small mammals, and birds.

Most of this decrease in alpha diversity is only locally significant. Certain communities are depauperate, but diversity at the landscape or regional level is unaffected. There are several instances where there may be large-scale decreases in species diversity, however. This may occur where large mammals or birds are displaced from large areas. An example of where this may occur is along Pacific coast rivers during winter where an avian-scavenging guild is impacted over an entire region by recreational boating. The guild members — consisting primarily of bald eagles, crows (*Corvus* spp.), and glaucous-winged gulls (*Larus glaucescens*)-- are nearly obligate scavengers on carcasses of spawned anadromous salmon (*Oncorhynchus* spp.). Boating activity along these rivers greatly decreases the ability of bald eagles to forage (Knight and Knight 1984, Skagen et al. submitted). Other guild members are unable to utilize salmon unless eagles have already opened the carcasses. If eagles are not able to feed, therefore, other scavenging species will decline or disappear, reducing the overall diversity of these ecosystems during winter.

At levels of the biological hierarchy above the species level, recreational impact has tended to increase diversity. The planting of trout in formerly-barren lakes has added another trophic level in many lakes and streams. Trail construction and campsite development both contribute new community types, increasing the diversity of communities in the landscape-- Whittaker's (1960) beta diversity. Grazing of packstock also creates new community types. Three of the eleven plant communities and phases that Johnson (1982) found in grazing areas in the Bob Marshall Wilderness were dominated by nonnative species — new plant communities created by grazing pressure. However, whether an increase in biotic diversity through the introduction of exotic species is worthwhile is questionable.

Recreational use seldom affects the diversity of biological entities above the scale of localized communities. Ecosystems and landscapes in wilderness are affected by such programs as fire management, insect and disease management, by non-conforming uses such as grazing of domestic livestock and mining, and by external influences such as air pollution. But recreational use cannot compete with these other agents at these large scales.

CONCLUSIONS

All of these effects of recreational use on biodiversity can be considered detrimental because they represent deviations from natural conditions. Even those that increase diversity conflict with the goals of wilderness management

and the notion of maintaining "native diversity" (Noss and Harris 1986). Certain of these impacts can be judged more serious than others, however. Those impacts that affect diversity at the larger spatial scales are more significant than those that only affect the diversity of local areas. Those that decrease richness are probably also more detrimental than those that increase richness. Using these criteria we offer the following suggestions about which sources of impact are most serious, which ecosystems are most threatened, and which components of ecosystems are most threatened.

The recreational activity that has caused the greatest impact on diversity at the landscape and regional level is fishing, hunting, and associated management practices. These activities have depleted and mixed genetic stocks, reducing the number of distinct subspecies. Hunting and game management practices have caused the development of unnatural animal populations. Structural characteristics (ages, sizes, and sex ratios), behaviors, and distributions have all been altered, across entire regions in many cases. Hunting also predisposes certain species to impact from so-called non-consumptive uses, such as hiking. Across the entire National Wilderness Preservation System we feel there can be little doubt that these are the recreational activities that most compromise the goals of both wilderness preservation and preservation of biological diversity.

Other activities that have probably reduced diversity at landscape or regional scales are animal harassment, grazing by packstock, and water pollution. None have been studied in sufficient detail to be certain how prevalent or severe these problems are. Grizzly bears have been impacted by recreation over their entire U.S. range; the same may be true of other large mammals. These impacts manifest themselves in population structure, genetic composition, and behavioral modifications, as well as in distributions and resulting effects on down the trophic levels. Where packstock are common and most existing meadows are grazed, this represents a significant compromise of wilderness preservation values, because meadow types may be degraded over their entire range. To avoid this, Sequoia and Kings Canyon National Parks have designated a representative example of each meadow type in the parks as off-limits to stock use. More wilderness areas might consider emulating this approach to preservation of biodiversity in the face of packstock use. Finally, water pollution can alter aquatic ecosystems at the landscape and regional level. This would be most likely in places with heavy use and scarce water resources. Certain wildernesses, such as the Pecos in New Mexico, have a small number of lakes, all of which are popular destination areas. It is likely that all of these lakes have been dramatically changed by historic use and resulting pollution. But we do not know.

The most threatened ecosystems are those that are rare but attractive to recreationists and those affected by the most disruptive uses. Aquatic ecosystems are probably the most at risk. Lakes and streams are the most common destination areas of wilderness visitors. They have been changed by fish introduction and planting programs, by angling itself. and by water pollution. Moreover, the mobility of water means that impacts are not confined to the point of origin.

Other ecosystems that may be threatened in some places are riparian ecosystems and meadows and grasslands favored by recreational packstock. Both ecosystems serve as major attractants and destination areas and, in certain environments, are rare. Riparian strips in arid environments may be heavily impacted and all riparian strips within a landscape or large wilderness may be altered. Grazed meadows and grasslands also can be seriously altered across their entire range.

The most threatened ecosystem components are probably the various components of aquatic ecosystems, from native fishes to phytoplankton. The implications of introducing an additional

trophic level in so many places will have ripple effects throughout those systems. Outside aquatic systems the large mammals are probably most affected, primarily on account of their large ranges. Impacts are not confined to the immediate vicinity of the impact source.

Recreational use of wilderness is not the primary threat to biodiversity and wilderness preservation. Fire management policies, non-conforming uses, and external threats all threaten biodiversity in wilderness more than recreational use. Of the recreational activities that do occur in wilderness, however, we should be most concerned about fishing, hunting, and associated management. We should seek ways to manage these activities such that impacts on biodiversity are minimized. We should learn a lot more about aquatic systems, which appear likely to be the most threatened ecosystems. We should also learn more about the impacts of animal harassment and the impacts of packstock on meadows and grasslands.

LITERATURE CITED

Behnke, R. J. 1979. Monograph of the native trouts of the genus Salmo of western North America. U.S.D.A. Forest Service, Lakewood, CO.

___, and D. E. Benson. 1980. Endangered and threatened fishes of the upper Colorado River basin. Cooperative Extension Service, Colorado State Univ. Extension Service Bull. 503A.

Bratton, S. P., L. L. Stromberg, and M.E. Harmon. 1982. Firewood-gathering impacts in backcountry campsites in Great Smoky Mountains National Park. Environ. Manage. 6:63-71.

Carlson, C. A., and R. T. Muth. 1989. The Colorado River: lifeline of the American Southwest. Pages 220-239 in D. P. Doge, ed. Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Chasko, G. G., and J. E. Gates. 1982. Avian habitat suitability along a transmission-line corridor in an oak-hickory forest region. Wildl. Monogr. 82.

Cole, D. N. 1981. Vegetational changes associated with recreational use and fire suppression in the Eagle Cap Wilderness, Oregon: Some management implications. Biol. Conser. 20:247-270.

___. 1985. Recreational trampling effects on six habitat types in western Montana. Research Paper INT-350. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. Science 199:1302-3110.

Dale, D., and T. Weaver. 1974. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. J. Appl. Ecol. 11:767-772.

Geist, V., R.E. Stemp, and R. H. Johnston. 1985. Heart-rate telemetry of bighorn sheep as a means to investigate disturbances. Pages 92-99 in N. G. Bayfield and G.C. Barrow, eds. The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America. Recreation Ecology Research Group Report No. 9.

Grime, J. P. 1973. Control of species density in herbaceous vegetation. J. Environ. Manage. 1:151-167.

Hutchins, M., and V. Geist. 1987. Behavioral considerations in the management of mountain-dwelling ungulates. Mountain Res. Develop. 7:135-144.

Johnson, T. W. 1982. An analysis of pack and saddle stock grazing areas in the Bob Marshall Wilderness, Montana. M.S. thesis, Montana State Univ., Bozeman.

King, M. M., and G. W. Workman. 1986. Response of desert bighorn sheep to human harassment: management implications. Trans. North Am. Wildl. Conf. 51:74-85.

Knight, R. L., and S. K. Knight. 1984. Responses of wintering bald eagles to boating activity. J. Wildl. Manage. 48:999-1004.

Leopold, A. 1933. Game management. Charles Schribners and Sons, New York.

Lovejoy, T. E., R. O. Bierregaard, Jr., A. B. Rylands, J. R. Malcolm, C. E. Quintela, L. H. Harper, K. S. Brown, Jr., A. H. Powell, G. V. N. Powell, H. O. R. Schubart, and M. B. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257-285 in Soule, M. E., ed. Conservation Biology: the Science of Scarcity and Diversity. Sinauer Assoc., Inc. Sunderland, Mass.

Lynch, J. F. 1987. Responses of breeding bird communities to forest fragmentation. Pages 123-140 in D. A. Saunders, G. W. Arnold, A. A. Burbidge, and A J. M. Hopkins, eds. Nature Conservation: the Role of Remnants of Native Vegetation. Surrey Beatty and Sons Pty Lim, London.

Noss, R. F., and L. D. Harris. 1986. Nodes, networks, and MUMs: preserving diversity at all scales. Environ. Manage. 10:299-309.

Reese, K. P., and J. T. Ratti. 1988. Edge effect: a concept under scrutiny. Trans. North Am. Wildl. Conf. 53:127-136.

Ryman, N., and F. Utter, eds. 1987. Population genetics and fishery management. Univ. Wash. Press, Seattle.

Skagen, S. K., R. L. Knight, and G. H. Orians. Submitted. Disturbance of an avian scavenging guild. Ecol. Applications.

Taylor, T. P., and D. C. Erman. 1979. The response of benthic plants to past levels of human use in high mountain lakes in Kings Canyon National Park, California, USA. J. Environ. Manage. 9:271-278.

Trotter, P. C. 1987. Cutthroat: native trout of the West. Colorado Associated Univ. Press, Boulder.

Warwick, S. I., and D. Briggs. 1979. The genecology of lawn weeds. III. Cultivation experiments with *Achillea millefolium L., Bellis perennis L., Plantago lanceolata L., Plantago major L.* and *Prunella vulgaris L.* collected from lawns and contrasting grasslands. New Phytologist 83:509-536.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Mono. 30:279-338.