RECREATION ECOLOGY LAB
at Utah State University

Outdoor Recreation and Ecological Disturbance

A Review of Research and Implications for Management of the Colorado Plateau Province

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Summary

Research on recreation ecology—the study of outdoor recreation activities and their associated ecological disturbance—has a more than 60-year history with over 1200 published studies. This knowledge collectively suggests that while outdoor recreation visitors on public lands can cause substantial ecological disturbance to natural resources, effective management works to minimize these disturbances and can sustain both recreation and conservation goals.

This paper provides a synthesis of recreation ecology knowledge to date, a discussion of functional relationships in recreation ecology and a summary of the implications of recreation ecology knowledge for management of recreation on the Colorado Plateau.

The primary findings suggest that outdoor recreation on public land is in very high demand in many locations on the Colorado Plateau, largely due to the unique, nature-dependent experiences and cultural history the region provides. Many areas also harbor sensitive resources, suggesting that recreation use must be planned for and managed in a manner to sustain ecological integrity and the experiences these resources provide.

Although specific research on recreation impacts on the Plateau is somewhat limited, this knowledge, combined with the broader recreation ecology literature, suggests that concentrating visitor use in previously impacted or hardened sites and trails will likely be a successful management strategy, while dispersal strategies may result in a proliferation of recreation disturbance.

Contents

Section 1: Introduction and Scientific Background . . . 3
Understanding Wildland Recreation Use on Public Lands . . . 3
The Colorado Plateau Province . . . 3
Recreation Visits and Trends . . . 3
Recreation Ecology—Visitor Use as an Ecological Disturbance . . . 3
The Context for Recreation Ecology Studies . . . 5

Section 2: Understanding Recreation as a Disturbance Agent in Natural Areas . . . 7
Disturbance to Vegetation and Soils . . . 7
Disturbance to Wildlife . . . 8
Disturbance to Aquatic Systems . . . 10
Introduction of Non-Native Species . . . 11
Impacts to Natural Sound . . . 11
Human Waste Impacts . . . 11
Visitor Impacts to Cultural Resources . . . 12

Section 3: Functional Relationships in Recreation Ecology . . . 13
Amount of Use . . . 13
Type and Behavior of Use . . . 15
Timing of Use . . . 16
Environment Type . . . 16

Section 4: Minimizing Recreation Disturbance: Implications for the Colorado Plateau . . . 18
Minimizing Vegetation and Soil Impacts . . . 18
Minimizing Wildlife Impacts . . . 19
Minimizing Disturbance to Aquatic Systems . . . 20
Managing Natural Soundscapes . . . 21
Minimizing Impacts to Cultural Resources . . . 21

Section 5: Conclusions and Policy Implications . . . 23

Literature Cited . . . 24

Section 1:

Introduction and Scientific Background

Understanding Wildland Recreation Use on Public Lands

The demand for public lands to accommodate contemporary outdoor recreation pursuits has increased to unprecedented levels, particularly over the last decade. Rapidly changing social and technological factors continue to influence how, when, and where visitors use public lands for recreation and tourism activities, often resulting in dramatic shifts in use. These increases in use levels, types and locations have been observed in many areas worldwide (Balmford et al., 2015) and at the individual park and park system level, including in many U.S. national parks (NPS, 2020). Managers of national parks, forests, and other public lands are often legally required to maintain a high degree of ecological quality while also allowing for an "unconfined" recreation experience with minimal visitor regulation and burden. This can be a challenging mandate, especially during times when use levels are rapidly increasing.

For the purposes of this paper, the term "wildland recreation" will be used to broadly identify recreation activities that occur primarily on public lands in the U.S. Further, the discussion will focus on non-motorized recreation activities occurring mainly in terrestrial locations of undeveloped (backcountry) lands. Although a wide range of scientific studies will be discussed, specific attention will be given, where possible, to research conducted on the Colorado Plateau. In this region, the primary managing agencies are the National Park Service (NPS), Bureau of Land Management (BLM), and USDA Forest Service (USFS). There are currently no, or very few, lands managed by either the U.S. Fish and Wildlife Service or the Bureau of Reclamation located within the generally accepted boundaries of the Colorado Plateau.

The Colorado Plateau Province

The Colorado Plateau Province is a physiographic region encompassing nearly 400,000 km^2 of land overlapping the Four Corners area, where the states of Arizona, Utah, Colorado and New Mexico all meet (Figure 1). With elevations ranging from approximately 600m AMSL to mountaintops reaching almost 4,000m AMSL, the area's deep canyons, plateaus, and buttes make it one of the world's most spectacular examples of geologic history. The range of natural colors in the landscape and sharp contrasts between riparian and high-desert environments, combined with mild winter temperatures, offer an enchanting and increasingly popular visitor experience. The area is highly valued for natural and cultural history, exemplified by 30 units of the National Park Service, including the iconic parks of Arches, Canyonlands, Grand Canyon and Zion.

Recreation Visits and Trends

Nationally, 151.8 million Americans over the age of six participated in some form of outdoor recreation in 2018—just over half (50.5%) of the American public (Outdoor Foundation 2019). This represents an increase in participation of approximately 11.6% over 2008 levels, when about 136 million people participated. These data are broadly inclusive of all outdoor recreation activities, but also include activities traditionally associated with backcountry areas, including participation in day hiking (47.8M), backpacking (10.5M), mountain biking (8.6M); hunting (15.6M) and wildlife viewing (20.5M).

Visitation to areas on the Colorado Plateau is specifically increasing—more rapidly and dramatically than national trends. An indicator of overall use in the region is the annual use statistics prepared by the National Park Service. Trends of use at six popular parks in the region show much greater increases than overall national trends: a range of increases of approximately 47% to 120% in visitation over a 10-year period, from 2009 to 2018 (Figure 2).

Recreation Ecology—Visitor Use as an Ecological Disturbance

While providing great benefits to individuals and society, outdoor recreation activities in wildlands can have undesirable consequences to ecological conditions. Recreation and tourism activities have been shown through many studies to cause direct and indirect disturbance to soil, vegetation, wildlife, water and natural sound components of a natural system (Figure 3). A virtually universal management objective in parks and public lands is minimizing this disturbance to a level acceptable to visitors, and assuring sustainable ecologic conditions. Determining the threshold of a sustainable level of disturbance to natural systems is often challenging, and frequently requires a thorough decision process, informed by the best available social and ecological science.

The discipline of recreation ecology—the study of how recreation activities affect ecological processes—has a history dating back to the 1930s and 1940s in the USA,

Figure 1. The Colorado Plateau Province. *Source: The National Geographic Society.*

and perhaps longer in Europe (Garthe, 2019). Much of the work has examined the relationships between visitor use types and intensities and ecological change. Over 1200 published works exist in this field. In the last 20-30 years, considerable effort has been directed at synthesizing this knowledge (e.g., Hammitt, Cole and Monz, 2015; Monz et al., 2013; Monz et al., 2010) to assist managers of public lands trying to accommodate the growing demand for recreation while maintaining ecological integrity. Broadly, these reviews suggest fundamental principles that can be derived from this knowledge, including primary themes:

- Outdoor, wildland recreation and tourism activities often directly affect both biotic and abiotic components of public lands including soil, vegetation, wildlife, water, air, and natural sounds (soundscapes).
- Recreation disturbance can cause indirect and cascading effects to ecosystem attributes, including ecosystem structure and function. For a given location, the relationship between ecologic change and recreation use can be described with curvilinear, step, and linear functions. The curvilinear response, while admittedly a simplification, is often a useful generalization. In many situations, the majority of change occurs with initial use, with additional use resulting in minimal change.

Although the aforementioned broad generalizations are possible and useful, the effects of recreation disturbance are also influenced by site-specific factors. Thus, the overall effect of recreation disturbance is often situational.

The amount, density, type, and spatial/temporal distribution of recreation use and behavior can influence the level of environmental change that occurs in a natural area. To some extent, all of these factors can be influenced by managers to minimize impacts.

Studies on recreation ecology have demonstrated that the above knowledge can effectively be applied to manage people and recreation environments in ways to minimize disturbance to more acceptable levels. Knowledge about recreation ecology is also integral to management, because these studies provide a scientific basis for selecting monitoring indicators and measurement protocols in contemporary adaptive management planning frameworks (IVUMC, 2013). The management of visitors and sites in ways that limit ecological disturbance is a second component of this paper.

The Context for Recreation Ecology Studies

Recreation ecology research is generally regarded as more valuable in less developed, wildland settings (Cole, 2004) and is therefore highly applicable to recreation occurring in less developed, or undeveloped settings on public lands. Commonly referred to as backcountry settings, these locations are some distance from roads, access points, facilities and development. Public land management agency mandates, and visitor preferences often call for maintaining naturalness in backcountry settings. As such, managers typically rely less on site modification and facility development, and more on management of recreation use and behavior, to maintain ecological and social conditions. In these situations, it is more important to understand the durability of the natural environment and the types and levels of use that can be supported. This is in contrast to developed, or frontcountry settings, where facility-level solutions to accommodate visitors are more the norm. While there may be a large degree of naturalness in frontcountry areas, it is also acceptable to build facilities (e.g., visitor centers, restrooms) and harden (pave or gravel) trails and sites in order to accommodate a high level of visitor use.

The visitor experience is also substantially different in frontcountry and backcountry locations in terms of the number of encounters with other visitors, ability of the visitor to experience nature, opportunities for solitude and a range of other factors. Most public lands have a combination of these types of locations to provide a range of visitor experiences, but the two settings require different management strategies. In terms of ecological disturbance, some recreation impacts that originate in frontcountry settings such as wildlife displacement, air and water pollution and invasive species introductions can have consequences to backcountry areas where naturalness is more important (Monz et al., 2010).

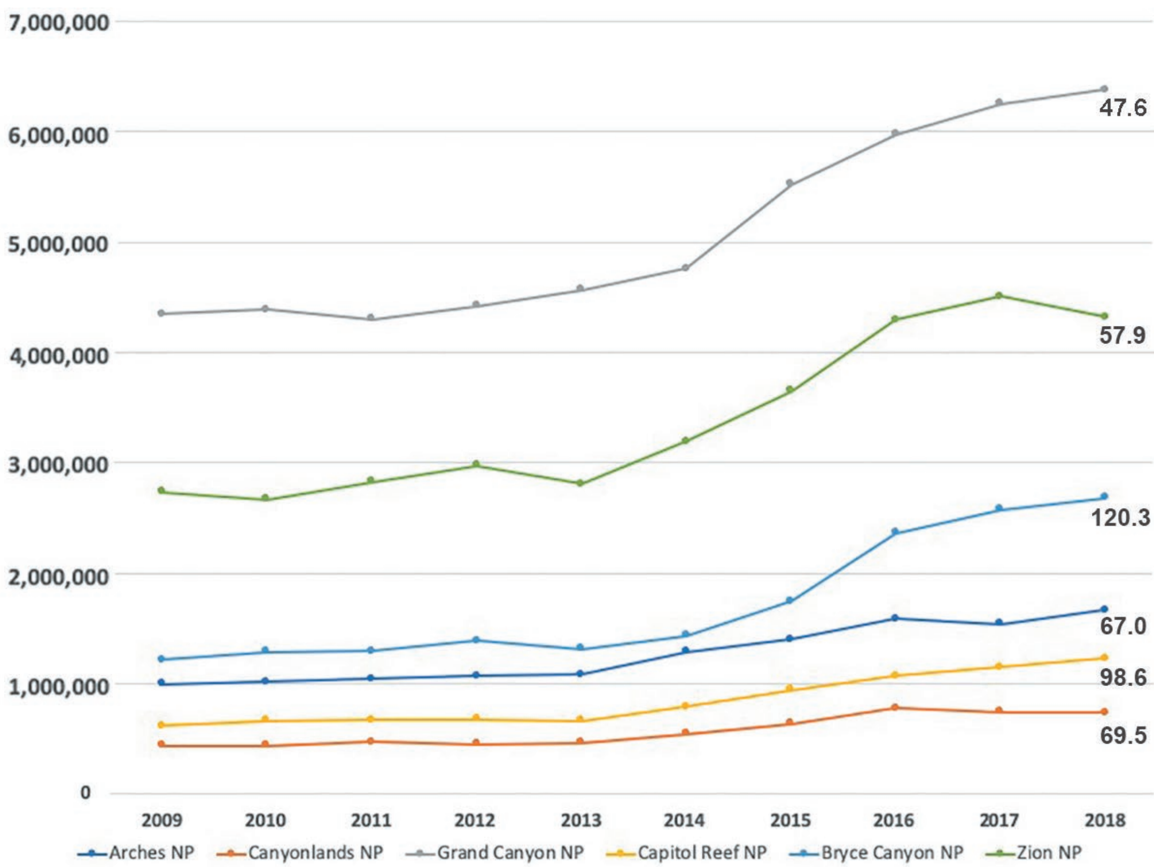

Figure 2. Recent 10-year trends in visitation to several popular Colorado Plateau national parks. The 10-year overall percentage increase is noted at the right of the figure. Source: National Park Service, https://irma.nps.gov/STATS/

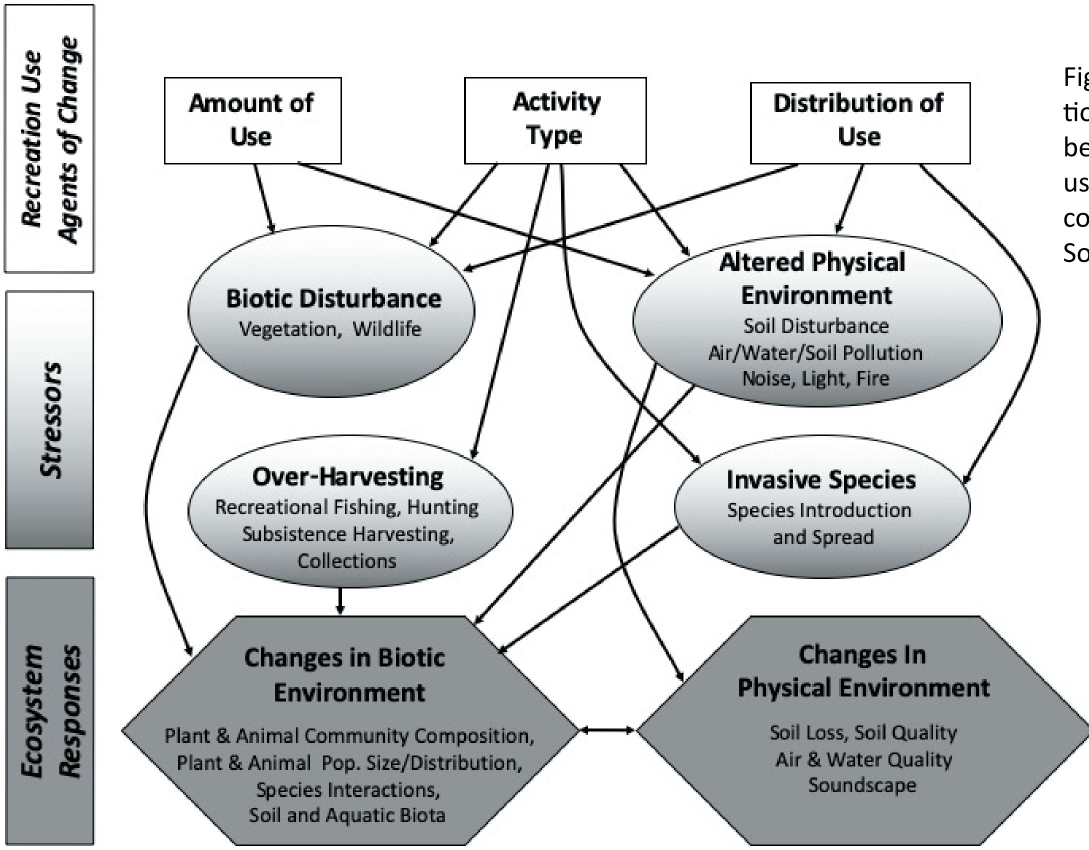

Figure 3. General relationships and interactions between outdoor recreation use and ecological change common to public lands. Source: *Monz et al., 2010*

Section 2
Understanding Recreation as a Disturbance Agent in Natural Areas

Much research on the impacts of outdoor recreation has focused on studying the consequences of hiking and camping in either concentrated-use settings (trails and campsites) or on more dispersed-use situations (e.g., "pristine" area camping). Concentrated-use studies often examine the trajectory of change on established trails and campsites, connecting change to actual use, environmental considerations and managerial factors. Trampling, the primary mechanism for disturbance of soils and vegetation, occurs in both concentrated-use and dispersed-use situations. Considerable research also exists on the effects of recreation on wildlife. Motorized and mechanized recreation has received less attention in the literature to date, but there is emerging research on the topic as these activities continue to grow in popularity, and technological advances allow recreationists to travel further into the backcountry and to new locations.

Disturbance to Vegetation and Soils

Trampling of vegetation and soil—by human feet, packstock hooves or tires—is the most widespread and well-studied mechanism of recreation disturbance to natural systems. This form of direct disturbance is a primary way that recreation activities can directly affect ecosystem components. Trampling has a relatively long history of study (e.g., Wagar, 1964; Bayfield, 1971), and a well-accepted standard methodology for experimental examinations (Cole and Bayfield, 1993) that has been applied worldwide. Numerous experimental trampling investigations and analyses have revealed several primary, direct effects:

- Abrasion and breakage of vegetation;
- Vegetation loss and compositional changes;
- Pulverization and loss of soil organic matter, and
- Compaction, displacement and loss of soil.

(See Hammitt, Cole and Monz, 2015; Kissling et al., 2009; Marion et al., 2016; Newsome et al., 2012.)

Some work has addressed the more indirect, functional effects of trampling, including reductions in soil macroporosity (Liddle, 1997; Monti and Macintosh, 1979), limitation of seed germination and growth (Alessa and Earnhart, 2000), the introduction and transport of non-native plants (Anderson et al., 2015; Pickering, et al., 2010a), changes to soil microbial populations (Zabinski and Gannon, 1997) and disturbance to crypobiotic soil crusts prevalent on the Colorado Plateau.

Trails

In backcountry areas, construction of formal trails (designated by the managing agency) generally involves the removal of vegetation and excavation/deposition of soils and rock to provide a hardened and usable tread. In contrast, informal (visitor-created) trails are often created by people on foot, horseback or bicycle, traveling along routes or to reach destinations not accessible by the formal trail system (Barros and Pickering, 2015, 2017; Wimpey and Marion, 2011). Trails of both types have the potential to cause vegetative and soil disturbance to varying degrees based on the sustainability of the design, vegetation/soil types, and type/amount of use (Hill and Pickering, 2009a, b; Marion and Wimpey, 2017; Wimpey and Marion, 2010). The most common disturbances include excessive expansion in trail width, and soil displacement and loss (Rangel et al., 2019; Tomczyk and Ewertowski, 2011). At the landscape scale, excessive informal trail formation has also been found to result in increased species habitat fragmentation, decreased habitat patch size, and increased edge habitat (Leung et al., 2011; Wimpey and Marion, 2011) suggesting there may be a range of indirect effects of informal trail proliferation to both vegetation and wildlife.

Recreation Sites

Many backcountry campsites are visitor-selected, created as a result of the common "at-large" camping management strategies employed on many public lands. Day-use activities also result in site creation at locations where visitors gather at backcountry destinations, or trailside at viewpoints and rest stops. Consequently, these sites are frequently unsustainable with respect to limiting site-level disturbances such as expansion and proliferation (Marion et al., 2018). Trampling impacts on these sites occur in progression, ranging initially from the reduction in vegetation height and the loss of woody and herbaceous plants, to the ultimate exposure and loss of underlying mineral soil, especially when affected by wind and water erosion (Hammitt et al., 2015; Marion et al., 2016; Tibor and Brevik, 2013). Recreation sites that have continuous use lose woody shrubs over time, and experience changes in the composition of groundcover vegetation from their pre-disturbance conditions, often harboring non-native plants (Eagleston and Marion, 2017, 2018). Land managers are often concerned with both the severity of recreation site disturbance and the total area of disturbance at a given

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location. The most common on-site ecological changes include vegetation loss and exposure and erosion of soil. Often, sites exhibit additional, related impacts due to careless or uninformed visitor behaviors, such as improperly disposed-of human waste, campfire-related impacts, and damage to trees and woody shrubs (Marion, 2016; Wang and Watanabe, 2019). Proximate to visitor-created sites, disturbances often include the creation and proliferation of informal trails, cutting of woody vegetation, and impacts to water and wildlife (Cole, 2013; Eagleston and Marion, 2017; Marion, Wimpey and Lawhon, 2018).

Some work on vegetation and soil disturbance has been conducted on campsites on the Colorado Plateau, with studies in Grand Canyon NP (Cole et al., 2008), Zion NP (Marion and Hockett, 2008), and Grand Staircase-Escalante NM (Romo et al., 2018). Some site and management-specific issues are raised in each of these studies, but common overall themes in findings are:

- The susceptibility of cryptobiotic soil crusts;
- The ubiquity of impacts that are avoidable with best practices (e.g., damage to trees, trash); and
- The importance of confinement strategies in order to limit spatial expansion and proliferation of disturbance.

For example, in a 20-year study of campsites in Grand Canyon, Cole et al. (2008) found that while designated sites were highly disturbed at the outset of the study, directing use to these locations resulted in little if any additional disturbance. The primary increase in disturbance occurred when visitors pioneered new sites, thus increasing the overall impacted area. In addition to disturbance to ground surfaces, work by Romo et al. (2018) suggests that best camping practices are not always followed in Grand Staircase-Escalante—impacts such as litter, fire scars/signs, and tree bark damage were common, found on 86%, 43% and 33% of the 135 sites inventoried, respectively.

An additional theme in the literature relevant to the Colorado Plateau region is recreation use and impact issues in riparian areas, which are often focal points of visitor activity. Although knowledge of recreation disturbance in specifically riparian systems is limited to a few published studies (e.g., Manning, 1979; Cole and Marion, 1988; Monz et al., 2000), results from this work, and studies conducted in the southwest USA, (Johnson and Carothers, 1982; Green, 1998) suggest that riparian locations typically exhibit a more rapid recovery upon cessation of recreation use, but persistent use often leads to more lasting impacts due to the loss and compaction of soil layers. Cole and Marion (1988) suggest that spatial confinement of disturbance is especially important to management of riparian areas, perhaps even more important on the Colorado Plateau, given the limited spatial extent of these ecosystems and their importance as locations of high biodiversity (Macfarlane et al., 2018).

Recreation Activities and Aeolian Dust

Although technically an aspect of soil erosion, the topic of aeolian dust (windblown silt and clay particles) is discussed separately, since from a non-motorized, backcountry recreation perspective, it occurs mostly during vehicle access to remote sites via unimproved roads. Broadly, the ecological and human health impacts of aeolian dust has received considerable attention in the literature due to its far-reaching effects in dryland areas of the western USA. Dust generation has the potential to reduce soil health in source locations, and alter nutrient cycling, resulting in faster snowmelt in deposition areas (USGS, 2020). Motorized recreation activities have been examined as a potential source of aeolian dust (e.g., Field et al., 2010; Goossens et al., 2012), including studies conducted on the Colorado Plateau (Nauman et al., 2018; Hahnenberger and Nicoll, 2014). However, little if any information is available on the impacts of vehicle travel across unimproved roads for access to non-motorized recreation trailheads or campsites. This is likely an issue on the Colorado Plateau, with the plethora of old mining roads combined with recent increases in recreation, but to date, no research has examined this issue specifically. On popular access routes, dust is likely an impact on vegetation adjacent to the roadway, and to the visitor experience, but the extent to which these activities contribute to the larger-scale issue of regional dust problems, such as those originating from industrial activities and land use practices, is unknown.

Disturbance to Wildlife

Recreation activities have the potential to negatively affect wildlife—through over-harvest during hunting and fishing, fish stocking that includes non-native species, and degradation of habitats through trampling, cutting of woody vegetation and water pollution. Visitors may also directly disturb or displace wildlife and create food attraction behaviors and dependencies if wildlife obtain human food and trash (Hammitt et al., 2015; Larson et al., 2016; Marion et al., 2016). Vehicle collisions with animals near and within public lands are also a major source of wildlife mortality—although to date it is unclear how many of the 1-2 million annual wildlife collisions are in direct proximity to public lands (Ament et al., 2019). Recently, the effects of anthropogenic noise have been shown to be a significant issue to both terrestrial wildlife and aquatic mammals; although much of this disturbance is due to sources originating outside of public lands or from motorized transportation sources within parks (i.e., park transit systems). Noise effects will be addressed separately under impacts to natural sounds later in this paper.

Of primary concern is how human activity alters the behavior of wildlife, although the type, severity and implications of specific animal responses is often situational. Wildlife responses to activities on trails vary significantly, depending on the type and behavior of the recreationist, as well as the species, age and sex of the animal, and prior exposure to humans (Knight and Cole, 1995). Recreation use on trails may prompt wildlife to change activity patterns, avoid trail-proximate locations, and increase vigilance and energy expenditures (Borkowski, 2006; George and Crooks, 2006; Taylor and Knight, 2003). However, if the recreation use is consistent and predictable, wildlife may habituate to visitor activities with few long-term detrimental effects. The unique context of each situation makes it difficult to broadly generalize how important these responses are to wildlife population health and specifically how individual wildlife may respond to recreationists.

Disturbance (and displacement, discussed below) are most problematic when wildlife and recreationists are in close proximity. These issues are perhaps most acute in situations like river corridors or canyon bottoms, where wildlife movement is limited, and rerouting visitor travel corridors is difficult. On the Colorado Plateau, researchers have explored this issue, particularly the effects of hiking on Mexican spotted owls, a federally threatened species (Swarthout and Steidl, 2001; 2003; Hockenbary and Willey, 2011). These owls occupy canyons, some of which are also popular for hiking. Studies document a range of owl response to hikers, perhaps the most impactful being flushing behavior, which was more likely to occur at distances of 12m for juveniles and 24m for adult owls. The authors suggest a range of possible management actions, using these distances as buffers for designated trails and travel routes, which in some cases would result in a limitation on hiking in certain locations.

Effects of Harvest and Vehicle Collisions

Although the harassment, disturbance and displacement of wildlife are serious concerns that produce animal stress and sometimes result in death, these effects are secondary to recreational hunting, fishing and trapping (Hammitt et al., 2015). Hunting can affect the behavior, distribution and population structure of wildlife; populations in places without hunting pressure have been shown to function differently compared to locations with hunting (Knight and Cole, 1995; Wood, 1993). A common rationale for hunting is that the practice functions to remove individuals from a population that would succumb to natural mortality (e.g., predation, disease) and consequently, populations exhibit compensatory responses to promote healthy populations. However, research is unclear on this issue, and there are several studies that contradict this belief for a range of species, including red deer, chamois and ruffed grouse (Batcheler, 1968; Small, 1992; Hammitt et al., 2015). In these studies, it appears that hunting may actually result in additive mortality. Alternatively, recent research on upland game bird species in Norway suggests that hunting may exhibit a compensatory response, provided hunting pressure is maintained at low levels (Sandercock et al., 2011). Hammitt et al., (2015) suggest that recreational hunting can produce three primary effects of concern:

- Near or complete elimination of a species at the local level;
- Reduction beyond a viable breeding population; and
- Reduction beyond a viable hunting or fishing population.

Hunting is highly regulated and monitored, and therefore annual harvests are often adjusted based on population data.

Recreation and tourism travel by personal auto near or within protected areas has the potential to result in vehicle collisions with wildlife, resulting in mortality, injury and damage to people and property. Although this issue is well acknowledged in the literature, and some information about the problem has been compiled and analyzed for locations such as the Greater Yellowstone Ecosystem (e.g., Hardy et al., 2008), little systematic data analysis has occurred in a broader context to understand fully what proportion of collisions are due to recreation/tourism activity. We do know that transportation infrastructure near and within habitat areas for wildlife can alter and impede wildlife movement, and resulting fragmentation and lack of connectivity is arguably the primary concern when striving for sustainable management of wildlife (Foreman et al., 2002).

Effects of Habitat Modification

Earlier sections of this paper cite some of the extensive literature examining effects of recreation activities on soil and vegetation. This knowledge has led to the suggestion that larger areas of recreation disturbance, in particular, can degrade wildlife habitat to a degree that some species become displaced, others attracted, and that ultimately population spatial distributions are altered. Although there is only limited empirical evidence of this, the ideas are well supported by examinations and modeling of larger-scale ecological disturbance (e.g., Thuiller et al., 2018). For example, reductions in the abundance of shrubs and trees in developed camping areas reduces sources of food and shelter for birds and small mammals (Webb, 1968). Research by Blakesley and Reese (1988) found that bird species present in and near campgrounds were different than those common to non-campground locations. Related research has found a shift toward more generalist species in areas disturbed by human presence and habitation, also true for developed camping situations, along with increased nest predation by generalists upon more sensitive species (Marzluff and Neatherlin, 2006).

Recreation activities and the development of trails and recreation sites are often associated with negative effects on wildlife habitat, but limited research also suggests habitat gain (Speight, 1973; Boyle and Sampson, 1985). Broadly, these include over-wintering sites for species that use open-water lakes and reservoirs developed for recreation, and the creation of habitat for edge species from trail, campsite, and pond development (Hammitt et al., 2015).

Roads and trails in recreation areas have the potential to fragment habitat and result in a loss of habitat connectivity (Gutzwilier et al., 2017). However, few studies have considered the landscape-scale effects due to recreation (Buckley, 2013), which could be important to wildlife because many species are affected by conditions at multiple spatial extents (Gutzwiller, 2002), and because many species' home ranges and populations often span large areas. Of the limited research available, examinations of wolf movement, for example, suggests that both roads and trails can change movement patterns of wolves, causing them to avoid high-use roads more than low-use trails. (Whittington, St. Clair, and Mercer, 2004). Roads, trails and other human development can affect local distributions of wolves, although areas of low human activity have less of an effect (Hebblewhite and Merrill, 2008).

Related to fragmentation is the idea of habitat connectivity and questions about the effective size of habitat "patches" needed to sustain wildlife populations. Although these concepts are common in landscape ecology (e.g., Turner et al., 2001) the examination of recreation and presence of visitors as agents of fragmentation/reduced connectivity is an emergent topic in the field, with limited empirical work and much still to be investigated (Gutzwilier et al., 2017). What has been done suggests that, in certain situations, recreation infrastructure has the potential to increase fragmentation; much less is known about the distribution and density of recreationists.

Effects of Disturbance and Displacement

Species displacement occurs when wildlife shift from a preferred or familiar habitat to a different location. Implied in this situation is that the new environment is of worse quality (e.g., less browse for ungulates), or has more competition or predation than the original preferred area. It is often suggested that displacement is more serious for wildlife than other disturbances that do not require the animal to move from a preferred location. Some past and contemporary research has examined this issue; for example, the displacement of bighorn sheep and mountain goats (Woodward, Gutierrez, and Rutherford, 1974); red deer (Batcheler, 1968; Coppes et al., 2017) and research on a range of medium and large sized North American mammals (Reilly et al., 2016). Several reviews have also commented on displacement due to recreation, including those found in Knight and Gutzwillier (1995) and Hammit et al. (2015).

Generalizing the effects of recreation on animal displacement is a relatively straightforward exercise—with human presence many, but not all, terrestrial mammals are likely to move to alternative locations. Displacement can also be temporal, in that some species become less active at certain times of day or seasons when humans are present in higher densities. What is much more difficult is to describe the importance and implications of displacement. Many factors influence the severity of this impact, including the intensity of visitor use, specific visitor behaviors (for example the presence of domestic dogs), specific species, and habitat type or availability (Reilly et al., 2017). Broadly, maintaining some habitat areas with little to no human use or trail development, and appropriate buffers around trails and sites where present is a sound management practice called for by most researchers and wildlife managers, and is an important precautionary approach to maintain protected area values for both people and wildlife.

Disturbance to Aquatic Systems

A significant body of research exists on the disturbance of water-based recreation activities in both freshwater and marine environments, including the effects on organisms, physical attributes and chemical composition and processes (Mosisch and Arthington, 1998; Monz et al., 2010; Hammitt et al., 2015). Although a detailed discussion of these effects is beyond the scope of this paper, common issues with water-based recreation in freshwater systems and non-motorized recreation are riverbank and lakeshore disturbance; introduction of pathogens via improper human waste disposal, and disturbance to benthic communities resulting in increases in turbidity (Hammitt et al., 2015). Although specific research is lacking, some of these issues are likely occurring in backcountry locations in the Colorado Plateau region, particularly in locations popular for river running. Of note is the potential for shore disturbance in riparian systems, discussed earlier under vegetation and soil disturbance.

Introduction of Non-Native Species

A growing body of research suggests that recreation and tourism activities have the potential to function as vectors for the spread of non-native species in terrestrial, freshwater and marine environments (e.g., Anderson et al., 2015; Pickering and Mount, 2010). Concerns about this issue have been raised for some time, particularly for invasive plant species introductions (e.g., Marion et al., 1986) and in regard to stocking non-native fish in freshwater environments to enhance fishing experiences (Hammitt et al., 2015). A recent review of the global literature on this issue suggests that locations where recreation and tourism activities are popular have a higher abundance of non-native species. This pattern was consistent, regardless of the type of activity (e.g., horse use, hiking, motor boats), and included marine, freshwater and terrestrial environments (Anderson et al., 2015).

In terrestrial environments where recreation and tourism activities are common, a primary concern is the transport of weed seeds on vehicles, clothing and horses (Pickering and Mount, 2010). Although specific research about recreation transport for weeds of concern on the Colorado Plateau is lacking, some research in arid environments in Australia suggests that hiking (Ansong and Pickering, 2013) and mountain biking (Pickering et al., 2016) can be important transport vectors. A primary finding of concern from this literature is the retention of seeds on clothing and on bikes for extended periods, even beyond a particular visit. Therefore, if equipment and clothing is not properly cleaned, seeds can be transported both within a particular location and from one location to another as visitors travel to different places. This seems to be particularly the case with grass species (Ansong and Pickering, 2013).

Impacts to Natural Sound

An extensive body of scientific study has found anthropogenic noise to be an ecological impact, particularly for wildlife, in both terrestrial and marine environments (Manning et al., 2018; Shannon et al., 2016). The extent to which recreation and tourism activities contribute to this issue is somewhat unclear, but, compared to general human activity near cities and developed locations, visitor transportation near and within public lands and motorized recreation activities clearly result in similar types and intensities of noise (Monz et al., 2016). Increasingly, public lands throughout the USA are becoming noisier as aircraft overflights, road development and industrial activities expand into new locations. Recent work has demonstrated that significant noise is ubiquitous on public lands throughout the USA (Buxton et al., 2017) including areas important for recreation (Manning et al., 2018). It has shown that lands with higher conservation status appear, over time, to attract development and activities in nearby locations that also bring noise (Rice et al., 2020). Overall, public lands, no matter how distant from population centers, can be significantly affected by noise—which can affect both wildlife and visitors.

National parks on the Colorado Plateau all have documented issues with compromised natural soundscapes and have active programs seeking to manage anthropogenic noise whenever possible (e.g., NPS Zion National Park, 2010). Much of this work is focused on maintaining a natural soundscape in the park, an effort largely directed to limiting noise propagating from nearby industrial and developed areas. However, emerging research also suggests that some significant noise sources are from visitor activities within public land boundaries. For example, road noise from vehicle traffic within a U.S. National Park was shown to extend over 1.5km into backcountry areas at some locations, requiring visitors to hike this distance from trailheads to experience natural sounds (Park et al., 2009).

Human Waste Impacts

Proper sanitation in backcountry settings has long represented a somewhat vexing problem for public lands management. The vast majority of backcountry settings on public lands are not served by facilities, nor would it necessarily be appropriate or feasible to provide them. Consequently, human waste management challenges are ongoing, particularly in backcountry attraction sites that may experience periods of high use.

To date, a small but well-executed number of studies have examined biophysical issues with backcountry human waste disposal. Generally, backcountry sanitation has been shown potentially to affect human heath via disease transmission, aesthetics due to improper disposal techniques and ecological processes via the introduction of nutrients and pathogens into the environment (Cilimburg et al., 2000; Bridle and Kirkpatrick, 2003). Several early studies demonstrated the persistence of fecal pathogens using shallow soil “cathole” disposal techniques (Temple et. al., 1980; 1982), with subsequent work examining the efficacy of disposal methods in situations where soils are limited and carry-out techniques are impractical (Ells and Monz, 2011) and in coastal backcountry (Graziano et al., 2007). Findings from this work suggest that in low-use backcountry settings, cathole disposal presents the most viable option and results in few issues, provided disposal occurs well away from water sources, and enough soil is available to adequately bury the waste. Some limited evidence suggests that pathogen persistence is very limited in arid environments with surface or shallow cathole disposal, due to the rapid desiccation of feces (Ells and Monz, 2011). In high-use backcountry settings, carry out techniques are often the best option, with best practices including the use of “wag bags” in hiking situations and portable compact toilets where they can be practically carried, such as in river running. On the Colorado Plateau, it is commonly required to carry a portable toilet for multi-day river trips.

Visitor Impacts to Cultural Resources

Humans settled areas on the Colorado Plateau at least 10,000 years ago (Powel and Smiley, 2002) and public lands in the region contain tens of thousands of known and yet to be discovered cultural resources that represent the history from these ancient times. The term “cultural resources” is broadly inclusive of any tangible remains of past human history in an area, for example, structures, prehistoric (archaeological) sites, historic or prehistoric objects, rock inscriptions, earthworks, and landscapes (NRCS, 2021). A primary management goal of public land units in the region such as Mesa Verde NP, Chaco Canyon NP, Grand Staircase-Escalante NM and many others is to preserve these resources in perpetuity. If cultural resources are lost or degraded, the primary purpose of these lands is lost, that is, the maintenance of these resources unimpaired for present and future generations (NPS, 2021). Cultural resources are often protected and managed as sacred locations for Native Americans and to allow visitors opportunities to gain a deeper understanding and respect for the past human history of public lands.

Visitor activities on the Colorado Plateau can damage cultural resources via a variety of intentional and incidental actions. These include unauthorized excavation or defacement (e.g., looting, graffiti), reuse of artifacts for recreational purposes (e.g., building campfire rings out of ancient masonry) and vehicle disturbance from driving on or near artifacts (Hedquist et al., 2014; Nickens, 1991). Research studies have examined both the direct and indirect effects of road proximity (Hedquist et al., 2014) and off-highway vehicle (OHV) activity (Sampson, 2007) to cultural sites and found both to be a concern. For example, disturbance from recent activities was prevalent at sites that are found within 300 m of a motorized access road while no disturbance was found at sites located greater than 800 m away. OHV use, where not confined to properly managed trails and routes has been shown to be particularly problematic in causing direct disturbance of sites and in increasing soil erosion which then subsequently resulted in disturbance to artifacts (Sampson, 2007).

Section 3

Functional Relationships in Recreation Ecology

Some of the most important research in recreation ecology have been studies examining factors that influence the intensity and areal extent of ecological disturbance. Several authors (e.g., Cole, 2004; Monz et al., 2010) have identified the primary factors that affect area and intensity, which include:

- Amount of use;
- Type and behavior of use including spatial extent;
- Timing of use; and
- Environment type and condition.

Management can influence all of these factors in some way, either by modifications to use and behavior, or via site management. Information regarding these functional relationships can prove very useful.

Amount of Use

Both historically and today, a common misconception has endured that there is a linear relationship between ecological disturbance and the amount of recreation—that is, increases in use result in direct proportional increases in impact. However, even early, observational recreation ecology studies rarely reported direct (linear) use-impact relationships for well-established trails and recreation sites (Cole, 1982). More rigorous approaches, including trampling experiments and campsite-control studies, have concluded that impact responses to use are rarely linear, but rather tend to follow curvilinear, sigmoidal or step functions, depending on the response of interest (Monz et al., 2013; Figures 4 and 5). Moreover, work by Cole (1995a) and others suggests that environmental differences usually contribute substantially to the response, and in some cases may be more important than simply examining the amount of use alone as the causal factor.

Numerous experimental trampling studies on vegetation and soil have been conducted over the last 40+ years in a wide range of locations where recreation disturbance is a potential issue (e.g., Monz, 2002; Hill and Pickering, 2009a; Barros and Pickering, 2015; Runnström et al., 2019). Findings from these studies generally suggest a curvilinear or sigmoidal use-impact response (Figure 4; Monz et al., 2013; Growcock, 2005). In general, these results suggest that the majority of disturbance is a consequence of the initial use in a given location, but subsequent use, even at high levels, results in little additional impact. Experimental results apply well to hiking trails, with the "trampling passes" in the studies equating directly to numbers of hikers along a given trail segment. For campsites, moderate experimental trampling (75-100 passes in experimental studies) often has been equated to a party of 3-4 people on a site for one night. Trampling studies have found a wide range of durability among vegetation types, with some highly durable to trampling, others very fragile. For example, Cole and Monz (2002) found that alpine fellfield grasses in Wyoming easily tolerated over 1000 trampling passes. Forest understory shrubs in a nearby, lower elevation location were found to be highly susceptible, with only 25 trampling passes resulting in long-lasting impacts. More on this is discussed in later sections of this paper.

The amount of use has also been examined as an influential factor in recreation behavior, such as off-trail use and associated impacts, but results appear highly dependent on other factors, such as landscape attraction features and possibly social factors (D'Antonio and Monz, 2016). It is therefore difficult to generalize the effect of increasing use on, for example, how far visitors might travel from a trailhead in order to experience solitude (i.e., the extent of visitor dispersal). In some cases, increasing use has been shown to lessen the spread of visitors, with visitors gathering at attraction sites (D'Antonio and Monz, 2016).

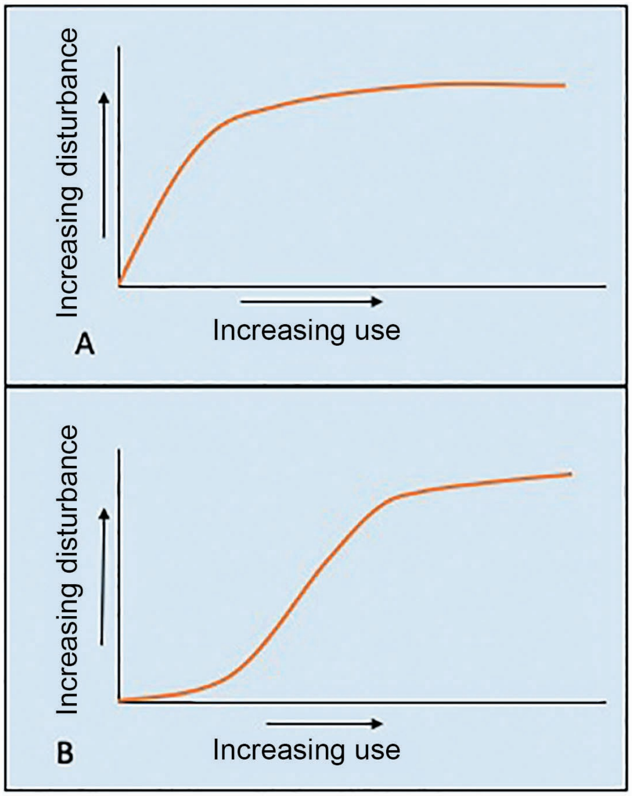

Figure 4. Two common models of the use-impact relationship for groundcover vegetation. (A) depicts a less resistant vegetation type while (B) is more resistant to initial use. With enough use, both types will ultimately be devoid of vegetation and become hardened to additional use. Source: Monz et al., 2013.

Much remains to be studied in this regard as many factors, not just amount of use, may be involved with how visitors disperse in a given location.

While the use-impact relationships for vegetation and soil disturbances are relatively well-documented, we know less about use-impact relationships on wildlife. Several authors have commented on the difficulties of generalizing across the broad range of behavioral and species-specific disturbance responses in wildlife, but one widely reported generalization regarding increased use and disturbance is how birds are displaced when approached by tourists or recreationists (Buckley, 2004; Steven et al., 2011). Knight and Gutzwilier (1995) described this as “fight or flight” behavior, and Monz et al. (2013) used a step function to depict the relationship between use and disturbance (Figure 5).

This suggests that, in some situations, wildlife may respond with sudden displacement behavior from their pre-disturbance locations as numbers of visitors increase, or if visitors approach the animals. This type of behavior also suggests that wildlife may exhibit a complete avoidance of areas that are more intensively used, resulting in decreased animal diversity close to high-use sites (Buckley, 2004; Steven et al., 2011; Newsome et al., 2013).

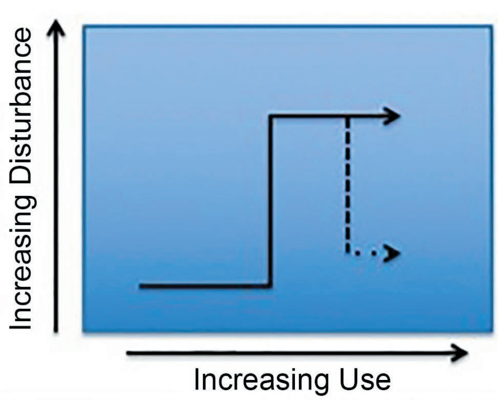

Figure 5. A generalization of wildlife responses to increases in visitor use. Wildlife tolerate some use, but are then displaced. Return of wildlife to the same location may occur upon the cessation of use. Source: Monz et al., 2013

Type and Behavior of Use

Type of use and mode of travel can greatly influence the degree of ecologic disturbance (Hammitt et al., 2015). Knobby tires on mountain bikes compact and displace trail substrates quite differently than horse hooves or human footwear. The forces exerted on a trail vary considerably, including their ground pressures, which range from 200 g/cm^2 for a hiker, 1500 g/cm^2 for an off-highway vehicle, to 4000 g/cm^2 for a horse (Liddle, 1997). Several studies have experimentally examined the effects of different modes of non-motorized travel to understand their ecological effects (e.g., Cole and Spildie, 1998; Deluca et al., 1998; Torn et al., 2009; Figure 6). Overall, studies have found horse traffic to be the most disturbing to vegetation and soils, with hiking being slightly less than the use of llamas as pack stock, followed by cross country skiing as having the least disturbance on trails due to the protective nature of the snow layer.

Of particular relevance to the Colorado Plateau have been studies examining the relative disturbance of mountain biking, given the prevalence and popularity of this activity in the region. Early work on this topic found little to no difference in ecological disturbance when mountain biking and hiking were compared experimentally (Wilson and Seney, 1994), or via a broad assessment approach (Bjorkman, 1998), including one study conducted in part on the Colorado Plateau (White et al., 2006). However, subsequent research suggests that this has likely changed due to shifts in riding styles and preferences and new bicycle technology. For example, a review by Pickering et al., (2010a) and field assessments by Newsome and Davies (2010) and Pickering et al., (2010b) suggest that with the increased emphasis on downhill riding (which results in skidding, high banks on turns, and generally higher speeds on trails) combined with participant-constructed informal trails and technical features such as jumps and mounds, the impacts can be severe. Generally, these types of disturbances can be reduced by creating trails designed and maintained for mountain biking activities—but this is challenging in many public land settings, as mountain biking activities often take place on multiple-use trails. Thus, these disturbances have the potential to displace other visitors and result in degraded trail conditions unless managed carefully.

Similarly, visitor knowledge and behavior related to minimum-impact practices can also significantly affect the nature and severity of impacts (Manning, 2003; Marion, 2014; Marion and Reid, 2007). Uninformed, unskilled, and careless behaviors often create more impacts than more experienced and motivated visitors applying best practices (Bromley, Marion and Hall, 2013; Marion, 2014; Settina, Marion and Schwartz, In Press). Group size can be an important factor when large groups fail to use large, previously impacted sites, or break up and camp on multiple smaller sites (Monz et al., 2000). Activity types and behaviors that result in expanding recreation use from concentrated, high-use areas to new, less visited and undisturbed locations are perhaps the most serious consideration. As illustrated by the use-impact relationship (Figure 4) disturbance can proceed rapidly if undisturbed areas are put into use, thus expanding the overall area affected by recreation (Hammitt et al., 2015). And therefore, spatial management of recreation use is a desirable strategy to limit the overall impact (Leung and Marion, 1999).

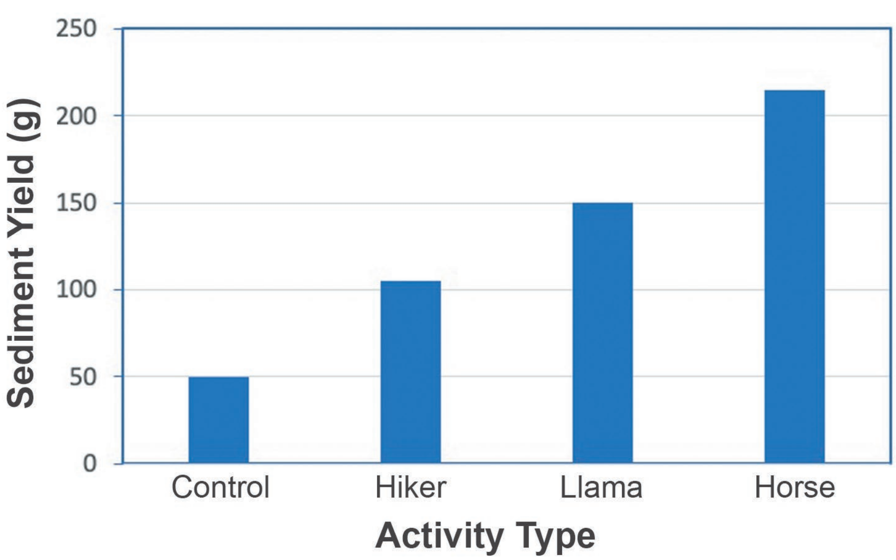

Figure 6. Soil disturbance on trails as a result of hiker, llama, and horse use. *Source: Deluca et al., 1998*

RECREATION ECOLOGY LAB

Timing of Use

Regardless of use type, land managers often report that heavy trail use during wet seasons can lead to substantially greater trail tread degradation (soil displacement, erosion, muddiness, and widening) than similar traffic in dry seasons, when soil substrates can support more use. Similarly, trampling of groundcover during seasons of active growth and maturation is often more damaging than when plants have gone to seed and died back (Hammitt et al., 2015). Wildlife are more vulnerable to disturbance when nesting, giving birth, raising their young, or coping with wintertime temperatures and reduced food supplies (Marion, 2019). Overall camping impacts are often exacerbated during peak-use periods, when established previously impacted sites fill, and visitors expand existing campsites or establish new ones (Wang and Watanabe, 2019). For example, on popular long-distance trails like the Appalachian Trail (A.T.) in the eastern U.S., a two-month period of peak use exists where many hikers are traveling south to north in accord with the hiking season. Overnight use during this period can often exceed existing site capacity, resulting in expansion and proliferation problems that have created numerous very large sites and clusters of sites (Marion et al., 2019a).

Anecdotal observations suggest that the recent improvements in headlamp and bicycle light technology have increased participation in hiking, mountain biking and trail running activities during nighttime hours, but little if any data or research is currently available to support this claim. While enjoying the night sky is a long-valued element of the outdoor recreation experience, and a primary value in U.S. National Parks (National Park Service 2020) including many on the Colorado Plateau, expanding unmanaged use to night hours has the potential for various issues with visitor use and ecological disturbance. Wildlife in particular may be especially sensitive to visitors at night, as historically this has been a time of limited human presence and movement on public lands.

Environment Type

The durability of sites where recreation is occurring is a difficult topic to generalize broadly because it is often situational, dependent on the specific response of the variable of concern. For example, a sub-alpine meadow may be resistant to vegetation loss, but shallow soil over bedrock may be highly vulnerable to erosion. The properties of resistance and resilience are also important considerations. Resistance is the ability of a location to withstand recreational use without being disturbed, and is often described as the amount of use a site can withstand before substantial change occurs. Resilience is the ability to recover from disturbance; that is, the time it takes for a site to return to pre-disturbance conditions. Some sites are resistant but not resilient—they can tolerate a substantial amount of use, but once impact occurs, it is long-lasting. Many desert and alpine locations provide good examples of sites that are often resistant, but not resilient. Alternatively, many riparian areas are resilient, in that they recover rapidly,

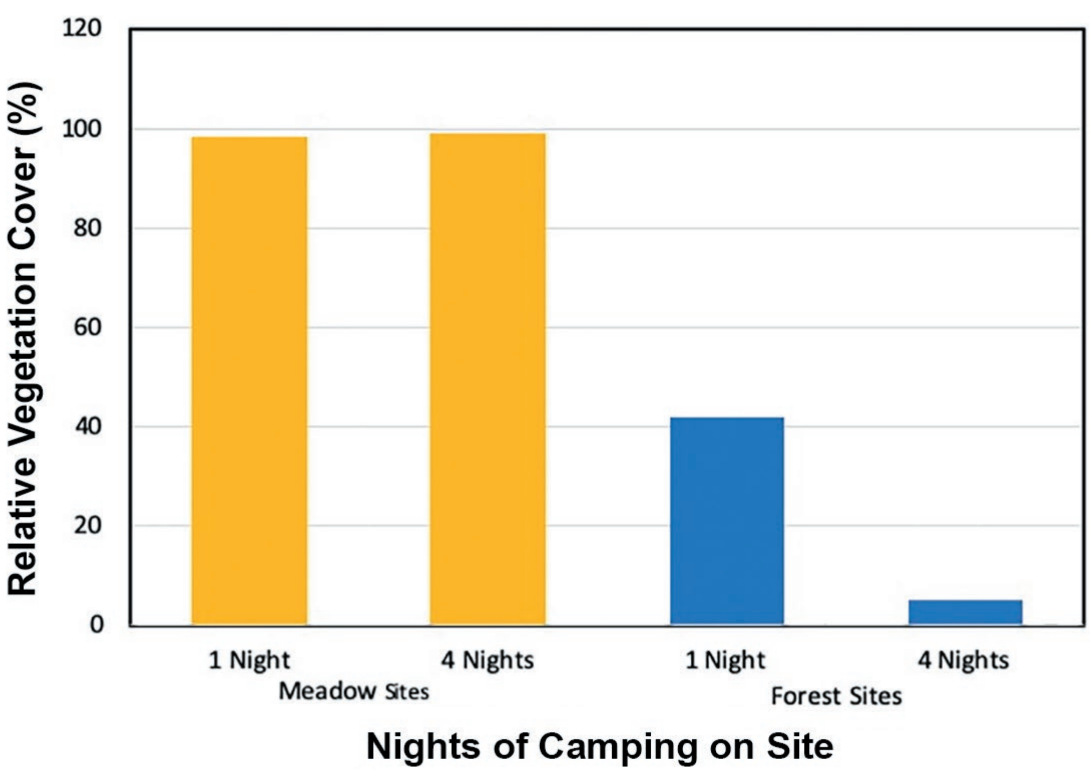

Figure 7. A comparison of two environment types subject to similar levels of camping disturbance. *Source: Cole and Monz 2003*

but not resistant, in that they show disturbance after little use. On sites designated for long-term recreation use, such as developed campgrounds or assigned site backcountry camping, resistance is the more important factor, because these sites will be used in perpetuity. In areas of highly dispersed use, however, resilience is at least as important as resistance, because management objectives in such places stress the avoidance of permanently impacted sites. A good example of research examining these properties is found in Cole and Monz (2003) where the trampling response of a resistant sub-alpine meadow, dominated by grasses, was compared to that of a more vulnerable forest understory dominated by broad leaf forbs (Figure 7). In the sub-alpine meadow, light camping use of up to four nights of camping had little effect on overall vegetation cover. Twelve nights of camping over the course of three seasons resulted in a slight decrease in cover. In contrast, the forest understory was substantially affected by just one night of camping, with over a 50% decrease in plant cover. Higher camping intensities resulted an almost complete loss of the vegetation.

Limited information on the effects of recreation use is available for more arid environments, but what has been done suggests that the cryptobiotic soil crusts, which are vital to maintaining a healthy ecosystem, are highly susceptible to trampling disturbance. Early work by Cole (1990) conducted in Grand Canyon NP, found that only 15 trampling passes (a one-way walk) destroyed the crust structure, and by 50 passes, visual evidence of cryptobiotic crusts was reduced to near zero. Recovery was found to be evident in one to three years, and visual estimates indicated a near complete recovery in five years. However, subsequent work by Belnap (1993) suggests that visual estimates were poor measurements of recovery of these complex functional soil systems, and that recovery rates are actually much longer. Belnap and Eldrige (2001) reviewed the global literature on cryptobiotic soils and found a wide range of recovery estimates, from as little as 14 years to hundreds of years. They suggest that some of this variation is due to site microclimate—shady and higher moisture sites recovered more quickly, while sun-exposed sites took much longer. Despite the difficulty in generalizing these findings, it is clear that cryptobiotic soil crusts are very fragile, with basically no resistance to recreation use, and full recovery is very slow, likely on the order of at least decades.

Minimizing Vegetation and Soil Impacts

The above summary of recreation ecology knowledge suggests several important approaches to minimizing recreation impacts. Where specific studies are lacking, much can be inferred as to what strategies would likely be successful for recreation use on the Colorado Plateau. As discussed, recreation use of all types has the potential to result in direct disturbance to vegetation and soil, so a focus on ground disturbance associated impacts is of primary concern. The asymptotic or sigmoidal nature of most vegetative and soil disturbance suggests relatively low thresholds of use before severe impacts form—especially on Colorado Plateau locations where soil crusts can be damaged severely with very light use. Consequently, management strategies that focus recreation use on existing sites and trails, and maintain overall visitor capacities such that these locations can accommodate use, will be most effective at limiting impacts to soils and vegetation. Cole (1997) argues that the curvilinear use-impact relationship further suggests that unused locations are the most precious and fragile, and thus should be intensively protected and managed to avoid the proliferation of impact.

For campsites, research findings suggest that managers should identify the most sustainable sites and encourage or require their use—commonly referred to as a confinement strategy (Table 1). This can either be deployed as a strong management recommendation that visitors use already impacted sites, or that they are required to camp in designated sites. Typical recommendations in most environments is that dispersal strategies for "pristine" camping are possible if visitors can be directed to durable, but previously unused locations for camping. Another option, at-large camping with higher levels of use, frequently results

Table 1. Camping management strategies, options, and guidance *(adapted from Marion et al., 2018).*

Camping Strategy	Use Level Typically Applied	Description	Effectiveness for the Colorado Plateau
UNCONFINED **"At Large" Camping**	All	Visitors have the freedom to select or create a campsite in the location of their choice, modified by management guidance to avoid certain locations	Likely ineffective in locations with soil crusts. Campsite proliferation is often an issue
DISPERSAL STRATEGY **Pristine Site Camping**	Very Low	Visitors are asked to camp on durable *previously undisturbed*, surfaces at low-use levels, thus avoiding lasting impact.	Very ineffective in locations with soil crusts. Difficult to achieve in most situations and requires highly skilled visitors
COFINEMENT STRATEGY **Established Site Camping**	All	Visitors are *encouraged to camp* in well-established campsites, often selected by managers	Likely effective with visitor compliance, but not all will comply. Allows for visitor choice.
COFINEMENT STRATEGY **Designated Site Camping**	Mod - High	Visitors are *required to camp only* on a subset of sustainable, designated campsites selected by managers to promote resource protection.	Likely effective, but limits visitor choice. Often requires management through a reservation system.

in substantial problems with site expansion and proliferation which maximizes aggregate impact within moderate to high-use areas (Cole, 1982; 2013; Marion et al., 2018). Under this policy, visitors often create large numbers of campsites with low occupancy rates, most concentrated in large, flat areas that tend to promote site expansion and proliferation. It is not likely that either of these strategies (dispersal or at-large camping) will be effective at limiting damage to cryptobiotic soils, given their extreme fragility, but may be more appropriate where soil crusts are absent and more durable surfaces can be found. For example, work by Romo et al. (2018) on the Colorado Plateau suggests that a significant number of naturally occurring sites free of cryptobiotic soils may exist, since assessments found cryptobiotic disturbance on a minority of existing campsites (28%). Given the fragility of these soils, any recreation use will likely result in disturbance—so it is unclear whether these were free of cryptobiotic soils naturally, or whether disturbances such as cattle grazing (prevalent in this study site) resulted in the loss of soil crust.

Site management has long been used to both focus visitor activities at broad spatial scales (such as the design and siting of trailheads), and at smaller scales (such as at site level to provide an attractive campsite that limits use to hardened surfaces). For a full discussion of site management, refer to Hammitt et al. (2015). Recent research has tested some of these longstanding approaches, and supports the assumptions that site terrain characteristics and micro-topography (rockiness) are factors that can be effectively applied to sustain high use at campsites while minimizing impacts to nearby resources (Marion, 2016; Marion et al., 2019a). When campsites are surrounded by substantial rockiness or slopes in excess of about 15%, visitors will naturally choose to concentrate their camping activities on the flat, smooth terrain within site boundaries.

Although, reducing overall use on well-established recreation sites and trails often does not result in less ecological disturbance, reducing peak use can be an effective strategy for reducing the number of campsites necessary, and their aggregate area of camping impact. Problems of campsite expansion and proliferation are likely magnified during peak-use periods, when all visible or accessible sites are filled (Wang and Watanabe, 2019). Improved mechanisms for matching demand with the supply of sustainable campsites can help reduce site expansion and proliferation.

Broadly, the management of travel corridors, routes and trails is often based on a process of confining use and consequent impact to locations where use is established, but in some situations, it is possible to manage off-trail use sustainably (Table 2). A number of research studies have shown that on established trails, design considerations and environmental factors such as trail steepness (grade), alignment angle to the prevailing slope, soil type, and tread drainage are often more important determinants of trail resource conditions than use level (e.g., Olive and Marion, 2009). Therefore, where appropriate, establishment and maintenance of sustainable trails should be of primary concern, with direction for visitors to confine their travel to these established routes. Dispersed, off-trail use, even at low levels, is unlikely to be an effective long-term strategy in plateau areas, except where travel can be completely confined to durable surfaces, away from colonized cryptobiotic crusts, such as along seasonal washes, across sand and slickrock. Establishment of "informal routes" at these locations might also be the most effective strategy, as route markers such as cairns can assist visitors in following routes, and thus limit the areal extent of disturbance.

On the Colorado Plateau, an additional use-related concern is the ubiquity of mountain biking, as recent research has called into question earlier findings that suggest little to no difference between mountain biking and hiking (e.g., Pickering et al., 2010b). The focus on downhill travel, higher speeds, skidding and banking on turns, combined with new bicycle technology (e.g., Fat Bikes, eBikes) which allows for travel across new terrain, suggests that this activity has the potential to both intensify and proliferate damage to soils and vegetation. Bicycle travel also tends to expand the total extent of recreation use, as cyclists tend to travel further than pedestrians. These issues are likely to be exacerbated with the emergence of eBikes (motor assisted bicycles), which have proliferated in many places, largely without regulatory control. Currently, no research studies have yet examined eBike impacts. Given these emerging issues, the management of bicycle use should be given careful consideration on the Colorado Plateau.

Minimizing Wildlife Impacts

Management strategies and actions that concentrate visitor use to minimize vegetation and soil impacts can be employed in a similar way to minimize wildlife impacts (Marion, 2019). Wildlife often adapt to consistent, non-threatening recreational activities. Containment strategies that spatially concentrate use on formal trails and impact-resistant recreation sites can limit negative wildlife impacts. Modifying the location and timing of use, such as shifting trails and recreation sites away from areas of high-quality wildlife habitat to areas of lower-quality habitat is also an effective strategy. Off-trail activities can be discouraged or prohibited in particularly sensitive areas or during sensitive times, such as temporary prohibitions on use near a bird rookery or nest (Gutzwiller and Knight, 1995). Use-level reductions may or may not be an effective strategy to minimize recreation impacts on wildlife, as modest limits in high-use locations are unlikely to lessen wildlife disturbance. However, in locations without established use, maintaining little to no use will maintain quality habitat (Marion, 2019). Managers considering these strate-

Table 2. Backcountry travel corridor/trail management strategies.

Backcountry travel management strategy	Use Level Typically Applied	Description	Effectiveness for minimizing impacts on the Colorado Plateau
UNREGULATED **Travel in locations without specific management and formal trails**	All	Visitors have the freedom to travel on routes and via modes of their choice.	Very ineffective in locations with soil crusts. Higher use locations will likely see the formation of networks of informal trails that are unsustainable.
DISPERSAL STRATEGY **Travel in areas of sparse vegetation; e.g., open summits, mesas**	Very Low to Low	Visitors are *asked to* travel on durable surfaces at low-use levels to avoid lasting impact. Durable surfaces include slickrock, sand, gravel, etc.	Likely ineffective in locations with soil crusts. Difficult to achieve in most situations and requires highly skilled visitors. Has been effective elsewhere, in some highly regulated settings, with low-use levels.
COFINEMENT STRATEGY **Travel on established but unmanaged routes: e.g., Canyoneering, climbing approach and descent**	Low-Moderate	Visitors are *encouraged to follow* well-established, sometimes informally marked routes	Likely effective with visitor compliance, but not all will comply. Allows for a more primitive experience and some visitor choice. More risk is assumed by the visitor, since routes are unmanaged.
COFINEMENT STRATEGY **Designated Trails**	Mod - High	Visitors are *required to travel only* on sustainably designed and maintained trails	Highly effective at limiting resource impacts. Limits visitor choice. In very high-use situations, often requires capacity

gies should always be mindful that opportunities to view and experience wildlife in their native habitat is one of the most valued aspects of an outdoor recreation experience.

An emerging perspective within wildlife and recreation management is the potential fragmentation of habitat by recreation access roads, trails, and recreation infrastructure. Although much remains unknown about the role of recreation in habitat fragmentation, and consequently its role in affecting distributions across the landscape, the general literature regarding landscape fragmentation suggests that recreation may have a significant effect. It would be prudent, therefore, to consider any alterations in recreation use or new trail, road or facility development that may expand use into new areas with full consideration of how it will affect critical habitat, migration corridors, the effective size of habitat patches and other landscape-level concerns.

Minimizing Disturbance to Aquatic Systems

In freshwater river and lake environments, water-based and shoreline recreation activities should be managed to minimize the potential inputs of pollutants (e.g., sunscreen, food scraps, pathogens, sediment runoff from trails and recreation sites) and direct trampling disturbance of shorelines and littoral zones (land areas closest to the water). This is particularly important in oligotrophic (nutrient poor, low productivity) lake ecosystems common to high mountain environments, but may be less vital to high-volume river systems on the Colorado Plateau. As mentioned, research suggests a linear relationship with use and some response variables such as E. coli bacteria (Hadwen et al., 2010; Monz et al., 2013). Therefore, in some spatially limited, high-use settings, limiting total numbers of recreationists at any one time may be an effective strategy.

Managing Natural Soundscapes

While many anthropogenic noise impacts originate outside public land boundaries and therefore may be beyond the ability of managers to directly influence, emerging research also suggests that significant noise sources result from visitor activities within boundaries. For example, road noise from vehicle traffic within a U.S. national park was shown to extend over 1.5km into backcountry areas at some locations, requiring visitors to hike this distance to experience natural sounds (Park et al., 2009). This suggests that management interventions, such as reductions in vehicle speeds, roadway surface treatments, and noise limits for motor vehicles and equipment (such as those recently adopted by the U.S. National Park Service—NPS, 2019) may be options to minimize noise propagation. Other research suggests that noise from hikers (e.g., loud talking, cell phones, etc.) can be reduced by 2-3 dB with educational interventions (Manning et al., 2010). Overall, these studies suggest the importance of noise management, and that some reduction is possible with indirect management strategies.

Minimizing Impacts to Cultural Resources

A contemporary approach, the Cultural Resource Management (CRM) framework is broadly inclusive of all aspects of the physical and metaphysical environment to which people ascribe meaning relating to culture (King, 2011). The idea of managing cultural resources is often seen as a bit of a misnomer—managers often focus on events that affect cultural resources as opposed to the resources themselves. Thus, activities such as the administration of public land, proper sighting of construction projects, protection of artifacts from unintentional damage and theft, interpretive programs to allow the public to develop meaningful connections to cultural resources, etc., are often the focus of programs of CRM. Effective CRM should seek to incorporate cultural resource issues into planning, avoid or eliminate adverse effects, provide interpretive services, and prescribe appropriate uses and care of cultural resources via the involvement of groups with cultural or spiritual ties to the resources to be managed (NPS, 2021).

As such, the management of public land visitors and visitor activities would be included under a broad program of CRM, and is often required to be included as part of a comprehensive land management planning process. Within comprehensive planning processes, recreation activities are often managed via "management by objective" strategies, with the most recent framework being the Interagency Visitor Use Management (VUM) approach (IVUMF, 2021). This and related frameworks rely on the development of indicators of quality and thresholds of acceptability in order to initiate and evaluate effective management. While properly executed VUM approaches can be effective for a wide range of visitor activities, it has long been acknowledged that indicator-threshold approaches are not useful in situations where no compromises can be made in the condition of the resource, i.e., for resources that are not renewable (McCool and Cole, 1997). For example, it would not be acceptable to allow some annual loss of artifacts from an archaeological site in order to allow visitors a more unregulated experience because over time the quality of the sites would be lost, and they are not restorable. These ideas have been explored more recently in the context of a research framework to advance management approaches, as significant knowledge gaps exist in how visitors experience and interact with cultural resources (Miller et al., 2021).

In light of some of these complexities in managing cultural resources, contemporary public land visitor management approaches to minimize resource damage (Hammitt et al., 2015) and managing depreciative behavior in a cultural resource context (e.g., Marion and Reed, 2007; Ward and Roggenbuck, 2003; Hedquist et al., 2014)) suggest numerous interventions to limit or eliminate physical damage and social impacts (Table 3). Although a range of strategies including limiting road and OHV access, site closure, guided entry, interpretive programs and law enforcement are possible, studies suggests that no one single strategy except for closure will completely eliminate damage or loss of cultural resources. This is problematic because even very low levels of damage or theft of artifacts results in significant degradation over time that cannot be practically restored (Widner and Roggenbuck, 2000).

Several explanations as to why this depreciative behavior occurs have been explored including issues with moral development and rationalizing seemingly insignificant actions (i.e., "Tragedy of the Commons"; Ward and Roggenbuck, 2003) and "deviant leisure" where actions such a theft and destruction are part of the experience (Miller et al., 2021). Until a greater understanding of some of these complexities is gained, it is prudent to develop very precautionary management strategies that emphasize protection of cultural resources by combining several of the established visitor management strategies to limit resource impact, including site closure and limiting road and OHV access (Table 3). In addition, since cultural resources are not renewable or replaceable, this suggests a high level of risk associated with many visitor activities to both resource preservation and the long-term visitor experience, and thus restrictive management actions may be warranted (Miller et al., 2021).

Table 3. Public land visitor management strategies for cultural resources

Cultural Resource Visitor Management strategy	Use Level Typically Applied	Description	Effectiveness for Minimizing Impacts to Cultural Resources
UNREGULATED **Travel in locations without specific management**	Low-Moderate	Visitors can travel in an unconfined manner and "discover" artifacts and sites in their natural state.	Likely ineffective over time as even small amounts of disturbance or theft results in significant loss or diminished condition. Particularly ineffective for motorized use.
COFINEMENT STRATEGY **Travel on established routes and designated trails**	Moderate-High	Visitors are *encouraged or required* to follow well-established, and/or marked routes and trails.	Likely effective with visitor compliance, but some will not comply. Trails can be routed away from sensitive sites that cannot be effectively managed and near locations that can be managed sustainably.
COFINEMENT STRATEGY **Guided Entry**	High	Visitors are only permitted to enter sites in an organized way with a qualified guide or ranger.	Highly effective at limiting resource impacts. Limits visitor choice but presents an enriching experience by incorporating interpretive components
COFINEMENT STRATEGY **Site Closure**	High	Visitors are not legally permitted to enter sites and often physically separated from resources. Can be applied continuously as in sensitive archeological sites or temporally, to honor spiritual practices of specific groups during certain times.	Highly effective at limiting resource impacts. Limits visitor choice and experience, but accommodations can be made through interpretive programs and visitor center displays.
LAW ENFORCEMENT	All	Intentional damage, destruction or theft of cultural resources in public land settings is a serious offence. On federal lands this can result in either a misdemeanor or felony charges, depending on several factors	Effective and necessary, but not all lands can be adequately patrolled and even small amounts of damage and theft can result in serious degradation over time.
INTERPRETATION AND EDUCATION	All	Programs designed to inform visitors as to the existence and value of cultural resources and best practices to experience them. Often includes information on laws and regulations.	Effective and necessary, but will not eliminate all damage and theft, particularly intentional actions.

Section 5

Conclusions and Policy Implications

- The demand for nature-based recreation on public lands continues to increase. This has been especially manifest in many locations on the Colorado Plateau where use has increased dramatically in the last decade. Future management of public lands will have to be proactive in order to accommodate a likely continued increase in demand while also protecting the natural landscapes visitors seek.
- Virtually all types of recreation use have the potential to result in ecological disturbance, particularly when activities are not managed. Management can take multiple forms, but (where practical), spatial confinement or concentration of use on maintained and designated trails, sites and routes can be highly effective at minimizing vegetation, soil, wildlife and other disturbances. Dispersal of use is likely to result in a proliferation of resource impacts over a broader spatial scale.
- Public land managers can, and often do, modify visitor activities and behaviors through regulations and minimum-impact educational programs.
- Numerous management challenges exist in public land areas on the Colorado Plateau, including widespread distributions of fragile cryptobiotic soil, limited wildlife habitat, and vast acreages with multiple entry points which are difficult to manage. Management decisions should be carefully considered and informed by the best available science in order to assure long-term sustainability.
- Expansion of recreation use into new, previously little-used locations, either via new activities or via an expansion of access, should be pursued cautiously. Numerous research studies suggest that ecological impacts will likely proceed rapidly as use expands to new locations—areal expansion and proliferation of resource impact is arguably the most damaging to ecological integrity. Therefore, sustainable management strategies will likely involve the concentration of recreational use and amenity development in previously-impacted or high-use areas.
- Frontcountry and backcountry areas present different management challenges due to the sensitivity of the landscape and visitor expectations. With this in mind, land managers should distinguish between frontcountry and backcountry areas and manage those areas accordingly.
- Mechanized and motorized use can increase human presence and potential disturbance further from frontcountry areas more rapidly than non-mechanized/motorized activities. Dust, noise and disturbance to cultural resources have all been documented as significant impacts from motorized activities. As with all recreation use types, motorized and mechanized use should be managed carefully in order to minimize these impacts, especially habitat fragmentation and disturbance to important species, especially wildlife.

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