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recreation

A Review and Synthesis of Recreation Ecology Research Findings on Visitor Impacts to Wilderness and Protected Natural Areas

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The 50th anniversary of the US Wilderness Act of 1964 presents a worthy opportunity to review our collective knowledge on how recreation visitation affects wilderness and protected natural area resources. Studies of recreation impacts, examined within the *recreation ecology* field of study, have spanned 80 years and generated more than 1,200 citations. This article examines the recreation ecology literature most relevant to wilderness and backcountry, with a focus on visitor impacts to vegetation, soil, wildlife, and water resources. We also review relationships with influential factors, such as the amount of use, visitor behavior, and vegetation type. An understanding of these impacts and their relationships with influential factors is necessary for land managers seeking to identify acceptable limits of impact or selecting management actions that will effectively avoid or minimize resource impacts.

Keywords: recreation ecology, visitor impacts, wilderness recreation

Since passage of the 1964 Wilderness Act, the US National Wilderness Preservation System (NWPS) has grown from 54 units and 9 million acres to 758 units and nearly 110 million acres.[1] The NWPS currently represents about 5% of the entire United States, an area slightly larger than the state of California. Four federal land management agencies are responsible for the stewardship of these protected lands: the National Park Service (≈44 million acres), the Forest Service (≈36 million acres), the Fish and Wildlife Service (≈21 million acres), and the Bureau of Land Management (≈9 million acres). The professional stewardship of these lands to maintain their wilderness character, defined in part as undeveloped lands retained in their natural condition and unhindered by human actions, requires objective information about internal and external threats (Landres et al. 2011). Recreational visitation, while recognized in the Wilderness Act as a core traditional use of wilderness, is also a principal internal threat to wilderness preservation.

This article provides a review and synthesis of the environmental impacts associated with recreational visitation of wilderness and other protected natural areas, along with a discussion of influential factors affecting the nature and severity of these impacts. The term *impact* in this article denotes any undesirable visitor-related biophysical change to natural resources. Such knowledge provides an essential basis for deliberations and decisions regarding the acceptability of visitor impacts and the selection of effective management actions designed to avoid or minimize resource impacts. The field of study that generates this knowledge is known as *recreation ecology*, which has been defined as the scientific study of ecological changes associated with visitor activities, including the role of influential factors (Leung et al. 2008, Monz et al. 2010a). This review is derived principally from studies conducted in designated wilderness areas and comparable wildland and backcountry settings in the United States, collectively referred to as protected natural areas. Studies from other countries are also included if they are directly relevant to specific impact topics. Additional discussion on this subject matter is available from Liddle (1997), Newsome et al. (2012), and Hammitt et al. (2015).

Recreation visitation to protected natural areas inevitably degrades natural resources intended for protection, creating tension between recreation provision and resource protection goals and mandates. Vegetation is trampled, soil is eroded, water quality is altered, and wildlife are disturbed. These impacts occur primarily in locations that re-

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ceive substantial visitation. A primary goal of protected area and wilderness management is to limit the areal extent of visitor impacts, the human "footprint" of highly disturbed land. Of equal importance is limiting the severity of impact to levels that are not ecologically, managerially, esthetically, or functionally significant. The professional management of visitor impacts to protected natural areas requires a thorough understanding of the various types of impacts, their severity, extent, and spatial distribution, and the influence of factors, some of which are causal factors such as the amount of use and visitor behavior, and others are noncausal factors such as environmental susceptibility. This review focuses on recreation impacts to vegetation, soil, water, and wildlife, including the role of key influential factors. Most of these impacts occur on or near recreation sites (e.g., campsites, picnic sites, boat launches, and vista points) and trail corridors. The accompanying article by Marion (2016) focuses on describing the most effective visitor impact management strategies and tactics derived from recreation ecology science and management experience.

Figure 1. Diagram of vegetation and soil impacts resulting from human trampling.

Synthesis of Research

Vegetation Impacts—Light Traffic

Visitor trampling associated with recreational activities results in a variety of impacts to vegetation, including a reduction in vegetation cover, height, and biomass, changes in species composition, and the introduction and spread of nonnative plants (Figure 1). Plant resistance is the intrinsic capacity of vegetation to withstand the direct effect of trampling by feet, hooves, and tires (Liddle 1997). Under light recreational traffic, most plants respond with a reduction in plant height. Even light trampling will break rigid stems, which can halt flower and seed development and reduce plant vigor (Cole 1987, Barros and Pickering 2015).

A meta-analysis of trampling studies by Pescott and Stewart (2014) found that plant morphological characteristics strongly influence the response of vegetation to trampling disturbance. For example, the brittle woody stems of shrubs and small trees and rigid stems of tall forbs (herbs) are susceptible to trampling damage, and their breakage eliminates the growing tips (perennating buds), flowers, and seed production (Cole 1995b, Cole and Monz 2002). In contrast, grasses and sedges (graminoids) with turf or tuft growth forms and low-growing herbs had substantially greater trampling resistance due to their flexible stems and leaves and perennating buds at or below the ground surface (Hill and Pickering 2009, Striker et al. 2011). In an experimental trampling study on an alpine grass and sedge turf, 500 passes by a hiker reduced cover 40%, whereas the same level of trampling in a subalpine forest with a forb and fern understory reduced cover 97% (Cole 1995a).

Studies show that these differences in morphology and trampling resistance are highly correlated with sunlight intensity (Liddle 1997, Cole and Monz 2003). Nonwoody shade-tolerant plants require large leaf surfaces supported by strong rigid stems that are easily crushed. In contrast, sun-loving plants (particularly graminoids) can obtain the necessary sunlight with small or narrow leaves and flexible stems. In a study of designated campsites in the Boundary Waters Canoe Area Wilderness (BWCAW), Marion (1984) found that the amount of sunlight was the most influential predictor of vegetation cover, ranging from an average of 4% cover on shady campsites (≥75% tree cover) to 52% cover on sunny campsites (≤25% tree cover).

Plant resilience, the capacity of vegetation to recover from trampling damage, is another important plant characteristic to consider (Liddle 1997). Similar to plant resistance under conditions of light traffic, woody plants and tall herbs with rigid stems are least resilient because all perennating buds are lost when stems are broken or crushed. Broken woody branches can re-

Management and Policy Implications

Outdoor recreation in wilderness and other protected natural areas is an important value and ecosystem service to our society, but visitor activities can also induce undesirable effects to various ecological components and visitor experience. To integrate wilderness protection and recreation objectives, managers require objective information on recreation impacts so they can evaluate the ecological and social significance of impacts as well as their control. This article synthesized recreation ecology research intended for enhancing our understanding of recreation impacts while advancing the practice of visitor impact management. The results suggest that advances in recreation ecology have gone further with vegetation and soil, whereas research on wildlife impacts has gained momentum in recent years. Recreation impacts on water quality remains a less active research area. The body of knowledge on recreation impacts has demonstrated its utility in informing visitor planning, management and education strategies, and actions being implemented in wilderness and other protected natural areas.

quire years to recover, and tall herbs are often unable to recover sufficiently to flower within the growing season. Thus, woody plants and tall herbs generally have low resilience (Cole 1995b), and their rates of germination and survival under trampling pressure are quite low (Marion and Cole 1996). Numerous studies have documented the substantially greater resilience of graminoids as a group, attributed primarily to stem flexibility, leaf durability, and fast growth rates (Sun and Liddle 1993, Pickering 2010). Plant resilience is also highly dependent on environmental attributes: plant recovery is generally higher in locations with greater sunlight, soil fertility, moisture, and long growing seasons (Marion and Cole 1996, Hartley 1999, Pescott and Stewart 2014).

Vegetation Impacts—Moderate/High Traffic

As recreational activity increases beyond initial and low levels of traffic, plant cover and biomass are reduced as plant health and vigor are degraded (Figure 1). Damage and removal of leaves renders plants unable to produce sugars and store carbohydrates in roots, which slows or halts flowering and seed production and reduces plant growth in subsequent years (Liddle 1997, Hartley 1999). Plants that are sensitive to trampling are greatly reduced in size and cover or are removed by moderate levels of trampling, whereas more resistant species may even increase their number and cover (Cole and Monz 2003, Cole 2013). Such compositional changes in vegetation occur slowly over many years, but the cumulative long-term effects can be substantial, e.g., forest herbs are replaced by grasses, low-growing herbs, and sometimes mosses (Marion 1984, Mortenson 1989, Liddle 1997). Over time, additional compositional changes often occur from the introduction and dispersal of nonnative plants, which may out-compete and replace native species (Underwood et al. 2004, Dickens et al. 2005, Pickering and Hill 2007). Fortunately, the majority of nonnative plants are disturbance associated and shade intolerant; however, a few can naturalize and become invasive, outcompeting native plants in undisturbed settings (Marion et al. 1986). These are the "high-priority" invasive species that land managers generally target for removal. Additional research is needed to determine the potential threats posed by introduction of nonnative plants along informal (visitor-created) trails or from new activities such as geocaching.

Higher levels of trampling, including intensive traffic at the center of campsites and trails, generally remove all plant cover (Figures 1 and 2) (Monz et al. 2010b). The most trampling-resistant species often survive only in slightly less trafficked peripheral areas, such as near trail and campsite borders. As previously noted, other factors, such as the amount of sunlight and soil nutrients or moisture, are also important determinants of vegetation survival. For example, trails and campsites in meadows can retain substantially greater plant groundcover than those in adjacent woods (Marion and Cole 1996). Long-term impacts from tree damage and felling, tree root exposure, and loss of tree regeneration can result in a reduction and loss of the forest canopy. Invasive species introduced to trails and campsites can spread to adjacent areas through self-propagation over time (Pickering and Hill 2007).

As described in the preceding discussion, herbaceous vegetation in forests is quickly lost under even relatively low levels of traffic. When the majority of vegetation cover is lost, further recreational traffic or use causes little additional impact to vegetation if visitors stay on well-established trails and recreation sites. Traffic can double or triple with limited increases in vegetation impact, a finding that has been illustrated in a large number of studies (Cole 1995a, Leung and Marion 2000, Monz et al. 2013). This curvilinear use-impact relationship is illustrated in Figure 3, where 70% of the vegetation loss occurring on high-use BWCAW campsites (≥60 nights/year) has already occurred on sites receiving just 10 nights of camping/year (Marion 1984).

The use-impact relationship is somewhat different for the more resistant and resilient graminoids. Grasses and sedges can withstand prolonged low levels of traffic, particularly in sunny locations. For example, Cole and Monz (2003) found that after four nights of camping, meadow sites recovered completely after 1 year, whereas forested sites incurred impacts after just one night of use and did not fully recover after 3 years. However, moderate to high levels of traffic will reduce and remove graminoid cover so soil is still exposed in high-traffic areas.

Impacts to Soil

Initial and low levels of trampling generally affect only vegetation and organic litter, such as dead plant leaves, grass, needles, and twigs. Initial trampling flattens and begins to degrade organic litter. Increased levels of trampling cause organic litter to be pulverized, which accelerates removal by wind or water or decomposition into the underlying organic soil (Figure 1). Organic soils are then exposed to traffic, but their low density and lack of structure allows rapid displacement and loss, particularly due to erosion in sloping terrain. Organic soils in flatter terrain absorb water and become mucky, particularly in low areas along trails. On recreation sites the loss of organic soil over time can expose large areas of underlying mineral soil, increasing soil temperatures and decreasing soil moisture. The loss of insulating organic litter and soil also reduces soil temperatures during the winter, particularly under compacted snow along snowmobile and cross-country ski trails, causing snowpack to remain frozen longer and impacting underlying vegetation and soil (Wanek 1971, Eagleston and Rubin 2013).

Recreation trampling quickly compacts exposed mineral soil (Figure 1). The ground pressure of nonmotorized recreational traffic ranges from approximately 4.12 pounds per square inch for hikers and 4.98 pounds per square inch for mountain bikers (Thurston and Reader 2001) to 62.3 pounds per square inch for a shod horse and rider (Liddle 1997). These mechanical forces cause soil particles to rearrange and pack together more tightly, increasing soil density and decreasing pore space. The degree of compaction is a function of the type and amount of recreational traffic (Lei 2004, Pickering et al. 2010) and several physical factors. Soils with a wide distribution of particle sizes are more compactable than those with equal-sized particles (Liddle 1997, Lei 2004). Soil compaction is limited by higher moisture levels and/or higher organic content (Marion and Merriam 1985a, Liddle 1997) but can occur rapidly with limited traffic once organic materials are substantially lost. For example, on BWCAW campsites, 97% of the soil compaction assessed on high-use sites (≥60 nights/year) had already occurred at moderate-use levels (20–40 nights/year) (Marion and Merriam 1985b) (Figure 3).

Compacted soils on recreation sites create a smooth hard surface that impedes seed germination and penetration by plant roots (Alessa and Earnhart 2000). Soil macroporosity is reduced when soils are compacted, limiting air and water permeability and contributing to reductions in soil biota (Liddle 1997). Developed campsites can experience up to a 20-fold reduction in water infiltration rates (James et al. 1979), resulting in

Figure 2. Although meadow grasses are more resistant and resilient to traffic than forest herbs, they are eliminated under heavy traffic. Trail management actions, such as adding woody debris, rocks, and transplanted vegetation (pictured) can help confine traffic to the intended tread.

less water available to plants, which may experience higher mortality during droughts (Marion and Merriam 1985b). Compacted soils on flat recreation sites cause water to pool, contributing to muddiness. Compaction of trail substrates helps deter soil displacement, but reduced water infiltration rates contribute to trail muddiness in areas with poor drainage, causing trail widening and the creation of secondary trails when trail users seek to circumvent muddy areas (Figure 4) (Leung and Marion 1999a, Wimpey and Marion 2010).

Soil erosion and loss, especially water-based erosion problems, are perhaps the most significant long-term recreation impacts and have received attention from recreation ecologists (Figure 1) (Olive and Marion 2009). Soil loss from wind can occur when trail or recreation site substrates are dry and loose and lack protective vegetation or litter cover. Soil erosion from water flow is more common, particularly in sloping terrain and in regions with intermediate to high rainfall. Soil erosion is also governed by soil properties, primarily soil texture (particle size), but also organic matter content, structure, and permeability. For example, less erodible soils can be fine-textured clayey soils whose particles aggregate and resist detachment or coarse-textured sandy soils, which are highly permeable and have larger particle sizes that resist transport. Medium-textured soils with silt and fine sand are most susceptible to erosion; their fine particles are easily transported by water or wind, are less permeable, and lack stable aggregates.

Trails in sloping terrain can intercept and channel water runoff, which can quickly erode trail substrates in areas lacking a sufficient density of effective tread drainage features. When erosion occurs on sloping trails, rocks and roots are exposed, causing hikers to walk around them and widening trails just as mud and water do in flatter terrains. Olive and Marion (2009) found that trail position, trail slope alignment angle, trail grade, type of use, and the proximity of water drainage features were the most significant determinants of soil loss from trails. Steep fall-aligned trails (aligned perpendicular to contour lines) are particularly susceptible to erosion due to the difficulty of diverting water from their treads (Leung and Marion 1996). Trail grade is a commonly cited factor influencing soil loss, particularly when grades exceed 10% and substrates lack native rock, applied gravel, or stonework (Farrell and Marion 2002, Nepal 2003).

Amount of use can be a significant fac-

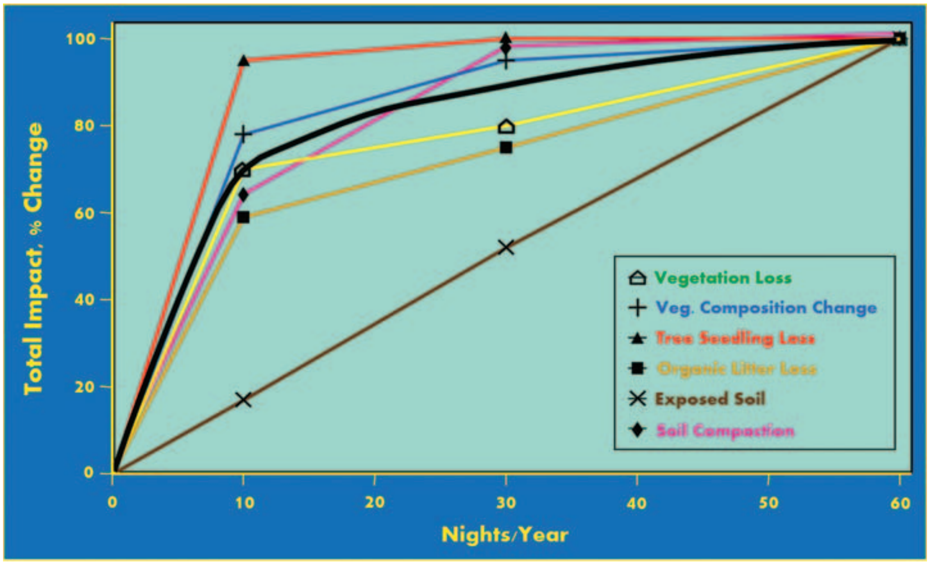

Figure 3. The generalized curvilinear use-impact relationship, depicted by the thick black line, as illustrated by measurements of six impact indicators assessed on campsites in the BWCAW (Marion 1984). Resource impacts are expressed as a percentage of the total impact assessed on the high-use sites.

tor at the low end of the use spectrum, but other factors cited above and the intensity of tread management are more influential at higher use levels (Farrell and Marion 2002, Nepal and Way 2007). For example, Deluca et al. (1998) found that sediment yield from a trail after 1,000 passes was significantly higher than after 250 passes (both are at the low-use end of the trail use spectrum). However, several other studies found amount of use to be a poor predictor of soil loss (Cole 1983, Farrell and Marion 2002, Dixon et al. 2004). Olive and Marion (2009) found type of use to be a substantially greater determinant of soil loss than amount of use, with horse and all-terrain vehicle use contributing significantly greater amounts of soil loss than hiking and mountain biking.

Soil loss on recreation sites can also occur through sheet and rill erosion of exposed soils. Most recreation sites are located in flatter terrain so soil loss is generally limited, although portions of sites, such as slopes down to and along shorelines, can experience substantial soil loss. Exposed tree roots provide common visual evidence of long-term soil loss. Authors J.L. Marion and H. Eagleston assessed soil loss on 81 long-established (>40 years) BWCAW campsites in 2014 (unpub. data, Feb. 12, 2016), finding mean soil loss to be 22.5 yd^3, a substantial amount. The majority (14.9 yd^3) was attributed to relatively small amounts of soil loss (2.4 in mean incision) occurring over the large flatter core use areas, whereas soil loss in steeper shoreline canoe landing areas (6.4 yd^3) was substantially greater (9.5 in mean incision) but quite limited spatially.

Soil loss is ecologically significant due to the extremely slow process of soil creation and the potential for secondary impacts from the eroded soils to water resources (e.g., turbidity and sedimentation). The managerial costs associated with limiting soil loss or repairing eroded areas can be substantial. Soil loss on trails and recreation sites is essentially permanent with respect to a human time scale. Such long-term change is often considered to constitute resource "impairment," which most land management agencies are specifically charged to prevent. For visitors, eroded trails and recreation sites may be difficult or unsafe to use or are esthetically displeasing. For example, trail treads that are rutted and have numerous exposed rocks and roots are functionally degraded; they slow traffic and increase the risk of injuries.

Campfires can dramatically change the chemical properties of the soil. The burning of firewood results in a loss of soil nutrients and an increase in pH. Visitors who burn paper with dyes, plastic, and other trash contribute to the production of toxic smoke and ash accumulations that can include a number of carcinogenic substances (Davies 2004). Campfires substantially alter soil properties, including a reduction in soil fauna, flora, and organic content; soil recovery can require 10–15 years (Fenn et al. 1976, Cole and Dalle-Molle 1982). For these reasons, the creation of multiple fire rings on campsites and the migration of fire sites around campsites over time represent significant resource impacts.

With growing availability of long-term monitoring data, recreation ecologists are increasingly interested in the longitudinal changes in recreation site conditions. For example, Cole (2013) applied two monitoring approaches to track campsite conditions in seven wilderness areas over one to three decades. He found that soil and vegetation conditions on most campsites generally degraded to a maximum point followed by some improvements, which are attributable to site management actions to concentrate recreational activities and rehabilitate impacted areas (Cole 2013).

Impacts to Water

Visitor impacts to water resources primarily concern the degradation of water quality, a core issue in the context of wilderness sustainability. Water quality degradation can be direct, resulting from activities with body contact, including swimming, canoeing, and wading (Figure 5). Indirect impacts on water quality are also common, contributed by recreation activities that take place along the shoreline or in close proximity, such as hiking, camping, and wildlife viewing (Cole and Landres 1996, Cole 2008, Hammitt et al. 2015).

Water impacts can be categorized as physical, biological, or chemical (Newsome et al. 2012, Hammitt et al. 2015). Physical impacts to water can bring about temperature and flow alterations, suspended matter, increased turbidity, snow compaction, and erosion. Biological impacts on water typically involve the introduction or spread of nonnative flora and fauna and increases in coliform bacteria (e.g., *Escherichia coli*) and protozoa (e.g., *Giardia lamblia*). Chemical impacts are primarily related to the influx of nutrients that lead to lowered dissolved oxygen rates but can also include pollution impacts from soap, sunscreen, food particles, and human and animal waste (Ursem et al. 2009).

Recreation impacts on water in wilderness and protected natural areas have not received as much attention as that on other ecological components affected by visitor activities. Among the studies that exist, most focus on biological impacts and their implications. This is probably due to the fact that direct impacts by recreation are often local-

Figure 4. Heavy horse traffic has compacted and incised the main tread, which captures and retains water; subsequent hikers and horse riders seeking to avoid mudholes widen trails. Although land managers need to provide usable trails, Leave No Trace guidelines ask visitors to stay as close to the center of the tread as possible to avoid trail widening.

ized, with minimal significance at the landscape level (Cole 2008). However, these impacts can be severe at local scales, especially on small but ecologically significant water bodies such as small streams, springs, and potholes (Hammitt et al. 2015). For example, King and Mace (1974) conducted one of the early empirical studies on water quality impacts of wilderness recreation. Their results showed significant increases in coliform bacteria and phosphate concentration in water bodies near campsites in the BWCAW, with pit toilets being cited as the source of contamination.

Recent research has devoted more attention to the water quality effects of pack stock animals, whose trampling on vegetation has long been studied (Stanley et al. 1978). The recent attention is driven partly by the information need for science-based planning and management efforts specific to pack stock use and partly by growing evidence that increasing presence of both humans and stock animals correlates with an increase of harmful bacteria in water, degrading water quality in wilderness areas (Deluca et al. 1998, Derlet and Carlson 2006, Clow et al. 2011, Kellogg et al. 2012). For example, in the Sierra Nevada Wilderness, Derlet and Carlson (2006) found 12 of

Figure 5. Heavy daily summertime traffic in the Zion National Park Narrows canyon results in substantial trampling to shoreline vegetation and river substrates, causing a number of direct and indirect impacts to riparian resources.

15 backcountry sites with pack-animal traffic yielded high levels of coliform bacteria. Water conditions tested near some campsites in Yosemite, Kings Canyon, and Sequoia National Parks would not pass water quality regulations enforced by the state of California (Clow et al. 2011). Similarly, Reed and Rasnake (2016) found elevated levels of *E. coli* and coliform bacteria in springs and streams near Appalachian Trail shelters within Great Smoky Mountains National Park, particularly during summer months. Heavy visitation and traffic along stream and lake shorelines also causes vegetation trampling that can increase the incidence of erosion and nutrient influxes to water bodies (Madej et al. 1994, Clow et al. 2011, 2013). Nutrient loading in open bodies of water can contribute to algal blooms and decreased water quality (Hammitt et al. 2015). One analysis on the Merced River in Yosemite National Park found a 27% increase in channel changes, including bank erosion due to heavy human traffic (Madej et al. 1994).

Swimming, boating, and kayaking are also popular activities increasingly pursued in wilderness waterways. These direct activities stir otherwise settled bottom sediments, leading to turbidity, nutrient increases, and reduced levels of dissolved oxygen (Marion and Sober 1987, Butler et al. 1996, Sunderland et al. 2007). This suspended matter can have substantial effects on water clarity and plant photosynthesis, harming aquatic vegetation, macroinvertebrates, and other fauna that live in or near water (Marion and Carr 2009). Increased nutrients spur heavy aquatic plant growth, reduced oxygen levels, and algal blooms (Hammitt et al. 2015).

Impacts to Wildlife

Wildlife are an integral component of wilderness ecosystems but also an important element of the wilderness recreation experience. The increasing presence of human visitors and their interactions with wildlife can cause changes in physiology and behavior that compromise wildlife health (Knight and Gutzwiller 1995, Hammitt et al. 2015). Some interactions are unsafe, and the resulting changes in wildlife behavior may lead to unpopular and costly management decisions to move or kill problem animals (e.g., food-attracted bears).

A significant body of research exists on wildlife ecology in wilderness (Schwartz et al. 2016). However, research focusing specifically on recreation impacts to wildlife was sparse until the 1990s. Earlier research on this topic has been summarized by Boyle and Samson (1985), Knight and Gutzwiller (1995), and Hammitt et al. (2015). Since the 1990s, there has been growing interest in recreation impacts to wildlife from wildlife scientists, recreation ecologists, and human dimensions researchers (Taylor and Knight 2003, Neumann et al. 2009, Monz et al. 2010a, Hammitt et al. 2015). Another aspect of wildlife impact research is related to noise effects, as reviewed by Barber et al. (2010). The slower growth of this research topic is understandable, given some unique challenges due to the various and complex contexts of interactions, spatial and temporal lag of the effects, and varying responses due partly to learned behavior. It is often more challenging to make generalizations about recreation impacts on wildlife based on direct observations or other measures of wildlife-human interaction (Pomerantz et al. 1988, Monz et al. 2013).

Researchers have classified human impact to wildlife as following four main routes: exploitation, disturbance, habitat alteration, and pollution (Pomerantz et al. 1988, Knight and Gutzwiller 1995). Exploitation entails immediate death of wildlife (vehicle collisions), whereas disturbance results in harassment that can lead to the temporal or spatial displacement of wildlife from favorable to less favorable habitat. Both are forms of direct impacts and are the result of immediate wildlife behavioral responses to a recreationist or recreation activity (Cole and Landres 1996, Neumann et al. 2009, Hammitt et al. 2015). Alternatively, habitat alteration and pollution are indirect forms of impact because habitat is altered, with changes to soil, water, flora and fauna, and/or the associated effects of introduced pollutants, flora, or fauna (Knight and Gutzwiller 1995). Indirect impacts can cause an alteration in behavior, distribution, survivorship, and reproductive ability (Pomerantz et al. 1988, Cole and Landres 1995, Hammitt et al. 2015).

Human-wildlife interactions result in varying wildlife responses due to the characteristics of the human activity (the amount, type, timing, predictability, and frequency of human interactions and the behavior of visitors), the wildlife (their individuality, the timing of their breeding, nesting, and rearing or young), and other factors (Taylor and Knight 2003). In Point Reyes National Seashore in northern California, Becker et al. (2012) recorded tule elk (*Cervus elephus nannodes*) responses (standing, walking away, and running) to off-trail hikers, off-shore boats, and other factors. Their results revealed that off-trail hikers triggered a higher level of disturbance behavior on elk than off-

Figure 6. Leave No Trace practices direct outdoor visitors to not feed wildlife and to store food and trash securely to prevent bears and other wildlife from associating humans with food.

shore boats. Other effects, such as physiological or population-level responses, are unknown and represent important future research needs.

Wildlife responses to visitors also vary in susceptibility to primary routes of impacts depending on human-wildlife characteristics, visitor or wildlife group size, and wildlife type, age, and sex (Knight and Cole 1995, Steidl and Powell 2006). For example, in Yellowstone National Park, overnight camping in wilderness areas have altered feeding and behavioral characteristics of the endangered grizzly bear (*Ursus arctos*). Coleman et al. (2013) found that grizzly bears were 35% more likely to roam in locations less than 650 ft of an occupied campsite, and 56% more likely to roam within 650 and 1,300 ft than in a random location. Even when campsite occupancy was ignored, grizzly bears were much more likely to roam within 2,000 ft of a campsite, suggesting a learned food-attraction behavior (Figure 6) (Coleman et al. 2013). In addition, moose (*Alces alces*) in the backcountry areas of Sweden have responded to skiing disturbances resulting in increased movement rates (doubling energetic usage per 2.2 pounds of body weight while increasing activity ranges) and short-term relocation (Neumann et al. 2009). Bird populations can also be significantly impacted by harmful wildlife viewing, causing decreased birth rates and nest abandonment. In the case of popular boreal bird populations in Oulanka National Park in Norway, Kangas et al. (2010) found that increased visitor pressure affected species composition as well as bird abundance, especially on open-cup nesters such as the willow warbler (*Phylloscopus trochilus*) and wood sandpiper (*Tringa glareola*).

Most research has examined short-term wildlife impacts; more studies investigating long-term assessments are needed (Cole and Landres 1996, Kangas et al. 2010). Research on the efficacy of management interventions to discourage wildlife feeding and other inappropriate human-wildlife interactions is also needed. One example is an unobtrusive observation study on visitor and chipmunk (*Tamias striatus*) behavior in Zion National Park by Marion et al. (2008). They found that a persuasive communication treatment improved visitor behavior (for more details, see Marion 2016). The long-term effects of wildlife feeding are more challenging to study. Hopkins et al. (2014) present an innovative approach to overcoming this challenge. They examined the long-term effects of bear management policies on the dietary composition of American black bears (*Ursus americanus*). Using stable isotopes derived from bear tissues, they estimated the proportion of human-derived foodstuffs and food waste ("human foods") in the diets of human food-conditioned bears over the past century in Yosemite National Park. They found that the proportion of human foods in bear diets show strong correspondence with bear management policies, from "intentional" feeding by park personnel and visitors (1923–1971) through the subsequent "no-feeding" policy, demonstrating the long-term effects of management policy.

More research is needed on how recreation impacts challenge and influence wildlife (Taylor and Knight 2003, Monz et al. 2010a, Marzano and Dandy 2012). Existing studies look at charismatic megafauna such as grizzly bears, bald eagles (*Haliaeetus leucocephalus*), and wolves (*Canis lupus*), but few investigate similar implications on arthropods, reptiles, amphibians, or small fish (Monz et al. 2013). In addition, some recreation activities are examined more closely than others, creating knowledge gaps. For example, hiking impact studies are more prevalent than studies of rock climbing or spelunking impacts (Taylor and Knight 2003). Revisiting and replicating past research and conducting longitudinal studies also help us understand wildlife recreation impacts over a long period of time (Hammitt et al. 2015).

Summary and Conclusions

Are we loving our wilderness and parks to death? We have all heard that question, prompted by concerns that millions of visitors drawn to our protected natural areas every year are degrading the plants, soils, water, and wildlife these areas were established to protect. Although more intensively visited wildland areas are degraded by recreational visitation, the vast majority of protected lands see little use and impact (Figure 7). *Recreation ecology* is a field of study that describes the types and severity of these resource impacts and how they are influenced by the type, number, and behavior of visitors. Managers require objective information describing these resource changes so they can evaluate their effects on ecosystem conditions and processes and the quality of visitor experiences. Information describing visitor resource impacts is also needed to determine their acceptability and the need for management interventions. Recreation ecology also investigates relationships between resource impacts and causal use-related factors and other influential factors such as topography, vegetation type, and substrates. Managers seeking to avoid or minimize visitor resource impacts require more comprehensive information about these interrelationships so they can improve their visitor use management practices and the sustainability of their recreation infrastructure, particularly trails and recreation sites.

This article has provided a concise review and synthesis of the recreation ecology literature. It shows that we know most about impacts to vegetation and soil, that knowledge about impacts to wildlife has increased significantly since 2000, and that research on impacts to water quality has lagged behind. The body of knowledge on recreation impacts has demonstrated its utility in informing visitor planning, management and communication strategies and actions being implemented in wilderness and other protected natural areas (Cole 2009, Hammitt et al. 2015). Specifically, the contributions to management are most evident in indicator development in support of carrying capacity and visitor use management frameworks, the siting, management, and restoration of recreation infrastructure to increase sustainability, and the development of more effective Leave No Trace practices and persuasive communication techniques. More discussion on the applications of this knowledge base is provided in the accompanying article (Marion 2016).

The body of recreation ecology literature continues to grow, particularly as a result of the adoption of recreation ecology as

Figure 7. Even for the highly visited Boundary Waters Canoe Area Wilderness, more than 98% of the area remains in pristine natural condition. Field research assistant Claire Underwood enjoying a BWCAW sunset after a day spent measuring camping impacts. (Photo by Jeff Marion.)

a focused line of research by our international colleagues (Pickering 2010, Newsome et al. 2012, Barros and Pickering 2015). The improved knowledge and sharing of effective visitor impact management practices will certainly benefit the management of US wilderness, as some impacts, influential factors, and management techniques are common across different protected natural areas.

Monz et al. (2010a) highlighted several significant research gaps in recreation ecology, including a stronger conceptual and theoretical foundation, better predictability through modeling, broadening spatial and temporal scales, integration with social and management science, and better understanding of synergistic effects with other stressors. These research gaps remain and are directly applicable to the wilderness context. Other research needs respond to the imbalance of research attention received by various wilderness ecosystems and recreation activities. The growing research interest in soundscape and dark sky as resource components presents a fruitful avenue for recreation ecology research that examines the impacts and visitor activities and related noise on these intangible resources important to both wildland ecology and visitor experiences (Hammitt et al. 2015).

Finally, emerging and diversifying recreation activities in wilderness partly enabled by technology, such as the use of global positioning systems (GPS) units or GPS-enabled smartphones for geocaching, off-trail hiking, locating campsites, biking, or even drones, also present important research questions about recreation impacts (both ecological and social) that must be addressed before we can identify their appropriateness and effective management strategies. Some questions can be addressed using conventional assessment and monitoring methods, but new research designs and measures may be required to fully understand the impacts of some new activities. By addressing these research needs, we will continue to advance the science and practice of wilderness management, integrating the important goals of sustaining natural resources and providing outstanding opportunities for wilderness recreation.

Endnote

1. For more information, see www.wilderness.net.

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