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PROFILE

Sustaining Visitor Use in Protected Areas: Future Opportunities in Recreation Ecology Research Based on the USA Experience

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Abstract Recreation ecology, the study of environmental consequences of outdoor recreation activities and their effective management, is a relatively new field of scientific study having emerged over the last 50 years. During this time, numerous studies have improved our understanding of how use-related, environmental and managerial factors affect ecological conditions and processes. Most studies have focused on vegetation and soil responses to recreation-related trampling on trails and recreation sites using indicators such as percent vegetation cover and exposed mineral soil. This applied approach has and will continue to yield important information for land managers. However, for the field to advance, more attention needs to be given to other ecosystem attributes and to the larger aspects of environmental conservation occurring at landscape scales. This article is an effort at initiating a dialog on needed advances in the field. We begin by reviewing broadly generalizable knowledge of recreation ecology, to separate what is known from research gaps. Then, based on the authors' perspective of research in the USA and North America, several research directions are suggested as essential for continued progress in this field including theoretical development, broadening scale, integration with other disciplines, and examination of synergistic effects.

Keywords Recreation ecology · Outdoor recreation · Recreation impacts · Tourism impacts

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Introduction

Recent trends in outdoor recreation in the United States suggest that public interest in nature-based recreation and appreciation of natural areas continues to grow (Cordell 2008). Participation in most outdoor activities has increased significantly since 1960, with activities such as camping, bicycling, canoeing and skiing increasing as much as tenfold during this time (Cordell 2004; Cordell and others 2008). Worldwide, participation in recreation and tourism in protected areas exhibit similar trends, although no global tabulation of park usage is available (Eagles and McCool 2002; De Lacy and Whitmore 2006). Associated with this increasing visitation are human disturbances and impacts to the environmental conditions of public parks, forests, wilderness, and private lands open to visitation.

Over the same timeframe, the field of recreation ecology has developed, largely in response to land managers' needs to maintain natural resource conditions in the face of rising demand for outdoor recreation opportunities. As a field of study, recreation ecology is broadly inclusive of the effects of outdoor recreation and tourist activities on ecosystem attributes. For example, two primary references in the field, Hammitt and Cole (1998) and Liddle (1997) describe recreation ecology as the study of the impacts of outdoor recreation and nature-based tourism on natural or semi-natural environments. Several recent reviews of the state of knowledge of recreation ecology indicate that more than one thousand recreation ecology articles have been published in the past few decades (Liddle 1997; Hammitt and Cole 1998; Leung and Marion 2000; Newsome and others 2001; Cole 2004). Although the majority of studies have been conducted in North America, Europe and Australia (Buckley 2005), recreation ecology research has been conducted throughout the world.

Despite this considerable research effort, studies are typically not theory-based, seldom build on previous work and consequently, seem to do little to move the field forward. To some degree, this reflects the fact that there have been few attempts to define the "cutting-edge" of recreation ecology research or to articulate a vision for where it should go in the future. The primary objective of this article is to attempt a first approximation of such a vision. We believe that while recreation ecology's accomplishments have been impressive despite relatively few practitioners (Cole 2006), current theory and research traditions need to be expanded in order to make the field more robust and more effective in supporting the sustainable use of protected areas worldwide.

To meet our objective, we begin with a concise review of major research themes in the field of recreation ecology. We provide this summary for both the reader unfamiliar with recreation ecology research and to frame our discussion. Attention to what has been well studied suggests what remains relatively unstudied. From this perspective, we go onto explore research themes that we believe have the most potential to move the field of recreation ecology forward. We do not attempt a comprehensive review of the literature as these have been conducted previously as noted. Furthermore, we confine our discussion to the effects of recreation and tourism *activities* on natural environments and do not attempt to explore in detail the effects of recreation and tourism development and infrastructure on environments. We acknowledge the importance of these effects and encourage opportunities for recreation ecologists to collaborate with environmental scientists on solutions to these issues. We also emphasize natural and semi-natural environments and most of our examples are from North America. This reflects our experience. Generally, the well-studied themes we explore and the avenues for new research should be broadly applicable worldwide. We see this article as the beginning of a dialog about the future scope and role of recreation ecology research—not the final word. We welcome future discussions, particularly those with our international colleagues, as valuable opportunities to advance our field.

Outdoor Recreation as an Agent of Ecological Change

Outdoor recreation, including nature-based tourism, has long been recognized as an agent of ecological change in natural systems, with the potential to affect soil, vegetation, wildlife, and water quality. Several conceptual models of the interrelationships between recreation use and ecological impact have been advanced over the years (Liddle 1975; Wall and Wright 1977; Manning 1979). More recently, stressor models have been developed for outdoor recreation (e.g., Monz and Leung 2006), in accordance with guidance developed for long-term ecological monitoring programs (Fancy and others 2009). A stressor model (Fig. 1) is presented here to illustrate that variations in the amount (density), activity type, and spatial and temporal distribution of use can result in disturbance to the biotic and physical environment. These disturbances, and other stressors such as over harvesting and the introduction and spread of invasive species can ultimately lead to more lasting changes in biotic communities and the physical environment. Conceptual models such as these provide a framework to both illustrate the implications of recreation use and potential impacts and to guide the direction of recreation ecology research and monitoring programs.

Considerable research in the 1960's and 1970's examining both the social and ecological aspects of outdoor recreation advanced the now well-accepted paradigm of outdoor recreation involving ecological, social and managerial dimensions (Manning 1999). With this tripartite perspective, understanding ecological change has historically been regarded as more valuable in less developed, wildland settings (Cole 2004). In these settings, agency mandates and visitor expectations generally call for preserving naturalness, so managers need to rely less on facility development and site engineering to limit impacts, and more on preventing recreation impacts from exceeding thresholds of tolerance. Consequently, it is more important to understand the durability of the natural environment and the types and levels of use that can be sustained without undesirable change. Thus, the majority of recreation ecology studies during this period addressed issues in wilderness and backcountry settings.

However, similar agency mandates and visitor expectations that promote the preservation of naturalness also apply to protected areas in more accessible day-use oriented *frontcountry* settings, which are increasingly creating new opportunities for recreation ecology studies. Many urban-proximate parks or popular tourism destinations contain natural-surfaced trails and recreation sites that permit different types of recreational experiences than would occur on artificially surfaced trails or sites (Ewert 1993; Schroeder 2007). Even in areas with artificially surfaced trails and sites, trampling can expand their

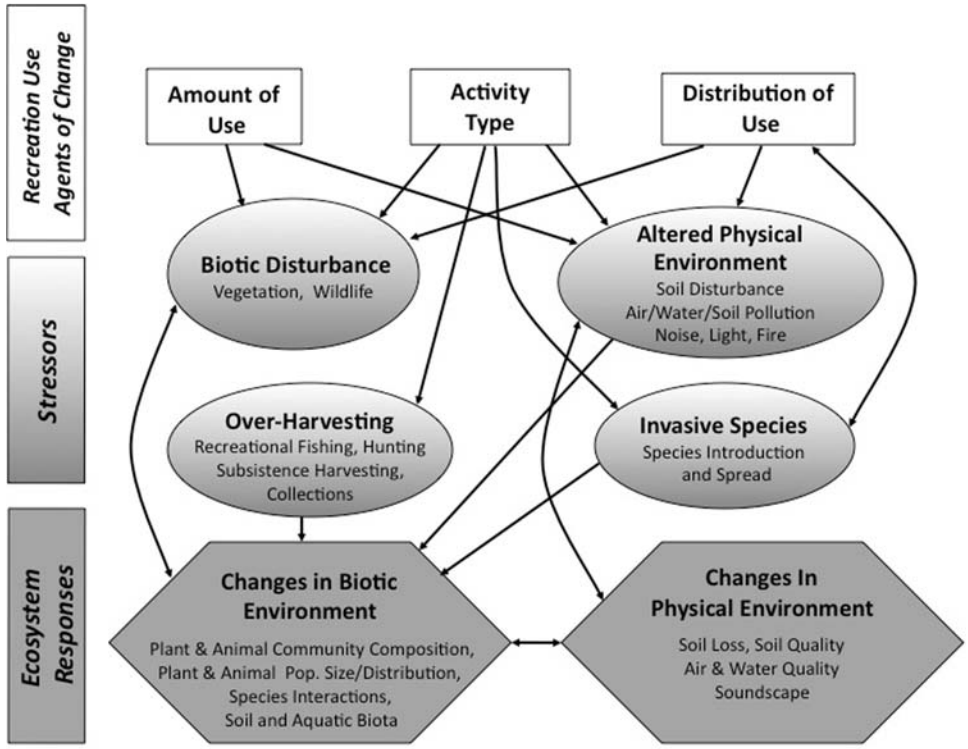

Fig. 1 A conceptual model of the ecological impacts of outdoor recreation (adapted from Monz and Leung 2006)

boundaries and informal (visitor-created) trails and recreation sites are often created (Pearce-Higgins and Yalden 1997; Park and others 2008). Furthermore, some recreation impacts that originate in more developed settings are salient because their effects can be manifest at a large spatial scale. Wildlife displacement, air and water pollution, and invasive species introductions are some examples (Taylor and Knight 2003). Important small-scale impacts include disturbance and loss of rare species (Johnson 1989).

Much of the recreation ecology research has focused on studying the consequences of hiking and camping in either concentrated use settings (e.g., along formal trails) or in more dispersed use settings (e.g., off-trail hiking and the formation of informal, visitor-created trails). Concentrated use studies tend to examine the trajectory of change on established trails and recreation sites, relating this change to use, environmental and managerial factors (Leung and Marion 2000). Trampling, while being a primary mechanism for disturbance of soils and vegetation in many recreation situations, occurs with both concentrated and dispersed uses.

Trampling

Trampling is arguably the most widespread and systematically studied mechanism of recreational disturbance on natural systems, perhaps due to the relatively long history of study (e.g., Wagar 1964; Bayfield 1971; Hill and Pickering 2009), and because trampling is the most visible form of disturbance from outdoor recreation activities. Experimental trampling studies provide the best opportunity to understand the response of vegetation and soil properties to increasing levels and types of use. Numerous investigations have contributed to this knowledge, revealing at least three direct impacts of trampling: abrasion and breakage of vegetation; exposure and displacement of soil particles; and soil compaction (Hammitt and Cole 1998; Liddle 1975; Sun and Liddle 1993). Some work has addressed the more indirect effects of trampling, including reductions in soil macroporosity (Monti and Macintosh 1979), inhibition of seed germination and growth (Alessa and Earnhart 2000), alterations of soil microbial populations (Zabinski and Gannon 1997) and soil nutrient status (Monz 2002). Generally, high trampling intensities significantly reduce plant biomass, alter species composition, and erode and compact soils (Cole 2004).

Studies of trampling disturbance have also contributed an understanding of the potential feedbacks and cascading events resulting from recreation disturbance. For example, Liddle (1997) highlights several studies where trampling disturbance of vegetation exposed the underlying soil to the effects of wind and water erosion. This is perhaps most dramatically illustrated by the work of Ketchledge and others (1985), where trampling triggered erosion along trails in mountain summit environments, resulting in complete soil loss to the underlying bedrock.

Trails and Visitor Sites

Studies that quantify the magnitude of soil and vegetation impact along trails and visitor sites (e.g., campsites, picnic areas, vista sites) dominate the recreation ecology literature. Resource impacts associated with trampling on trails include an array of direct and indirect effects (Table 1). Even light traffic can remove protective layers of vegetation cover and organic litter (Cole 2004; Leung and Marion 1996). Trampling disturbance can alter the appearance and composition of trailside vegetation by reducing vegetation height and favoring trampling resistant species. The loss of tree and shrub cover can increase sunlight exposure, which promotes further changes in composition by favoring shade-intolerant plant species (Hammitt and Cole 1998; Leung and Marion 2000). Visitors can also introduce and transport non-native plant species along trail corridors, some of which may replace undisturbed native vegetation and migrate away from trails (Cole 1987). The abundance and composition of exotic plant species has also been linked to different types of trail surfacing (Hill and Pickering 2006).

The exposure of soil on unsurfaced trails can lead to soil compaction, muddiness, erosion, and trail widening (Hammitt and Cole 1998; Leung and Marion 1996). The compaction of soils decreases soil pore space and water infiltration, which in turn increases muddiness, water runoff and soil erosion. The erosion of soils along trails exposes rocks and plant roots, creating a rutted, uneven tread surface. Eroded soils may smother vegetation or find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz 1993). Visitors seeking to circumvent muddy or badly eroded sections contribute to tread widening and creation of parallel secondary treads, which expand vegetation loss and the aggregate area of trampling disturbance (Leung and Marion 1999a; Liddle and Greig-Smith 1975).

Formal developed trail systems rarely access all the locations that visitors want to go so the establishment of informal (visitor-created) trails is commonplace in heavily visited areas (Grabherr 1982; Wood and others 2006). Often referred to as *social* trails, their proliferation in number and expansion in length over time are perennial management concerns. Furthermore, informal trails can contribute substantially greater impacts to protected area resources than formal trails due to their lack of professional design, construction, and maintenance (Marion and Carr 2007). In summary, most trail-related resource impacts are limited to a linear corridor of disturbance, though impacts like altered surface water flow, invasive plants, and wildlife disturbance can extend considerably further into natural landscapes (Tyser and Worley 1992). However, even localized disturbance within trail corridors can harm rare or endangered species or damage sensitive plant communities, particularly in environments with slow recovery rates.

Table 1 Direct and indirect effects of recreational trampling on soils and vegetation

Effects	Vegetation	Soil
Direct	Reduced height/vigor	Loss of organic litter
	Loss of ground vegetation, shrubs and trees	Soil exposure and compaction
	Introduction of non-native vegetation	Soil erosion
Indirect	Altered composition—shift to trampling resistant or non-native species	Reduced soil pore space and moisture, increased soil temperature
	Altered microclimate	Increased water runoff
		Reduced soil fauna

Trampling also causes recreation impacts to visitor sites similar to those previously described for trails (see Table 1). Differences include the nodal configuration of trampling disturbance and campfire-related impacts, including tree damage, fire sites, offsite firewood collection and associated trampling (Reid and Marion 2005), and altered chemical composition of soils (Arocena and others 2006). Sites can range in size from several hundred to more than 750 m^2 (Marion and Cole 1996), generally more than half of which is non-vegetated and more than one-quarter has also lost most organic litter. These larger expanses of exposed soil are generally in flatter terrain, though wind and sheet erosion can remove soil over time. Soil erosion is a more substantial problem when sites are located along shorelines, where eroded soil from the site and steeper shoreline access trails can drain runoff directly into waterways (Leung and Marion 1998). Other concerns related to their large size are the loss of woody vegetation and its regeneration over time. Gaps in forest canopies caused by these sites can alter microclimates and create sunny disturbed locations that give invasive vegetation a start (Marion and others 1986).

Wildlife

The viewing and photographing of wildlife are often core activities for recreationists and tourists at protected natural areas (Manfredo 1992). To date, investigations into the effects of recreation on wildlife have been less systematic than those of vegetation and soils. Consequently, current knowledge is somewhat less definitive and generalizable. Regardless, numerous studies have investigated the effects of recreation on wildlife (Hammitt and Cole 1998; Knight and Gutzwillier 1995; Steidl and Powell 2006). Recreation activities cause disturbances that result in energetic and physiological stresses (e.g., Bélanger and Bedard 1990), temporal or spatial displacement from preferred environments (Anthony and others 1995), reductions in reproduction rates and population levels (Burger 1995), and alterations in species composition and diversity (Gutzwiller 1995).

Human and wildlife interactions frequently result in the development of wildlife dependencies on human food sources and food attraction behavior that inevitably harm both wildlife and visitors (Larson 1995; Orams 2002). Impacts include property damage, threats to human safety, and food-conditioned wildlife that reach unnaturally high and unsustainable population levels (Marion and others 2008). Additionally, food attracted wildlife may move from protective natural habitats to exposed recreation sites where they are more vulnerable to predators, hunters, poachers, dogs, or collisions with vehicles (Edington and Edington 1986; Newsome and others 2005).

Aquatic Environments

Research studies have been conducted on various recreation uses and their resultant impact on organisms, physical attributes and chemical composition and processes in aquatic systems (Mosisch and Arthington 1998). In marine environments, studies have examined the effects of trampling in intertidal areas (Keough and Quinn 1998) and the effects of tourist activities on coral reefs (Rouphael and Inglis 1997). In addition, a substantial amount of attention has been given to various aspects of overall motor boat use in marine environments including resultant pollution from antifouling agents applied to hulls (Alzieu 2000), damage to submerged aquatic vegetation (Hastings and others 1995) and disturbance of marine fauna (Wells and Scott 1997). While relatively few studies have specifically examined recreational boating, recent reviews of this literature conclude that these activities can have a significant effect on marine environments particularly where use levels are high (Warnken and Byrnes 2004).

Several reviews have examined recreation impacts in freshwater environments (Liddle and Scorgie 1980; Kuss and others 1990; Hammitt and Cole 1998) including the effects of recreational power boating and water skiing (Mosisch and Arthington 1998). In addition to direct disturbance from recreation uses of the water bodies, inland freshwater environments are subject to issues of nutrient influx, pathogen introduction and sedimentation from recreation uses on adjacent lands. While numerous site-specific and activity-specific influences exist, recreation effects on freshwater quality appear to be more density dependent than in terrestrial environments (Kuss and others 1990).

Functional Relationships in Recreation Ecology

Arguably the most important research in recreation ecology has been studies examining the factors that influence the intensity and area of impact. The principal factors that influence intensity and areal extent are: (a) amount of use; (b) type and behavior of use; (c) timing of use; and (d) type and condition of the environment. Protected area managers can often influence these factors; hence information regarding these relationships has important implications for management strategies useful in limiting impacts (Hammitt and Cole 1998).

Amount of Use

The relationship between the amount of recreation use and impact to vegetation and soil is often expressed as being asymptotic and curvilinear (Fig. 2). This relationship was first described by Frissell and Duncan (1965), further investigated by Cole (1981) and supported by numerous, subsequent studies. These findings suggest that initially, even small increases in amount of use (trampling) result in pronounced increases in impact to vegetation and soils. Therefore, where use levels are low, small differences in the amount of use can result in substantial differences in impact levels. However, where use levels are high, sites with large differences in use can show similar levels of impact. This research generalization has been widely utilized in the management of recreation use within protected areas through actions that concentrate use on designated trails and visitor sites in popular areas to limit the areal extent of impacts.

Type of Use

The types of recreational activities and modes of travel continue to diversify within protected areas resulting in a wider range of effects on ecological conditions. Impacts associated with motorized travel differ greatly from those associated with equestrian and foot traffic and in addition, various mechanized uses (powerboats, off-highway

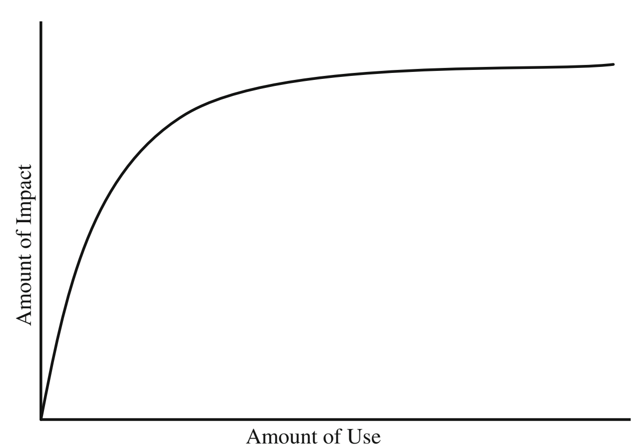

Fig. 2 Use-impact relationship. *Source*: Cole (2004)

vehicles (OHVs), snowmobiles, mountain bicycles) also differ greatly in their effect on ecological conditions (Cole and Spildie1998; Webb and others 1978; Wilson and Seney 1994; Torn and others 2009).

Motorized and mechanized recreation has received somewhat less attention in the recreation ecology literature to date but may become more important in the future as these activities grow in popularity. In general terms, the potential for ecological impact with motorized use generally exceeds that of other analogous non-motorized activities, primarily due to (1) the ability of vehicles to travel great distances, allowing visitors to access more terrain in a shorter time, including remote locations, and (2) the higher ground pressures and greater torque applied to soil/vegetation surfaces (Buckley 2004; Hammitt and Cole 1998; Liddle 1997). Numerous ecological consequences have been investigated, including soil displacement (Anders and Leatherman 1987), vegetation damage (Liddle 1997), seed and pathogen spread and effects on animal populations (Buckley 2004).

Timing and Seasonality

The ability of environments to tolerate recreation use varies greatly between seasons, and with other events such as breeding season for wildlife and moisture content for soils. Although specific research on this topic is sparse, Hammitt and Cole (1998) suggest that spring is the season of highest vulnerability in many environments due to higher rainfall and soil moisture that increase the susceptibility of vegetation and soils to damage, and because wildlife recover from winter and breed in this season. Wildlife are also vulnerable at other times of year, but with different consequences to the animal's annual cycle (Knight and Cole 1995). For example, winter disturbances that interrupt wildlife feeding or cause undue exertion can have a significant impact on energy balance (Hobbs 1989).

Environment

Numerous environmental factors, including vegetation characteristics, soil properties, topography and ecosystem characteristics affect the nature and intensity of recreation impacts (Liddle 1997). Hammitt and Cole (1998) suggest that it is difficult to generalize given the plethora of influential environmental factors and the site-specific nature of the role of these factors. For further discussion on this complex topic, see the reviews in Hammitt and Cole (1998), Liddle (1997), and Leung and Marion (2000). Nonetheless, certain commonalities have been reported across environments and some conclusions are warranted.

First, vegetation characteristics can strongly influence the ability of a trail or visitor site to sustain recreation. Resistance (ability to withstand impact) and resilience (ability to re-grow) are largely a function of plant growth form, with graminoids (grasses and sedges) exhibiting the greatest tolerance to recreational traffic and erect broad-leafed forbs exhibiting the least (Cole 1995a, b). Substrates (e.g., sand, gravel, rock) with little to no vegetation and organic cover are exceptionally durable. High shear strengths of vegetation mats and the underlying root zone are also found to contribute to the resistance of trails against widening and incision (Morrocco and Ballantyne 2008). Second, well-drained soils with developed organic horizons in areas with low grades are best able to tolerate traffic (Marion and Merriam 1985). For trails, terrain and topography are the primary driving variables, with steep trail grades and alignments parallel to the prevailing slope being most susceptible to degradation, primarily due to higher volumes and velocities of water runoff that are difficult to remove from incised treads (Olive and Marion 2009).

Spatial Aspects

Existing research has investigated the spatial aspects of recreation impact predominantly at the visitor site-level scale (Cole 1981; Marion and Cole 1996; Cole and Monz 2004). There is also a general acknowledgement in the literature that issues of scale are important in recreation ecology (e.g., Cole 2004). Despite relatively few empirical studies, managers frequently employ spatial strategies to reduce visitor impacts (Leung and Marion 1999b) and some important generalizations are warranted.

First, at the site-level, survey and experimental work reveal a radial pattern of impact wherein the most intense trampling damage is concentrated in the center of the site, with impact decreasing toward the periphery (Cole and Monz 2004; Stolhgren and Parsons 1986). Second, a distinctive aspect of recreation activity patterns is that visitors consistently use the same places. Manning (1979) referred to this as "node and linkage" use patterns where recreation impacts tend to be highly concentrated, with recreational activities and their associated impacts restricted to the most common destinations (nodes or sites) and travel routes (linkages). This pattern of consistent and concentrated use suggests that recreation impacts will be severe at small spatial scales, and thus severe for individual organisms, but of less significance at large spatial scales. In other words, some recreation impacts may be less important when examined in light of landscape integrity or regional biotic diversity (Cole 2004).

Finally, recreation impacts are very important at the scale of human perception. Studies examining campers in wildland settings demonstrate that visitors often view small areas of impact as "natural" and "healthy" because the impact improves the functionality of the area to support use (Farrell and others 2001). Cole (2004) suggests that this is due to the perception that the small areas are "healthy dwelling sites," while more expansive areas of disturbance suggest abuse and damage.

Temporal Aspects

Recreation ecology studies have tended to examine impacts at one point in time and, thus far, studies examining impact patterns along a timeline are rare. The available work suggests that for campsites, impacts proceed rapidly at first (1–3 years after establishment) with less change thereafter (Cole and Hall 1992; Marion and Cole 1996). Recovery rates vary considerably with the nature of impact and ecosystem type, but in general, deterioration occurs much more rapidly than recovery. For example, residual effects of trampling have been observed after 30 years in Glacier National Park, MT (Hartley 1999) and over 42 years in Rocky Mountain National Park, CO (Willard and others 2007). However, Marion and Cole (1996) report no observable evidence of disturbance in the amount of vegetation cover or soil compaction on closed riparian sites in the eastern US after just six years, though vegetation composition and structure remained quite dissimilar from undisturbed control sites.

Temporal patterns at larger spatial scales are also an important consideration as limited existing research suggests that impacts proliferate and spread where use distribution is not controlled (Cole 1993; Cole and others 2008). Impacts proliferate largely because new visitor-created trails and sites appear much more rapidly than established trails or sites can recover. An important implication of this universal finding is that rest-rotation schemes that seek to allow recovery on temporarily closed sites or trails will be ineffective (Leung and Marion 1999b).

A Charge for Future Research

The above generalizations and the research traditions from which they have evolved have contributed greatly to our understanding of recreation disturbance to ecosystems. These traditions have also limited the scope and nature of our understanding. After some 50 years of recreation ecology studies, we suggest that the field can benefit from some expanded research objectives and methodologies, similar to how other scientific fields of inquiry have advanced, from largely descriptive methods to more sophisticated measurements and modeling of complex processes. We identify and describe *six* main themes to guide the further development of recreation ecology research if it is to strengthen its role in sustainable recreation/tourism and protected area conservation.

Conceptual and Theoretical Development

The field of recreation ecology could benefit from further theoretical development, both in terms of testing existing theory and in developing new generalizations for parameters and systems thus far unexamined conceptually. The use-impact relationship (Fig. 2) stands as one of the few well-developed research generalizations and future work could continue to test this relationship and explore new response variables.

For example, at least two recent studies (Cole and Monz 2004; Growcock 2005) observed a sigmoidal response to use and impact as opposed to the more commonly reported single asymptote at the top of the curve (Fig. 2). Although this sigmoidal response was suggested in some earlier work (Cole 1992; Liddle 1975), recent studies add empirical evidence. This finding, if supported through further study, may have some practical implications to dispersed area management in low use situations, particularly on non-vegetated substrates or trampling-resistant vegetation. Growcock's (2005) work further suggests that along the stress-response curve, different effects may be more pronounced at differing phases of impact, i.e., that plant physiological stress precedes mechanical damage and loss of plant cover. Further elucidation of these more subtle responses to trampling disturbance may require more sensitive techniques of assessing change than have been previously employed in trampling studies (e.g., Cole and Bayfield 1993).

Prediction

Currently, recreation ecology has limited predictive capabilities and expansion of these capabilities is essential for further growth of the field. Cole (1995a, b) modeled the response of 18 vegetation types in terms of the response of vegetation cover. In addition to quantifying vegetation response to applied trampling, this work also provides a generalized response of vegetation types based on dominant vegetation type: shrubs, forbs, and graminoids. Many opportunities exist to expand predictive capabilities, including modeling specific stress responses of additional ecosystem attributes to spatially-based models that offer landscape level predictive capabilities of ecosystem responses under varying use scenarios. Liddle (1997) described this opportunity as a combination of the Cole and Bayfield (1993) experimental design and mapping techniques, but to date little work of this nature has been conducted. Opportunities also exist to expand current visitor use simulation models (Cole 2005) to include a recreation ecology dimension. For example, Marion (2008) applied trail use estimates from simulations to characterize trail conditions at Acadia National Park.

Considerations of Spatial and Temporal Scales

Early studies in ecology focused largely on readily observable ecosystem characteristics, such as flora and fauna, plant community types, and population numbers (Golley 2006). As the field developed and theory advanced, more sophisticated measurements of ecosystem processes were performed. While a full review of issues of scale in ecology is beyond the scope of this article, ecologists have clearly recognized the importance of spatial and temporal scales for some time in both a research (e.g., Weins 1989) and a management context (e.g., Christensen and others 1996). Moreover, in wildlands, there is particular interest in impacts to ecosystems occurring at large spatial scales and general agreement that these impacts are the most important (Cole and Landres 1996). As previously stated, while there is general concurrence that recreation impacts are important at the site-scale, due to their high intensity and their potential to be located in sensitive environments (Hammitt and Cole 1998), recreation impacts at larger spatial scales remain largely uninvestigated.

We assert that the effects of recreation on large-scale processes may well exist and should be a consideration for protected area managers and scientists. In recreation ecology, we currently have knowledge of the stress response of variables at only one spatial scale–the small plot level. It has been suggested that some recreation impacts, such as grazing by recreational animals, displacement of wildlife, and exotic species introductions and dispersal, do have large spatial scale implications (Hammitt and Cole 1998; Cole 2002), but currently these impacts are some of the least studied. Moreover, emerging recreation activities, such as off highway vehicle use (OHVs), clearly have the potential to affect very large areas and alter ecosystem processes (e.g., dust and sediment loading; alteration of surface water hydrology, large-scale wildlife displacement). Such issues also represent some of the opportunities to integrate recreation ecology into large ecosystem research initiatives. In the short run, meta-analyses of existing datasets to the extent possible may shed light on recreation ecology issues at larger spatial and temporal scales. Some work has begun to examine issues of scale in this fashion including temporal scale trends of campsite condition (Cole and others 2008) and larger spatial scale (across several protected areas) issues of camping impact (Reid and Marion 2005). Over the long term, multi-scale research designs and measures at multiple scales are needed to address the aforementioned large-scale issues. Small-scale studies still have their place as they are often vital to protected area management, but they will be more valuable if site-based datasets can be linked to larger, long-term datasets.

Integration with Social and Management Science

There is a growing perspective in the recreation and tourism field that recreation ecology studies and social science research can and should be conducted in concert (Moore and others 2003; Manning and others 2005; Newman and others 2001). A common goal of management is to avoid the impairment of protected area ecosystems. The notion of impairment is normative, however. Decisions about what constitutes impairment are dependent on both human values and ecological science. Human perceptions of the acceptability of impact can be influenced by such confounded concerns as aesthetics and inappropriate conclusions about the significance of observed effects. This line of research has been explored in a few studies (Knudson and Curry 1981; Symmonds and others 2000; Farrell and others 2001; Manning and others 2004) and much could be learned from continued efforts in coordinated social science and ecological studies of recreation impacts.

Synergistic Effects with Other Stressors

Knight and Cole (1995) suggest that the combined effects of recreation disturbance and other stressors are important considerations in wildlife research that need further study. Existing studies reveal recreation to be a stressor to wildlife during certain times of the year (Hammitt and Cole 1998), but research examining the synergistic effects of recreation combined with other disturbances should receive greater attention. In addition to wildlife, numerous opportunities to examine combined stress responses in other ecosystem attributes such as vegetation, soils and aquatic systems could also prove beneficial.

Broadening the Scope of Traditional Recreation Ecology

Traditional approaches in recreation ecology remain important and applicable to emerging issues. The last 25 years have seen marked increases in participation in outdoor recreation activities that either previously did not exist or were not popular. Mountain biking, sport rock climbing, all terrain vehicle (ATV) riding, geocaching—to name a few—are all relatively new recreational activities. Basic descriptive research is needed about the ecological impacts of these activities. Even some traditional activities have been understudied. For example, the use of recreational pack stock has been established for so long in many protected areas that there has been little attempt to assess the effects of grazing on meadows. Limited research (Cole and others 2004) suggests that even light grazing can have substantial adverse effects on rare and valued environmental attributes. Further research is needed to understand stress/disturbance responses and how they vary with such important variables as grazing intensity and environmental attributes.

The types of stress/disturbance responses examined should also be broadened. Less easily observable responses deserve more attention. Examples include trampling effects on soil biota and the effects of harassment on the reproductive capacity of animal populations. In particular, the effects of recreation on ecological processes, such as biogeochemical cycling and plant-soil interactions, are poorly understood. In addition, although some recreation ecology research has been conducted on every continent, relatively few studies have been conducted outside Europe, Australia and North America. Enlarging the geographic scope of work should provide insights into the generalizability of findings (Pickering and others in press), factors that cause variation in stress response, and unique impact issues, such as visitor-associated fungal disease of trees in Australian parks (Buckley 2004; Buckley 2005; Buckley and others 2006).

Finally, there is a growing acknowledgement of the importance of recreation and tourism development and infrastructure impacts (e.g., Buckley and others 2000; Hunter and Shaw 2007). Involvement in the analysis of development issues may be an important future role for recreation ecologists. Recreation ecology research and knowledge can contribute to the management of development impacts through site selection, design and planning. For example, recreation and tourism infrastructure greatly affect visitor use and density patterns in associated protected areas. Recreation ecologists can collaborate on the design and planning of infrastructure such that the delivery of visitors to protected areas occurs in such a way as to avoid and limit undesirable visitor use-related ecological impacts.

Constraints to Research Progress

Although numerous government and university scientists conduct occasional recreation ecology research, worldwide less than a dozen researchers consider recreation ecology to be their primary focus (Marion 2006; RERN 2009). Forty-nine colleagues have signed up as Recreation Ecology Research Network (RERN) members as of September 2009. The membership consists of university faculty members and doctoral students primarily, with some colleagues from government agencies, research institutes, conservation organizations, and private consulting firms. While 12 countries/territories on four continents are represented in the membership, nearly 70% of the members reside in three countries: the United States, Australia and the United Kingdom. The online forum of RERN, the RECECOL listserv, records a list of approximately 108 subscribers, indicating some other colleagues are interested in staying informed of current recreation ecology discussion and information.

Funding empirical recreation ecology studies seems particularly challenging, as heretofore the majority of funding has come from land management agencies that require assessment and monitoring for management plans and to evaluate compliance with legal mandates. Local and state government land managers rarely have funding to support such activities, though their management objectives and information needs are similar. The applied nature of available funding has also strongly restricted the scope of recreation ecology research, with a focus on descriptive studies and the development and application of monitoring protocols. In the U.S., this is particularly true for National Park Service funding; U.S. Forest Service funding allows greater latitude, while the U.S. Fish and Wildlife Service and the Bureau of Land Management and state agencies have rarely supported recreation ecology studies of any type. To compensate, scientists have conducted unfunded studies or include additional objectives and data collection efforts to address topics of academic interest. Funding to conduct rigorous hypothesis-based studies that employ experimental research designs is rare.

Conclusions

Recreation ecology research has contributed significantly to the management and conservation of protected areas worldwide. Recent advances in the field and in related disciplines suggest that an increased emphasis on predictive capabilities and further theoretical development are crucial to advancing this field. Moreover, expanding existing research paradigms to include emergent activities, broader geographic scope and expanded spatial and temporal scales will allow recreation ecology information to be more useful to broader environmental conservation efforts. Funding limitations, particularly given the applied nature of the majority of recreation ecology research funding, remains the most significant barrier to further advancement in this field of study.

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