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Abstract: We evaluated scientific literature on recreation impacts and benefits to wildlife, lands, waters, and people. Our objective was to describe how current recreation ecology science can and cannot inform current recreation management frameworks. We found substantial evidence for recreation impacts to wildlife behavior, physiology, vegetation cover/composition, and soil properties. The body of literature we evaluated also provided support for the economic and social benefits of recreation to people. There is a disconnect between current science and requirements within recreation management decision-making frameworks, notably around the quantitative relationships between recreational use and impacts to wildlife at levels of ecological organization relevant to wildlife management. There is also a lack of information related to recreation impacts on ecological pattern and process at varying spatial scales, and no attempt in current frameworks to take into account conditions within the context of a broader landscape. We suggest the need for more scientific study that emphasizes quantitative relationships and measures responses at varying levels of ecological organization across multiple spatial scales. Given the evidence suggesting negative impacts, land managers should err on the side of caution when identifying limitations around visitor use.

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To Whom it May Concern:

I am sending you a manuscript entitled, "Recreation Impact Science Applications to the Interagency Visitor Use Management Framework." I work for the Greater Yellowstone Coalition, a 501(c)(3) non-profit that works on conservation issues in the Greater Yellowstone Ecosystem. In our landscape, increasing recreational pressure resulting from record-breaking visitation, and some of the fastest county-wide growth in the nation, is raising concern about the potential impacts of recreational use on this ecosystem. As a result of declines in recreation and trail funding, land managers are up against substantial limitations in their ability to effectively plan for growing recreational pressures. This manuscript is an interdisciplinary literature review aimed at identifying the ways in which the body of recreation impact literature we evaluated can and cannot inform a currently used recreation management decision-making framework.

We found substantial evidence for recreation impacts to wildlife behavior, physiology, vegetation cover/composition, and soil properties. The body of literature we evaluated also provided support for the economic and social benefits of recreation to people. There is a disconnect between current science and requirements within recreation management decision- making frameworks, notably around the quantitative relationships between recreational use and impacts to wildlife at levels of ecological organization relevant to wildlife management. There is also a lack of information related to recreation impacts on ecological pattern and process at varying spatial scales, and no attempt in current frameworks to take into account conditions within the context of a broader landscape. We suggest the need for more scientific study that emphasizes quantitative relationships and measures responses at varying levels of ecological organization across multiple spatial scales.

We believe the Journal of Outdoor Recreation and Tourism readers will find the strong management applications of this work highly relevant. We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal.

Sincerely,

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Recreation Impact Science Applications to the Interagency Visitor Use Management Framework

Abstract:

We evaluated scientific literature on recreation impacts and benefits to wildlife, lands, waters, and people. Our objective was to describe how current recreation ecology science can and cannot inform current recreation management frameworks. We found substantial evidence for recreation impacts to wildlife behavior, physiology, vegetation cover/composition, and soil properties. The body of literature we evaluated also provided support for the economic and social benefits of recreation to people. There is a disconnect between current science and requirements within recreation management decision-making frameworks, notably around the quantitative relationships between recreational use and impacts to wildlife at levels of ecological organization relevant to wildlife management. There is also a lack of information related to recreation impacts on ecological pattern and process at varying spatial scales, and no attempt in current frameworks to take into account conditions within the context of a broader landscape. We suggest the need for more scientific study that emphasizes quantitative relationships and measures responses at varying levels of ecological organization across multiple spatial scales. Given the evidence suggesting negative impacts, land managers should err on the side of caution when identifying limitations around visitor use.

Management Implications:

Efforts to refine current visitor use management frameworks should include an attempt to more explicitly consider projects in the context of broader spatial scales. Land managers should consider erring on the side of caution in developing strategies to manage visitor use in a way compatible with desired conditions for an area, given the literature suggests recreation may have negative impacts on wildlife, vegetation, soil, and water resources. There is a strong need for more scientific study at varying spatial scales and varying levels of ecological organization.

Keywords:

Recreation, Impacts, Benefits, Management, Frameworks, Greater Yellowstone Ecosystem

Introduction:

Outdoor recreation in the United States is changing - technology advancements are accelerating the emergence of new, fast-paced forms of recreation (Zinn and Graefe 2007), and more people are participating in outdoor recreation nationally (Cordell 2012). Simultaneously, many counties that comprise the Greater Yellowstone Ecosystem (GYE) are growing faster than most places in the United States (U.S. Census Bureau 2017). Despite high growth rates in the GYE and national trends in recreation participation, very little data exists on trends or spatial patterns in recreational use in the region (Regan 2018). Recreation impact monitoring is under-prioritized (Cole 2006). When monitoring does occur, it is rarely empirically based (Cole 2006). As a result, decisions about management tools to address recreation impacts are often founded on anecdotal evidence and managers have little information to assess the effectiveness of their approaches for mitigating recreation disturbances (Cole 2006). Visible recreation impacts are low in spatial extent, which makes it difficult to imagine recreation may have impacts for ecological processes at landscape scales (Cole 2006). Given wild landscapes the way we know them are threatened by climate change (Shaw and Loomis 2008, Moen and Fredman 2007), understanding ways to mitigate the potential cumulative impacts of added human pressure may be key to maintaining the health of the GYE into the future.

Meanwhile, land managers say they are facing new pressures as recreational demand increases, as well as challenges resulting from unmanaged recreation impacts on natural resources, all while agency funding continues to decline (Collins and Brown 2007). Public lands and opportunities for recreation play an important role in the social and economic health of many western communities (Rasker 2012), and outdoor amenities are a primary driver of the growth happening in western states (Rasker 2012). These challenges highlight the need for a proactive, coordinated approach to recreation planning and management that ensures recreation opportunities are maintained in ways that do not degrade the natural resources of the GYE. The purpose of this literature review is to describe the opportunities and limitations of the body of literature we evaluated to inform current recreation management frameworks, with an emphasis on the Interagency Visitor Use Management Framework.

Methods:

In addition to a review of current recreation management theory and tools, we looked at recreation impacts on both non-human nature and humans. We will describe our findings around recreation impacts to non-human nature as they relate to impacts on individual organisms and associated implications for populations and communities. We also evaluated the impacts of recreation on vegetation, soil, and water resources and the implications of those impacts for processes that affect communities and ecosystems. We assumed recreation impacts to other humans would be social, so limited our search in this realm. For the purposes of this review, we assumed that recreation entirely benefits humans, and focused our benefit search efforts on the economic and social aspects of recreation.

We conducted an opportunistic literature search on each of the previously listed topics between May 2016 and October 2017. We carried out a series of searches in google scholar, and collected relevant articles within the first 15 pages of returned search results. To start, we conducted simple searches on recreation impacts to lands, waters, wildlife, and people. After gathering an initial round of articles, we elaborated our searches to include recreation impacts to vegetation, vegetation communities, soils, soil erosion, water quality, wildlife behavior, wildlife physiology, wildlife survival, wildlife reproduction, wildlife populations, and wildlife communities. We also searched for economic benefits of recreation, social benefits of recreation, and health benefits of recreation, as well as recreation influences on conservation values. We assessed the literature cited in every article we collected, and obtained/reviewed articles with titles directly relevant to our searches. In total, we collected and reviewed 152 articles. We recognize this search protocol was not systematic and therefore our sample of literature may be biased.

Results:

Current management frameworks:

The paradigm in recreation management has shifted from that of managing for pre-determined visitor numbers (i.e. the notion that the ecological system has a recreation carrying capacity), to one where management is guided by decision making frameworks that allow for a wider variety of strategies to achieve desired outcomes (Marion 2016, Farrell and Marion 2002). This shift is largely attributable to application of the most well-established theory in the field of recreation ecology; the relationship between intensity of recreational use and biophysical impact to soil and vegetation is curvilinear (Marion 2016). In other words, in some situations, limiting the amount of use is ineffective at addressing trampling impacts (except in places where use is low; Marion 2016). Recreation management decisions need to be tailored to the particular conditions of an area. A decision-making framework allows for flexibility in particular management strategies to address or mitigate recreation impacts, which is important given that the influential factors are highly variable depending on the particular system of interest (Marion 2016). Farrell and Marion (2002) proposed the Protected Area Visitor Impact Management (PAVIM) Framework that simplifies decision-making and attempts to integrate stakeholder values into the decision-making process.

Most recently, the Interagency Visitor Use Management Council developed a decision-making framework (IVUM 2016). This framework has been increasingly adopted for use among federal agencies, and we will use this framework at the end of the review to evaluate the applications and limitations of the information we gathered.

The first step of the Interagency Visitor Use Management Framework (IVUM) is to build a foundation of information in order to determine if a project is needed. The outcome of planning at this stage is an understanding of the current conditions of the given area of concern. The framework guides the next phase of planning toward identifying visitor use management direction for the area under consideration. This involves identifying the desired conditions for the area and defining the appropriate visitor activities. Identifying appropriate activities requires a scientific understanding of the impacts of certain uses on the desired ecological or social conditions of the area. Thresholds or indicators can inform what levels of visitor activities are appropriate to maintain desired conditions. Next, the IVUM defines management strategies needed to achieve the desired conditions for the area under consideration. Identifying appropriate management strategies requires both an understanding of the potential impacts of the visitor activities allowed in the area, as well as knowledge around what management techniques are effective at mitigating the associated impacts. Management strategies may include attempts to modify the timing, location, or spatial distribution of human use. They might also involve reducing the amount of use (in other words setting a carrying capacity for an area), increasing the availability of recreation opportunities, modifying visitor behavior or expectations, or increasing the ability of the given area to handle more use. The final phase of this particular management framework is to monitor conditions and adjust strategies as needed.

<u>Recreation impacts to organisms, populations, and communities:</u>

Overview:

Until the 1980s, many thought the main impacts on wildlife were consumptive (e.g. hunting). However, a survey of land managers in 1988 provided anecdotal evidence that many forms of recreation can indirectly impact wildlife (Pomerantz et al. 1988). The study of wildlife response to outdoor recreation is a growing realm of scientific research (Larson et al. 2016, Marion et al. 2016). The primary themes related to current knowledge of recreation impacts to wildlife were derived in a recent rigorous review by Larson et al. (2016). In general, outdoor recreation has adverse impacts on wildlife (Larson et al. 2016, Boyle and Samson 1985), however there remain substantial gaps in our understanding of the implications of those impacts. To date, the majority of scientific studies measured behavioral and sometimes physiological responses of wildlife to outdoor recreation (Larson et al. 2016). Examples of behavior change related to recreational activity include increased movement rates (resulting in larger home range sizes), habitat avoidance, altered feeding activity, and evidence of flight or changes in alertness (Stalmaster and Kaiser 1998). Physiological responses are documented as changes in wildlife stress hormone levels in areas with varying degrees of human activity (Thiel et al. 2008, Arlettaz et al. 2007, Creel et al. 2002).

While there are relatively less studies that assess recreation impacts to population or community level response (Larson et al. 2016), some hypothesize the impacts of human recreation are analogous to the ways in which individual level behavior based on predation risk may ultimately influence fitness, mate acquisition, parental investment, and as a result population dynamics (Frid and Dill 2002). However, there is a need for further scientific study into the consequences of behavioral or physiological change to survival and reproductive success of individuals, and ultimately to broad scale changes in populations and communities (Larson et al. 2016, Wisdom et al. 2004) over long time frames (Larson et al. 2016, Marion et al. 2016, Courtemanch 2014, Leung and Marion 2000, Boyle and Samson 1985). Of the studies evaluated by Larson et al. (2016), only 9.3% quantified wildlife responses indicative of impacts at the community level, and only 1.9% of the studies measured direct metrics of survival. Evidence of recreational impacts to birds may be an exception to this theme, as we found more evidence for changes in the community make-up of bird species in relation to human recreation (Steven et al. 2011, Miller et al. 1998). These responses may be due to human influences on nestling success (Remacha et al. 2016).

Additionally, little is known about the quantitative relationship between recreational use intensity and strength or significance of impacts to wildlife (Larson et al. 2016). An idea of thresholds beyond which recreational use negatively impacts wildlife would provide useful metrics for monitoring (Larson et al. 2016); these indicators could be included in management frameworks.

Finally, as is usually the case, recreation ecology literature in the wildlife field is biased in favor of charismatic megafauna and North American ecosystems (Larson et al. 2016, Marion et al. 2016). In the following sections, we take a closer look at individual, population, and community level effects of outdoor recreation on carnivores, ungulates, birds, and other terrestrial organisms.

Recreation Impacts to Individual Organisms:

Human activity tends to influence the spatial and temporal activity patterns of wildlife (Courtemanch 2014, Coleman et al. 2013, Becker et al. 2012, Cadsand 2012, Rogala et al. 2011, George and Crooks 2006, Wisdom et al. 2004, Kasworm and Manley 1990). These changes may persist even after human activity subsides (Wisdom et al. 2004). Grizzly bears, wolves, and elk may even avoid habitat immediately surrounding roads, trails, or campsites, regardless of actual human presence (Kasworm and Manley 1990, Rogala et al. 2011, Coleman et al. 2013). Avoidance behavior could diminish foraging opportunities (Coleman et al. 2013), but very few studies have quantified the actual effects of avoidance behavior.

Recreational activity might influence other wildlife behaviors, like decreases in feeding activity (Stalmaster and Kaiser 1998), declines in song occurrence and consistency among subalpine breeding birds (Gutzwiller et al. 1994), or habituation to human foods and activities that in turn create safety concerns for both humans and wildlife (Merrill 1978). For example, wintering bald eagles may not resume feeding activity in a given day after 40 disturbances from humans (Stalmaster and Kaiser 1998); we found very few examples of thresholds like these that could be incorporated into management frameworks.

Wildlife behavioral responses to human activity may be dependent on the season (Fortin and Andruski 2003, Papouchis et al. 2001). In ungulates, strong behavioral responses like flight or heightened vigilance may be most related to birthing periods (Papouchis et al. 2001) or when herds contain young calves (Fortin and Andruski 2003). For hibernating animals, denning periods could be particularly vulnerable times; some evidence suggests human disturbances might disrupt denning bears from distances of 1 kilometer (Linnell et al. 2000). While denning bear response to human disturbance varies, there are occasions where den abandonment occurs and if the den contains cubs, the energetic costs of den abandonment could potentially influence bear survival rates (Linnell et al. 2000). On the other hand, a recent anecdote suggested a female bear endured 11.5 snowmobile passes a day without abandoning her den (Hegg et al. 2010), highlighting the difficulty in making generalizations in the relatively little studied realm of recreation impacts to wildlife.

In addition to seasonal variation in potential wildlife behavioral response to human disturbance, other factors may amplify wildlife response to human presence. For example, there could be an interaction between nearby road traffic and the amount of trail use that drives the degree of impact that use has on wildlife behavior (Rogala et al. 2011). Or, faster approach speeds by recreationists may elicit stronger flight responses in ungulates (Stankowich 2008). Ungulates may be less likely to respond to human activity when they are closer to escape terrain or are approached by humans from different elevations (Taylor and Knight 2003, Papouchis et al. 2001). Recreationists influenced a stronger flight response in ungulates in areas with less cover and in the morning or evening (Taylor and Knight 2003) and mountain goats selected for more rugged terrain that provided greater security when exposed to human disturbance (Cadsand 2012). In general, dispersed human activity has a stronger influence on ungulate flight response relative to the impacts of more predictable disturbances (Stankowich 2008, Taylor and Knight 2003, Miller et al. 2001, Papouchis et al. 2001). Trails can become a source of predictable activity (Miller et al. 2001).

Some species may be particularly vulnerable to human activity, like amphibians, reptiles, and birds (Larson et al. 2016). Among bird species, ground nesting species are particularly sensitive (Gutzwiller et al. 1994). A recent study found bighorn sheep in the Teton Region (WY) avoided the 'footprint' of winter recreationists regardless of use intensity in the area (Courtemanch 2014).

Among the recreational users we engage in our work, we have found there are conflicting perceptions around the impacts of different types of recreation on wildlife, often founded on anecdotal evidence. A recent meta-analysis suggested there is more evidence of adverse impacts of non-motorized recreation to wildlife than motorized recreation (Larson et al. 2016). However, the spatial scale of study might influence whether or not relationships are detected; it could be that motorized recreation has negative effects on wildlife at larger spatial scales than non-motorized recreation (Larson et al. 2016), and wildlife responses at multiple scales are not often studied. The same Larson et al. (2016) meta-analysis revealed winter recreation has the most negative effects on wildlife. Evidence from individual studies ranges from indicating responses do not vary depending on the type of recreation (Wisdom et al. 2004, Taylor and Knight 2003) to highlighting stronger behavioral changes resulting from motorized recreation relative to quieter uses, and stronger impacts from mountain biking than hiking, or horseback riding (Naylor et al. 2009, Wisdom et al. 2004). In general, there is little empirical evidence describing the relative impacts of different types of recreation on bird species or other wildlife (Steven et al. 2011, Marion and Wimpey 2007), and a lack of studies at multiple spatial scales make it impossible to generalize about the differential impacts of various use types.

It is difficult to make generalizations about energetic costs for wildlife of habitat avoidance or behavioral responses to human presence. In some studies, the implications of habitat avoidance and increased movement for energy expenditures were unknown (Courtemanch 2014). There are some cases where increased movement rates yield a large increase in energy expenditure (e.g. a doubling of expenditures in wintering moose; Neumann et al. 2009), while in others disturbance may only constitute a small portion of daily energetic budgets (e.g. 5.5% in wintering elk; Cassirer et al. 1992) or is negligible (Reimers et al. 2003).

Recreation may also have physiological implications for wildlife. Human activity in the winter positively correlates to stress hormone levels detected in some wildlife species, including elk, wolves, and some bird species (Thiel et al. 2008, Arlettaz et al. 2007, Creel et al. 2002). However, the implications of increased cortisol levels for fitness and survival are often either unknown (Arlettaz et al. 2007), or there is no evidence to suggest consequences for actual population dynamics (Creel et al. 2002). There might be threshold levels of human use intensity where stress responses could drive changes in survival (Creel et al. 2002); these potential thresholds are not often assessed due to a lack of quantitative studies (Larson et el. 2016). Given that stress responses are likely caused by a variety of factors, such as temperament in conjunction with human visitation (Martin and Reale 2008), understanding these thresholds for survival implications may be the most tangible management application.

There are not many examples demonstrating a link between human activity, wildlife stress response, and associated declines in reproduction and survival (Ellenberg et al. 2007). However, we know from studies of other disturbances (e.g. Blas et al. 2007, Cabezas et al. 2007) that physiological stress responses may lead to declines in body condition or survival. The implications of stress responses associated with human activity may be similar; further study is needed to confirm.

Recreation and Wildlife Populations:

The majority of studies on recreation impacts to wildlife are focused on impacts to individual organisms, and do not evaluate population level metrics (Larson et al. 2016). Behavioral responses resulting from human disturbance might not necessarily have implications for population demographics (Gill et al. 2001); for example, Olympic marmots increased activity levels in response to hikers but showed no changes in survival or reproductive rates (Griffin et al. 2007). Some hypothesize that behavioral responses to human disturbance in species relying on mobile prey may be most likely to have implications for survival rates (Gill et al. 2001).

For example, an experimental study of human disturbance during elk calving season in Colorado revealed human activity as an important explanatory component for the variation in calf/cow proportions (Phillips and Alldredge 2000); this relationship could have implications for population dynamics. In general, evidence suggests there is an inverse relationship between the level of human development (e.g. homes, road density) and grizzly bear survival (Schwartz et al. 2010). However, the implications of recreation specifically for grizzly bear survival have not been well studied. Additionally, a meta-analysis suggested that in most cases where it was evaluated, human activity negatively related to reproductive success in bird species (Steven et al. 2011). For example, nesting success of two bird species studied in the United Kingdom was negatively correlated to the number of visitors (Beale and Monaghan 2004). Reproductive success is a mechanism that directly affects a population.

Recreation and Wildlife Communities:

A meta-analysis of the effects of winter outdoor recreation on fauna of alpine ecosystems indicated that winter recreation (primarily skiing) may influence fauna richness, abundance, or diversity in high mountain environments (Sato et al. 2013). Anthropogenic noise may mask interspecific wildlife signals; chronic noise exposure could have implications for reproductive success and in turn the structure of terrestrial communities (Barber et al. 2009). Varying levels of quiet forms of recreation in Northern California were related to a greater abundance of non-native carnivore species relative to the community composition of entirely protected areas (Reed and Merenlender 2008). Dogs accompanying recreationists may also relate to changes in native communities (regardless of the dog policy characterizing the area; Reed and Merenlender 2011). Recreational activity tends to favor corvid species like crows and ravens, and has negative implications for nesting success, abundance, or occurrence of native bird species (Steven et al. 2011, Kangas et al. 2010, Marzluff and Neatherlin 2006, Gutzwiller and Anderson 1999). The mechanisms driving responses in wildlife communities are not well understood; for example, edge effects could explain differences in bird species composition along a gradient of distance to trails and human activity (Miller et al. 1998). Caution should be applied in making generalizations, as there is not enough empirical information to understand the relationship between recreation intensity and the degree of ecological impact at the community level (Sato et al. 2013).

Recreation impacts to vegetation, soil, and water resources:

Overview:

The impact of outdoor recreation on vegetation communities and soil properties is the most heavily studied realm of recreation ecology (Monz et al. 2016, Monz et al. 2010), while relatively little is known about the impacts of recreation on water resources (Marion et al. 2016, Liddle and Scorgie 1980). In general, there is a lack of information on recreation impacts to vegetation, soil, and water resources at broad spatial scales (Monz et al. 2010). There is a need for stronger understanding about whether or not changes in soil properties or plant communities in the immediate vicinity of campsites, for example, has implications for vegetation composition or soil properties across a drainage, watershed, or landscape (Cole 1981).

Early studies documented resource degradation from human trampling (Liddle 1975). Trampling from various forms of outdoor recreation causes a range of potential effects, from relatively minimal impacts such as reduced plant height or loss of organic litter to severe changes including altered plant species composition, loss of plant regeneration, or exposed mineral soil which leads to increased erosion and runoff (Marion et al. 2016, Barros et al. 2013, Monz et al. 2010, Turton 2005). The degree of impact depends in large part on the resistance and resilience of a particular site (Pickering 2010, Cole and Spildie 1998); the ability of a site to handle and recover from disturbance is constrained by the characteristics of the vegetation that define the area (Marion et al. 2016). The relationship between use intensity and impact on soil/vegetation resources is well defined; impact increases with use level up to a point, beyond which increased use yields no change in degree of impact (Marion et al. 2016, Monz et al. 2013, Monz et al. 2010, Deluca et al. 1998). In general, land managers have incorporated this scientific theory into recreation management frameworks (Monz et al. 2013).

Vegetation:

In addition to the physical impacts of trampling, human activity might decrease seed density in soils of subalpine forest disturbed by camping activity (Zabinksi et al. 2000); the implications of this impact for forest composition at broader scales was not studied. The degree of recreation impacts to vegetation and soil is dictated by ecosystem resistance and resilience (Pickering 2010, Pickering et al. 2010, Pickering and Hill 2007). When forest understory is characterized by woody shrubs and erect forbs, the community may be less resistant than one where turf forming grasses or matted forbs dominate (Cole and Monz 2002). During periods of chronic disturbance, plant communities that are more resistant will endure disturbance better, while plant communities that are more resilient are more responsive to acute disturbances (Cole and Monz 2002). For example, in a Montana forest with a forb dominated understory, resistance to disturbance was low, relative to a shrub dominated understory (Cole and Spildie 1998). However, the forb environment recovered more quickly than the shrub type from trampling disturbance, especially at the highest impact intensity implemented in the study (Cole and Spildie 1998).

Alpine environments or subalpine meadows may be particularly vulnerable to soil loss and loss of native vegetation, especially when social trails are created (Monz et al. 2010b), or pack stock are grazing at moderate intensities (Cole et al. 2004). Social trails develop more readily in sensitive high alpine environments (Monz et al. 2010b). Some environments may be more or less susceptible at certain times of the year; for example, moist trails during the spring season are more vulnerable to soil compaction (Monz et al. 2010). Along a main trail access to a popular mountain in Argentina, vegetation impacts were more severe in meadow environments than steppe vegetation (Barros et al. 2013).

There is not a large amount of empirically based knowledge around the relative impacts of different recreation use types (Monz et al. 2010, Pickering et al. 2010), although there is substantial evidence for stronger motorized recreation impacts to vegetation and soil than other use types (Monz et al. 2010). Additionally, human travel by horse may be more likely to alter vegetation composition, ground cover, or vegetation height around trails thank hikers (Torn et al. 2009, Cole and Spildie 1998). Evidence suggests even rock climbing may influence abundance of certain vegetation species on cliff faces and bases where use is high (Camp and Night 1998). However, in some cases there is a lag following disturbance where the intensity of use may be a more important correlate of the ability of vegetation to recover than the type of use; these may be cases where intensity is low enough that it has not exceeded a threshold in the curvilinear use-impact relationship (Cole and Spildie 1998). Grazing pack stock also impacted plant composition and productivity in subalpine mountain meadows, even at moderate grazing intensities (Cole et al. 2004).

Soil:

Recreation may compact soil, increase erosion rates, result in loss of organic soil and exposure of mineral soil, or alter soil chemical properties (Eagleston and Rubin 2013, Arocenaa et al. 2006, Deluca et al. 1998). Trampled, wet soils may increase runoff, while trampled, dry soils may be more susceptible to sediment loss (Deluca et al. 1998, Wilson and Seney 1994). Soil chemical properties may be substantially different immediately surrounding fire pits and dishwashing stations at campgrounds, indicative of the importance of proper waste disposal at backcountry campsites (Arocenaa et al. 2006).

Winter recreation could have implications for increased soil erosion rates on trails during spring melt and runoff, although whether or not there is actually any net soil loss remains uncertain (Eagleston and Rubin 2013). Factors like soil moisture or recreation intensity may not matter for sedimentation loss when soils are exposed to horse traffic, indicative that horses may have more substantial impacts on soils than other use types (Deluca et al. 1998).

Water:

The scientific community lacks understanding around the mechanisms driving ecological changes resulting from human activity in water bodies (Marion et al. 2016, Liddle and Scorgie 1980), yet the gravel-bed river floodplains that often characterize mountain landscapes play an important role in fostering species diversity, ecological processes, habitat connectivity, and habitat productivity (Hauer et al. 2016). There is little quantitative information; as a result, there is no well documented relationship between recreation intensity level and degree of ecological impact to water bodies (Liddle and Scorgie 1980). The field of recreation ecology would benefit from substantial investment into studies of recreational impacts to aquatic systems (Johnson and Carothers 1982).

The physical impacts of human trampling and associated soil erosion can have indirect consequences for aquatic ecosystems; a review of the impacts of land and water based recreation on riparian systems found multiple studies that documented sediment inputs into stream corridors from recreational trails (Johnson and Carothers 1982). Motorized boats containing propellers may cause direct physical impacts to aquatic vegetation in freshwater systems (Liddle and Scorgie 1980). There is some evidence to suggest that motor boats may also be indirectly responsible for erosion as a result of wave action (Liddle and Scorgie 1980). Trampling of vegetation in riparian corridors can result in loss of vegetation cover, changes in species composition, introduction of exotic species, and introduction of parasites (Johnson and Carothers 1982).

Recreation could also result in chemical pollution or nutrient inputs into water bodies (Clow et al. 2013, Clow et al. 2011, Derlet and Carlson 2006, Liddle and Scorgie 1980). Evidence suggests backcountry hikers do not affect water quality in areas near streams, however horse packing resulted in increased nutrient inputs in the form of coliform bacteria, especially in mixed use sites where backpackers were also present (Clow et al. 2013, Clow et al. 2011, Derlet and Carlson 2006).

Recreation Impacts to Vegetation, Soil, and Water Resource Related Ecological Processes:

The majority of the recreation ecology research on the relationship between human use and vegetation or soil characteristics is fairly fine scale (Monz et al. 2010). While there is information regarding impacts of recreation on ecological processes (and thus community or ecosystem function) at localized spatial extents, there is a need for an understanding of whether or not human use degrades ecological processes and ecosystem function at much broader landscape scales.

One mechanism that could disrupt ecological processes at multiple scales is habitat fragmentation, which decreases biodiversity, alters nutrient cycling and ultimately ecosystem processes, and decreases species richness/changes community composition (Haddad et al. 2015). User created trails may be common in areas where recreational use is high (Barros et al. 2013, Monz et al. 2010) and as a result cause habitat fragmentation (Ballantyne et al. 2014, Pickering et al 2012). Dense formal and informal trail networks with a lot of access points reduce habitat patch sizes, resulting in edge effects (Ballantyne et al. 2014, Pickering et al. 2012). Edge effects may alter forest composition and thus habitat quality (Harper et al. 2005). Informal trails are also not designed in ways that mitigate erosion and runoff potential (Wimpey and Marion 2011).

A recent meta-analysis suggested one recreational influence that could have impacts across a landscape may be the introduction or spread of non-native seeds and pathogens (Pickering et al. 2010); horse dung is an example of a conduit for transportation of exotic seeds (Campbell and Gibson 2001). Trails may also facilitate the movement and establishment of new species (Dickens et al. 2005, Benninger-Truax et al. 1992). Human waste paper in backcountry areas can be a conduit for disease transmission, especially near water bodies (Cilimburg et al. 2000). Additionally, increases in non-native rodents, insects and birds that increase in abundance in areas impacted by humans could result in new vectors for disease transmission along riparian corridors (Johnson and Carothers 1982).

Non-motorized winter activity on trails compacts snow and may in turn increase soil erosion rates during spring melt and runoff, however further empirical evidence is needed to confirm whether there is actually any net soil loss (Eagleston and Rubin 2013). Soil erosion may reduce the productivity of an area, result in economic loss among agricultural producers, and disrupt stream ecology (Pimentel and Kounang 1998, Wood and Armitage 1997, Pimentel et al. 1995). Recreation may also lead to freshwater nutrient inputs. This process in turn leads to algal production and disruption of the ecosystem services provided by native aquatic plants, resulting in disrupted ecosystem function (Smith et al. 1999).

Recreation Impacts to People:

A given environment likely has both an ecological and a social carrying capacity in terms of the amount of recreational activity that is tolerable (Manning, 1999). In other words, outdoor recreation may have impacts on people as well as ecological impacts. Most are seeking a particular type of outdoor experience when they recreate, and have wide variety of reasons for participating in their activity (Coupal et al. 1999). As a result, other people's choices may impact their experience. There has been substantial scientific investigation into the issue of crowding, and how to identify the social carrying capacity of a given place. While some studies have found human use intensity on trails only affects a small portion of the array of potential visitor experiences in wilderness (especially remoteness and solitude; Cole and Hall 2012), crowding is a topic on the minds of many recreational users in Greater Yellowstone (Regan 2018). Research that identifies social norms among a collection of personal opinions might be helpful in identifying the social carrying capacity for recreation in various places (Manning 1999). Because crowding is a perception often influenced by characteristics of visitors, traits of the people encountered while recreating, and the context of a situation (Manning et al. 2000), it is difficult to make generalizations about the use level that constitutes the social carrying capacity of outdoor environments. This issue is one land managers must balance in recreation planning and design, and one that warrants more investigation.

Another social issue that is increasingly documented in the literature is that of equity in outdoor recreation. Evidence suggests factors like time, income level, and gender may contribute to perceived constraints on participation in outdoor recreation (Johnson et al. 2001). Race was not identified in the

Johnson et al. (2001) study, however the authors pointed out that structural injustice over a long time-frame may be responsible for perceptions of outdoor recreation in the first place (i.e. the perceived barriers are different than those studied). The outdoor recreation industry cites participation in outdoor recreation as an important determinant of environmental attitudes and behaviors, however environmental attitudes vary substantially among various ethnic groups (Johnson et al. 2004). The probability that a given demographic can participate in outdoor recreational activities falls into a hierarchical structure (Lee et al. 2001). Elderly minority women with low incomes are at the bottom of the hierarchy, while young white men that have higher incomes sit at the top (Lee et al. 2001). Accessibility of outdoor recreation to all demographics is an environmental justice concern that has been under-represented in the scientific literature (Floyd and Johnson 2002).

There is also a growing tourism industry around outdoor recreation, which may have implications for the cultural and social integrity of communities. A review of past studies on resident attitudes toward tourism in their local community suggested people perceive tourism as having some negative social impacts, such as crowding, traffic, and loss of the cultural fabric of the place (Andereck et al. 2005). Those that view the social aspects of tourism in a more positive light are also more likely to be directly benefiting economically from the industry (Andereck et al. 2005).

Recreation Benefits:

Overview:

There is substantial evidence suggesting that outdoor recreation plays a significant role as an economic driver (Rasker 2012, McGranahan et al. 2011). Throughout the Rocky Mountain West, communities are shifting from extractive or agricultural industries to those characterized by lifestyle and access to recreational amenities, in turn shifting their economy to one driven by the service sector (Alexander 2009). The documented social benefits of outdoor recreation are extensive, from playing an important role in human health, well-being, and quality of life, to serving as a conduit for fostering appreciation of the outdoors (Abraham et al. 2012, Zaradic et al. 2009, Bedimo-Rung et al. 2005). Below we take a closer look at the economic and social benefits of outdoor recreation.

Economic:

Communities in the west are outpacing the rest of the United States in terms of economic growth (Rasker 2012). The factor that sets the west apart is public land (Rasker 2012). In Montana alone, National Parks account for $252,004,000 in income and 8,984 jobs (Headwaters Economics 2017). The three states that comprise the GYE benefit from 199,000 direct jobs created by outdoor recreation, $20.5 billion in consumer spending, $6.1 billion in wages and salaries, and $1.25 billion in state and local tax revenue (OIA 2017). There are strong correlations between access to and availability of protected public lands and economic prosperity; every 10,000-acre increase in public lands relates to a $436 increase in average per capita income (Rasker 2012). The west is shifting to a knowledge-based economy where jobs are highly skilled and high paying, primarily because people want to live where there are opportunities for an outdoor lifestyle (Rasker 2012). As a result, western communities are attracting talented workers (Rasker 2012); natural amenities are a driver of population growth in the Greater Yellowstone Ecosystem (Rasker and Hansen 2000) and around the world (Wittemyer et al. 2008). In communities where outdoor amenities are readily available, an educated workforce and interest in entrepreneurial opportunity can interact to yield employment growth in rural counties (McGranahan et al. 2011).

Evidence suggests biking has a tangible, substantial impact on the economies of communities where biking opportunities exist (Argys and Mocan 2000). Economic estimates indicate that a proposed 262 mile Yellowstone and Grand Teton National Park bike pathway could create 1540 jobs, $4.8 million in labor income, $131.8 million in gross regional output, and $74 million in value added impacts (Jenson and Scoresby 2015). Other recreation types like angling generate economic activity in communities surrounding places like the Henry's Fork of the Upper Snake River (Loomis et al. 2005). When the fishery is healthy, angling generates 1438 jobs and $49 million in income in along the Henry's Fork alone (Loomis et al. 2005).

A review of the literature on the economic impacts of wilderness suggested that the economic contributions of wilderness areas may exceed that of extractive industries, and as the use of wilderness areas increases, so does the economic value and impact of wilderness (Holmes et al. 2016). Visitation to federally protected wilderness areas yielded an estimate of recreation value that translated to $634 million in 2001 (Loomis and Richardson 2001). A study of the estimated economic losses attributable to loss in recreation user days resulting from the mountain pine beetle outbreak in Rocky Mountain National Park illustrates the degree of economic benefit from outdoor recreation; a benefit transfer modeling approach indicated the losses in recreational value translated to anywhere from a $5 million to $59 million loss, depending on the severity of the outbreak (Rosenberger et al. 2013). Results of an Oregon recreation survey indicated that in-state non-motorized recreation alone generated $2.1 billion in expenditure, 21,730 jobs, $1 billion in value added economic impact, and $672 million in labor income (Lindberg and Bertone-Riggs 2015). A study of expenditures associated with recreation on a coastal wetland in Louisiana indicated users spent $118 million during the study in that area alone (Bergstrom et al. 1990).

Social:

People value wilderness areas for the cultural and spiritual values they provide (Cordell et al. 1998). A 2008 study in Teton Valley, Idaho suggested study participants living in households that participated in non-motorized outdoor recreation activities were more likely to demonstrate concern for environmental issues (Peterson et al. 2008). The distinction between environmental attitudes and actual behaviors is important, however, and one study found that outdoor recreation positively mediated the relationship between environmental attitudes and actual behaviors only in cases of appreciative recreation (i.e. hiking, bird-watching, wildlife-watching; Thapa 2010). Other evidence suggests a correlation between participation in hiking and backpacking activities and contributions to conservation organizations (Zaradic et al. 2009). Managing for wildlife viewing opportunities (and thus healthy wildlife habitat) could enhance some recreational experiences; taking into account the social context of a setting could have unexpected benefits for habitat conservation (Duffus and Dearden 1990).

Outdoor environments and the opportunities they provide are immensely beneficial for mental and physical health (Abraham et al. 2012, Bedimo-Rung et al. 2005). Prevalence and availability of outdoor opportunities around a community is positively correlated with the proportion of adults that will be physically active (Rosenberger et al. 2009); this participation has positive implications for societal health issues like obesity. Evidence suggests there is a positive relationship between emotional well-being and participation in nature-based activities (Korpela et al. 2014). Participation in outdoor recreation is also an important correlate of reduced stress levels (Godbey 2009); stress has been linked to many modern diseases.

Scientific gaps and management strategies:

The first step of the IVUM is to build the foundation of information needed to understand whether or not management action in a given area is needed. This process necessitates understanding the current conditions of the area of interest. Information needs for this phase of decision-making are beyond the scope of this literature review. However, the Greater Yellowstone Coalition recently developed an inventory of outdoor recreation in the Greater Yellowstone Ecosystem that suggested information on recreational use patterns, intensity, and user expectations is minimal across the region (Regan 2018). Where accurate measures are most useful to monitor conditions, point sampling monitoring protocol are most effective, whereas if monitoring is aimed at gaining a general spatial understanding of where altered management needs to be directed, managers may consider implementing the problem assessment protocol described by Marion and Leung (2001).

Next in the decision-making process outlined by the IVUM is to define visitor use management direction for the area of concern; land managers can define the desired conditions for the area using stakeholder input. Based upon the desired conditions, managers must then identify the appropriate visitor activities for the area. Identifying activities compatible with desired natural resource conditions is one place where information derived from the scientific literature should play a role in decision-making. One step specifically outlined in the IVUM in this phase is to establish thresholds and indicators based on the visitor use management direction defined. Using the body of literature we evaluated, it would be very difficult to define thresholds of visitor use for various wildlife species, given the rarity of studies that actually assessed the quantitative relationships between human use and wildlife response. Leung and Marion (2000) identified the need for scientific information that helps managers develop indicators.

Our literature sample also indicates not much is known about the relationship between recreational use and measures of population health among species, such as survival and reproduction. If a desired condition for a given area includes a healthy elk herd, for example, land managers are not equipped with much information regarding what level of human recreational activity might be detrimental to that goal. Given the scientific literature is biased in favor of charismatic megafauna (Larson et al. 2016), land managers may not be adequately taking into account the impacts of allowed uses on other species, including birds, reptiles, and amphibians, all of which contribute to biodiversity and thus ecosystem function (Duffy 2009).

Information about the relative impacts of different use types on wildlife varies and it is difficult to make generalizations. The relative impacts may also depend on the spatial scale studied (Larson et al. 2016). As a result, defining specific visitor activities compatible or incompatible with desired wildlife conditions of the area of concern is not possible.

Regardless of the uncertainties of various recreation impacts to wildlife populations or communities, there is substantial evidence that in most cases when studied, human presence has some sort of negative effect (Larson et al. 2016). Therefore, in cases where wildlife is a priority, decision makers should err on the side of caution by identifying ways to limit visitor activities to mitigate effects during the most vulnerable seasons.

When identifying visitor activities compatible with the desired vegetation and soil conditions for a site, there is a substantial amount of scientific information to draw on, including a well-supported theory regarding the relationship between intensity of use and impact on vegetation (Marion et al. 2016, Monz et al. 2013, Monz et al. 2010, Deluca et al. 1998). At some threshold of use, increased intensity does not make a difference for the amount of impact (Marion et al. 2016, Monz et al. 2013, Monz et al. 2010, Deluca et al. 1998). Any visitor activities will impact vegetation composition and soil properties in areas where use is concentrated. The resistance and resilience of the particular area of consideration should be considered when identifying appropriate visitor activities. Turf forming grasses and matted forbs are among the more resistant community types, while forests with understorys dominated by forbs and woody shrubs may be less resistant but recover more quickly (Cole and Monz 2002). The potential for soil erosion and runoff at high use levels, especially when soils are particularly moist or particularly dry, should also be evaluated, as these are processes that can be detrimental to aquatic ecosystems. Visitor activities that facilitate spread of non-native species should also be carefully evaluated, as this is a process that may disrupt community or ecosystem structure and function at multiple spatial scales.

The IVUM framework does not explicitly mention consideration of desired conditions and appropriate visitor activities in the area of interest within the context of desired conditions at broader spatial scales. This is problematic in any scenario, but especially so in a place like the Greater Yellowstone, where there is an intact ecosystem with functions operating across a massive landscape. Wildlife migrations are perhaps the broadest scale functions characterizing the structure of Greater Yellowstone. Landscape connectivity is important to maintaining function of broad scale landscapes (Turner 1989). The ecological processes operating at landscape scales that may affect populations or communities include the heterogeneity of habitat patches in close proximity to one another, the availability of supplemental habitat patches, source-sink population dynamics, and neighborhood effects (Dunning et al. 1992). The lack of scientific information on recreational impacts at multiple spatial scales, especially broad spatial scales, makes it very difficult to identify how those effects might translate to habitat patterns that effect process within a larger landscape context. Current decision-making frameworks must take into account effects of recreation within this broader context if a landscape like Greater Yellowstone is to persist well into the future. Some evidence suggested informal trail networks may contribute to habitat fragmentation; this is a realm of recreation ecology research ripe for growth.

The next stage of the IVUM framework aims to identify management strategies that ensure desired conditions are maintained in light of allowed visitor activities. Development of tools at this stage requires not only an understanding of the potential impacts (as outlined in the previous few paragraphs), but also an understanding of what strategies are effective at mitigating impacts (Marion 2016). As many as 40.5% of the literature evaluated by Larson et al. (2016) did not provide management recommendations based on the study findings. Additionally, very few studies on recreation impacts to wildlife, vegetation, or soil are structured around testing the effectiveness of a given management strategy (Larson et al. 2016, Marion and Leung 2001). This is a clear area where more information would improve decision-making.

The following are strategies discussed in the literature we evaluated:

1) Bear proof campgrounds using zoning techniques and infrastructure that safely concentrate attractants (Creachbaum et al. 1998); human disturbances involving food habituated bears are more likely around degraded campgrounds (Merrill 1978).
2) Modify spatial or temporal patterns of recreational use (Marion 2016).
    a. Implement seasonal closures around sensitive areas like winter range or nesting sites (Courtemanch 2014, Beale and Monaghan 2004).
    b. Limit dispersed activity in sensitive wildlife habitat (Stankowich 2008, Taylor and Knight 2003, Miller et al. 2001, Papouchis et al. 2001).
3) Modify use amount
    a. Identify thresholds like that defined in Stalmaster and Kaiser (1998) and use as standards guiding use amount compatible with the desired conditions of an area.
4) While empirical evidence is lacking regarding changes in social or resource conditions resulting from modification of visitor behavior (Marion and Reid 2007), this is often a proposed strategy (Marion 2016). Information is most effective when limited to 2 messages per media platform

(Cole et al. 1997). Source credibility is important (Marion et al. 2008) and use of multiple media platforms that appeal to users at multiple phases along the spectrum of moral development are effective (Manning 2003).

   a. Use education around use impacts to increase support for management actions; evidence suggests there is a disconnect in recreational user awareness of their impact (Taylor and Knight 2003).
      i. The strongest correlate of behavioral intent to engage in leave no trace practices may be the perceived effectiveness of such actions; there is real opportunity to positively influence user behavior via education about the importance of leave no trace practices (Lawhon et al. 2013).
   b. Use education to modify user behavior in ways that reduces careless or unintended impacts (Manning 2003).

5) Incorporate patches of forested area into the habitat mosaic of heavily developed recreation areas, like ski resorts (Patthey et al. 2008).
6) Disperse recreational activity at low use levels and concentrate/contain activity at high use levels (Marion et al. 2016).
7) Enhance resource resistance (Marion 2016).
8) Rehabilitate degraded resources using closures, scarification, seeding, transplants and soil amendments (Marion 2016, Stohlgren and Parsons 1986).
9) Identify and address user expectations; sustainable recreation management is most achievable if planning integrates user desires with consideration of conservation priorities and the environmental susceptibility of an area (Goeft and Alder 2001).
   a. Ensure proper trail design and maintenance that meets user expectations, in turn mitigating development of user created trails (Pickering et al. 2010, Marion and Wimpey 2007, Goeft and Alder 2001).

The final stage of the IVUM framework aims to implement identified strategies, monitor success in achieving or maintaining desired conditions, evaluate outcomes, and adjust strategies as needed. In any scenario, it is important to remember there may be synergistic effects of recreation and other environmental stressors (Monz et al. 2010, Cole 1981). Given how little is known regarding these potential reactions, and the reality that every species and system will respond differently to stress depending on other factors that characterize the area, this evaluation and adjustment stage of decision-making is key.

Wilderness Management strategy:

Wilderness management is particularly challenging, given the subjective nature of managing for particular values or experiences such has solitude, primitive and unconfined recreation, and untrammeled landscapes. Some argue there is a need for a widely accepted definition of wilderness character, with associated terminology and measurement standards (Landres et al. 2012). While wilderness research has driven a lot of improvement in wilderness management over the years (Cole 2007), a definition of wilderness character would provide a foundation for more consistent and effective recreation planning, management, and monitoring (Landres et al. 2012). Globally, wildness is a scarce resource (Sanderson et al. 2002), this fact underscores the importance of preserving wilderness character. While the level of visitor use in wilderness areas does not necessarily influence a wide variety of potential visitor experiences, there is evidence to suggest that experiences related to solitude and remoteness (which are both wilderness values) are impacted when trail use levels are high (Cole and Hall 2012). An important challenge wilderness area managers face is a lack of data on which to make decisions, as only ½ of the wilderness areas in the United States have any recreation related baseline data, and only 2.7% have an inventory of user-created trails (Cole and Wright 2004).

Conclusions:

Human recreation has clear fine scale impacts on vegetation and soil, and likely results in behavioral and physiological stress responses in wildlife. Evidence that describes the implications of these impacts for both patterns and processes at broad spatial scales and over long time frames is lacking. Regarding recreation impacts to wildlife, quantitative studies that measure responses like survival or reproduction would provide more insight into potential impacts to higher levels of ecological organization, like populations and communities.

Humans also have impacts on each other, and maintaining high quality recreational experiences must be balanced with accommodating rising participation in recreation and new types of uses. There are also social concerns around the accessibility of outdoor recreation to all demographics in the United States.

Outdoor recreation plays an important economic and social role in growing Western communities. With declining budgets and new pressures, land managers are up against big challenges to plan and design recreational opportunities that maintain high quality experiences, conserve natural resources, and accommodate growing demand for recreation.

Visitor use management frameworks are an opportunity to develop a coordinated, integrated approach to recreation planning, design, and management across jurisdictions. However, these frameworks would benefit from stakeholder input, more information about recreational use and user expectations, and science that answers some of the big remaining questions about the impacts of human presence in wild landscapes.

For conservation of landscapes like the GYE, desired conditions and appropriate visitor activities must be evaluated in the context of a broader ecological structure functioning at a landscape scale. Given the current body of knowledge surrounding recreation impacts is fairly heavy in the realm of trampling impacts to vegetation/soil and it is very difficult to make generalizations regarding impacts to wildlife/waters (Marion et al. 2016), it is likely that many of the specific management strategies outlined in various recreation management frameworks are based on research on vegetation and soil impacts. This kind of research is inherently fine scaled; the current framework would benefit from a toolbox of strategies and associated actions that are derived from knowledge around recreation impacts to ecological processes at much broader scales.

Declaration of Interest:

The author is employed by the Greater Yellowstone Coalition, a 501(c)(3) non-profit that works to protect the lands, waters, and wildlife of the Greater Yellowstone Ecosystem.

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