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From recreation ecology to a recreation ecosystem: A framework accounting for social-ecological systems

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ABSTRACT

Recreation ecology has its foundations in the premise that recreationists have a negative impact on ecosystems, and are thus treated as an ecological stressor. However, ecology is the study of interactions between organisms and the environment, not just an organism's impacts on the environment. While we do not dispute the evidence that recreationists can negatively impact ecosystems, recreation can also have positive effects for conservation. Contextualizing interactions between recreation and ecology within broader multi-scale social-ecological systems can advance our scientific knowledge of these interactions to provide a basis for more effective management of protected areas that host recreation. In this paper, we propose the concept that recreation-ecosystem interactions are part of a system with a range of positive, negative, and neutral interactions with feedbacks of variable intensity occurring between multiple levels. We simplify this concept into a two-dimensional quadrant system to describe the spectrum of interactions within a range of social-ecological systems, which could be developed for countless natural and social systems. For example, the social portion of this system includes values such as cultural, health and well-being, tribal, and many others; examples of the ecological portion include vegetation, biodiversity, soils, and more. As an illustrative example, we develop the system for recreation-wildlife interactions. We also emphasize the importance of integrating recreation and wildlife research and management through approaches based on this framework. Future research in this area might be improved by considering this novel framework to balance the needs of humans and protect natural ecosystems in protected area management decisions.

Management implications: The framework aims to help outdoor recreation managers and researchers better

- Address existing gaps in research and management,
- Collaborate with those working in complementary fields ,
- Develop more integrative recreation planning and management tools, and
- Resolve persistent problems in outdoor recreation management.

1. Introduction

Ecology is the study of interactions between organisms and between organisms and their environment. While this may sound simple, ecology is an extremely complex science. It is inherently interdisciplinary as the term "organisms" encompasses all disciplines of the life sciences, "environments" includes all other disciplines of the natural sciences, and "interactions" implies systems analysis of these plus social, political, and economic sciences. There is no inherent unit of analysis, so the concept of the ecosystem has been adopted; it is defined by the ecologist and can refer to any level or scale of analysis ranging from a microbe to the entire planet. As such, ecology is a wide-ranging field with specific studies

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bounded in part by the analyst and the problem or question that is being investigated.

As a result of this complexity, ecology has had conflicting philosophical and methodological foundations and approaches since at least the 1930s (Pickett & Grove, 2009). One philosophical basis of ecology is "naturalism" and questions of whether or not humans should be considered natural elements of ecosystems or if natural systems exclude human influence. Keller and Golley (2000, p. 12) argue that many ecologists are unclear about which definition of nature they embrace. They further argue that both philosophical and methodological ecology have come to embrace the idea that human dominated communities are also 'natural systems' and that ecology is a 'science of synthesis' interpretation of nature.

> "While the potential for synthesis has attracted many to ecology as an integrative subject, ecologists have seldom been overcome by such exalted ambitions. Rather, they have tended to subdivide nature into parts and to confine their study to those parts, applying Newtonian analysis to go deeper and deeper into the details of dynamic behavior and adaptation. Nevertheless, the alternative of synthesis is always present and generates an attraction for integrative work. The constant pull between analysis and synthesis is ever present in ecological inquiry" (Keller & Golley, 2000, p. 15).

Recreation ecology is a branch of ecology with a traditional focus on advancing the understanding of negative impacts of recreational activity on the biophysical elements of the environment, likely a result of the early conceptualizations of this field as encompasing a one-way relationship (Bayfield & Barrow, 1985; Cole, 1987; Liddle, 1997). Examples of topics illuminated through recreation ecology research to date include the impacts of recreation on vegetation, soil loss, water quality, spread of invasive species, impacts to wildlife (Hammitt et al., 2015), and incidence of wildfire (e.g., Ganteaume et al., 2013). However, the topic of recreation ecology is inherently interdisciplinary, requiring a need to understand both the recreationists (i.e., social science topics) and the ecosystems where they recreate (i.e., natural science topics); recreation ecologists typically have training in both social and natural sciences.

A subset of work in this field has framed research questions as stemming from a two-way relationship, and many authors articulate their work as contributing toward the goal of improving the balance between biodiversity conservation and provision of recreation opportunities. Indeed, an alternative conceptualization of recreation ecology has been proposed in efforts to broaden the field to investigate two-way relationships between outdoor recreationists and the ecosystems in which they recreate (e.g., Edington & Edington, 1986; Leung & Marion, 1996; Ryan, 2015). For example, Edington & Edington (1986) examined the contributions of biological sciences to recreation planning and management. They recognized the two-way nature of the recreation-ecology relationship; ecological communities and processes can be impacted by recreational activities, but they can also constrain recreational opportunities, the quality of recreation experience, and recreationists' health and well-being. However, even this two-way conceptualization focuses on negative impacts, rather than accounting for benefits gained through human-nature interactions. Recreation ecology generally continues to focus on one-directional human-impact research, studying how recreationists change biophysical attributes of a landscape.

Beyond traditional recreation ecology, research investigates the benefits of natural ecosystems on the recreationists that enjoy them (e.g., Thomsen et al., 2018), benefits of recreation on the protected ecosystems in which it occurs (e.g., Cerveny & Miller, 2019; Heflinger et al., 2013), and negative impacts of ecosystems on recreation (e.g., Kubo & Shoji, 2014; Lischka et al., 2018; Manfredo & Dayer, 2004). Some explorations have applied ecological concepts to understand recreation opportunities, activities, and behavior (e.g., Hamilton, 1996; Morse, 2020; Morse et al., 2009; Schroeder, 1990). However, empirical research investigating the relationships between social and ecological systems in the recreation context within the same research project (e.g., D'Antonio et al., 2013) are sparse, or difficult to publish within a single article due to content or length limitations. A recent review of the recreation ecology literature revealed this scarcity, with only five out of 145 (3.4%) articles published in four journals over a 41-year period considered interdisciplinary studies combining environmental and social sciences (Sumanapala & Wolf, 2019). These authors indicated that this type of research is gravely needed to build a better understanding of how these social and ecological systems work together in the outdoor recreation and tourism context. This could be improved upon through the development of a framework for such interdisciplinary studies in recreation ecology.

Despite the synthetic ideals of ecology, and the existence of applicable research, most empirical and review studies in the field of recreation ecology focus on the negative impacts of recreation on features of the natural environment. Why are there so few examples of recreation ecology research that meet the synthesis goals of ecology (Keller & Golley, 2000)? Although collaborations between resource-oriented recreation ecologists and social scientists are common, several barriers have slowed the progress of this field. Interdisciplinary researchers often face challenges of publishing their work in journals that focus on a single discipline, university faculty members face challenges related to promotion and tenure, and certain funding structures and priorities can prevent the success of interdisciplinary studies (Campbell, 2005; Boden & Borrego, 2011). Fortunately, many of these barriers are being broken down in recent years. The diversity of journals accepting and encouraging interdisciplinary work has increased, the creation of interdisciplinary research institutes within universities is opening doors for interdisciplinary careers, and funding agencies are creating new programs to fund interdisciplinary and convergence research. We suggest a long-term goal to develop the interdisciplinary understanding of public land management that enables agencies to emphasize studies examining social elements contributing to positive and negative recreation impacts equally with the ecological elements, involving social science team members from early stages (Campbell, 2005; Lischka et al., 2018). These barriers to bridging social and ecological research echo across multiple fields, several of which have begun successfully integrating social and ecological studies in recent years (e.g., Bouamrane et al., 2016; Edelenbos et al., 2015; Fedele et al., 2019; Steelman, 2016).

Our aim in this paper is to provide a framework for situating recreation ecology research in the larger social-ecological system rather than focusing only on impacts of visitor use on biophysical conditions. This is much more than a semantic debate. From a policy perspective, most protected area designations carry public use and enjoyment, community economic benefit, cultural resource protection, and many other requirements that suggest positive interactions between humans and natural systems are also important subjects for an ecology of recreation. While humans have an outsized impact on the environment, they also can bring outsized benefits, including societal benefits (e.g., political support for funding and protected area designations, organizational stewardship activities) and individual benefits (e.g., health, well-being, and spiritual benefits to recreationists). While recreation ecology publications sometimes acknowledge these benefits and their contributions to sustainable management, research that exists on these and other topics is usually not the focus, or synthesized well, in recreation ecology.

While recognizing the importance of research and understanding of human impacts on natural systems, we suggest that the field of recreation ecology move beyond human impact research and fully embrace the synthesis approach of Keller and Golley (2000). Recreation ecology research would advance by embracing two-way interactions between humans and protected areas, interactions that include both positive and negative effects, feedback loops, and broader spatial scales of analysis. This will improve our understanding of how a recreation ecosystem functions and when it is impaired by recreation and non-recreation forces. Additionally, cooperation between scientists and the

organizations that fund their work would help to move the field forward in this way. In this paper, we provide a simple framework of what that future might look like, explain the framework using examples from recreation-wildlife interactions research, and present concepts from systems research that better reflect an ecological field of recreation research and management.

1.1. Systems thinking for recreation ecology

To conceptualize recreation ecology within a larger social-ecological system we can look to others who have been building integrated models (Berkes et al., 2003; Gunderson & Holling, 2002; Liu et al., 2007; Morse et al., 2013; Ostrom, 2005, 2009; Walker et al., 2004). It is important to abandon an ecology with 'humans apart' and to understand that for recreation ecology the social and ecological systems are inextricably linked and integrated at multiple levels (Berkes et al., 2003). We must also understand that these are dynamic systems that change over time and co-evolve through emergence and feedbacks (Levin, 1999; Norberg & Cumming, 2008).

Too many of our recreation tools have failed to address a systems approach; they are fragmented and only tell part of the story (Morse, 2020). Experience-based management focused on the motivations and outcomes of recreation, primarily to the individual (Moore & Driver, 2005). Benefits-based and outcome-focused management identified a broader range of both positive and negative social, economic, and environmental impacts (Driver, 2009). However, these studies still tended to be linear, following the behavioral experience model from individual motivations to conduct an activity in a preferred setting to achieve a variety of outcomes. Few studies have been produced that are process-based, systems-level, and multi-scalar or that provide analysis of feedbacks. Recreation ecology has primarily taken this linear approach, with outcomes as negative impacts of recreation.

Despite the linearity of past approaches, new research in outdoor recreation has begun to outline a more holistic approach, focusing on complexity, emergence, and feedbacks (McCool & Kline, 2020). Morse (2020) recently outlined a social-ecological complex adaptive systems model framing recreation as an integrated multi-level dynamic system to help guide future research. While presented in a way that can examine systems, neither of these papers explicitly addressed wildlife. Furthermore, research specifically addressing recreation-wildlife interactions in a social-ecological systems framework are absent from the literature. However, several integrated models have been developed specifically looking at human-wildlife interactions as social-ecological systems (Carter et al., 2014; Dressel et al., 2018; Lischka et al., 2018; Morzillo et al., 2014). By elaborating on examples of human-wildlife systems and recreation-ecology systems, we aim to "connect the dots" between recreationists and ecosystems in a social-ecological systems framework.

Morzillo et al. (2014) highlighted the importance of feedbacks in human-wildlife interactions to understand how these feedbacks influenced future behavior, changes to the landscape, and changes to policy. Their dynamic model is an improvement on linear or static representations and can help to further identify elements missed in current manifestations of recreation ecology. Carter et al. (2014) builds heavily on the Coupled Human Natural Systems (CHNS) approach developed by Walker et al. (2004), Liu et al. (2007), and Ostrom (2009). The authors presented two case studies on human wildlife interactions in China (giant pandas, *Ailuropoda melanoleuca*) and Nepal (Bengal tigers, *Panthera tigris tigris*). Through application of the CHNS framework they looked at the causes and consequences of changes in habitat and wildlife populations alongside human populations and land use. Wildlife tourism was but one of the many human-wildlife interactions assessed. Instead of looking at one-directional relationships, Carter et al. (2014) analyzed the relationships and feedbacks between people and wildlife across multiple scales and over time. They presented both positive (i.e., cultural and sacred ties, economic benefits of tourism, population management of undesirable species) and negative (i.e., predation on livestock and people) wildlife impacts on humans and human impacts on wildlife such as hunting, loss of access to the forest, change in land cover, and direct spatial overlap and disturbance. The authors also explored how social and ecological changes and disturbances over time such as fire, earthquakes, and political upheaval, and cultural change have changed the nature of the interactions. Finally, they addressed feedbacks that occurred in each case in the form of conservation policies, land use restrictions, and collaborative approaches (Carter et al., 2014).

Other examples examining human-wildlife interactions within a social-ecological systems framework highlight the importance of integrating social science early and thoroughly in addressing human-bear conflicts (Lischka et al., 2018) and understanding the critical role of political systems in wildlife management across the landscape (Dressel et al., 2018). Furthermore, Keough and Blahna (2006) documented examples of how social and economic data were used in integrated, ecosystem-wide analyses to address ecological degradation from recreation for three Utah ecosystems. These studies illustrated that when both social and ecological factors are considered throughout decision-making, social and ecological goals can be met simultaneously, rather than one goal predominating. Attention has also been given to describe the social-ecological systems for recreational fisheries (Arlinghaus et al., 2017) and invasive species in the recreation context (Morris et al., 2018).

What recreation ecology can take from each of these models and frameworks are the lessons from the integration of the social and ecological systems and the explicit framing as a dynamic system where feedbacks occur across multiple scales and both systems over time. Recreation is but one form of interactions between humans and wildlife. The outcomes of one recreation-wildlife interaction will feedback and become the inputs to the next round of decisions or actions (Morse, 2020). And while recreation impacts generally are measured at specific sites of recreation activity and recreation infrastructure, the 'feedback' of a positive recreation experience with wildlife can take the form of increased stewardship, support for conservation policy, and across a system of areas of conservation. A more systemic, dynamic, and multi-scalar application of recreation ecology can be developed following the insights from the broader realm of interdisciplinary human-wildlife research.

In this paper, we further develop a concept proposed by Lischka et al. (2018) and discuss four quadrants of potential social-ecological interactions (see Fig. 1). The authors used the research outlined above to develop their model, and we expand upon it by adding an axis to indicate the range of positive, neutral, and negative interactions. As both ecosystems and social systems are made up of multiple components (e.g., ecosystems: wildlife, vegetation, soils, climate; social systems: culture, economics, history, politics), we added layers to exemplify these components in Fig. 1. This model accounts for many aspects contributing to the complexity of the social-ecological system of recreation ecology, including hierarchy, emergence, and feedbacks. Hierarchy is demonstrated through the inclusion of multiple nested levels within the social system of outdoor recreation in protected areas (i.e., individuals, groups, institutions, and society) and the ecological system (i.e., individuals/local sites, populations/areas, communities/regions, and ecosystems/ecoregions). Feedbacks occur across this range of hierarchical levels between systems, with ecosystem components having positive, neutral, and negative effects on people, and vice versa, as indicated by the double-headed arrows in Fig. 1. These feedbacks also occur at different time scales, which could be considered a third axis of this system, but are omitted from the diagram for simplicity. Feedbacks, or interactions, between components at lower levels emerge into patterns at higher levels. Additionally, the diagram accounts for the opposing perspectives of anthropocentrism vs. ecocentrism; the right half of the diagram (quadrants 1 and 4) is built on an anthropocentric viewpoint (i.e., focusing on how nature affects humans), while the left half of the diagram (quadrants 2 and 3) encompasses an ecocentric perspective (i.e., focusing on how people affect nature). Due to uncertainty within this

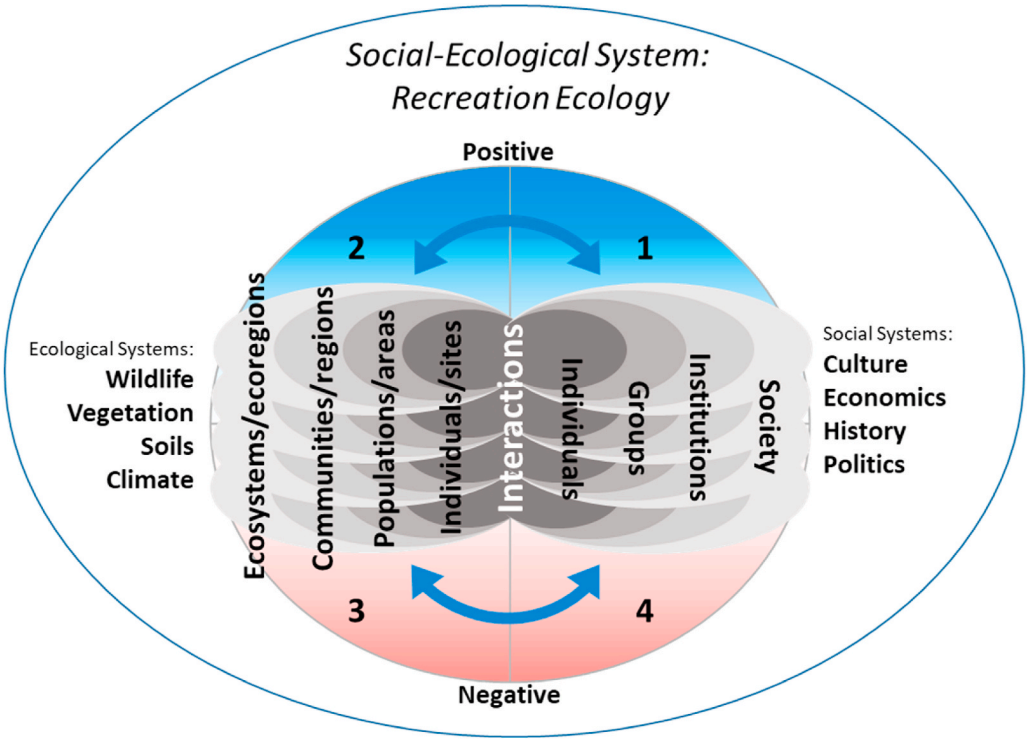

Fig. 1. Social-ecological systems framework for recreation ecology. This diagram includes examples of ecological and social systems (non-exhaustive), which occur at a range of nested scales (i.e., individuals/sites, populations/areas, communities/regions, and ecosystems/ecoregions). Interactions between social and ecological systems can range from positive to negative, to a varying degree of intensity. Neutral interactions are also possible. Curved arrows depict feedbacks between social and ecological systems. Numbers depict four quadrants of possible interactions between these systems.

complex system, this framework is conceptual rather than causal.

We argue that to advance the field of recreation ecology and develop effective management, research in all four of these quadrants will be more effective if applied through a social-ecological systems framework. Furthermore, such a framework can help coordinate funding organizations and researchers to address land management problems in a way that considers tradeoffs within the recreation ecosystem.

2. Recreation and wildlife in a social-ecological systems framework

As we have established, ecology is an inherently interdisciplinary

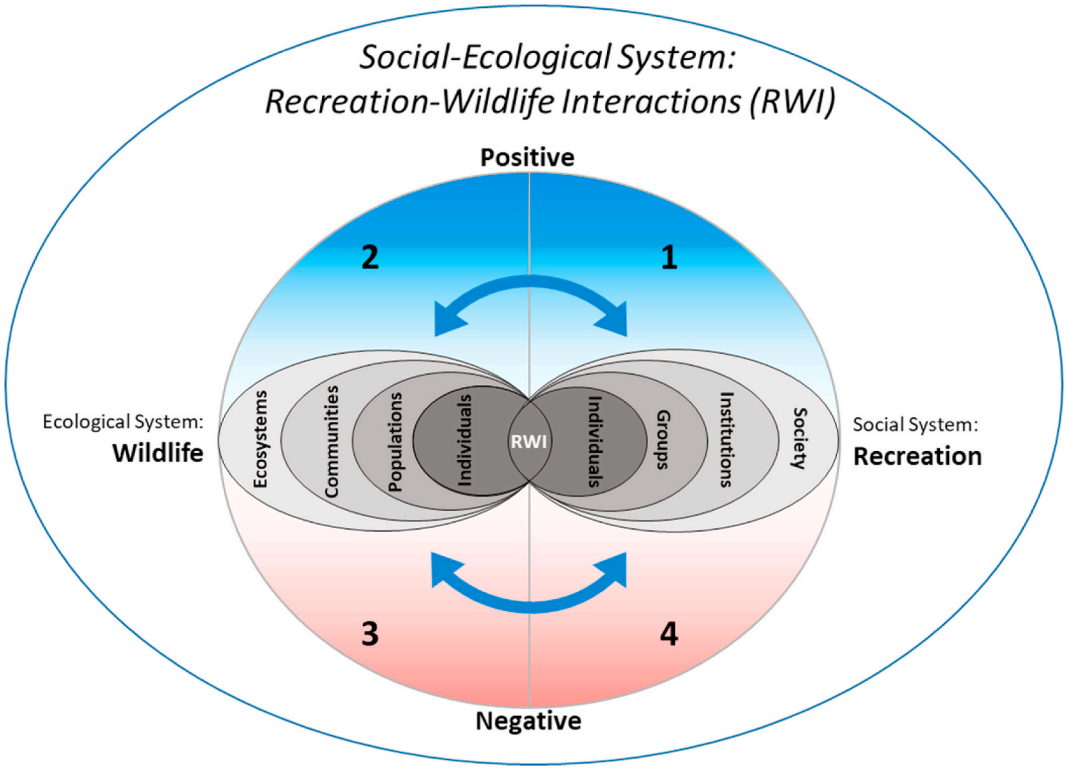

Fig. 2. Social-ecological systems framework for recreation-wildlife interactions. This figure depicts an example of how one ecological system (wildlife) interacts with recreation. (Figure is adapted from Lischka et al., 2018, with permission and from Miller et al., 2020a).

field of research which necessarily integrates concepts from the life sciences with those from the social sciences. In this paper we describe the social-ecological system using an example of interactions between recreation and wildlife, as illustrated in Fig. 2. While recognizing that simplifying the social-ecological systems framework for recreation ecology to the single issue of wildlife-recreation interactions is reductionist in itself, we offer this as an example of the larger system. Using this example, we contextualize the concept within the current scope of recreation ecology, then provide a brief overview of research that falls within each quadrant and contextualize that research within the social-ecological system of recreation ecology. To strengthen the integration of disciplines, we bring attention to prominent fields from which research originates in each quadrant. Research on connections and feedbacks between hierarchical levels within the system is conducted within fields such as systems ecology, psychology, economics, sociology, and anthropology.

These overviews are not intended to be comprehensive, but rather a brief synopsis of research that falls within each quadrant, and their contributions to the framework overall. We begin by describing the quadrant that is most frequently addressed in recreation ecology research, negative effects of recreation on wildlife.

2.1. Quadrant 3: negative effects of recreationists on wildlife

This quadrant represents the dominant theme of current recreation ecology research, and draws from research in fields such as wildlife biology, conservation biology, and ecology. Negative impacts of recreation on wildlife are well-documented (e.g., Bateman & Fleming, 2017; Larson et al., 2016; Miller et al., 2020a). Direct effects to wildlife individuals and populations include mortality or injury, such as that caused by recreational vehicles, or immediate disturbance, such as when sensitive species respond to the presence of recreationists by fleeing (Knight & Gutzwiller, 1995). Sport hunting and fishing is a special case of this quadrant in which targeted species are intentionally removed from the population. Recreation can also indirectly affect wildlife through altering wildlife habitats, which can lead to lower survival rates or displaced populations (Miller et al., 2020a). Soil compaction, altered vegetative structure, invasive species spread, and even increased wildfire risk have all been attributed to recreation in protected areas. These activities can reduce habitat quality or eliminate habitat entirely.

Direct impacts manifest at the individual, population, and community levels. Individual responses to recreational activity can be behavioral (e.g., flight, vigilance) or physiological (e.g., increased stress level) (Knight and Gutzwiller, 1995). A population can be temporally or spatially displaced from preferred habitat by recreational activity (e.g., Wisdom et al., 2018). At the community level, shifts in predator-prey dynamics have been documented in response to recreation (e.g., Berger, 2007; Shannon et al., 2014). For most taxa, there is considerably more research presenting impacts on short-term responses of individuals to recreation compared to the higher-level implications for wildlife communities in the longer term (Larson et al., 2016; Miller et al., 2020a). This is likely due in part to the complexity of community-level impacts and difficulty of carrying out long-term projects, considering funding priorities. However, understanding these higher-level effects of recreation is critical for managing to minimize lasting negative effects of recreation on wildlife. It is also important to note that some impacts of recreation on wildlife (e.g., food subsidy, increased species richness) have negative effects on native communities and biodiversity conservation, although these can be interpreted as positive impacts to individuals (Larson et al., 2016; Miller et al., 2020a).

The vast majority of wildlife-oriented recreation ecology research focuses on this quadrant. However, following our argument about shifting from framing recreation ecology as “human impacts research” to a “science of synthesis”, we emphasize that this is simply one quadrant of the recreation ecology system.

2.2. Quadrant 4: negative effects of wildlife on recreationists

The challenges that wildlife species pose for humans, when mentioned, are often incidental to recreation ecology research. Negative interactions between humans and wildlife are often referred to as human-wildlife conflict, and there is a substantial body of literature on this subject, which has been synthesized for a broad range of species and settings (Edington & Edington, 1986; Nyhus, 2016). Recreation-wildlife conflicts can result in threats to human safety when animals bite, claw, gore, or otherwise attack a person (e.g., Bombieri et al., 2019), or through the transmission of zoonotic diseases or parasites (e.g., ticks, rodents) (Van Gestel et al., 2021; Vitek et al., 1996). Such conflicts can be fatal or cause human injury (e.g., Gunther & Haroldson, 2020). Conflicts also occur when wild animals damage visitors’ property (e.g., black bears breaking into vehicles) (Lischka et al., 2018), or become a nuisance (e.g., spilled trash in campgrounds) (Gore et al., 2006). Risk related to wildlife encounters can decrease recreation opportunities, such as when active populations of potentially dangerous species lead park management to restrict recreation (Gunther & Haroldson, 2020), or when public anxiety is exaggerated through media coverage of rare events such as shark attacks (Sabatier & Huveneers, 2018). Fear of animals has been found to be more pronounced for those with low contact with nature (Zhang et al., 2014), and can lead to low support for wildlife conservation (Johansson et al., 2012; Knight, 2008) (an example of a feedback with quadrant 3).

Research on this topic spans disciplines including applied ecology, wildlife biology, conservation biology, infectious disease, environmental psychology, and environmental economics. The level at which research occurs varies by research question. For example, research on the spread of zoonotic diseases from wildlife to humans may typically occur at the human ‘group’ level, to address a group that may have been exposed to a disease (Vitek et al., 1996). In a comprehensive review of human-wildlife conflict research, Nyhus (2016) addressed the importance of addressing the scales of conflicts, and emphasized the importance of landscape-scale collaborations to fill data gaps. In general, quadrant 4 is in need of research addressing higher levels of complexity.

2.3. Quadrant 1: positive effects of wildlife on recreationists

Protected ecosystems simultaneously provide wildlife habitat and settings for outdoor recreation, the latter of which contributes approximately 2.2 percent of the United States’ gross domestic product (USDC BEA, 2018), thus benefitting recreationists as well as human society in general. Beyond these economic benefits, a large body of literature presents an array of positive outcomes of encountering wildlife and their habitats in outdoor recreation. Fields such as environmental economics and environmental psychology investigate the benefits that people gain from environments that affect them, and the concept is often quantified in terms of ecosystem services. Incorporating these benefits into the study of recreation ecology is critical in developing knowledge of the two-way relationships between social and ecological systems. Incorporating human benefit research into protected area management is an important way to ensure that recreationists receive maximum benefit from their experience while maintaining critical habitat for wildlife, thus realizing the dual goals of protected area management.

Wildlife-based recreation is an important draw for visitors, with more than 103 million Americans participating annually (USDI FWS & USDC CB, 2016, p. 132). Observing wildlife in nature can lead to psychological health benefits and spiritual fulfillment (Curtin, 2009). Research on the motivations for participating in hunting has helped managers understand the benefits associated with this wildlife-based activity (Pierce et al., 2001). These benefits include opportunities to obtain food (Gigliotti, 2000), spend time outdoors (Hammitt et al., 1990; Reis, 2009), see game animals, strengthen social relationships, perfect outdoor skills, and develop memories (Decker & Connelly, 1989; Duda et al., 1995; Larson et al., 2014). Many of the same benefits are

important to recreational anglers (Cooke et al., 2018). Some species are known to deliver a wide range of ecosystem services; for example, beaver habitat is known to provide excellent recreational fishing opportunities (Thompson et al., 2021). Indicative of the interconnectedness of parks and people in this social-ecological system, Taff et al. (2019, p. 1) found that "managing tourism in parks and protected areas in a manner that reduces impact is essential to providing beneficial cultural ecosystem services related to human health and well-being."

Expanding from wildlife to habitat, recreationists' decisions to participate in outdoor recreation, their frequency of participation, and ultimately the benefits gained through recreation, can be affected by environmental quality (Habibullah et al., 2016; Venohr et al., 2018). This is a concern addressed in traditional recreation ecology research, as well as in environmental education and even public health. For example, participation in freshwater aquatic recreation is influenced by water clarity (Keeler et al., 2012). Because wildlife-dependent activities are enhanced by the availability of target species for viewing, the presence of habitat for those species influences the quality of these types of activities (Venohr et al., 2018). Forest bathing, or immersing oneself in natural environments such as those protected for wildlife habitat, is becoming increasingly recognized to provide physiological and psychological benefits to people (Hansen et al., 2017). Furthermore, wildlife species and the habitats that support them also provide educational opportunities, which can lead to positive feedbacks for wildlife when outdoor science education participants later support nature conservation goals (Jackson et al., 2021). While environmental psychology studies often aim to understand interactions between people and wildlife at the 'individual' or sometimes 'group' level, environmental economics generally investigates benefits gained at the 'society' level.

2.4. Quadrant 2: positive effects of recreationists on wildlife

Recreation ecology research generally has little mention of the ways that recreationists can benefit wildlife or habitat. However, outdoor recreationists can act as powerful supporters of public land and wildlife conservation goals, and can provide incentives for habitat and ecosystem protection, such as the establishment of public and private protected areas (Leung et al., 2018). Recreationists can support public lands and conservation goals by donating time, money, and effort toward environmental protection, or simply by choosing to act in more environmentally friendly ways. Ultimately these behaviors can benefit wildlife in a variety of ecosystems. In many settings and situations, outdoor recreationists are environmental stewards, and environmental stewardship is sometimes considered a form of outdoor recreation (Schild, 2019). Illustrating the negative impact bias in most ecological research, the human "ecological footprint" is always considered to be negative, but humans can also have a *positive* ecological footprint (Wolf et al., 2013). Studies documenting positive effects of recreationists on wildlife come from both natural and social science fields, such as ecology, wildlife biology, and environmental psychology.

Nature-based recreation experiences can foster connections to place, strengthening environmental values and promoting individuals and groups of recreationists' conservation behaviors (Larson et al., 2018). Positive associations between conservation behaviors and participation in outdoor recreation, specifically wildlife-dependent activities, have been found in different settings (e.g., Cooper et al., 2015; Teisl & O'Brien, 2003; Zaradic et al., 2009). Observing wildlife in nature can enhance visitors' environmental behaviors, such as supporting conservation programs, improving treatment of wild animals (Ballantyne et al., 2018), donating to support local conservation efforts, enhancing wildlife habitat on public lands, advocating for wildlife-based recreation, and participating in local environmental groups (Cooper et al., 2015). These feedback loops often operate at different scales, with benefits reaching more species than initiated the positive experience. Although few of the studies cited here fully integrate social and natural sciences within one publication, collectively they suggest that nature-based recreation and tourism may have substantial benefits for conservation (Cerveny & Miller, 2019). Integrating such results with our knowledge of negative recreation impacts on ecosystems can have important policy implications for public lands and protected areas.

Outdoor recreationists' positive impacts on wildlife have also been institutionalized. In particular, revenue generated through hunting and fishing licenses often supports conservation of wildlife and habitats (Heflinger et al., 2013) as well as research and monitoring. Non-consumptive wildlife tourism can also generate funds to advance conservation goals, especially when the industry has both public and political support, and when effective regulation occurs at multiple levels of government. For example, this was documented in the case of apex predator tourism (Macdonald et al., 2017).

Studies within this quadrant focus on the higher levels of our framework; the examples above emphasize benefits of recreation at the broad 'ecosystem' level. Wildlife individuals can also be positively affected by the presence of outdoor recreation, by some classifications. For example, recreation infrastructure can improve habitat for some species. Larger animals in particular have been found to use recreation trails to move more easily through dense ecosystems (Kays et al., 2016; Miller et al., 2020c) or across packed snow (Whiteman & Buskirk, 2013). Habituation has also been characterized as a positive effect of recreation for some species (Bateman & Fleming, 2017). However, habituation can lead to harmful effects for individuals, such as when habituated animals deemed dangerous to humans are killed in accordance with park management requirements. Furthermore, it is critical to note that benefits to wildlife individuals and populations can be detrimental to biodiversity at the community or ecosystem level. This illustrates an important strength of contextualizing human-wildlife interactions within the full social-ecological system; focusing on only one quadrant of the system or level of complexity produces incomplete knowledge and may lead to counter-intuitive results of management practices.

3. Wildlife-recreation system: a case study of the desert tortoise

As we describe in this paper, published literature on interactions between wildlife and recreation is dominated by quadrant 3, i.e., negative effects of recreation on wildlife. Here we present a case example of two-way interactions between recreation and wildlife that encompasses all four quadrants, is multi-scalar, and includes feedback loops between the wildlife and recreation components of the social-ecological system. This case study was first described by Keough & Blahna (2006); we put this into the context of our framework, providing updates about its status.

The Mojave desert tortoise (*Gopherus agassizii*) has been listed as threatened by the U.S. Fish and Wildlife Service under the endangered species act (ESA) since 1990 (USDI FWS, 2009), and approximately 80% of its habitat lies on federally managed lands (Averill-Murray et al., 2012). Recreation was not among the factors cited in the original listing decision. However, the tortoise recovery plan describes off-highway vehicles as a factor in degrading and fragmenting tortoise habitat and in direct mortality of tortoises above and below ground. The plan also reports that non-motorized recreation may impact the species (e.g., camping, target shooting; USDI FWS, 2011). Other threats described include collecting tortoises as pets, past deliberate killing, and mortality in areas with uncontrolled motorized use (Berry et al., 2014), although the magnitude of these threats is unknown (USDI FWS, 2011). These threats all fall into quadrant 3 of our model (Fig. 2), i.e., negative effects of recreation on wildlife, and occur at multiple levels (e.g., individual recreationists collecting individual turtles may decrease the population size and alter community dynamics and ecosystem functioning).

As part of the recovery plan implementation, several desert tortoise reserves were created. One of these, the Red Cliffs Reserve in Washington County in southwestern Utah, approached desert tortoise protection as an integrated, social-ecological problem (Keough and Blahna 2006). The Reserve was in a rapidly developing part of the state that also

received more recreation use than most of the Mojave Desert. The creation of the Reserve initially had negative effects on some stakeholders, such as recreationists and developers (quadrant 4). While supporting creation of the Reserve, recreationists feared that the conditions of the Reserve might affect access for both motorized and non-motorized recreation. Developers believed that the Reserve's creation would dramatically restrict development. With opposing interests in the area coming from various stakeholders (e.g., environmentalists, recreationists, and developers), those creating the Reserve recognized the need for partnership to avoid the past conflicts of desert tortoise conservation efforts. By demonstrating the mutual benefits to be gained by recreationists and other people through the creation of the Reserve (quadrant 1), such as providing previously unavailable recreation opportunities on the lands acquired for the Reserve while preserving habitat for the tortoise, leaders convinced stakeholders to participate in the partnership. The Washington County Habitat Conservation Plan was created and designed through a decision-making process for the Reserve to meet both ecological and social goals, and to be flexible and adaptive to feedbacks from both ecological and social entities at different levels of the system (Keough & Blahna, 2006). Through the establishment of the Reserve, multiple stakeholders, such as land developers, federal and state agencies, local officials, recreationists, utility companies and environmental groups, came together to create a protected habitat for the desert tortoise (quadrant 2). Furthermore, the Reserve benefits multiple ecosystem components at a range of levels, from the individual tortoises to entire ecosystems protected by the reserve. The Washington County Habitat Conservation Plan was renewed after it expired in 2016, indicating it was a strong example of collaborative ecosystem management. Building complexity such as feedbacks from multiple levels of both social and ecological systems into this collaboration supports its sustainability.

The increasing popularity and interest in the desert tortoise by the public has spawned a new spectrum of recreation opportunities, including a "Celebrate Desert Tortoise Week" in Palm Springs, California, in partnership with the US Fish and Wildlife Service (USDI FWS, 2020). Activities include hikes in tortoise habitat, a drive-in movie to hear more about the species and visit with "tortoise ambassadors," and scavenger hunts. Although these activities were not reported for the Red Cliffs Desert Reserve, they exemplify the potential for novel recreation outcomes resulting from attention to threatened species (quadrant 1). However, concerns over continued population declines and loss of habitat for the tortoise have led to multiple lawsuits, some of which have resulted in large area closures for off-highway vehicles. Additionally, in the Red Cliffs Reserve (now Red Cliffs National Conservation Area), the Bureau of Land Management recently approved an amendment to permanently close recreational target shooting in a newly established portion of the reserve, as part of mitigation for a new highway through the area (USDI BLM & USDI FWS, 2021). These are further examples of negative impacts of wildlife to recreationists (quadrant 4).

4. Discussion

Many subfields of ecology are transitioning toward Keller and Golley's (2000) interpretation of ecology as a science of synthesis. In fact, Michael Rosenzweig (2003) called for a new management science of 'reconciliation ecology' which views the role of humans and nature together and meeting the goals and needs of each through features of environmental design and ongoing adaptive management. He contrasted this approach with the current focus of management science on 'reservation ecology' and 'restoration ecology,' which tend to focus on negative interactions and default to separating humans and nature rather than integrating them where possible.

While there have been efforts made within the field of recreation ecology to frame questions as two-way interactions between recreationists and ecosystems (e.g., Edington & Edington, 1986; Leung & Marion, 1996; Ryan, 2015), application of this research in the full social-ecological system is limited. The few examples of research framing recreation ecology as two-way interactions (e.g., D'Antonio et al., 2013) contribute toward our argument for a new concept of recreation ecology within the social-ecological system. Addressing both directions of the two-way interactions between different components of the recreation ecosystem (i.e., the biophysical components of the ecosystem and the social components of the recreationists visiting it) is a critical step in resolving outdoor recreation management problems. Applying the social-ecological system described by many (Berkes & Folke, 1998; Colding & Barthel, 2019; Ostrom, 2009) and most recently applied to the outdoor recreation field by Morse (2020) can elucidate the complexity of the system and feedback mechanisms that lead to emergence of these issues.

Recreation ecology is not alone in its efforts to apply systems thinking and to approach natural resource management from within a social-ecological systems framework. The concept was first applied to natural resource management by Berkes and Folke in 1998, and has been increasingly applied to a wide range of natural resource areas over the past 20 years (Colding & Barthel, 2019). Notably, researchers have applied social-ecological systems frameworks to wildfire management (Steelman, 2016), climate change adaptation (Fedele et al., 2019), payments for ecosystem services (Morse et al., 2013), water resources management (Edelenbos et al., 2015), hunting (Hiedanpää & Pellikka, 2015), livestock grazing and fish recovery (Charnley et al., 2018), and biodiversity conservation (Bouamrane et al., 2016). We can learn from the steps taken by researchers in these fields, such as innovative collaborations and funding structures, to develop our own application of recreation ecology to the social-ecological systems framework.

Developing and applying the social-ecological system of recreation has direct implications for management and policy. For example, positive impacts of recreationists on natural systems, manifested through political and economic support for biodiversity and habitat restoration, and active participation in conservation stewardship, are well documented outside of recreation ecology research. Furthermore, the positive effects of natural systems, including wildlife and biodiversity, on humans, is the underlying foundation for the burgeoning field of ecosystem services (Asah & Blahna, 2020). Merging results of complementary fields with recreation ecology to integrate positive and negative interactions in recreation ecology research, at a range of scales, will provide a more complete picture of the recreation ecosystem. Considering the scale of impacts is critical in addressing these impacts; for example, while it is important to manage local negative impacts of recreation to ecosystems, these impacts may not justify park-level management actions when weighing potential decreases in benefits to recreationists with detriment to wildlife. While recognizing that understanding human impacts is a critical component of this ecosystem, we emphasize the importance of placing this information within the larger system to better account for trade-offs, particularly at landscape scales. Expanding land management policies to account for this larger ecosystem of human-environment interactions will ultimately lead to more effective and sustainable actions in the long-term.

5. Conclusions

Our recreation ecology application of the social-ecological system offers a framework through which recreation ecology research can encompass an 'ecology of recreation', a more complete accounting of the recreation ecosystem. This framework expands the current focus on the negative impacts of recreation, which is only one quadrant of our four-quadrant model. Ultimately, we hope that application of this framework can help outdoor recreation managers and researchers better address existing gaps in research and management, collaborate with those working in complementary fields, develop more integrative recreation planning and management tools, and resolve persistent problems in outdoor recreation management.

The field of recreation ecology is at a turning point. A key question at

this moment is: What happens if we do not make changes in how we address the disconnects in the current management of outdoor recreation? For decades, researchers and practitioners have sought to address many of the same issues that we still face today: how do we provide outdoor recreation opportunities that (1) minimize disturbance to wildlife and other ecosystem components while maintaining the infrastructure on which recreation depends, (2) are available to a broad diversity of current and potential visitors, and (3) maximize benefits to participants and to nearby communities (Cerveny et al., 2020)? Other fields, such as fire ecology, social forestry, sustainable development, and protected area management, have seen great progress resulting from the integration of formerly siloed research into a social-ecological system. For recreation ecology, many pieces of the puzzle already exist to connect these previously disparate pieces. What is needed is a coordinated effort to systematically broaden the relevancy of this field. This will involve collaboration with related fields, such as those listed in section 2 of this paper. With the social-ecological systems framework of recreation ecology presented in this paper, we aim to help coordinate this effort. Ultimately, we posit that making this change in the recreation ecology paradigm can help the outdoor recreation field move beyond those persistent problems and improve outdoor recreation management for future generations. In the broadest sense, the expansion of the recreation ecology field reflects the debate between biocentric and anthropocentric values of nature recognizing that it is not an 'either-or' debate, but that both perspectives are needed in research to help managers weigh the trade-offs of recreation management actions.

Finally, developing a clearer understanding of the recreation ecosystem will also help us more effectively place it into a full systems analysis, such as was demonstrated in the role of tourism in tiger and panda conservation (Carter et al., 2014). Outdoor recreation and tourism are just one component of conservation, amidst climate change, land use change, population growth, poaching, and countless other pressures that affect wildlife populations and their habitats. The framework we present here (Fig. 1) is thus a presentation of one component of a much larger system of landscape management.

CRediT authorship contribution statement

Anna B. Miller: Conceptualization, Writing – Original draft preparation, Review & Editing, Methodology. **Dale J. Blahna:** Conceptualization, Writing – Original draft preparation. **Wayde C. Morse:** Writing – Original draft preparation. **Yu-Fai Leung:** Writing – Review & Editing. **Mary M. Rowland:** Conceptualization, Writing – Original draft preparation, Review & Editing.

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