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Sustaining Wildlife With Recreation on Public Lands: A Synthesis of Research Findings, Management Practices, and Research Needs

Anna B. Miller, David King, Mary Rowland, Joshua Chapman, Monica Tomosy, Christina Liang, Eric Abelson, and Richard L. Truex

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Cover photo: A green-winged teal takes flight in the Seedskadee National Wildlife Refuge, Wyoming. Photo by Tom Koerner, U.S. Fish and Wildlife Service.

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Abstract

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Humans and wildlife interact in multifaceted ways on public lands with both positive and negative outcomes for each group. When managed well, wildlife-based tourism and other forms of recreation can benefit conservation goals. Public lands planners and managers often must decide how to best manage recreational activities and wildlife habitats that overlap spatially and temporally. We conducted an extensive literature review and categorized recreational activity into five types based on the use of motorized equipment, season, and location (terrestrial vs. aquatic), expanding on findings summarized in prior reviews. Our findings provide a reference for public lands planners and managers who need information about how wildlife species respond to recreational activities and to associated changes in their habitats. We also describe management principles gleaned from the literature and outline priority research and administrative study areas to advance our understanding of recreation-wildlife interactions.

Keywords: Wildlife, outdoor recreation, habitat, public lands, synthesis.

Executive Summary

Public lands provide both natural resources for humans and habitat for wildlife. When they interact on public lands, humans and wildlife species can have both positive and negative effects on each other. When managed well, wildlife-based tourism and other forms of recreation can benefit conservation goals. Planners and managers are often faced with difficult decisions regarding how to best manage recreational activities and wildlife habitat that overlap spatially and temporally in the lands they manage. Although the body of literature on wildlife responses to recreational activities is large and growing, existing reviews do not contain the level of detail required to support science-based decisionmaking.

This report, as the product of a collaborative project by wildlife biologists, recreation social scientists, and public lands managers from across the United States, expands on findings summarized within existing reviews to serve as a reference for planners and managers who need information about how wildlife respond to recreational activity and associated changes in their habitats. The team worked to conceptualize the project, develop the document's scope and organization, provide critical guidance and insight from the end user's perspective, and review drafts. The synthesis and writing were completed by a postdoctoral research fellow with support from the USFS Washington office.

Although it is not the focus of this report, we emphasize the importance of framing management of human-wildlife interactions within a social-ecological system. We present a broad overview of recent research in each of four quadrants, spanning positive to negative effects that wildlife has on humans and that humans have on wildlife.

The report is structured in terms of five categories of recreational activities: (1) nonmotorized summer activities, (2) motorized summer activities, (3) nonmotorized winter activities, (4) motorized winter activities, and (5) aquatic activities. Within each category, we provide a synthesis of existing research for each of six taxonomic groupings of species. For the purposes of this review, we consider "wildlife" to include the following vertebrate classes: birds, reptiles, mammals, and amphibians, which are traditionally considered targets for habitat management on public lands (e.g., National Forest Management Act (NFMA 219.19), but also invertebrates, which are increasingly subjects of conservation and management concern (Rowland et al. 2013). Although not a focus of this review, we also address the effects of recreation on fish for aquatic recreation only. We discuss both the effects of recreational infrastructure on wildlife habitat and documented responses of wildlife to recreational activities.

Despite the large body of literature on this subject, few general trends emerge that are widely applicable to the diverse range of settings hosting both wildlife and recreation. However, we discuss some trends that appear repeatedly in a range of species and settings. Four primary trends and wildlife responses to recreation include the following:

- Animals tend to have stronger responses to less predictable forms of recreation.
- Reproductive status is important; pregnant females and young tend to be more vulnerable.
- Season is also important; responses may differ between summer and winter.
- Habitat generalists are less vulnerable than habitat specialists.

Minimizing negative effects on wildlife while maximizing the benefits gained by recreationists is a difficult goal, one that comes with tradeoffs. To work toward this goal, we provide a discussion of planning and management practices that include the following:

- Implementing guidelines for minimizing specific recreational impacts, such as those associated with trails, ski slopes, drone use, and caving.
- Consolidating rather than dispersing recreational use; research generally indicates that this reduces the human footprint and corresponds with a reduced overall impact on wildlife.
- Using geospatial analyses to identify areas of least potential conflict between recreation and wildlife and ideal areas of positive recreation-wildlife interaction.

We hope this report will be useful to managers in their planning and evaluation activities and will help them achieve the dual objectives of furnishing recreational opportunities to the American people while conserving the wildlife populations they value.

Contents

National Park Service

Mountain lions in the Santa Monica Mountains National Recreation Area, California, share the area with visitors.

Chapter 1: Introduction

Public lands and protected areas serve a combination of goals. They provide recreational opportunities and natural resources such as timber and minerals while conserving biodiversity and ecosystems, including wildlife habitat and populations. Recreational opportunities on public lands provide a multitude of benefits to both individuals and surrounding communities, including spending that supports both national industries and local communities, personal and social benefits such as improved health and well-being, sustained family ties and traditions, and cultural and spiritual practices. Both humans and wildlife rely on public lands. For wildlife, important habitat features are species-specific and can range from large fragmented landscapes to highly specialized microhabitat. Managing public lands for multiple goals can be difficult, as both social and ecological systems are highly complex. This report focuses on one aspect of these complex systems: wildlife interactions with recreation. Understanding how target species might respond to different types and characteristics of recreation can inform and improve management practices.

The presence of wildlife is often an important feature of nature-based recreation. Providing opportunities for recreationists to connect with nature is central to promoting public interest in wildlife conservation. Wildlife attracts participation in activities such as hunting, fishing, photography, and nature study and enhances other types of recreation as well; for example, 43.6 percent of visitors to U.S. national forests engage in wildlife-dependent activities (i.e., wildlife viewing, hunting, and fishing) (USDA FS 2016). More than 100 million Americans participate in wildlife-oriented recreation annually, with associated spending accounting for nearly 1 percent of the U.S. gross domestic product (USDI FWS and USDC CB 2016). Observing wildlife in nature leads to psychological health benefits and spiritual fulfillment (Curtin 2009) and can contribute toward enhancing visitors' environmentally friendly behaviors, such as supporting conservation programs and improving treatment of wild animals (Ballantyne et al. 2018). Wildlife tourism can benefit conservation if animals and their habitats are effectively protected. Collaboration with local stakeholders and effective educational interpretation and outreach can contribute toward avoiding or mitigating conflict with conservation efforts. Funds generated by wildlife tourists can be used to advance conservation goals (Macdonald et al. 2017).

For the U.S. Forest Service, forest plans developed under the 2012 planning rule (Federal Register 2012) must include components to guide social and economic sustainability in the plan area, an element of which is sustainable recreation, which is defined as "the set of recreation settings and opportunities on the National Forest System that is ecologically, economically, and socially sustainable for present and future generations" (36 CFR Ch II 219.9). Moreover, assessments for plan revision or development must identify and evaluate all information about recreational settings, opportunities, and access, and the infrastructure related to recreational facilities. Habitat for wildlife is also considered an ecological benefit provided for in forest planning as part of integrated resource management (Federal Register 2012).

In this report, we focus on balancing recreation demands with maintaining wildlife populations and their habitats. The presence of recreationists and associated infrastructure on public lands that host wildlife populations leads to human-wildlife interactions, defined as the “spatial and temporal juxtaposition of human and wildlife activities where humans, wildlife, or both are affected” (Lischka et al. 2018: 105). These interactions have potential effects on nested levels of humans and wildlife, including individual animals and people, populations of species or groups of people, wildlife communities and human institutions, ecosystems that provide wildlife habitat, and human societies (see fig. 1.1 for more detail). Overall, the extensive body of literature on this subject leads to the conclusion that recreation does negatively affect wildlife, and can in some cases result in an overall decrease in biodiversity (e.g., Buckley 2004). However, few general patterns have emerged regarding the ways in which recreational activity affects wildlife, especially when considering the level of wildlife populations and communities (Marion et al. 2016, Monz et al. 2013, Tablado and Jenni 2017). This lack of distinct patterns is due in part to human-wildlife interactions being highly complex, varying with countless combinations of factors related to human activities, wildlife characteristics, and environmental settings.

We developed this report to help practitioners understand potential effects of recreation on wildlife and wildlife habitats. We first present an overview to frame human-wildlife interactions within a social-ecological system, then focus on research on one portion of human-wildlife interactions: the negative impacts of recreation on wildlife and habitat. Further discussion of the full social-ecological system, and a brief overview of research on other parts of this system, are provided below in “Human-Wildlife Interactions Within a Social-Ecological System.” Throughout the report, we organize our synthesis of existing research by recreation type and taxonomic group, with references cited for further information. We provide detailed results of particularly relevant studies, especially those that are contrary to larger trends. We present patterns as a reference to indicate potential impacts of recreation on wildlife species (see, in particular, the “Factors Influencing Wildlife Response to Recreation” section in chapter 2). However, these patterns will not apply in every case, as these effects are highly context dependent. Furthermore, the absence of effects may also reflect limitations in the scientific literature, which may not include studies of the effects of every kind of recreation on every species

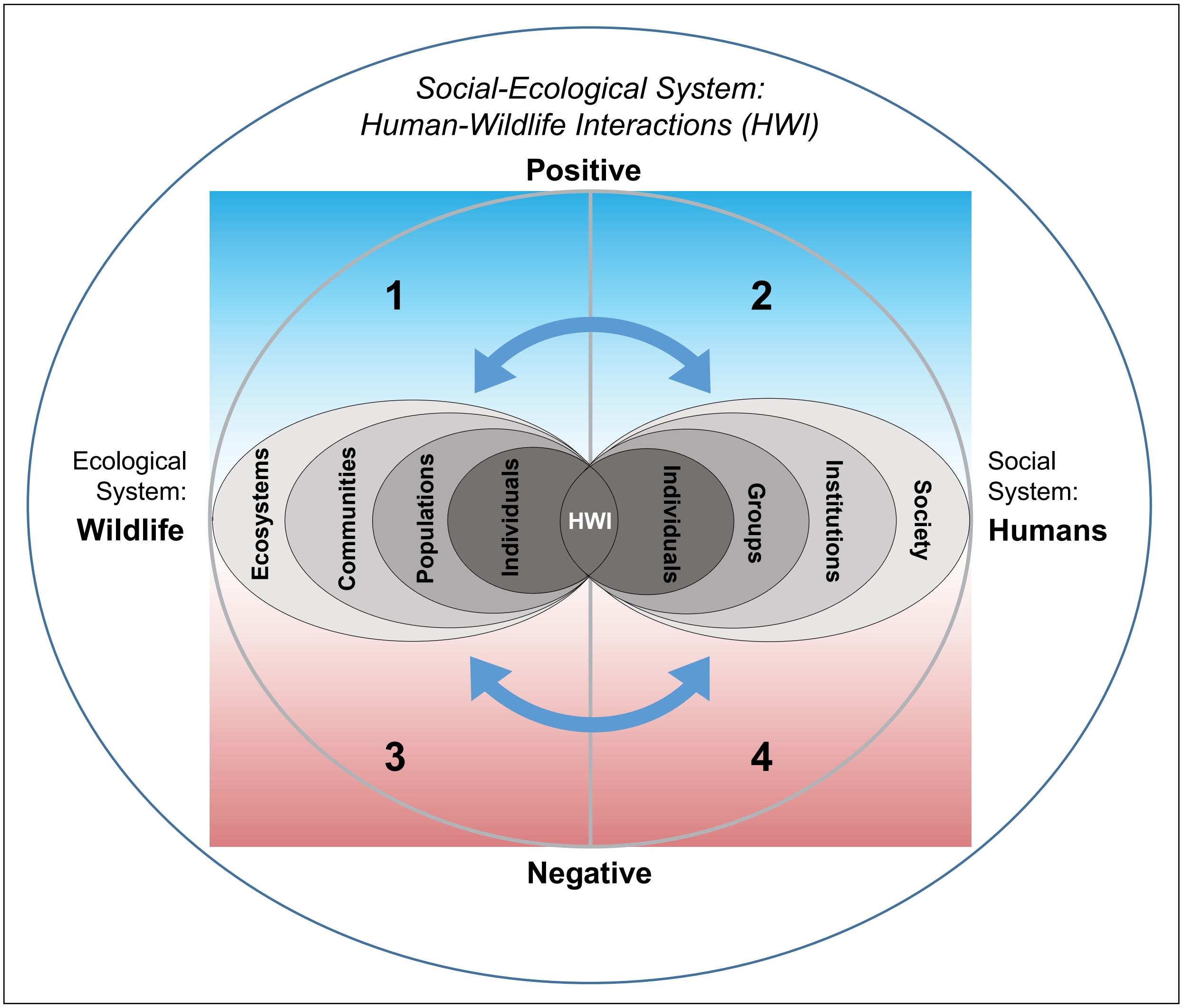

Figure 1.1—In this diagram of human-wildlife interactions (HWI) within a social-ecological systems (SES) framework, interactions driven by humans and wildlife range from positive to negative and occur at a range of nested levels, from the individual level to the ecosystem or society level. Quadrants are labelled 1 through 4: (1) positive effects of wildlife on humans, (2) positive effects of humans on wildlife, (3) negative effects of wildlife on humans, and (4) negative effects of humans on wildlife. In this report we focus on quadrant 4, while recognizing that this is just one part of the full system. Adapted with permission from Lischka et al. (2018).

or studies with nonsignificant results, and can be limited in terms of experimental design or may contain other flaws. Following the synthesis of research findings (chapters 3, 4, and 5), we present a concise list of management principles identified by researchers to ameliorate potential recreation impacts (chapter 6). We then conclude with a discussion of priority areas for future research and administrative needs to further improve our understanding of recreation impacts on wildlife in U.S. public lands (chapter 7). Further research is needed to better understand how humans experience wildlife to develop a social-ecological system of public land management.

Providing recreation opportunities on public lands is a critical element in supporting the ultimate protection of wildlife species and habitat. The impacts of recreation can be viewed as a tradeoff, because such activities as logging, mining, agriculture, and residential or commercial development may have more negative effects on wildlife than human disturbance from recreation on otherwise protected land (e.g., Kays et al. 2016). However, certain habitat-level effects (such as fragmentation or reduction of habitat) and some types of recreation have more negative impacts on certain species than do other activities, depending on the context (i.e., environment-, human-, and animal-specific factors) (Tablado and Jenni 2017). Our aim in this report is to provide a reference for public land managers that facilitates informed decisions based on current knowledge of the potential impacts of recreation on wildlife. Many frameworks for conceptualizing these interactions have been proposed, with several particularly useful frameworks summarized here.

Human-Wildlife Interactions Within a Social-Ecological System

> One of the anomalies of modern ecology is the creation of two groups, each of which seems barely aware of the existence of the other. The one studies the human community, almost as if it were a separate entity, and calls its findings sociology, economics, and history. The other studies the plant and animal community and comfortably relegates the hodge-podge of politics to the liberal arts. The inevitable fusion of these two lines of thought will, perhaps, constitute the outstanding advance of this century.
>
> —Aldo Leopold (1949: 188)

Ecological and human systems are highly interconnected, making up a social-ecological system. The importance of improving the sustainability and resilience of natural resource management by framing management within a social-ecological systems framework has been emphasized by prolific researchers such as Berkes and Folke (2000), Folke (2006), Leopold (1949), and Ostrom (2009). Social-ecological systems explicitly include humans (i.e., the social system) as a part of the ecosystem. This outlook is consistent with the way many traditional societies view their relationship with the environment, and has been present in the human ecology literature for decades (e.g., Park 1936). Likewise, adaptive management indicates the need for management systems to be able to respond to environmental feedback from both social and ecological systems (Berkes and Folke 2000).

Within this social-ecological system, humans can have positive and negative effects on wildlife and wildlife habitat, and wildlife can have positive and negative effects on humans. Effects occur at multiple nested levels for both humans and wildlife, from the individual level to the level of society (for humans) and ecosystems (for wildlife). Although interactions do not always fall into four discreet categories, we simplify this discussion by considering four quadrants of human-wildlife interaction: (1) positive effects of wildlife on humans, (2) positive effects of humans on wildlife, (3) negative effects of wildlife on humans, and (4) negative effects of humans on wildlife. Additionally, both conflicts and synergies exist between different recreational groups. This report synthesizes the research for only one portion of the social-ecological system presented in figure 1.1, focusing primarily on the negative effects of humans on wildlife and wildlife habitat (i.e., quadrant 4), within the context of outdoor recreation and nature-based tourism. This focus was determined as a way to address the management need from which this project originated: to provide a resource for managers faced with decisions regarding how to manage recreation to minimize the impacts on wildlife. Note, however, that the bulk of scientific literature within this system falls within quadrant 4, leaving a pronounced need for more research to develop our knowledge in quadrants 1, 2, and 3 (e.g., Kling et al. 2017). Elements of quadrants 1, 2, and 3 are incorporated at different points throughout the report, including the introductions of chapters 3 through 5 and in chapter 6, "Management Principles." However, this report does not attempt to present the full social-ecological system within which human-wildlife interactions occur. Because it is crucial to consider the full social-ecological system in establishing effective management of people and wildlife in shared spaces, we first review literature that contributes to our understanding of quadrants 1, 2, and 3. This is followed by a discussion of recent work that integrates human-wildlife management issues within a social-ecological system framework.

It is crucial to consider the full social-ecological system in establishing effective management of people and wildlife in shared spaces.

Quadrant 1: Positive Effects of Wildlife and Habitat on People and Social Systems

Natural ecosystems deliver a wide range of benefits to people and social systems. These benefits range from spiritual to economic, and have been quantified using concepts such as ecosystem services (e.g., MEA 2005) as well as direct monetary benefits derived from outdoor recreation. At the national level, the Outdoor Industry Association estimated that consumer spending associated with outdoor recreation totals $887 billion annually (OIA 2017), while the Bureau of Economic Analysis estimated that outdoor recreation contributed $412 billion to the U.S. gross domestic product in 2016 (i.e., 2.2 percent of the nation's economy) (USDC BEA 2018). A public lands-focused study estimated that Americans spent $51 billion in nearby communities during recreational trips on public lands and waters in 2012 (English et al. 2014). Public lands that host outdoor recreation and tourism activities can bring substantial economic benefits to local communities. White and Stynes (2010) quantified the dollar amount spent per party in local communities by different recreational activity groups (see fig. 2.4). Although economic expenditures vary widely, these authors found that participants in the three main types of snow-based recreation spent the most overall, while visitors to primitive areas spent the least overall. Overnight trips, especially those by nonlocal visitors (i.e., those traveling more than 50 miles to their destination) tend to spend the most in local communities per trip (White and Stynes 2010).

Many benefits of natural ecosystems to people are quantified through the concept of ecosystem services. Ecosystem services are tied directly to a broad range of elements of human well-being—including areas such as security, livelihoods, access to food and goods, health and well-being, social relationships—and indirectly to freedom of choice and action (MEA 2005). Outdoor recreation itself is a cultural ecosystem service (MEA 2005). Many federal agencies such as the Forest Service are mandated to address impacts on ecosystem services when evaluating agency operations (e.g., USDA FS 2012). Human health and well-being are linked to natural environments through such pathways as air quality, physical activity, social cohesion, and stress reduction (Hartig et al. 2014). Additionally, research indicates that experiencing nature and exposure to biodiversity can have positive effects on people's mental well-being (Carrus et al. 2015, Roly et al. 2013, Wolf et al. 2017).

The decision to participate in an outdoor recreation activity, and the frequency of participation, can be affected by environmental quality (e.g., Habibullah et al. 2016, Venohr et al. 2018). For example, participation in freshwater aquatic recreation is influenced by water clarity (Baer et al. 2016, 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 (e.g., Venohr et al. 2018). Scenery, which is in some cases associated with environmental quality, also plays an important role in the quality of recreation experiences (Palmer and English 2019).

Wildlife-oriented recreation is an important draw for visitors, with more than 103 million Americans participating annually. Observing wildlife in nature can lead to psychological health benefits and spiritual fulfillment.

Wildlife-oriented recreation is an important draw for visitors, with more than 103 million Americans participating annually (USDI FWS and USDC CB 2016). 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 and Connelly 1989, Duda et al. 1995, Larson et al. 2014). Many of the same benefits are important to recreational anglers (Cooke et al. 2016, 2018). Indicative of the interconnectedness of parks and people in this social-ecological system, Taff et al. (2019: 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."

Quadrant 2: Positive Effects of People and Social Systems on Wildlife and Habitat

Outdoor recreationists, local community members, and other people can act as powerful supporters of public land and conservation goals. This support comes in many forms and is often referred to as environmental stewardship, recently defined as "the actions taken by individuals, groups or networks of actors, with various motivations and levels of capacity, to protect, care for or responsibly use the environment in pursuit of environmental and/or social outcomes in diverse social-ecological contexts" (Bennett et al. 2018: 597). People 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. In many settings and situations, outdoor recreationists are environmental stewards, and environmental stewardship is sometimes considered a form of outdoor recreation (e.g., Schild 2019).

Nature-based recreation experiences can help foster connections to place, strengthening environmental values and promoting 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 by multiple research groups (e.g., Cooper et al. 2015, Larson et al. 2011, Teisl and O'Brien 2003, Zaradic et al. 2009). Observing wildlife in nature can contribute toward enhancing 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 recreation, and participating in local environmental groups (Cooper et al. 2015). These studies suggest that nature-based recreation and tourism may have substantial benefits for conservation (Cerveny and Miller 2019, Miller et al. 2020a).

The economic benefits brought by outdoor recreationists and tourists who visit public lands can contribute financially toward meeting conservation goals. In particular, revenue generated through hunting and fishing licenses often supports conservation of wildlife and habitats (Heflinger et al. 2013). Nonconsumptive 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 (Macdonald et al. 2017).

Quadrant 3: Negative Effects of Wildlife and Habitat on People and Social Systems

Negative interactions between humans and wildlife are often referred to as human-wildlife conflict. Nyhus (2016) synthesized the literature on human-wildlife conflict for a broad range of species and settings. Negative effects of wildlife on humans include real and perceived threats to human health, safety, welfare, livelihoods, and property (Nyhus 2016). These impacts can be both direct and indirect. Direct impacts include human injury or death resulting from animal attacks, collisions between animals and vehicles, and transmission of zoonotic diseases or parasites. Material and economic loss can occur when crops, livestock, game species, and property are damaged by wild animals. Indirect impacts of human-wildlife conflict include the opportunity costs associated with guarding property from such damage, as well as diminished psychological well-being, disruption of livelihoods, and food insecurity (Nyhus 2016).

In the recreation context, human-wildlife conflicts can result in threats to human safety when animals such as mountain goats (Tsong 2010) or brown bears (Bombieri et al. 2019) bite, claw, gore, or otherwise attack a person. 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).

Quadrant 4: Negative Effects of People and Social Systems on Wildlife and Habitat

The bulk of this report focuses on the negative effects of people and social systems on wildlife and their habitat. At the extreme, these interactions can lead to the lethal removal of problem individuals, or of entire populations of species considered to be a threat to human populations (e.g., Treves and Karanth 2003), and can lead to biodiversity loss (Buckley 2004, Cole and Knight 1990, Pickering and Hill 2007). Some negative impacts on wildlife originate from human perceptions of real or potential threats to human health, livelihoods, property, and lives (Nyhus 2016), in which case damage to wildlife individuals or habitats can be intentional. Impacts can also be unintentional, such as when habitat features are altered or people disturb animals simply by being present in important wildlife habitat (e.g., Bateman and Fleming 2017, Larson et al. 2016, Tablado and Jenni 2017).

Negative impacts by people on wildlife can be intentional or unintentional.

Frameworks for conceptualizing human-wildlife interactions as part of a social-ecological system—

Human influences on the environment and wildlife populations are shaped by many social and ecological parameters. Management of human-wildlife interactions will benefit from moving away from individual social and ecological approaches toward an integrated social-ecological systems approach. To address this need, several research groups have recently developed frameworks for conceptualizing the social-ecological system of human-wildlife interactions (e.g., Dressel et al. 2018, Jochum et al. 2014, Lischka et al. 2018, Tablado and Jenni 2017, Venohr et al. 2018). Here we summarize lessons learned from these studies. Although this set of studies is not exhaustive, they present a collection of findings relevant for those who aim to manage human-wildlife interactions within a social-ecological system. Additionally, we suggest a method for combining human values with wildlife data by using geospatial information science.

Management of human-wildlife interactions will benefit from moving away from individual social and ecological approaches toward an integrated social-ecological systems approach.

Compiling elements from decades of models on human-environment interactions, Jochum et al. (2014) developed the Integrated Adaptive Behavior Model of human-wildlife encounters. This model includes social factors that influence ways that people interact with ecological systems, such as beliefs and cultural and emotional dispositions, benefits received (actual and potential), barriers to environmentally friendly behavior (e.g., social pressures, perceived control, perceived risks, and environmental constraints), emotions, personal experiences, attitudes, cognition, and affect (Jochum et al. 2014). However, this model does not explicitly integrate ecological parameters.

The need for interdisciplinary efforts to solve wildlife management issues is emphasized by many authors. In particular, Dressel et al. (2018) found that applying uniform solutions that ignore local social and ecological factors can be highly ineffective for managing wildlife. These authors found that multilevel governance systems aim to create a better match between social and ecological aspects of wildlife management, and presented a social-ecological system mapping method to understand the challenges underlying wildlife management (Dressel et al. 2018). In this study, the importance of ecological vs. social components of the system varied spatially. For example, in some areas, co-occurrence of carnivores with moose was the most important challenge for management, while governance aspects shaped management challenges in other areas. These findings reinforced the importance of adaptive management within a social-ecological systems framework.

Venohr et al. (2018) presented a multi-loop concept linking ecological quality, recreational quality, and ecosystem management. Although the model is specific to freshwater environments, it can be applied to other settings as well. Findings suggested that combining an integrative recreation ecology management concept with information about peak visitation can inform new management for freshwater and other ecosystems.

To conceptualize human-wildlife conflict within a social-ecological system, Lischka et al. (2018) developed a framework and discussed lessons learned from a case study on human-bear conflict in Colorado (see box 1).

Box 1

According to Lischka et al. (2018), human-wildlife interaction programs are more successful when:

- Social science is integrated from the beginning and throughout the research process.
- The spatial scale of social and ecological data is aligned.
- Drivers and consequences of both human and animal behavior are considered and accounted for.

The lack of patterns emerging from the large body of literature on human-wildlife interactions in the recreation context may be due in part to the absence of a conceptual framework consistently applied to this body of literature. Tablado and Jenni (2017) provided a framework for understanding the complexity of human-wildlife interactions, presenting a compilation of factors that influence these interactions in the recreation context (fig. 1.2). This conceptual framework suggests that context-dependent, human-dependent, and wildlife-dependent factors (referred to as “modulators”) influence wildlife response mechanisms. These mechanisms for wildlife response to outdoor recreation occur at increasing levels of complexity, including (1) sensory detection; (2) short-term behavioral changes and physiological responses; (3) changes in survival, reproduction, space use, and chronic stress; and (4) changes in population trends and distribution. At higher levels, such as at the population level, the complexity of interactions increases and can obscure direct associations between recreation and wildlife (Tablado and Jenni 2017). Examples of modulators at the lowest level of response (i.e., activation of senses and detection) are the number of people approaching, the noise level they produce, and their speed of movement. At the highest level of this framework (i.e., changes in population trends and distribution), examples of modulators include the spatial and temporal scale, as well as the pervasiveness, or distribution, of recreational activity (Tablado and Jenni 2017). Applying a framework for understanding wildlife response to recreation might reveal overarching patterns of effects of recreation on wildlife, and

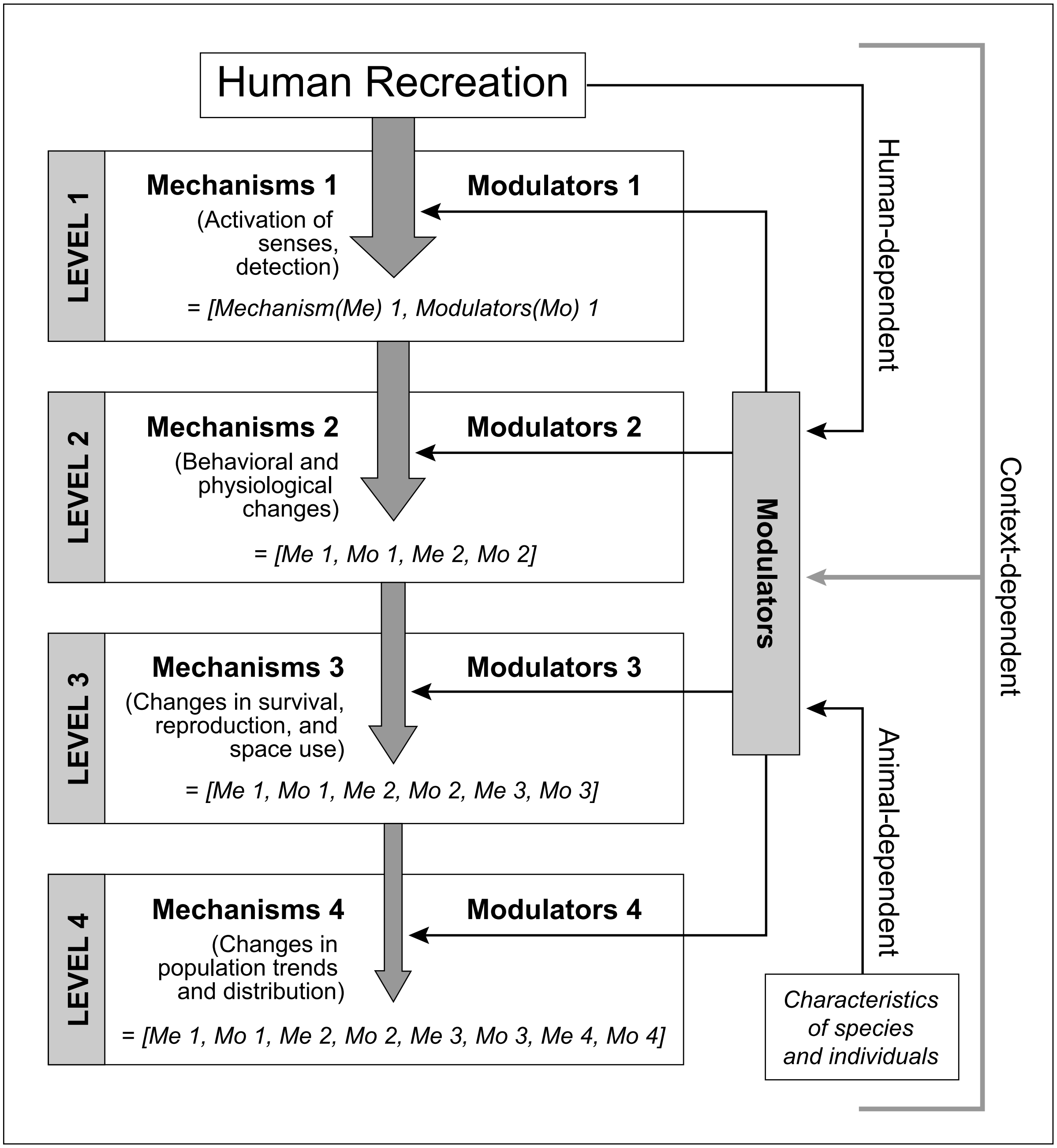

Figure 1.2—Conceptual framework described by Tablado and Jenni (2017), showing the different levels in the process of interaction between recreationists and wildlife. The resultant response of animals to human disturbance can be modulated by factors that depend on the source of the disturbance (e.g., characteristics of human activity), on properties of the animal, and on the spatiotemporal context (e.g., habitat, climate, timing). Decreases in the width of the dark gray arrows from top to bottom represent the dilution of the association between human disturbance and animal response, a result of the confounding effects of the accumulation of modulating factors across levels. Reproduced with permission.

could contribute toward understanding the effects of recreation on wildlife populations in the long term.

Geospatial tools are commonly used to understand the spatial extent of wildlife populations (e.g., Austin et al. 2009). Human uses and values have also been mapped by several research groups, using a variety of participatory methods to understand how people interact with landscapes (e.g., Brown and Kyttä 2014, Cerveny et al. 2017, Harner et al. 2017, McClain et al. 2013). Wildlife and human systems have been combined to better understand natural resource management in some settings (e.g., Dressel et al. 2018, Lewis 1995, White and Ward 2011). Integrating social and ecological systems through geospatial analysis is a promising approach for improving the management of human-wildlife interactions on public lands. By consulting with user groups and stakeholders, researchers can determine how the landscape is used and valued (Cerveny et al. 2017). Combining the resulting information with geospatial data such as habitat for target species or movement pathways of migratory species can help identify locations where human-wildlife conflicts are likely, as well as where recreational activity can best be concentrated to avoid conflicts with wildlife. Participatory mapping approaches also can be used to identify conditions for optimal wildlife encounters in areas that are safe for people and least intrusive to wildlife habitat or movement. An example is shown in figure 1.3, in which Human Ecology Mapping data (Cerveny et al. 2017) were integrated with elk nutrition data to indicate priority areas to target for elk habitat improvement and recreation improvement.

Recent reviews on the impacts of recreation on wildlife—

Several broad review papers have summarized the extensive body of literature investigating the impacts of recreation on wildlife. Larson et al. (2016) wrote what is perhaps the most comprehensive systematic review in recent years, having reviewed 274 articles and summarized patterns of effects interpreted as negative and positive[1] by recreational activity, taxonomic group, and level at which wildlife respond (i.e., individual, population, and community-level effects). These authors considered "negative" responses to be those such as decreased species richness, diversity, survival, reproduction, occurrence, abundance, foraging, or weight, and increased vigilance or stress. Responses in the opposite direction were considered "positive." However, a positive response to recreation does not necessarily

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[1] Within this report, we do not aim to interpret effects as negative or positive. Instead, we present and summarize findings on the effects of outdoor recreation on wildlife species and habitat without assigning value. However, to summarize the effects of different types of recreation on wildlife, we report findings from previous studies and reviews in which impacts are labeled as negative, positive, and neutral.

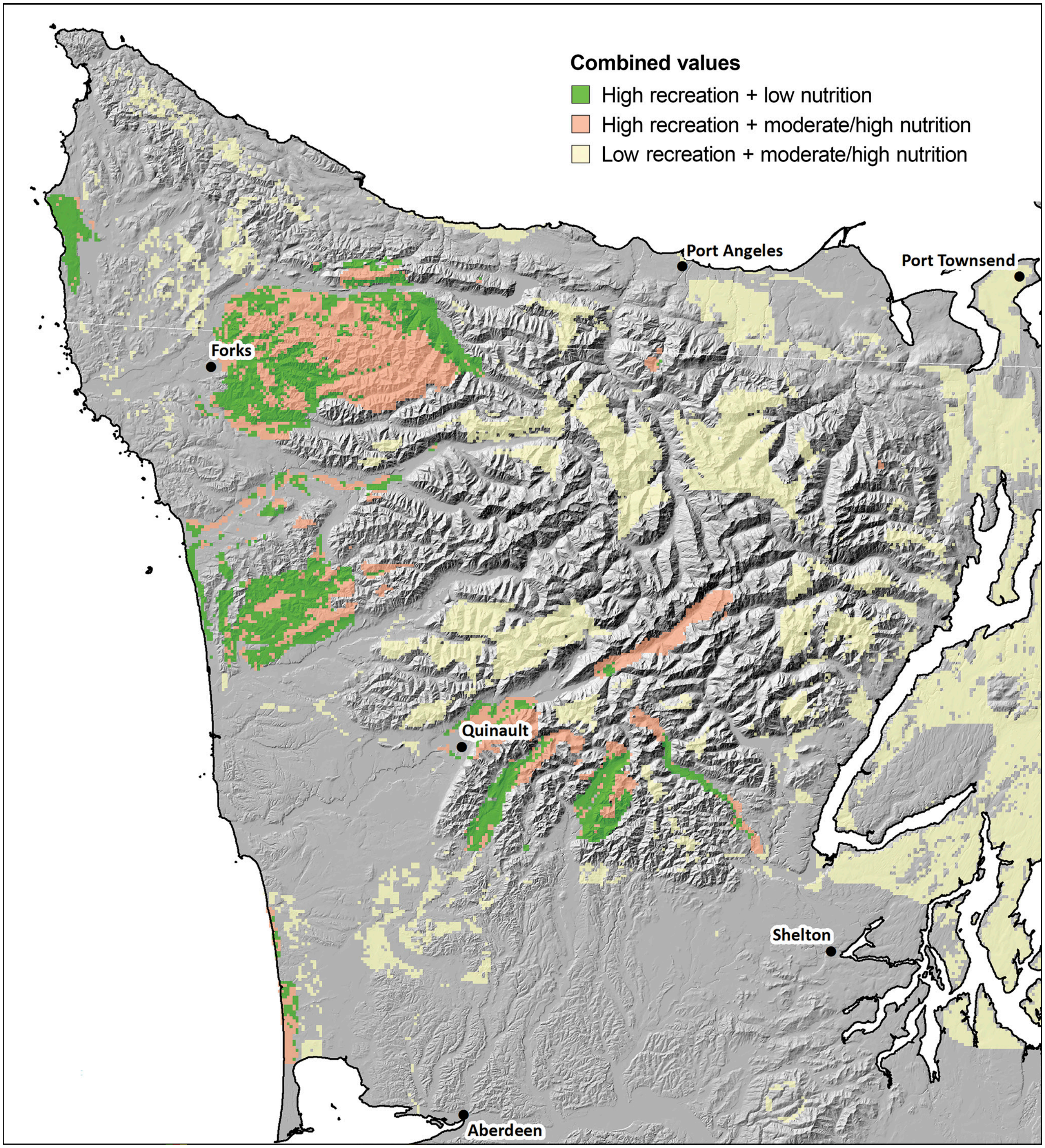

Figure 1.3—Integration of recreation values and a wildlife resource (in this example, elk nutrition) using three combined categories of recreation and nutrition with direct management implications on the Olympic Peninsula, Washington. The high recreation–low elk nutrition areas would not be targeted for elk habitat improvement as they offer little benefit to elk, and these areas are highly valued by recreationists. In contrast, in areas of low recreation value but moderate or high elk nutrition, road closures could be emphasized to facilitate use by elk of better nutritional resources with less potential conflict with many stakeholders. Map by Michael Wisdom; sociospatial data collected by Cerveny et al. (2017).

correspond with benefits to broad-scale biodiversity conservation; e.g., increased species richness in a site can result from an increase in nonnative species. This review also indicated the distribution of published studies on this topic by ecosystem type and geographically.

Several other recent reviews (table 1.1) provide more detailed information specific to certain recreational activities, taxonomic groups, or settings. These articles offer excellent syntheses of the existing research regarding recreation effects on wildlife. However, many of the existing reviews do not present explicit guidance for biologists charged with conducting effects analyses of specific projects because of the broad level at which patterns are identified, making these findings difficult to apply on the ground. Additionally, the existing syntheses do not consider the full spectrum of recreation uses occurring on public lands, such as the use of electric bikes, unmanned aerial vehicles (UAVs, commonly known as “drones”), skijoring, slack lining, adventure racing, geocaching, and many other activities. In this report, we aim to bring together these review papers and other resources in one comprehensive document, with the goal of assisting biologists, recreation specialists, environmental planners, landscape architects, and others in informing analyses regarding the effects of recreation on wildlife.

Goals, Scope, and Methods for This Review and Synthesis

This report presents a synthesis of existing literature that investigates the effects that recreation has on wildlife and wildlife habitat. Furthermore, it aims to organize the synthesis in a way that supports public land managers faced with decisions regarding how to best manage recreational activities and wildlife habitat that overlap on the lands they manage. Developing a quantitative systematic review on the effects of recreation on wildlife and habitat was not within the scope of this report, as this has recently been done by other authors (see table 1.1 for a list of recent reviews on a variety of relevant topics). Instead, this report expands on findings summarized within existing reviews to serve as a reference for public land planners and managers who seek information regarding wildlife response to recreational activity and associated wildlife habitat alterations.

Methods: literature review—

The scope of this project was developed by a group of eight primary contributors (the authors), and with consultations from each of our networks. We asked National Forest System wildlife managers and recreation planners to identify their information needs, which are addressed by this report.

The information presented in this report was collected from key review articles that summarized the effects of recreation on wildlife and wildlife habitat covering

Table 1.1—Recent reviews on the impacts of recreation on wildlife by recreational activity, wildlife taxonomic group, and settings

Recreational activity	Wildlife taxonomic groups	Setting or other detail	Citation
All recreation categories	All taxa	All settings	Larson et al. 2016
All recreation categories	All taxa	All settings	Bateman and Fleming 2017
All recreation categories (nonconsumptive wildlife tourism) [a]	All taxa	All settings	Green and Higginbottom 2000
All recreation categories	Ungulates	All settings, ungulate flight response to humans	Stankowich 2008
All recreation categories	Birds	All settings	Buckley 2004
All recreation categories	Brown bears	All settings	Fortin et al. 2016
Summer recreation	All taxa	Focus on United Kingdom	Marzano and Dandy 2012
Nonmotorized summer recreation: hiking, biking, equestrian	Birds, mammals, reptiles, amphibians, invertebrates	All settings, with a focus on Oregon	Hennings 2017
Nonmotorized summer recreation	Birds	All settings	Steven et al. 2011
Rock climbing	Birds and snails	Rock climbing	Holzschuh 2016
Motorized recreation	Terrestrial organisms	Chronic noise exposure	Barber et al. 2009
Motorized summer recreation [b]	All taxa	Drylands	Switalski 2018
Winter recreation	Birds, mammals, reptiles, invertebrates Habitat-level and community-level effects	Alpine and subalpine areas	Sato et al. 2013
Winter recreation	Ungulates	Snow-based recreation review, with an Alaskan case study	Harris et al. 2014
Motorized winter recreation (snowmobiles)	Carnivores (grizzly bear, wolverine, lynx) and ungulates	Snow-based recreation	Switalski 2016
Linear recreation routes	Focal species from all taxa	Linear routes, eastern Washington	Gaines et al. 2003
Road-based recreation; access to recreation areas	Birds and mammals	Roads and other infrastructure	Benitez-Lopez et al. 2010

[a] Nonconsumptive wildlife tourism is defined as "human recreational engagement with wildlife wherein the focal organism is not purposefully removed or permanently affected by the engagement" (Duffus and Dearden 1990: 215), and "overlaps with general tourism, nature-based tourism, ecotourism and adventure tourism" (Green and Higginbottom 2000: 183).

[b] This study focused on all-terrain vehicles in arid or semiarid (often referred to as "dryland") ecosystems.

the range of outdoor recreation occurring on public lands. Although the focus is on the interactions of recreation and wildlife within the United States, the literature review draws on examples from outside the country as well, especially in cases that have not been widely studied in the United States. These key review articles draw on hundreds of individual studies, many of which were consulted to provide sufficient detail to contribute to the scope and structure of this report. Specifically, the review article by Larson et al. (2016) provided an important reference, having cited 274 articles, most of which are included in this report. In addition to including references cited by Larson et al. (2016), we also performed literature searches specific to each recreational activity category, using search terms such as "recreation," and "wildlife," combined with recreation-specific terms such as "motorized," "ATV," "ski," or "drone." Below we list recent reviews that provided a base of information for each section. Additionally, we provide further detail on results from individual research articles referenced within these reviews in the corresponding recreational activity section:

- **Nonmotorized summer recreation:** Bateman and Fleming (2017), Hennings (2017), Larson et al. (2016).
- **Motorized summer recreation:** Bateman and Fleming (2017), Hennings (2017), Larson et al. (2016), Switalski (2018).
- **Nonmotorized winter recreation:** Bateman and Fleming (2017), Hennings (2017), Larson et al. (2016), Sato et al. (2013).
- **Motorized winter recreation**: Bateman and Fleming (2017), Harris et al. (2014), Hennings (2017), Larson et al. (2016), Switalski 2016.
- **Aquatic recreation:** Bateman and Fleming (2017), Hennings (2017), Larson et al. (2016).

Presenting the direction of effects—

There are discrepancies in the interpretation of effects of recreation on wildlife. Some sources interpret a certain effect as positive, while another might consider the same effect negative. Two of the most recent review articles contradict each other on this point, with one emphasizing the widespread extent of negative impacts of recreation on wildlife (Larson et al. 2016), while another revisited and reinterpreted the results presented in over 100 articles, concluding that the negative effects of recreation on wildlife are widely over-reported (Bateman and Fleming 2017).

Habituation is a specific wildlife response which exemplifies this discrepancy. For some species and situations, habituation to a recreational activity may be considered positive in that it reduces stress on animals, whereas in other situations it may be considered negative for others by increasing potentially harmful

Box 2

Wildlife responses, e.g., habituation, can be inconsistently interpreted in the literature as "negative" or "positive." Examples of how responses were interpreted by Larson et al. (2016):

- Negative responses include a decrease in species richness or abundance; behavioral responses to human disturbance; physiological conditions attributed to human disturbance.
- Positive responses include increased survival and decreased stress.

interactions between humans and wildlife. To further complicate this, animal behaviors measured in the short term have often been mislabeled as habituation, an inherently long-term response (Bejder et al. 2009).

As noted earlier, we do not aim to interpret effects as negative or positive. However, to summarize the effects of different types of recreation on wildlife, we report findings from previous studies and reviews in which impacts are labeled negative, positive, and neutral. Because we refer extensively to findings presented by Larson et al. (2016), the examples of effects considered negative and positive by these authors are summarized here. Negative responses include a decrease in species richness or diversity, survival, reproduction, occurrence, or abundance; behaviors assumed to reflect negative response to human disturbance (e.g., decreased foraging, increased vigilance); and physiological condition assumed to reflect effects of human disturbance (e.g., decreased weight, increased stress). Examples of positive responses include increased survival and decreased stress. Furthermore, we endeavor to convey cases in which there is disagreement among researchers, as well as the nature and source of this ambiguity.

Dane Johnson

Wildlife response to recreationists is variable; some individuals may not flee even in close proximity to humans, although physiological responses such as an elevated heart rate may occur.

Chapter 2: Overview of Recreation Impacts on Wildlife

Introduction

This report presents documented effects of recreation on wildlife in five categories of recreational activity: (1) nonmotorized summer, (2) motorized summer, (3) nonmotorized winter, (4) motorized winter, and (5) aquatic. Land-based summer recreation is addressed in chapter 3, land-based winter recreation in chapter 4, and aquatic recreation in chapter 5. Dividing recreation into its nonmotorized and motorized forms reflects their key qualitative differences in terms of overall impacts and effects on animal species and their populations during spring and summer breeding in contrast to winter survival and maintenance activities. The direct effects of hunting (e.g., mortality) on species and populations are not addressed in this report, as those are regulated and controlled by state, federal, and tribal agencies. Furthermore, such effects on populations have been studied in detail and comprise a separate and well-developed body of literature. However, examples from the literature of the effects of hunting as a nature-based activity on human well-being provide useful insights on the general value of wildlife to humans. In this report, we include hunting-related activities, such as scouting or travel to hunting and fishing locations, as these activities have common characteristics with nonhunting recreation.

Each of these five recreational activity sections begins with an introduction describing which activities the category includes, the occurrence and participation levels of these activities, their projected growth, and their associated economic and social benefits. These recreational activity categories are outlined in table 2.1.

Following each recreational category's introduction is an overview of how it is expected to affect animal behavior, wildlife population dynamics, and wildlife habitat. Further detail is then provided for each of five broad taxonomic categories: (1) invertebrates, (2) reptiles (3) amphibians, (4) birds, and (5) mammals. In addition, fish are discussed in the aquatic recreation chapter. Within each class of recreational activity and taxonomic category, impacts are finally subdivided into impacts on habitat, individuals, populations, and communities to better resolve the complexity of these potential effects. For taxonomic categories with more published information (i.e., birds and mammals), species are further divided into subcategories. In some cases, effects at the community level are inseparable from habitat alterations, and are thus presented together.

Table 2.1—Organization of this report, by recreational activity category

	Nonmotorized	Page	Motorized	Page
Summer	Chapter 3	43	Chapter 3	75
Winter	Chapter 4	95	Chapter 4	112
Aquatic	Chapter 5	125		

Impacts on Habitat

Impacts of recreation on wildlife habitat differ from impacts on wildlife individuals, populations, and communities (which are discussed below) because they can exist in the form of infrastructure whether or not recreationists are present (Cole and Landres 1995). In this report, we define habitat as the species-specific resources that lead to occupancy (e.g., reproduction, survival) (Hall et al. 1997). Infrastructure built for recreational uses, such as trails, campgrounds, parking areas, visitor centers, ski lifts, and lodges can restrict recreational activity to a developed area while also providing entry to otherwise inaccessible areas (Leung and Marion 1999). The construction of new recreation infrastructure can also affect wildlife use of habitats (Miller et al. 2020b). Recreational infrastructure can affect the amount, quality, and connectivity of wildlife habitat; however, negative impacts on habitat are not reported for all recreational activities, and some species are less affected by habitat alterations than others (e.g., Bateman and Fleming 2017, Hennings 2017, Larson et al. 2016, Tablado and Jenni 2017). Acknowledging that some forms of recreation likely affect wildlife habitat more than others, our aim in this report is to convey documented effects in a way that is useful to managers.

In some cases, recreation on public lands can lead to habitat loss or reduced habitat quality. As a result, wildlife may sometime move into areas of lower quality habitat to avoid areas affected by human activity.

In some cases, recreation on public lands can lead to habitat loss or reduced habitat quality, with individuals or populations sometimes shifting geographically into areas of lower quality habitat to avoid areas affected by human activity. Development of recreational infrastructure such as lodges, campgrounds (Leung and Marion 1999), extensive road networks (McGregor et al. 2008, Shepard et al. 2008), or ski areas (Mansergh and Scotts 1989, Strong et al. 2002a) can cause habitat fragmentation and decrease mobility for some species. Larger human-made structures that are not limited to recreational activities, such as highways and housing developments, have been found to fragment large landscapes, disrupting migration of large mammals (e.g., Alexander and Waters 2000). However, such large-scale anthropogenic disturbances are outside the scope of this report.

Habitat fragmentation occurs when contiguous habitats are divided into smaller, isolated fragments (Fahrig 2003), e.g., through construction of a road network to access public lands for recreation and other uses. Some species are sensitive to habitat fragmentation, such as large carnivores that may require a large area of continuous habitat, and habitat specialists (i.e., species that thrive only in a narrow range of environmental conditions), while other species are more tolerant of or even benefit from habitat fragmentation (Crooks 2002). Although the presence of low-density unpaved trails developed for recreation is not typically associated with habitat fragmentation for mid- to large-sized species, trails can fragment habitat for species with lower mobility, especially when trail density is high or when trails are wide and paved. For small species and habitat specialists (e.g., amphibians, reptiles, and small mammals), trails have been found to inhibit travel (Schmidt and Zumbach 2008, Woltz et al. 2008).

Site-level studies demonstrate specific impacts of recreation on wildlife habitat. Recreation can alter soil characteristics (Cole and Landres 1995, Marion and Wimpey 2017) and vegetative communities (Cole and Monz 2003, Marion et al. 2016). Recreationists moving between and through public lands can lead to an increase in the spread of invasive species, the colonization of which can be further facilitated if native species are not resilient to conditions associated with recreation (Dickens et al. 2005, Underwood et al. 2004). Water quality can be degraded by sedimentation associated with increased erosion from recreational infrastructure such as trails (Hammitt et al. 2015, Marion et al. 2016) and by pollution from motorized vehicles entering water sources (Havlick 2002). Such impacts can degrade wildlife habitat, changing the provision of important resources such as food, shelter, and water.

Impacts on Wildlife: Individuals, Populations, and Communities

In contrast to habitat effects, which affect wildlife indirectly through changes in habitat, direct impacts on wildlife from outdoor recreation are manifested as changes in their behavior or physiology, which may ultimately affect survival and population stability (Tablado and Jenni 2017). Categories of wildlife response to human activity have been described by multiple authors. Knight and Temple (1995) described three learned responses that wildlife may show in response to recreationists, including habituation, attraction, and avoidance, as well as physiological responses. These response types were applied within a hierarchical framework by Tablado and Jenni (2017) (fig. 1.2), which separates four levels of "mechanisms," including (1) activation of senses or detection; (2) behavioral and physiological changes; (3) changes in survival, reproduction, and space use; and (4) changes in population trends and distribution. Because responses at a certain level can occur only if a response was present at lower level(s), these levels are described as hierarchical. This means that recreational activity can have negative effects on demographic rates only if animals detect people and react to them. However, research on wildlife responses at higher levels (e.g., changes in population trends) is more complex than at lower levels (e.g., documenting flight response in ungulates). For this reason, many more studies document wildlife responses at lower levels than those documenting effects at the population or community level. However, some authors have drawn conclusions regarding how low-level responses (i.e., behavioral and physiological changes) may lead to population- or community-level changes.

Recreational activity can have negative effects on demographic rates only if animals detect people and react to them.

Impacts on individuals—

At the individual level, wildlife responses to human recreation are described as either behavioral or physiological, primarily because these response types are measured differently and thus generally are studied within different fields. Physiological responses can be present even when behavioral responses are not observable. These two types of effects, as well as direct mortality, are described below.

Behavioral responses can occur in both the short term and long term, and can be learned, innate (genetic), or a combination (Knight and Temple 1995). These responses can be passive (e.g., staying still to hide or remain cryptic) or active (e.g., fleeing or being aggressive toward the perceived threat) (Tablado and Jenni 2017). Short-term behavioral responses include attraction, avoidance, and tolerance, while longer term behavioral responses include habituation and sensitization (Bejder et al. 2009, Knight and Temple 1995). Table 2.2 provides a few key definitions of these terms as used in this report. Behavioral responses are measured frequently, consisting of 45.5 percent of articles reviewed by Larson et al. (2016). In their review, the highest proportion of positive effects were those corresponding with behavioral

Table 2.2—Categories, definitions, and examples of short-term and long-term learned behavioral responses of wildlife to human activity

Behavioral response	Definition	Example	Source
Short-term responses:			
Attraction	The strengthening of an animal's behavior because of rewards or positive reinforcement.	A chipmunk is attracted to areas where recreationists leave food.	Knight and Gutzwiller 1995
Avoidance	The strengthening of an animal's behavior because of persecution or negative reinforcement.	Grizzly bears in an area with high human activity levels often flee from people, while those in an area with no or little human activity do not.	Knight and Gutzwiller 1995
Tolerance	Intensity of disturbance that an individual tolerates without responding in a defined way.	Terns ignore heavy vehicle and boat traffic. This is measured in the short term, and evidence of this tolerance increasing over time is absent.	Nisbet 2000
Long-term responses:			
Habituation	Waning of a response to a repeated stimulus that is not associated with either a positive or negative reward.	Birds habituate to stimuli that are predictable and nonthreatening, such as road traffic, but are startled by sudden and unpredictable noises such as gun shots.	Eibl-Eibesfeldt 1970
Sensitization	Increased behavioral responsiveness over time when animals learn that a repeated or ongoing stimulus has significant consequences for the animal.	Avoidance of noise or other stimuli associated with danger; entails an increased energy expenditure to avoid danger.	Richardson et al. 1995

responses to outdoor recreation (9.8 ± 2.5 percent) (fig. 2.1). In this report, behaviors such as reduced flight initiation distances in habituated animals, increased foraging, or decreased vigilance would be considered positive behavioral responses. Most studies at the individual level measure short-term behavioral responses, such as spatial and temporal avoidance of human activity through quantifying alert distance, flight initiation distance, distance fled, timing of daily activity patterns, and vigilance behavior. Measuring long-term responses is difficult and far less frequently studied. Furthermore, the terms "habituation" and "sensitization" are often misapplied to other forms of tolerance (Bejder et al. 2009).

Physiological responses are commonly measured by heart rate, stress level (e.g., corticosterone or fecal cortisol concentration), and infestation by parasite or infection by pathogen loads. Physiological impacts can lead to reduced growth rate, increased metabolic rates, impaired response to injuries, reduced investment in rearing young, and reduced reproductive success, and in some cases can threaten species at the population level (Bateman and Fleming 2017, Tablado and Jenni 2017). Physiological responses to recreation can be direct (e.g., increased heart rate in response to human approach) or indirect (e.g., lack of habitat resources leading to compromised health, which allows parasites to infest an individual). In a recent review on the impacts of recreation on wildlife, physiological responses to recreation were the third most frequently reported effects overall (62.5 ± 4.9 percent

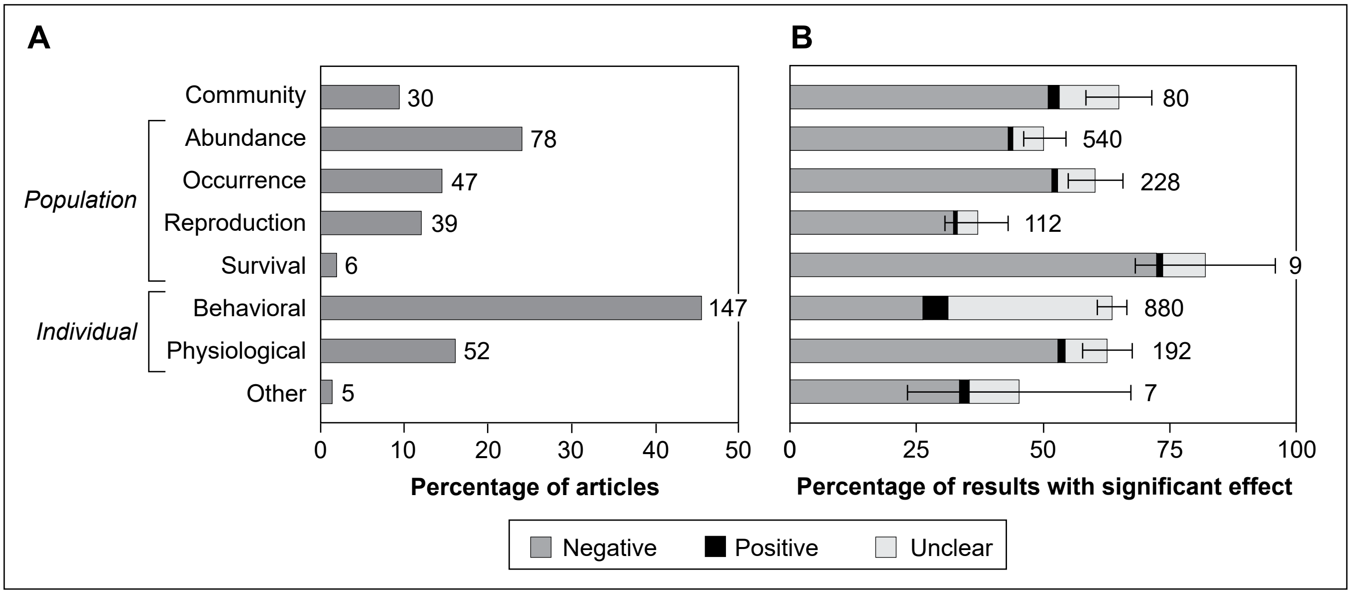

Figure 2.1—Types of animal responses to recreation, from the articles reviewed by Larson et al. (2016). Responses are categorized into individual, population, and community levels. (A) percentage of articles in which each response type is tested (numbers of articles follow the bars); (B) percentage of results in which a statistically significant effect of recreation on an animal species was observed (number of results follow the bars). Total percentages are divided into negative, positive, and unclear effects of recreation. Error bars show standard error for the sum of all effects. Source: Larson et al. 2016.

percent), following effects on individual-level behavior and population-level occurrence. In this review, physiological responses had the highest proportion of negative effects among response types (52.7 ± 4.8 percent) (fig. 2.1) (Larson et al. 2016).

Mortality can be caused by nonconsumptive recreation (i.e., recreational activities wherein wildlife is not purposefully removed or permanently affected by the activity) (Duffus and Dearden 1990), especially with fast-moving motorized vehicles. For example, manatees have been killed by motorboats in Florida (Rycyk et al. 2018); amphibians and reptiles by passing traffic both on roads and in off-road areas (Bulte et al. 2009, Bury and Luckenbach 2002, Schmidt and Zumbach 2008, Woltz et al. 2008); and invertebrates (Knisley and Hill 2001) and piping plover chicks by motorized traffic on beaches (Melvin et al. 1994). Wires and cables from ski lifts can cause direct mortality to birds (Miquet 1990, Watson and Moss 2004).

Impacts on populations—

The term "population" refers to a group of individuals of a given species that interbreed within an area of interest. Recreation can affect wildlife populations through loss or alteration of habitat, reduction of fitness of some or all individuals within a population, and alteration of population demographic processes (e.g., reproductive, survival, immigration, and emigration rates) (Tablado and Jenni 2017). Such effects can lead to reduced population size, increased probability of local extirpation, and changes in geographic distribution (Tablado and Jenni 2017). Examples of impacts at the population level include reduced population size in beetles in southern California drylands resulting from motorized recreation (Van Dam and Van Dam 2008); permanent displacement of moose in Canada by cross-country skiing (Ferguson and Keith 1982); and reduced reproductive success and survival in deer mice in the Great Basin Desert in response to disturbance from motorized recreation (Previtali et al. 2010). Although large highways and infrastructure associated with urban/suburban areas have been found to alter ungulate migration patterns, outdoor recreation on public lands generally involves human developments at a small enough scale that disruption of major migration pathways (i.e., for larger terrestrial species) is generally not a concern (Alexander and Waters 2000).

Impacts such as altered habitat, reduced fitness, and altered population demographic processes can lead to population-level effects such as reduced population size, increased probability of local extirpation, and changes in geographic distribution.

In a recent review on the impacts of recreation on wildlife, results that had direct implications at the population level (including survival, reproduction, abundance, and occurrence) were reported in 52.6 percent of articles reviewed (Larson et al. 2016). Studies on abundance were most prevalent (24.1 percent), followed by those on occurrence (14.6 percent), reproduction (12.1 percent), and survival (1.9 percent). The number of studies indicating negative effects of recreation on wildlife occurrence was proportionately high, compared with other population-level effects (51.3 ± 4.6 percent) (fig. 2.1).

Impacts on communities—
For the purpose of this report, a "community" refers to individuals and populations of all species within a given area of interest. At the community level, effects of human recreation are measured through species richness, species diversity, and composition metrics (Larson et al. 2016). Studies on effects at the community level made up only 9.3 percent of articles included in Larson et al.'s review. However, results of these papers showed the highest occurrence of effects (64.6 ± 6.6 percent), compared with individual- and population-level effects. The majority of effects documented at the community level were negative (fig. 2.1) (Larson et al. 2016).

Individual-level responses of wildlife to recreation can result in community-level effects. For example, although habituation might be regarded as beneficial to some species at certain places and times (e.g., Bateman and Fleming 2017, Larson et al. 2016), it can also be considered negative at the community level (e.g., George and Crooks 2006, Larson et al. 2016). Species that are more likely to habituate to recreation-related disturbances are often habitat generalists, because these species can, by definition, adapt to a wide range of ecological settings. Some studies have documented habitat generalists moving into a disturbed area while habitat specialists become displaced (e.g., Ballenger and Ortega 2001, Rolando et al. 2013). Habitat specialists require specific resources that can be reduced or removed when recreation moves into a previously undisturbed area.

Habitat specialists require specific resources that can be reduced or removed when recreation moves into a previously undisturbed area.

In some cases, habitat generalists are also nest predators, and their increased presence in an area can have direct negative effects on specialist species whose nests they prey on. One specific example are corvids (e.g., crows), which are urban adaptors (Marzluff and Neatherlin 2006) that can habituate quickly to human disturbance (Jiménez et al. 2011, Storch and Leidenberger 2003), sometimes at the expense of other species (Gutzwiller et al. 2002). Examples of increased nest predation have been documented along recreational trails (Carney and Sydeman 1999, Lafferty et al. 2006, Miller et al. 1998) and in aquatic recreation settings (Keller 1991). However, other researchers have found the opposite effect, with nest predators less active in areas with recreational activity, such as in the case of beach-nesting sea turtles (Leighton et al. 2010) and riparian areas in Colorado (Miller and Hobbs 2000).

Examples of habitat specialists being more susceptible than generalists to habitat alterations induced by vegetation changes span both summer and winter recreation and have been found by both motorized and nonmotorized activities. This general pattern has been documented in birds, mammals, reptiles, and amphibians (Hennings 2017). Instances range from species that use both a small and highly specialized area such as riparian zones (Nowak and Santana-Bendix 2002, USDI FWS 2002) to species that require large expanses of unfragmented territory (Crooks 2002).

Activity Type Comparison

In general, winter terrestrial activities present proportionately more evidence of negative effects on wildlife than other types of recreation (Larson et al. 2016). Possible explanations include the following: (1) movement away from recreationists is more energetically costly during winter months; (2) food availability and quality is lower in winter for many species, which limits their ability to relocate to avoid areas with human activity; (3) relatively severe habitat degradation occurs in alpine and subalpine areas, which regenerate slowly and are common snow-based recreation areas. Negative effects of snow-based activities were observed 1.3 times more frequently than for all other terrestrial activities, with 64.4 ± 10.1 percent of effects reported in articles on winter terrestrial recreation considered negative, compared with 39.6 ± 4.6 percent of effects reported for all other terrestrial activities considered negative. However, far fewer articles were reviewed on snow-based recreation (14 articles) compared with all other terrestrial recreation types (168 articles) (Larson et al. 2016).

Box 3

- Snow-based recreation had 1.3 times more evidence of negative effects than all other types of terrestrial recreation.
- Nonmotorized recreation had 1.2 times more evidence of negative effects than motorized recreation.

Source: Larson et al. 2016.

Nonmotorized activities had 1.2 times more evidence of negative effects of recreation than motorized activities (Larson et al. 2016). For example, behavioral or occurrence responses to nonmotorized but not motorized recreation were recorded for three North American mammals (wolverine, coyote, and bobcat) (George and Crooks 2006, Krebs et al. 2007, Malo et al. 2011). However, the opposite was true in the behavior of Hector’s dolphin (Bejder et al. 1999) and the abundance of ghost crabs (Steiner and Leatherman 1981). Similar findings have been reported by other sources as well. A review and metaanalysis of the effects of recreation on ungulates indicated that people on foot incited larger antipredator responses than people in vehicles, on horseback, or on bicycles (Stankowich 2008). This might be explained by the appearance of a human on foot being more frequently associated with threatening activities such as hunting than are humans in vehicles. Note, however, that the geographic extent affected by motorized recreation might be larger than that affected by nonmotorized recreation because of the larger area that can be covered by vehicles (Harris et al. 2014, Larson et al. 2016), as well as the extent of associated noise (Barber et al. 2009, Keyel et al. 2018). Motorized vehicles can also cause other types of disturbance not considered by Larson et al. (2016), such as soil loss and vegetation disturbance (van Vierssen Trip and Wiersma 2015).

Further detail on the number of articles reviewed by Larson et al. (2016) on each recreational activity category, as well as the proportion of effects on wildlife classified as negative, positive, and unclear, are summarized in figure 2.2.

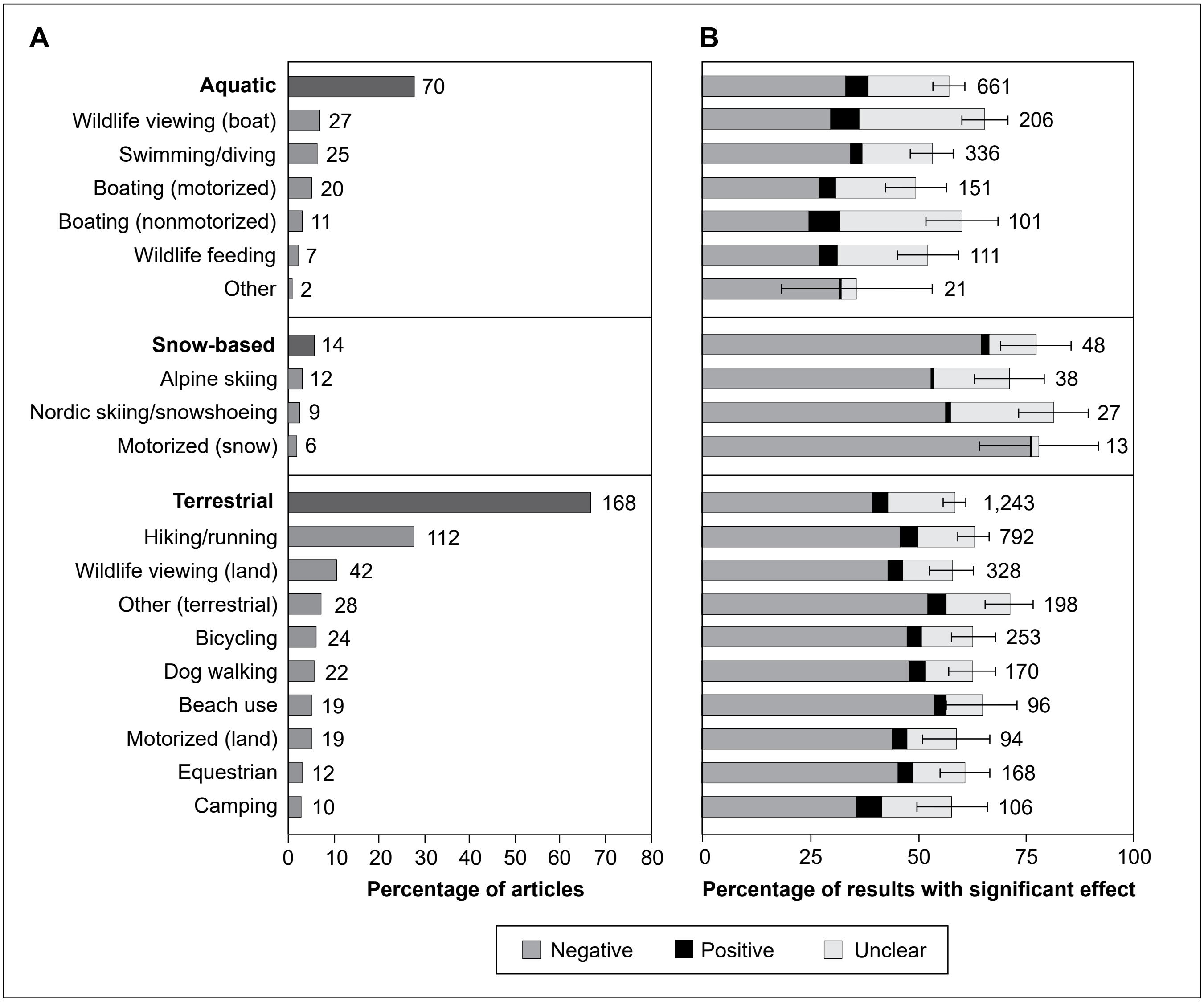

Figure 2.2—Response of wildlife to recreation activities, from the articles reviewed by Larson et al. (2016). (A) percentage of articles that included each recreational activity (numbers of articles follow the bars); (B) percentage of results in which a statistically significant effect of recreation on an animal species was observed (number of results follow the bars). Total percentages considered negative, positive, and unclear effects of recreation are shown. Error bars show standard error for the sum of all effects. Source: Larson et al. 2016.

Differential Coverage of Taxonomic Groups

Research on mammals and birds makes up nearly 80 percent of the literature on the impacts of recreation.

Most literature reviewed by Larson et al. (2016) was on mammals (42 percent of articles) and birds (37 percent), followed by invertebrates (12 percent), reptiles, (6 percent), fish (5 percent), and amphibians (<1 percent). Most studies on fish are not included in this report, because we did not include marine ecosystems aside from beach and dune ecosystems. Research on mammals focused on ungulates (29 percent of articles) and carnivores (26 percent), and research on birds focused on passerines (25 percent), wading birds and gulls (24 percent), and hawks, eagles, and vultures (10 percent).

The proportion of positive effects reported in studies was highest in mammals (5 ± 2 percent) and birds (4 ± 2 percent). Overall, positive effects were greatest in ducks and swans (10 ± 23 percent) and songbirds (7 ± 8 percent). Among songbird families, corvids (e.g., crows and jays) had the most positive effects (56 ± 5 percent). Among mammalian orders, rodents had the most documented positive effects (14 ± 12 percent). See the "Presenting the direction of effects" section in chapter 1 for an explanation of positive and negative effects.

The proportion of negative effects reported in studies was highest for amphibians (68 ± 20 percent of results), reptiles (56 ± 9 percent), and invertebrates (51 ± 5 percent). Within the invertebrate group, insects and crabs had proportionately high negative effects (51 percent ± 6 percent). Among bird orders, evidence for negative effects was greatest in eagles and hawks (48 ± 24 percent) and shorebirds (e.g., plovers, lapwings: 58 ± 19 percent). Among mammalian orders, Artiodactyla (e.g., moose, elk, deer, wild sheep) had the most negative effects (49 ± 8 percent).

Characterization of Recreation in National Forests

The Forest Service's National Visitor Use Monitoring (NVUM) survey collects information on the activities in which recreationists on national forests participate, and the amount of time they spend participating in each activity during a visit. Table 2.3 summarizes the data collected from 2012 through 2016 (USDA FS 2016). The NVUM survey also asks respondents to indicate the main reason for their visit and to identify all activities in which they participated. For the sake of simplicity, we include only the responses indicating an individual's primary reason to visit a national forest, referred to here as the "main activity." In this table, we also categorize other types of outdoor recreation that are not addressed by the NVUM survey but are discussed in this report. These types of recreation were identified by Forest Service wildlife managers in 2018 as a concern for wildlife and are addressed in the "Potential Effects of Emerging and Under-Researched" recreation sections in chapters 3, 4, and 5.

Table 2.3—Recreational activities, by category, as quantified by the National Visitor Use Monitoring (NVUM) Survey on U.S. national forests

Activity	Participation	Main activity	Average time in main activity
	- - - - - Percent	*- - - - -*	*Hours*
Summer nonmotorized:			
Hiking/walking	45.7	24.9	3.1
Viewing natural features	43.8	12.4	2.8
Relaxing, hanging out, escaping	31.7	4.7	11.9
Viewing wildlife	28.6	1.6	3.5
Picnicking	9.7	1.5	4.8
Developed camping	7.6	3.1	36.3
Nature study	5.7	0.3	4.2
Hunting	5.6	4.8	10.2
Visiting historical or prehistorical sites	5.5	0.4	3.1
Bicycling:	5.3	3.6	3.1
Fat-tire bikes	NA	NA	NA
Night bicycling	NA	NA	NA
Mountain bike technical trail features	NA	NA	NA
New trail blazing[a]	NA	NA	NA
Gathering forest products	3.3	0.9	5.4
Primitive camping	2.7	0.6	32.5
Backpacking	1.8	0.7	30.1
Horseback riding	1.0	0.7	5.7
Rock climbing	NA	NA	NA
Dog use (walking and off leash)	NA	NA	NA
Caving	NA	NA	NA
Geocaching	NA	NA	NA
Off-trail adventure races	NA	NA	NA
Slacklining	NA	NA	NA
Stargazing	NA	NA	NA
Sport tree climbing	NA	NA	NA
Paragliding	NA	NA	NA
Ziplining	NA	NA	NA
UAV/drone flying	NA	NA	NA
Total main activity		60.2	

Table 2.3—Recreational activities, by category, as quantified by the National Visitor Use Monitoring (NVUM) Survey on U.S. national forests (continued)

Activity	Participation	Main activity	Average time in main activity
	Percent	*Percent*	*Hours*
Summer motorized:			
Driving for pleasure	20.9	4.6	2.8
Motorized trail activity:	3.0	1.2	5.3
Off-highway vehicle use	3.0	1.4	5.8
E-bikes	NA	NA	NA
Motorcycles, dirt bikes	NA	NA	NA
Side-by-sides (two-seat all-terrain vehicles)	NA	NA	NA
Other motorized activity:	0.3	0.1	5.4
Unauthorized trail blazing [a]	NA	NA	NA
Total main activity		7.3	
Winter nonmotorized:			
Downhill skiing and snowboarding	16.0	15.4	4.7
Cross-country skiing and snowshoeing	2.8	2.2	3.0
Activities in developed areas	NA	NA	NA
Skijoring (nonmotorized)	NA	NA	NA
Snowbikes, fat-tire bikes	NA	NA	NA
Activities in undeveloped areas	NA	NA	NA
Split board skiing	NA	NA	NA
Kite skiing	NA	NA	NA
Skijoring	NA	NA	NA
Backcountry glade skiing	NA	NA	NA
Snowbikes, fat tire bikes	NA	NA	NA
Sledding	NA	NA	NA
Total main activity		17.6	
Winter motorized:			
Snowmobiling	1.6	1.4	5.0
Heli-skiing	NA	NA	NA
Skijoring (motorized)	NA	NA	NA
Total main activity		1.4	

Table 2.3—Recreational activities, by category, as quantified by the National Visitor Use Monitoring (NVUM) Survey on U.S. national forests (continued)

Activity	Participation	Main activity	Average time in main activity
	- - - - - *Percent*	- - - - -	*Hours*
Aquatic:			
Fishing	9.4	5.6	5.9
Nonmotorized water activities	2.8	1.4	5.6
Kayaking, canoeing, rafting, stand-up paddleboarding, packrafting	NA	NA	NA
Swimming	NA	NA	NA
Motorized water activities	2.3	0.8	7.6
Pleasure boating, water skiing			
General: launching watercraft	NA	NA	NA
Total main activity		7.8	
Other:			
Nature center activities	6.2	0.6	2.0
Resort use	1.5	0.2	39.5
Other nonmotorized (including swimming)	5.4	2.1	3.2
Other activity (not included above)	5.1	3.3	3.2
Total main activity		6.2	

This table indicates the percentage of respondents who participated in each activity during their national forest visits ("Participation" column), the percentage of respondents who reported each activity as the main reason for their visit ("Main activity"), and the average number of hours respondents spent participating in the main activity (Average time spent in main activity). These data represent responses during 2012 through 2016 (USDA FS 2016). For activities not explicitly included in the NVUM survey (shown in italic type), no data are available for the participation, main activity, and average time spent on the main activity, thus these are given as not applicable (NA).

[a] New trail blazing: Unauthorized trail blazing is a concern to public land managers for reasons of safety to recreationists, maintenance of recreational infrastructure, and impacts on natural resources. Further detail and examples are as follows:

- Nonmotorized summer: new unauthorized trails blazed by nonmotorized recreationists, including hikers, mountain bikers, rock climbers, and other types of summer nonmotorized recreation.
- Motorized summer: new unauthorized trails blazed by motorized recreationists, including ATVs, side-by-sides, jeeps, and other types of summer motorized recreation.

These data indicate that 60.2 percent of outdoor recreation in national forests falls under the category of nonmotorized summer activities. Nonmotorized winter activities are the second most popular category, accounting for 17.6 percent of main activities in national forests. Motorized recreation is less popular, with 7.3 percent in summer months and 1.4 percent in winter months. Aquatic recreation accounts for 7.8 percent of primary outdoor recreation activities in national forests (fig. 2.3). Nonmotorized recreation evidently makes up a larger proportion of recreational activities in both summer and winter seasons.

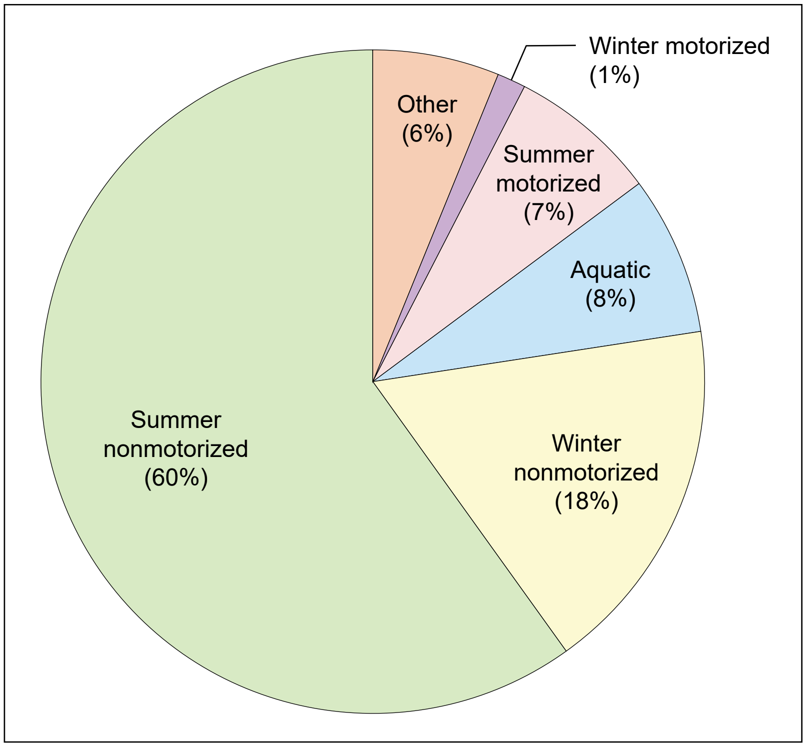

Figure 2.3—Percentage of each type of recreation, as addressed in this report, which respondents to the National Visitor Use Monitoring survey indicated as the main reason for their visit, referred to as the "main activity" throughout this report. Based on data from 2012–2016 (USDA FS 2016).

Overall participation in outdoor recreation on U.S. public lands is projected to grow with U.S. population growth (White et al. 2016). Participating in outdoor recreation contributes valuable benefits to both participants and nearby communities, and is an important way that people interact with the natural environment (White et al. 2016). In 2016, expenditures related to outdoor recreation made up 2.2 percent of the U.S. gross domestic product (USDC BEA 2018), with wildlife-oriented recreation accounting for nearly half of that contribution (USDI FWS and USDC CB 2016). Towns near popular recreational areas can benefit when visitors (particularly those traveling more than 80 km [50 mi] to reach the site) spend money on fuel, lodging, food, outfitters, and guides. White et al. (2016) summarized the projected increase in participation and amount of money groups spend by type of recreational activity and trip type (fig. 2.4). Understanding these expected changes in participation as well as the benefits provided by different types of recreation can increase understanding of corresponding changes in impacts of recreation on wildlife as well as increases in social benefits. When managed well, wildlife-based tourism can benefit conservation by generating funds to support conservation goals, promoting environmental values, and fostering stewardship behaviors (Cooper et al. 2015, Macdonald et al. 2017, Miller et al. 2020a).

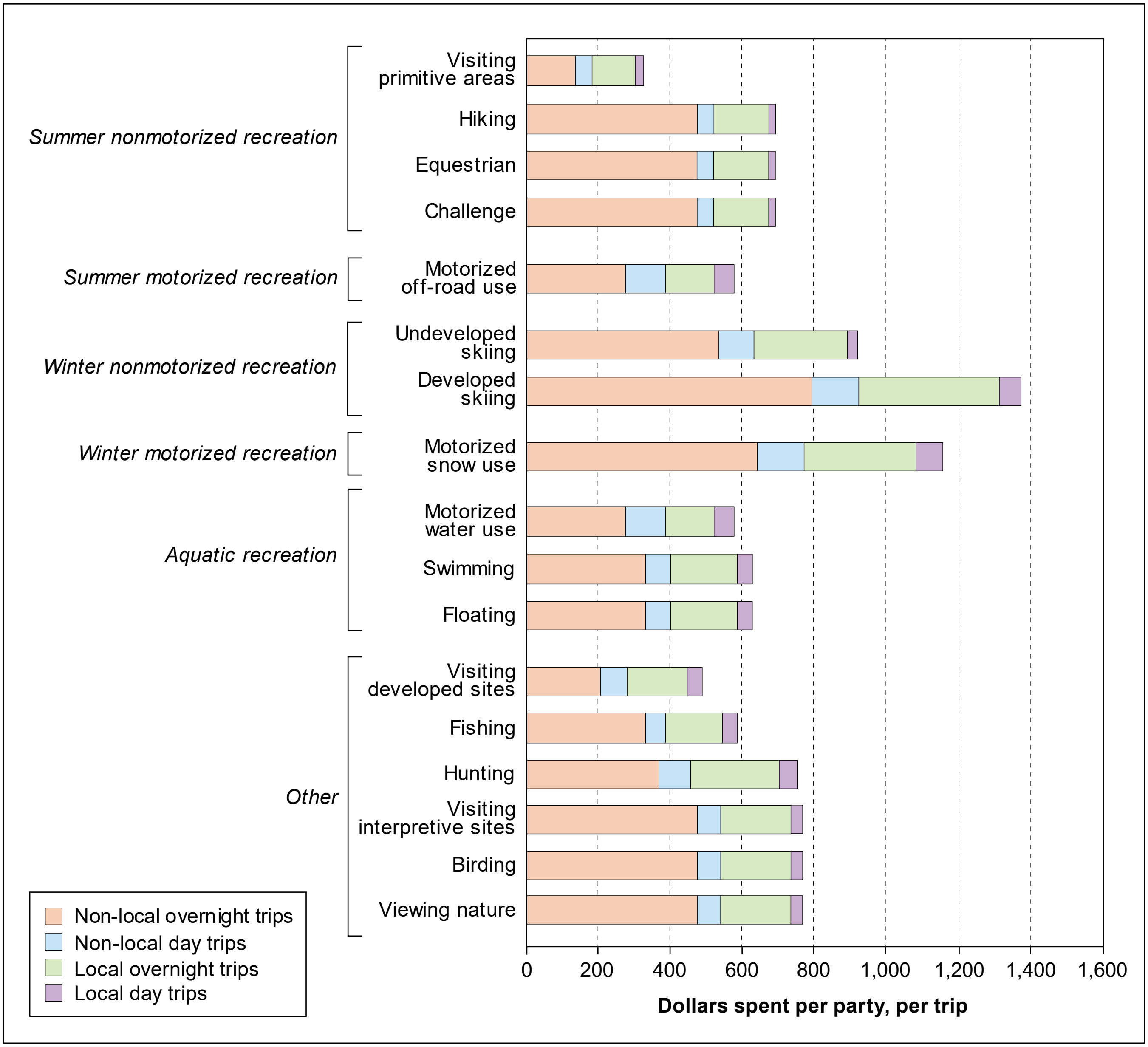

Figure 2.4—Average spending of parties on recreation trips to U.S. Forest Service lands for local and nonlocal day and overnight trips (see legend), and projected percentage increase in participant days. Dollar amounts shown are 2007 dollars. Source: White and Stynes 2010.

Factors Influencing Wildlife Response to Recreation

Although a large and growing body of literature explores and documents effects of recreation and related human disturbances on wildlife, these studies can go only so far in their applicability to specific situations faced by land managers. In this section, we provide information from the literature about several characteristics of (1) recreation, (2) wildlife, and (3) environmental factors that influence human-wildlife interactions in the recreation context. Because much of this section is informed by Hennings (2017) and Tablado and Jenni (2017), further detail can be found in these sources. Starting with information summarized in these studies, we add further information to match the diversity of recreational activities covered within this report. Where appropriate, we contrast the different types of recreation.

Recreation Factors

Many studies on the impacts of recreation on wildlife investigate the response of wildlife at different levels of recreation "intensity." This term often refers to a combination of frequency (e.g., people per day or week), duration, group size, noise produced, speed of approach, and sometimes directness of approach. Other factors related directly to the type of recreation include predictability, light pollution, and timing (daily and seasonal). Here we describe how these characteristics of recreational activity can affect wildlife.

Frequency and duration of recreational activity; number of recreationists—Results were mixed on the effects on wildlife of the frequency and duration of recreation. This mixture of responses echoes the range of behavioral responses to recreation (see chapter 1), suggesting, in the long term, that some species become habituated to frequently repeated recreation while others become sensitized to such activity. For ungulates, increasing displacement has been found with increasing numbers of nonmotorized winter recreationists, although using ecotourism principles decreased this effect (Cassirer et al. 1992, Duchesne et al. 2000, Lesmerises et al. 2018) (for further discussion, see pages 106–107). However, bison spatial distribution was not influenced by the frequency of human disturbance from nonmotorized winter recreationists (Fortin and Andruskiw 2003) (page 106). Wolverines were also found to respond more strongly to increasing frequency and duration of recreation (Heinemeyer et al. 2019) (page 122).

Mountain hares showed physiological and behavioral changes in areas with frequent nonmotorized winter recreation (Rehnus et al. 2014) (page 109). Bird densities have been found to be lower in areas with more frequent human visitation (Heil et al. 2006), and northern goshawk nesting behavior changed during periods of constant motorized activity (Dunk et al. 2010) (page 86). However, a study on corvids found that some species are positively associated with higher visitor numbers, while others had the opposite response (Walker and Marzluff 2015) (page 59). Bat behavior was not affected by tour group size in caves (Mann et al. 2002).

Speed of approach—

Faster and more direct approaches by recreationists tend to incite a larger response from animals that perceive humans as a potential threat (Stankowich and Blumstein 2005, Ydenberg and Dill 1986). An animal's ability to see a person approaching with sufficient time to flee influences its response to this potential threat, as documented for grassland birds (Fernández-Juricic et al. 2005). Faster approaches generally elicit a response at a farther flight initiation distance (FID) and cause longer flight distances (Boyle and Samson 1985, Buckley 2004, Burger 1981, Gander and Ingold 1997, Glover et al. 2011, Stankowich and Blumstein 2005, Stankowich and Coss 2006, Ydenberg and Dill 1986). Recreationists who approach wildlife quickly and quietly, such as joggers and mountain bikers, can be more disturbing to wildlife than hikers (e.g., Burger 1981, Gander and Ingold 1997, Naylor et al. 2009, Mayo et al. 2015, Wisdom et al. 2018). One exception to this pattern is found in the case of bald eagles in Idaho, which were least tolerant of walkers, followed by bicyclers and fishermen (Spahr 1990).

According to an extensive meta-analysis that included results from 61 studies on fear in animals, the perceived risk of nonmammalian species to danger increases by 60 percent when a predator increases its speed, and reptiles are more sensitive to fast approaches than any other taxonomic group (Cooper et al. 2003, Stankowich and Blumstein 2005). Deer have also been found to respond more strongly to faster approaches (Stankowich and Coss 2006).

However, recreationists who move especially slowly through the landscape, such as photographers and wildlife viewers who actively seek out and approach wildlife, may be particularly threatening to wildlife (Boyle and Samson 1985, Cline et al. 2007, Klein 1993). These individuals typically stay in the area longer than other visitors.

Directness of approach—

Animals generally respond at greater distances from direct approaches, as measured by the alert distance and FID (Barja et al. 2007, Smith-Castro 2008, Stankowich and Blumstein 2005, Stankowich and Coss 2006). One exception to this pattern was documented in grassland birds in Argentina where four out of five species were alert to tangential approaches at greater distances than to direct approaches (Fernández-Juricic et al. 2005). Grassland birds may have a different antipredator response than forest birds, preferring to hide rather than flush when approached directly (Hennings 2016). This is supported by a study in Colorado, which found that grassland birds responded most strongly to dogs, with or without a human present (Miller et al. 2001).

Predictability—

Animals typically respond more strongly to recreational activities that are less predictable in location or time. This has been found for birds (Miller et al. 2001, Stalmaster and Kaiser 1998, Thomas et al. 2003), and ungulates (Brown et al. 2012, Cassirer et al. 1992, Ciuti et al. 2012, Freddy et al. 1986, Harris et al. 2014, Neumann et al. 2011, Papouchis et al. 2001, Taylor and Knight 2003). Even unmanned aerial vehicles (UAVs) with predictable flight paths have evoked less flight response in wildlife species compared with UAVs that move unpredictably (Mulero-Pazmany et al. 2017). Examples of animals having heightened response to less predictable recreation span summer, winter, and aquatic recreation, and involve both nonmotorized and motorized types of recreation. When recreation is predictable, animals are more likely to habituate (Cassirer et al. 1992, Dorrance et al. 1975, Epsmark and Langvatn 1985, Schultz and Bailey 1978).

Daily timing—

The timing of recreation is an important factor in how it affects wildlife. Some animals alter the timing of their daily activities, such as movement and foraging, to reduce interactions with recreationists. This is well documented in mammals (Schultz and Bailey 1978), including coyotes, gray foxes, mule deer (Nix et al. 2018, Reilly et al. 2017), black bear, deer, elk, wolves (Barrueto et al. 2014, Rogala 2011, Spitz et al. 2019), and wild sheep (Marchand et al. 2014). Altered daily activity patterns are more sparsely documented for birds, which are generally more diurnal and difficult to observe at night (Hennings 2017). However, shorebirds in Florida (Burger and Gochfeld 1991a), waterfowl under heavy hunting pressure (Bélanger and Bédard 1995, McNeil et al. 1992), and pelicans in India (Gokula 2011) were found to forage more at night in response to human disturbance. Bald eagles also altered their feeding behaviors when disturbed by boat passes in the early morning (Stalmaster and Kaiser 1998) (page 136). It is unknown if shifting activity such as foraging and movement to the night to avoid interactions with humans affects the fitness of these wildlife species (Hennings 2017).

Noise pollution—

Recreational activities produce a range of sounds, varying by decibel level, consistency, and how often the sound is created. Noise can travel for miles, especially in open and flat landscapes (Keyel et al. 2018). A review of the cost of chronic noise exposure for terrestrial organisms highlighted the point that increased noise levels, including those from transportation networks and motorized recreation, reduce the distance and area over which acoustic signals can be perceived by animals (Barber et al. 2009). Some sounds produced by recreational activities are not detectable by wildlife (e.g., Grubb et al. 2010), and it is important to consider a species' range of detection when evaluating if they will be affected by a given sound (Francis et al. 2017). However, there are examples of marine species that are affected by sounds outside of their range (Shannon et al. 2016).

Animals have been documented to respond to sound volumes as low as 40 dB (comparable to a bird call, babbling brook, or the sound within a library) (Shannon et al. 2016), and louder sounds often elicit a stronger response in noise-sensitive species (Hennings 2017). A recent review indicated significant effects of recreation-related noises on wildlife physiology, movement, and vocal behavior. However, this topic has not been widely studied compared to other noise-producing activities (e.g., transportation, industrial, and military sources) (Shannon et al. 2016). Sounds ranging from those produced by off-highway vehicles (Brattstrom and Bondello 1983) to human conversations (Karp and Root 2009) have been shown to directly and negatively affect species' behavior. Noises can cause individuals to flush, resulting in energetically costly displacements. Noise can also alter breeding behavior, disrupt migration routes, mask communication, and reduce habitat (Barber et al. 2009, Ouren et al. 2007, Reed et al. 2012, Shannon et al. 2016).

Studies on the effects of noise to wildlife generally focus on birds (Shannon et al. 2016), with examples including change in song pitch (Ortega 2012), impaired antipredator responses (Petrelli et al. 2017), altered feeding behavior (Burger and Gochfeld 1998), and increased stress levels and altered breeding behavior (Blickley et al. 2012a, 2012b) (see page 85). Insectivorous and ground-foraging birds are particularly sensitive to noise (Francis 2015, Karp and Guevara 2011, Petrelli et al. 2017). For mammals, negative responses to noise have been documented for bats (Mann et al. 2002) (see "Caving" on page 70); manatees (Shannon et al. 2016); and wolverines (Switalski 2016) (page 119). However, some animals can habituate to loud noises, such as waterbirds; shorebirds (Hockin et al. 1992); red-tailed hawks (Anderson et al. 1989) (page 91); and elk (Brown et al. 2012) (page 87).

Light pollution—

Night-time recreation typically involves some form of artificial lighting, such as lighting installed along trails, headlights of motorized vehicles, and flashlights or headlamps carried by recreationists. Nocturnal species are most likely to show effects from ecological light pollution. In particular, bats have altered their foraging, movement, emergence, roosting, and hibernation in response to artificial light (Boldogh et al. 2007, Hudzik 2015, Laidlaw and Fenton 1971, Longcore and Rich 2004, Stone et al. 2015).

Artificial light can affect wildlife behavior (Beier 2006), interfering with species' sensory perceptions and changing the ways in which they interact with their environment. Laboratory studies have shown that artificial light can alter species' perceptions of time cues, shift circadian rhythms (Longcore and Rich 2004, Miller 2006), reduce fitness through immunosuppression, and alter reproductive physiology (Swaddle et al. 2015). Artificial light can disorient animals (Swaddle et al. 2015) and affect animal physiology (Navara and Nelson 2007), reproduction in moths (van Geffen et al. 2015), foraging by shorebirds (Dwyer et al. 2013), movement of bats

(Stone et al. 2009), communication by songbirds (Kempenaers et al. 2010), and the community ecology of invertebrates (Davies et al. 2012).

Artificial light attracts some species, e.g., orb-weaving spiders (Heiling 1999); bats (Bruce-White and Shardlow 2011, Rydell and Racey 1993); and some diurnal birds (Lebbin et al. 2007, Santos et al. 2010), while others avoid artificial light, e.g., mice (Bird et al. 2004, Bliss-Ketchum et al. 2016); Columbian black-tailed deer, and Virginia opossum (Bliss-Ketchum et al. 2016). Artificial lights can interfere with songbird migration and cause wildlife mortality, though these effects may be more associated with wind turbines and power lines than recreation infrastructure (Longcore and Rich 2004; Longcore et al. 2008; Manville 2005, 2008). In some cases, responses to light have been found to be heritable, such as for nocturnal orb-web spiders that prefer artificially lit areas (Heiling 1999). Evolutionary implications of light pollution are not widely studied (Swaddle et al. 2015), but results suggesting disrupted circadian and seasonal behaviors point to potential decreases in individual fitness and ecosystem modification (Russart and Nelson 2018).

Wildlife Factors

Hunted vs. nonhunted populations—

Game species such as elk are generally more tolerant of human presence and activities on nonhunted lands than on hunted lands (Proffitt et al. 2012). This is seen in a meta-analysis on ungulates (Stankowich 2008) as well as a case study on a sheep species in France (Marchand et al. 2014).

Size of individuals—

In general, larger animals seem to be more sensitive to disturbance from recreation than smaller animals (Cooke 1980, Stankowich and Blumstein 2005). This trend has been documented for birds (Fernández-Juricic et al. 2004, Møller 2008, Stankowich and Blumstein 2005) and carnivores (Crooks 2002, Prugh et al. 2009), with larger species tending to have higher alert and FIDs and sometimes more avoidance behavior. One explanation may be that larger animals are more visible to predators (as is also the case with animals in open areas), and thus larger animals perceive more risk from potential threats than less visible animals (Blumstein 2006, Blumstein et al. 2005). Larger animals can also see predators from farther away than smaller animals, such as in the case of birds (Blumstein et al. 2005). However, there is species-specific variation to this trend, with exceptions found in bison (Taylor and Knight 2003) and birds in India (Burger and Gochfeld 1991b).

David King

A gray jay approaches a hiking party on the White Mountain National Forest in New Hampshire. This high-elevation specialist delights visitors to the high country, although the practice of feeding them should be discouraged..

Group size—

Larger groups of terrestrial animals tend to be more sensitive to human disturbance than smaller groups (Brown et al. 2012, Ciuti et al. 2012, Czech 1991, Fairbanks and Tullous 2002, Glover et al. 2011, Knight and Cole 1995a, Stankowich and Blumstein 2005, Taylor and Knight 2003), as observed through larger FIDs in larger herds. Two factors can explain this trend:

- Larger herds may have individuals acting as lookouts while the rest of the herd forages. When the “lookout” individuals sound an alarm, the entire group will likely respond (Blanc et al. 2006, Ciuti et al. 2012).
- Larger groups are more visible than smaller groups and individuals. In some cases, more visible groups of animals are more wary of disturbances (Blumstein 2006, Blumstein et al. 2005, Glover et al. 2011).

However, the opposite effect has also been found. This can be explained by the idea that animals in larger groups may perceive a reduced predation risk compared with smaller groups, i.e., they find "safety in numbers" (Knight and Cole 1995a, 1995b; Ydenberg and Dill 1986).

Reproductive status and sex—

The reproductive status of individuals, and the related composition of groups of animals, can affect the response to human disturbances such as recreation. Groups with females, especially pregnant females, and young have been found to be more sensitive to human disturbance. This has been documented repeatedly for ungulates (Fortin and Andruskiw 2003, Nellemann et al. 2000, Neumann et al. 2011) (pages 106–107); carnivores (Riley et al. 2003) (box 8); and birds (Dunk et al. 2010) (page 92). Examples of lasting effects from these studies include habitat loss (Fortin and Andruiskiw 2003, Nellemann et al. 2000, Neumann et al. 2011, Riley et al. 2003), reduced productivity and long-term populations impacts (Nellemann et al. 2000), and reduced breeding success (Dunk et al. 2010).

In Saskatchewan, Canada, global positioning system- (GPS)-collared bison were found to have larger areas of daily movement as human disturbance from recreation increased in both snow-free and winter seasons. Areas of daily movement of herds containing young bison were also larger year-round (Fortin and Andruskiw 2003). Female reindeer and their calves showed the most substantial decrease in their use of the 10 km zone surrounding a high-altitude resort in Norway, with maternal reindeer avoiding the zone entirely. This avoidance may lead to reduced forage intake during winter, possibly reducing herd productivity, and eliciting long-term impacts on populations (Nellemann et al. 2000).

Animal fitness—Animals in good condition may be more tolerant of human disturbance than those in poor condition. This has been observed through longer FIDs from human approach for individuals with a good body condition (Stankowich and Blumstein 2005), which can be explained by considering that the decision to take flight is a cost/benefit decision, and fleeing is energetically costly. However, an antipredator strategy based on crypsis (i.e., avoiding being detected) can also be used by some animals with poor body condition. For example, in some cases lizards with intact tails (i.e., good body condition) flee from human approach at greater distances than those whose tails have not fully regenerated following loss to a predator. However, this effect is complicated by the observation that the presence of a tail facilitates flight. As lizards with shorter tails should have slower escape speeds, results indicating that lizards with short tails have a shorter flight initiation distance suggest a switch to a crypsis-based antipredator strategy (Stankowich and Blumstein 2005).

Environmental Factors

Habitat structure and availability—

Birds and ungulates tend to be less disturbed by human activity in situations where predators are less likely to see them, such as in habitats with tall or complex vegetation structure (Stankowich 2008).

Birds that nest or forage on the ground and in shrubs are generally more sensitive to human disturbance than those that nest, perch, or forage in the canopy or in cavities (Alwis et al. 2016, Blakesley and Reese 1988, Fernández-Juricic et al. 2001, Kangas et al. 2010). Studies have indicated that nest success depends partially on vegetation cover and nest concealment (Westmoreland and Best 1985). For ground-dwelling birds, the variables most related to response include the number of recreationists, area of tourism infrastructure, and habitat characteristics. Vegetative cover can reduce birds' antipredator response. Birds perched higher in trees tend to wait longer to flush (Battle et al. 2016, Fernández-Juricic et al. 2001, McGarigal et al. 1991, Smith-Castro 2008).

Ungulates also respond less strongly to human disturbance when a refuge from threats is nearby. Deer and elk have longer FIDs in response to human activity when forest or shrub habitat is nearby, perhaps because they can move quickly to the safety of cover (Ciuti et al. 2012, Jayakody et al. 2008, Stankowich 2008, Stankowich and Blumstein 2005, Zhou et al. 2013). This effect has also been found in sheep (Frid and Dill 2002) (page 91).

Habitat alteration such as clearing areas for ski slopes or campgrounds can affect which species remain in these areas, such as small mammals (Negro et al. 2009, Rolando et al. 2013) (pages 105 and 109).

Sounds travel farther in open areas than in areas with dense vegetative structure. Denser vegetation may reduce the effect of recreation, especially those forms of recreation that produce loud sounds, on species sensitive to these noises (Keyel et al. 2018).

Season—

Because seasonal behaviors vary by species, the information provided here requires biological knowledge of local species of concern. As described above, the reproductive status of individuals influences the response of individuals and groups to recreational activity. Birds may be especially vulnerable to human disturbance during the nesting season (Fernández-Juricic et al. 2009, Keeley and Bechard 2011). Additionally, responses are often muted in winter, likely owing to the higher cost of energy to respond during cold months with limited food resources (e.g., Lafferty 2001a, Thiel et al. 2008).

C. Adams, National Park Service

Wildlife photographers keep what they hope is a safe distance from a moose in Grand Teton National Park, Wyoming.

Chapter 3: Summer Recreation

Nonmotorized Summer Recreation

Nonmotorized summer recreation is the most popular category of outdoor recreational activity in U.S. national forests. It accounts for 60 percent of the main activities pursued by national forest visitors and includes the widest variety of activities (table 2.3) (USDA FS 2016). The most popular activities are hiking/walking, viewing natural features, viewing wildlife, and relaxing. Less popular activities include picnicking, developed camping, nature study, visiting historical or prehistorical sites, gathering forest products, bicycling, primitive camping, backpacking, and horseback riding (table 2.3). Further activities that fall within this category but are not recorded in the Forest Service's National Visitor Use Monitoring survey include rock climbing, dog walking, caving, riding fat-tire bikes, using mountain bike technical trail features (e.g., jumps and bridges), night biking, trail running and ultra-running, geocaching, participating in off-route adventure races, slacklining, stargazing, sport tree climbing, paragliding, ziplining, and use of unmanned aerial vehicles (UAVs).

Participation in nonmotorized summer recreation activities is increasing, and economic contributions to local communities are relatively high when recreationists come for overnight visits (fig. 2.4) (White and Stynes 2010). Viewing nature and hiking are the fastest growing nonmotorized summer activities, followed by camping and mountain biking. High participation and projected increases in participation in nonmotorized summer activities, combined with a moderate amount of money spent per party per trip, means that these activities contribute substantially toward the economic benefits generated by national forests (see fig. 2.4 for comparison of economic contributions and projected increase in participation with other recreational activity categories) (White and Stynes 2010).

In many regions, climate change is expected to lengthen the season for summer recreation, as snow melts earlier and starts to accumulate later in the year (Hand et al. 2018). A recent study found trail-based horseback riding to be the nonmotorized summer recreational activity most affected by climate change. Equestrian participation rates and number of riders are expected to increase, although an individual rider will recreate on fewer days per year (Askew and Bowker 2018). Other activities within this category (nature viewing and visiting interpretive sites) are expected to be largely unaffected by climate change (Askew and Bowker 2018). However, it will be important to consider potential changes in human-wildlife interactions on public lands, especially with the lengthening snow-free season, as climate change alters wildlife distributions and activities (Miller et al., n.d.).

Nonmotorized summer recreationists can gain a wide range of benefits from their activities, including physical and mental health and well-being, social


David King

A cyclist rides across a meadow on conservation lands in central Massachusetts. These lands provide recreation and solace for urban dwellers and also support forest-dependent wildlife in the interstices of the urban landscape.

Recreationists participating in nonmotorized summer activities sometimes volunteer as stewards for public lands.

connections, and connection to nature. Wildlife-based recreation can specifically benefit participants' psychological health and spiritual fulfillment (Curtin 2009), and provide opportunities to obtain food (Gigliotti 2000), spend time outdoors, see animals, perfect skills, and build relationships and memories (Cooke et al. 2018, Decker and Connelly 1989, Duda et al. 1995, Larson et al. 2014). Recreationists participating in activities within this category sometimes volunteer as stewards for public lands. Groups often form around a recreational activity (e.g., mountain biking, hiking, climbing, hunting); land management unit (e.g., forest, park, grassland); or specific recreational infrastructure (e.g., trail).

Nonmotorized summer recreation activities are wide ranging in terms of speed, noise, means of transportation, predictability, group size, frequency, and infrastructure required. Infrastructure can range from no infrastructure for dispersed recreation to paved trails and campgrounds with running water, mini-markets, and other amenities. In many cases, recreation that does not take place on a trail, such as rock climbing, requires access trails and can result in proliferation of unofficial trails when adequate trails are not available.

General Impacts of Nonmotorized Summer Recreation on Wildlife

These impacts are particularly difficult to summarize owing to the high diversity of recreational activities that take place in a diverse set of environments, resulting in effects on a diverse suite of animals. Primary concerns include the effect of infrastructure and the intensity of recreational use (see "Factors Influencing Wildlife Response to Recreation" in chapter 2).

Habitat effects and infrastructure—

Infrastructure built for nonmotorized summer recreation can both concentrate recreational activity within a developed area and provide entry to otherwise inaccessible areas (Leung and Marion 1999). Building new trails and campgrounds according to sustainability guidelines (e.g., International Mountain Biking Association guidelines) (IMBA 2004) can substantially reduce negative impacts on wildlife habitat and populations. A few key techniques in sustainable trail design include minimizing the extent to which water will erode the trail by avoiding fall lines and incorporating water drainage features when necessary. Traversing hillsides instead of open, flat areas can be effective in preventing erosion while also reducing user-created trail proliferation and trail widening, as "side-hill" trails (i.e., those

Box 4

The most substantial impacts of nonmotorized summer recreation to wildlife habitat fall into two categories:

Concentrated use (e.g., trails and campgrounds):

- Introduction of invasive species along trail corridors.
- Alteration of the vegetative structure along trail corridors, most pertinent to insects and insectivorous birds.
- Disturbance and change in vegetative structure and connectivity for species that carry out important activities, such as nesting and feeding at or near the ground level.
- Habitat reduction, as a result of clearing areas for trails and campgrounds.
- Amphibian mortalities on paved trails.
- Proliferation of informal trails.

Dispersed use:

- Reduced leaf litter from trampling
- Habitat alteration, depending on the extent and intensity (i.e., frequency of visitation) of dispersed activity.

Incorporating features of the landscape that recreationists want to visit might help reduce the proliferation of user-created trails.

that follow the contour of surrounding topography) are naturally contained by their topography (Marion and Leung 2004, Walden-Schreiner and Leung 2013). Additionally, incorporating features of the landscape that recreationists want to visit, such as waterfalls or viewpoints, might help reduce the proliferation of user-created trails (Hockett et al. 2010). Avoiding habitat for particularly sensitive wildlife may also be a priority in some places (Marion and Leung 2004), and avoiding constructing new trails during seasons when wildlife is particularly sensitive to disturbance might decrease negative effects to wildlife (Miller et al. 2020b).

Although it concentrates visitor activity within specified locations, the creation of new infrastructure such as campgrounds and trails can have consequences for wildlife species. Recreational trails are not known to contribute to habitat fragmentation for most wildlife species, especially trails that are unpaved and relatively narrow. However, recreational activity and infrastructure can effectively fragment habitat for some species. For example, animals that are less able to cross trails can experience habitat fragmentation. Amphibian mortalities have been widely observed at road crossings and on paved multi-use trails (Hennings 2017). Underpasses and overpasses have been successful at reducing such mortalities (Schmidt and Zumbach 2008, Woltz et al. 2008). Additionally, when highly disruptive activities occurring along a trail create an avoided corridor, species sensitive to these activities can experience habitat fragmentation. Nonmotorized summer recreational activities with a relatively high disturbance factor include those that involve loud conversations, high frequency of use, unpredictable patterns of movement, quickly moving traffic, or a combination of these factors.

The proliferation of informal trails is a particularly important concern in nonmotorized summer recreation. These trails are not formally built and maintained by land management agencies or partners but are created by visitors for various reasons. Where access trails are required for recreational activities that are dispersed by nature, such as rock climbing, gathering forest products, or primitive camping, users may forge informal trails to reach desired locations. Mountain bikers sometimes create informal trails to add to their existing trail options or to create new trail technical features (Ballantyne et al. 2014, Pickering et al. 2010). Hikers also create informal trails in places where trails require maintenance or are impassable, where a high volume of traffic or wet conditions lead to trail widening, and where existing trails do not provide access to a desired feature (Hockett et al. 2017, Leung and Marion 1996, Wimpey and Marion 2011). The construction of new trails can lead to alterations in habitat use by some mammals (Miller et al. 2020b). As with trails, campgrounds can confine recreational use to a specified area and thus limit impacts to a smaller footprint than dispersed camping (Leung and Marion 1999), but the clearing required to create a campground can alter vegetative structure and lead to habitat loss.

Dispersed use can change the resources provided for some sensitive species.

Because it is not limited to designated areas, dispersed use can alter habitat across wider spaces than activity in designated areas. Dispersed use can change the resources provided for some sensitive species, with trampling leading to altered vegetative structure, reduced leaf litter, and increased soil erosion (Liddle 1997). The extent of these effects depends on the intensity and season of dispersed activity. Although it is widely accepted that leaf litter and vegetation can be altered by a low level of use, the direct impacts of dispersed recreation on wildlife are not as well understood (Monz et al. 2013).

Effects on individuals and populations—

It is difficult to generalize about nonmotorized summer recreation, as so much variation exists within this category. However, several patterns emerge. In general, animals respond more strongly to recreationists when they approach on foot (compared to on horseback or in a motorized vehicle) (e.g., Harris 2014, Stankowich 2008), and when they move quickly (e.g., Stankowich and Blumstein 2005), create loud noises (e.g., Barber et al. 2009, Keyel et al. 2018), have less predictable movement (e.g., Harris et al. 2014, Miller et al. 2001), or spend longer amounts of time in the area (Hennings 2017). One hypothesis regarding the somewhat counterintuitive but comparatively strong response to an approach on foot is that a person on foot may resemble a predator more than a person on horseback or in a vehicle. Last, the presence of dogs has been found to elicit very strong responses from many species (Hennings 2016).

Dispersed recreation is generally less predictable than recreation that occurs in areas with developed infrastructure. Because less predictable disturbance typically affects wildlife more, dispersed recreation can have a greater per-person impact than recreation at developed sites. However, it is important to consider the relative sensitivity of species of concern to unpredictable activities vs. high frequency or large groups of recreationists in one place (more typical of developed sites). Dispersed recreation activities include off-trail hiking activities such as geocaching,

Box 5

Comparing effects of nonmotorized recreation by different attributes of recreational activity on wildlife, the following qualities are associated with larger disturbance:

- Approach on foot
- Faster speed of approach
- Loud noise
- Less predictable activities
- Long duration

some forest product gathering, primitive camping, hunting, accessing rock climbing areas, off-trail adventure races, leaving the trail for other reasons (often for nature study or to access an off-trail viewpoint) or creating new unauthorized trails. Photographers and birdwatchers, as well as groups with small children, are among the recreationists with the largest impacts on wildlife, as these groups spend a long time in one area, often venturing off trail, and can have less predictable behaviors (see Hennings 2017).

Nonmotorized summer recreation occurs not only during the summer but also during spring and fall shoulder seasons, when weather permits. The lengthening of shoulder seasons by climate change will likely increase the level of nonmotorized summer activity, extending the number of days per year in which these activities take place. Some areas are finding that trails are cleared of snow earlier in the spring, sometimes even before trail crews have had a chance to carry out annual maintenance activities. This can have compounding effects on wildlife, especially for populations that are experiencing altered annual patterns as a result of climate change (e.g., Lamborn and Smith 2019, Scott et al. 2007, Tratalos et al. 2005).

Tony Webster

A sign warns visitor to avoid contact with bears on the Kootenai National Forest in Montana.

Impacts on Habitat, Individuals, and Populations by Taxonomic Group

Invertebrates

There are few studies on the impacts of nonmotorized summer recreation on invertebrates. However, invertebrates are the taxonomic group with the third most documented negative effects from recreation overall, with just over half of effects reviewed considered negative (Larson et al. 2016). These findings suggest that insects are mostly affected by recreation through associated changes in vegetative structure and plant species.

Impacts on habitat—

Invertebrates including butterflies, ground beetles, and spiders can be affected by changes in vegetative structure (Blair and Launer 1997, Hagar et al. 2004, Halinouski and Krytskaya 2014, Ulrich et al. 2010). Some of these changes are associated with creating new infrastructure for recreation such as the amount of land covered by paths, campsites, campfires (Ulrich et al. 2010) and forest thinning (Hagar et al. 2004). However, when compared to urbanized areas, relatively natural recreational areas have been associated with higher species richness, diversity, and abundance of butterflies (Blair and Launer 1997) and higher abundance and species richness of carabid beetles (Halinouski and Krytskaya 2014). Another study found that butterfly species richness and diversity were somewhat lower in recreational areas as compared with biological reserves where recreation was prohibited (Blair and Launer 1997). In a study in Russia, increasing levels of recreation were associated with potential community disassembly for spiders (Ulrich et al. 2010). Reduction of habitat for insects can have cascading effects as these are foundational elements of the food web in many ecosystems.

Impacts on individuals, populations, and communities—

In forests, quick movement from mountain bikes was associated with increased rates of flushing by the endangered Ohlone tiger beetle known to mate and forage along trails in California, which may disrupt foraging and mating, thus affecting fitness and reproductive success (Cornelisse and Duane 2013).

Although occasional stream crossings by recreationists may not cause widespread and lasting impacts, long-term negative effects have been found for in-stream invertebrate communities, indicating lower water quality. This has been found for hiking, mountain biking, and horseback riding trails in southwestern Virginia (Kidd et al. 2014), Yosemite National Park in California (Holmquist et al. 2015), and Zion National Park in Utah (Caires et al. 2010). Long-term effects were detected in Yosemite but not in Zion, suggesting that the higher densities of crossings in Yosemite may cause lasting negative impacts on aquatic invertebrates and water quality, and that some aquatic systems are resilient to more dispersed recreational disturbance.

Walking along beaches can affect invertebrate populations. On an intertidal zone in eastern Australia, trampling caused 5 to 55 percent reduction in invertebrate abundance and richness along the portion of the beach where most tourist activity was concentrated (Schlacher and Thompson 2012). On heavily used beaches, this could have implications for shorebirds, some of which feed on invertebrates found on beaches. Soil compaction from trail use likely alters below-ground invertebrate communities, although no studies were found on this topic (Hennings 2017).

Box 6

Summary of Impacts of Nonmotorized Summer Recreation on Amphibian Habitats

- Amphibians require both aquatic and terrestrial habitats, and most impacts of recreation result from impacts on habitat.
- Habitat can be negatively affected by recreational structures (e.g., trails and access roads).
- The same recreational structures can provide opportunities to create new microhabitat features (e.g., adding rock piles and logs to trail borders).
- Underpasses or other crossing structures can improve connectivity between habitat patches.

Amphibians

There are few studies on the impacts of nonmotorized summer recreation on amphibians. However, amphibians are the taxonomic group with the most documented negative effects from recreation overall, with more than two-thirds of reported effects reviewed considered negative (Larson et al. 2016).

Impacts on habitat—

Amphibians require connectivity between aquatic breeding sites and adjacent terrestrial foraging habitats.

Amphibians require connectivity between aquatic breeding sites and adjacent terrestrial foraging habitats (Semlitsch 2002) and are susceptible to fragmentation and habitat degradation from recreational structures, such as trails and access roads (Goff 2015, Semlitsch et al. 2007), as well as paved roads that provide access to recreational areas (Hels and Buchwald 2001). A study in the southern Appalachians found that salamander abundance along relatively narrow, low-use forest roads, as well as abandoned logging roads, was significantly lower than in adjacent upslope sites, with the effect extending up to 35 m on either side of the roads (Semlitsch et al. 2007). However, the creation of recreational trails has been found to result in microhabitat for salamanders, when cleared trees are placed alongside of trails. Adding rock piles and logs to trail borders can offset negative effects of recreational infrastructure such as trails on amphibians, by creating new microhabitat where existing habitat was removed or disturbed (Davis 2007, Fleming et al. 2011).

Adding rock piles and logs to trail borders can offset negative effects of recreational infrastructure such as trails on amphibians.

Building crossing structures such as underpasses accompanied by fences to guide amphibians beneath trails and roadways can reduce mortality along trails (Hennings 2017) and roads, and improve connectivity within and between habitat patches (Schmidt and Zumbach 2008, Woltz et al. 2008). Hardened surfaces associated with developed recreation, such as roads, can degrade amphibian habitat. In a study of five native pond-dwelling amphibian species in Oregon, all were negatively associated with the percentage of impervious surface within 200 m of breeding areas (Guderyahn et al. 2016). For example, northwestern salamanders occurrence was reduced to nearly zero in ponds with more than 25 percent built surface within 200 m (Guderyahn et al. 2016). Percentage thresholds for forest cover needed to support amphibian populations have also been found: 30 percent cover within 100 m of breeding ponds for spotted salamanders and 88 percent for wood frogs (Homan et al. 2004). Both research groups found that the relationship between amphibian population size and percentage of forest cover within 1000 m of breeding ponds varied by species, with spotted salamander populations requiring an even higher percentage of forest cover within 1000 m (Homan et al. 2004), while wood frog and Pacific chorus frog populations increased with decreasing forest cover within 1000 m (Guderyahn et al. 2016, Homan et al. 2004). This discrepancy might be explained by species disproportionately using patches near their breeding sites, and being unable to disperse among habitat patches in fragmented landscapes. Maintaining adequate resources provided by natural habitat is important in amphibian conservation.

Impacts on individuals, populations, and communities—

Most of the impacts of recreation on amphibians are related to these species' habitats, as summarized in "Impacts on habitat" above. Responses specific to nonmotorized summer recreation indicate that frogs are vulnerable to such human disturbance. In an experimental study in Spain, frogs using streambanks took longer to recover to predisturbance activities with increasing levels of simulated human disturbance in the form of walking (Rodríguez-Prieto and Fernández-Juricic 2005). These researchers concluded that such a disturbance would affect the species at the population level. Results also suggested that frogs may be less tolerant of humans in areas with a relatively open habitat structure. To reduce the local disturbance to this species, these authors recommended setting up buffer areas of more than 2.5 m from streams or reducing visitor rates to less than five visits per hour (Rodríguez-Prieto and Fernández-Juricic 2005).

Reptiles

There are relatively few studies on the impacts of nonmotorized summer recreation on reptiles. However, reptiles are the taxonomic group with the second most documented negative effects from recreation, with over half of effects reviewed considered negative (Larson et al. 2016).

Impacts on habitat—

Reptiles are often habitat specialists in terrestrial and sometimes aquatic environments. Reptile species that require connectivity between habitat patches, such as turtles that require connectivity between aquatic habitat and upland nesting sites, are susceptible to fragmentation from roads when these structures prevent their movement or cause mortalities (Roe and Georges 2007). Enhancing habitat by building underpasses for reptiles (Woltz et al. 2008) can offset negative impacts on habitat and improve connectivity within and between habitat patches. Clearings on south-facing slopes provide especially valuable habitat for reptiles (Pilliod and Wind 2008). Maintaining such areas is important for reptile populations and may entail restricting recreational activity in these spaces. Coarse woody debris, such as logs, is subject to collection for firewood use around camping areas, which could reduce cover for reptiles.

Impacts on individuals, populations, and communities—

Responses specific to nonmotorized summer recreation indicate that reptiles are vulnerable to such human disturbance. A review and meta-analysis on fear responses in wildlife found that reptiles are vulnerable to faster approaches, which induce an antipredator response (Stankowich and Blumstein 2005). Some reptiles tolerate closer human approach when their body temperature is warm (Rand 1964, Rocha and Bergalo 1990), while others tolerate closer approach when they are cool (Blamires 1999). These species-specific behavioral responses correspond with two different predator response strategies (Stankowich and Blumstein 2005), and exemplify the importance of habitat structure for predicting reptile responses to human recreational activity.

In Italy, two reptile species (western whip snake and wall lizard) were strongly negatively associated with the amount of human use (i.e., walking, jogging, and horseback riding along paths), and somewhat negatively associated with reductions in leaf litter caused by trampling. In this study, reptile species richness decline with increasing amount of human use (Ficetola et al. 2007). Two Spanish studies also documented effects of recreational activity on the wall lizard. In areas with higher levels of tourism (i.e., people walking on paths), wall lizards had reduced fitness (i.e., more ticks, poorer body condition, and dampened immune system), as compared to lizards in areas where very few tourists were observed (Amo et al. 2006). Another study reported evidence of habituation-like responses in sites with tourists compared with control sites, indicated by shorter flight initiation distances and flight distances (Diego-Rasilla 2003).

The documented effects of recreation on turtles is sparse and mixed. A 20-year study in Connecticut followed the effects of recreation on wood turtles, a species that lives in both aquatic and terrestrial forest and grassland ecosystems in the Eastern United States. Using a mark-recapture method before and after recreation was introduced, this study found that wood turtle populations declined in tandem with the number of recreational hiking and fishing permits issued. In this study, two separate turtle populations being tracked disappeared completely within 10 years of opening the site to recreational use. Although the exact causes were not identified, the authors speculated that recreationists may have collected wood turtles as pets, or that turtles experienced increased predation from crows, raccoons, or other species attracted by garbage and dead fish left behind by hikers and anglers (Garber and Burger 1995). In an urban area of northern California, the western pond turtle flushed underwater in response to runners (2 percent of turtles flushed), walkers (5 percent), bicyclists (6 percent), and vehicles (45 percent) (Nyhof and Trulio 2015). However, another study in Illinois found no effect by recreation—measured by the number of recreational vehicles—on painted turtle habitat selection or decisions to emerge from the water and nest (Bowen and Janzen 2008). The inconsistency between these and many other findings highlights the importance of species-specific and population-specific studies.

The inconsistency between findings of research studies highlights the importance of species-, population-, and case-specific studies.

Some snake responses to human recreation are species specific while others may be more universal. In a park in New Jersey, basking northern water snakes were more responsive to pedestrians than were eastern garter snakes (Burger 2001). However, most snakes remained stationary when a person walked directly past them without stopping or approaching, and all snakes retreated within 0.5 m of a direct approach. The number of people in a group also affected snake behavior, with groups of three inciting a response from more water snakes, while groups of two incited a response from a higher percentage of garter snakes. This author recommended that trails be at least 0.4 m from water bodies for snakes to have sufficient space to bask without being disturbed by passing pedestrians (Burger 2001). However, considering multiple types of recreation, Hennings (2017) reported the average distance from which reptiles respond to recreation by flushing or becoming alert to be 216 m (see table 5.1).

Birds

The impacts of nonmotorized summer recreation on birds have received considerable attention in the scientific literature. In a recent systematic literature review of the impacts of recreation on wildlife (Larson et al. 2016), 37 percent of 274 articles focused on birds, second only to mammals. Birds accounted for the second highest proportion of positive effects reported in the literature, particularly for corvids (e.g., Jiménez et al. 2011). Two notable review articles that synthesized the findings of previously published studies focused specifically on recreation impacts to birds (i.e., Buckley 2004, Steven et al. 2011), reaching a much higher level of detail about birds than Larson et al.'s broad review (2016). Buckley et al. (2004) included both motorized and nonmotorized ecotourism, concluding that most recorded impacts on birds from ecotourism, recreation, and associated human disturbance are negative, and often strongly negative. The few exceptions to this were birds that habituate to loud noises, nest close to tourist accommodations, and maintain reproductive success despite low levels of human disturbance. Such effects were primarily observed in waterbirds and shorebirds (e.g., Carney and Sideman 1999, Hill and Rosier 1989, Hockin et al. 1992). Steven et al. (2011) focused on nonmotorized recreation and concluded that this type of recreation "has negative impacts on a diversity of birds from a range of habitats in different climatic zones and regions of the world" (Steven et al. 2011: 2287). Recreational disturbance is evident in a wide range of species, including songbirds, shorebirds, waterbirds, and raptors.

Impacts on habitat—

Cleared areas in forests, such as trails and campgrounds, can create edges and alter vegetative structure, sometimes having stronger effects on avian communities than trail use in protected areas (Grooms and Urbanek 2018). For birds, edge habitats are often associated with reductions in breeding success (Anderson and Keith 1980, Carney and Sydeman 1999, Lafferty et al. 2006, Miller et al. 1998, Verhulst 2001), refuge from predators (Fernández-Juricic et al. 2004), and prey for insectivores (Hagar et al. 2004, Lindell et al. 2007). Birds that use on- and near-ground areas for nesting and foraging are more susceptible to disturbance from recreation than species that use areas higher in the canopy (Fernández-Juricic et al. 2005, Thompson 2015, van der Zande et al. 1984), because these vegetative structures have been altered. However, an experimental study investigating the impacts of trail construction and presence on wildlife found no significant effects on habitat use by wild turkeys, a species that forages on the ground and roosts in trees (Miller et al. 2020b). Fragmentation affects a greater proportion of Neotropical migrant birds than temperate resident birds, as indicated by Neotropical migrants being more likely to avoid edges (Lindell et al. 2007).

Box 7

Summary of Impacts of Nonmotorized Summer Recreation on Birds

- Disturbance increases with intensity (a combination of people per day, noise level, and speed) of recreational activity.
- Less predictable activities and those that create more noise have a larger disturbance effect.
- Migratory birds are generally more sensitive to human disturbance than are resident species, considering activity as well as associated habitat alterations.
- Larger birds wait longer to flush than smaller bird species.
- Cryptic birds wait longer to flush than non-cryptic species.
- Species that use areas on or near the ground, for nesting, foraging, or other activities, are more sensitive to human activity.
- Habituation and sensitization in birds is species specific. Year-round residents, corvids (crows), and species common to urban areas are especially prone to habituation. Many species exhibit sensitization (the opposite of habituation) to human disturbance.
- Recreationists with dogs may represent the highest disturbance type of recreation for birds.

Adapted from Hennings 2017.

Reduced breeding success along trails can be explained by increased nest predation in edges created along wide trails or in areas with higher levels of recreation (Carney and Sydeman 1999, Lafferty et al. 2006, Miller et al. 1998), as well as increased nest abandonment (Anderson and Keith 1980), reduced time at the nest (Verhulst 2001), and a decreased likelihood to nest near trails (Miller et al. 1998). Some researchers have found decreased nest predation by mammalian predators such as raccoons along trails (e.g., in lowland riparian areas in Colorado) (Miller and Hobbs 2000); however, others have found the opposite (Sinclair et al. 2005). A higher abundance of mammalian nest predators was found along wider segments of paved greenways in a study in North Carolina (Sinclair et al. 2005). This effect was influenced by surrounding vegetative structure, with an increased abundance of mammalian nest predators found along greenway segments within wider forest corridors and adjacent to areas with fewer buildings. These authors suggested that narrow, unpaved trails might have a lower risk of avian nest predation by mammals, as compared with the wide, paved trails typical of greenways (Sinclair et al. 2005).

Jason Blake

A choice camping spot near a stream on the Gifford Pinchot National Forest, Washington.

A series of studies, primarily in urban and fragmented habitats in Spain and the Americas, led to the conclusion that vegetative structure can influence the flush distance of some ground-feeding bird species (Fernández-Juricic et al. 2005, Hennings 2017). Specifically, results suggest that increased tree height can increase tolerance for some species, as taller trees provide cover from predators (Fernández-Juricic et al. 2001). Other species appear to be less tolerant of human activity in areas where shrubs are taller, suggesting an obstructive effect of vegetation that increases these species' vulnerability to predators (Fernández-Juricic et al. 2004).

Birds that prey on insects may have reduced food sources as a result of changes in vegetative structure along trails, specifically if deciduous shrubs are reduced in forests or forbs are reduced in grasslands (e.g., Hagar et al. 2004). Insectivores are more likely to avoid edges than noninsectivores in both temperate and tropical regions (Lindell et al. 2007).

Species that nest and forage higher in trees are generally less vulnerable to recreational disturbance (Fernández-Juricic et al. 2005, Thompson 2015, van der Zande et al. 1984), but may be vulnerable to emerging recreational activities that take place in the canopy, such as the sport of ziplining. However, no studies were found on this type of recreational activity.

Impacts on individuals, populations, and communities—

The effects of recreational activity on birds depends on several species-specific factors. Habitat specialists and migratory species are more susceptible than habitat generalists or resident species to being disturbed by recreation (see Hennings 2017). Species with a proclivity to become sensitized rather than habituated to human activity may also be more likely to be negatively affected by recreation, although this topic is debated (see Bejder et al. 2009, Nisbet 2000). In some cases, birds have been found to become sensitized to recreation, e.g., shorebirds, in response to pedestrians, dogs, and cars (Pfister et al. 1992); and grouse, especially hunted populations (Storch 2013). Meanwhile, other studies have noted a lack of sensitization, particularly in areas of high disturbance, (e.g., shorebirds, in response to walkers, joggers, and dog-walkers) (Glover et al. 2011, Gray 2006); and insectivores in response to conversational noise in a Peruvian rain forest (Karp and Guevara 2011). Some of the recreation-specific factors at play include the noise generated, speed, predictability, and proximity to critical bird habitat (for more detail, see "Factors Influencing Wildlife Response to Recreation").

The predictability of human activities is often linked with recreational activity type. Photographing and observing wildlife (e.g., birding for pleasure) typically requires a recreationist to spend a long time in the area, leave designated trails or areas in which recreationists typically remain, and sometimes follow individuals (Boyle and Samson 1985, Burger 1995, Cline et al. 2007, Klein 1993, Marzano and Dandy 2012). This behavior is less predictable and thus more disturbing to birds. Because noise is a source of disturbance for some bird species (e.g., Dowling et al. 2012, Hill 1992, Ortega 2012, Parris and Schneider 2009, Petrelli et al. 2017), people having loud conversations and children making loud noises can also be more disturbing to birds, owing to noise as well as unpredictable behavior. Furthermore, if birds are alert to human presence from long distances, such as from sounds produced by recreationists, this can create shorter undisturbed period between trail users, and may have negative effects on individuals' fitness levels.

This body of literature suggests that increasing recreational demand is likely to reduce avian biological diversity. Negative effects of recreation on avian biodiversity will be stronger in higher use sites (Buckley 2004).

Forest and grassland birds—Forest and grassland birds are known to respond to nonmotorized recreation behaviorally by flushing from human approach (Blumstein 2003, Fernández-Juricic et al. 2001), and increasing their breeding territory size (Davis et al. 2010). Some species become habituated to recreational activity while others show signs of sensitization (e.g., Cooke 1980, Jiménez et al. 2011). Reduced nest success associated with recreation-induced habitat alterations might have implications at the population level for some species (Chace et al. 2003, Davis et al. 2010). Additionally, a comparatively high frequency of recreational activity is associated with lower bird species richness (Cardoni et al. 2008; Fernández-Juricic 2000, 2002; Fernández-Juricic et al. 2001, 2004, 2005; Trulio and Sokale 2008). However, in the White Mountains of New Hampshire, researchers found no evidence that forest birds avoided even heavily used hiking trails (DeLuca and King 2014). Although effects are all highly species specific, migratory birds are particularly sensitive to increased use levels and are less able to habituate to human disturbance than are resident species. Habitat specialists are also likely more heavily affected by recreation that alters the resources provided in habitat areas. Further detail on these general findings are summarized below.

Behavioral responses of forest and grassland birds to recreation include flushing (Blumstein 2003, Fernández-Juricic et al. 2001), increasing territory size, and abandoning nests (Davis et al. 2010). In both wooded and open areas, the distance from which a human's approach begins affects the response of some bird species, with birds flushing earlier from approaches starting from farther away (Blumstein 2003). Two possible explanations are (1) to avoid needing to flee at maximum velocity and (2) to reduce the amount of time during which the individual must be vigilant. One study found that recreational disturbance caused a federally endangered migratory species (golden-cheeked warbler) to increase the size of its breeding territories and abandon nests at a higher rate in sites with mountain bike trails as compared with control sites within a military base in Texas (Davis et al. 2010).

Habituation and habituation-type responses to recreationists have been found in some year-round resident species (Bisson et al. 2009, Cooke 1980, Fernández-Juricic et al. 2001, Jiménez et al. 2011), corvids in particular. This is evident from the combination of dampened behavioral and physiological responses in a European study, where corvids in tourist areas flushed more readily, did not fly as far, and had fewer parasites and lower stress hormones compared with corvids in control sites with no recreation (Jiménez et al. 2011). This study concluded that species differ in their ability to adjust to novel conditions, such as crowded tourist areas, and that short-term behavioral adjustments may permit some species to mitigate the effects of environmental change, while the community as a whole may not be able to adjust (Jiménez et al. 2011).

Migratory birds tend to be more sensitive to disturbance than resident species. Long-distance migratory birds are generally more specialized than resident birds, requiring large areas to maintain populations, wide travel corridors, and high-quality stopover habitat (Burke and Nol 1998, Croonquist and Brooks 1993, Hennings and Soll 2010, Hodges and Krementz 1996, Keller et al. 1993, Lindell et al. 2007, Maurer 1993, Pennington et al. 2008, Thurmond et al. 1995). Migratory birds also have less time at a location to adjust to changes in land use and routine human disturbances. Increased sensitivity to humans in migratory birds has been documented in many cases in the United States (Hodges and Krementz 1996, Lee et al. 2002, Lindell et al. 2007, Keller et al. 1993, Maurer 1993, Pennington et al. 2008, Rodewald and Matthews 2005, Rodewald and Shustack 2007, Villard et al. 1995) and other countries such as India (Burger and Gochfeld 1991b). Migrating birds have been found to require areas of low disturbance to acquire sufficient fat stores, while resident species did not (Marsh 2015).

Migratory birds tend to be more sensitive to disturbance than resident species.

Habitat generalist bird species have been found to increase near trails and fragmented habitats, while specialists have lower abundance in areas with human use (Burhans and Thompson 2006, Canadian Wildlife Service 2007, Devictor et al. 2008, Heil et al. 2006, Karp and Guevara 2011, Mallord et al. 2007, Miller et al. 1998, Morelli et al. 2016). In a study comparing recreational and control areas in woodland and grassland areas near Boulder, Colorado, most species were found to flush or become alert to humans within approximately 75 m from trails (Miller et al. 1998). Patterns of human recreation, such as visitor use, food subsidy (e.g., in picnic areas), and amount of road edge, have been found to influence corvid distribution (Walker and Marzluff 2015). In Mount Rainier National Park, the number of visitors present during point counts was positively associated with Steller's jay and Clark's nutcracker presence, while common ravens used areas with fewer people but with a high density of road edge. Gray jays, common ravens, and Clark's nutcrackers were each more likely to use sites with anthropogenic food subsidy than sites without subsidies (Walker and Marzluff 2015).

With implications at the population level, reduced nest success is associated with recreation in some cases. In Colorado, researchers found increased songbird nest parasitism by brood parasitic brown-headed cowbirds in proximity to urban areas, roads, and recreational trails (Chace et al. 2003). Golden-cheeked warblers also had reduced nest success in sites with mountain bike trails compared to control sites (Davis et al. 2010).

The diversity of bird species was negatively affected by the presence of recreational areas in the Cantabrian Mountains of Europe (Jiménez et al. 2011), and breeding bird species richness was negatively associated with higher pedestrian traffic in urban parks in Madrid, Spain (Fernández-Juricic et al. 2001).


Francisco Valenzuela

Horseback riders are among the visitors to public lands throughout the nation.

Some forest and grassland bird species appear to be negatively associated with trails (Burhans and Thompson 2006, Miller et al. 1998), especially ground-nesting birds (Thompson 2015). Recreational disturbance is especially high for species that forage on or near the ground (van der Zande et al. 1984).

Waterbirds, shorebirds, and waders—Shorebirds and waterbirds have been reported to respond to nonmotorized summer recreation through avoidance, flight, decreased foraging success and feeding rate, spatial and temporal displacement, habituation, and sensitization. Reduction in individual fitness and breeding success might have negative effects at the population level. Reduced species richness and abundance have been associated with trail use. Further details on these general findings are summarized below.

Some shorebird species become sensitized to recreational activity. Sensitization can involve decreased foraging success (Gray 2006), shift toward more nighttime feeding in highly disturbed sites (Burger and Gochfeld 1991a, McNeil et al. 1992), decreased feeding rates (Lafferty 2001a), fleeing from human approach (Klein 1993), and avoidance of heavily disturbed areas (Burger and Gochfeld

1991b). Some authors have suggested that a protective buffer of 100 m surrounding waterbird habitat in Florida would minimize disturbance to most species (Burger and Gochfeld 1991a, Rodgers and Smith 1997). In Florida, sanderlings increasingly shifted to nighttime feeding and moved to less crowded beaches as the number of people within 100 m increased (Burger and Gochfeld 1991a). Some species such as green-backed herons appear to wait longer before fleeing from human approach, likely due to their reliance on cryptic coloration and predation avoidance behavior (Klein 1993).

Other shorebirds have been found to exhibit habituation. At a beach in Holland, oystercatchers, curlew, and redshank were found to become habituated to recreational activity (people sitting, walking, running, bicycling, and children playing, both with and without dogs) (Fitzpatrick and Bouchez 1998). Note that this response is species specific. In Wisconsin, many piscivorous species were found to be widespread regardless of the degree of human influence (measured by presence of housing and motorized boats), suggesting habituation to humans (Newbrey et al. 2005). In Florida, eight waterbird species fled in response to approach by humans on foot, while seven other waterbird species did not (Klein 1993).

Shorebirds, waterbirds, and wading birds are vulnerable to disturbance, especially at high levels of use. Anglers, birdwatchers, and shoreline hikers have been found to displace waterfowl from feeding grounds, reduce breeding pairs and breeding success, and lower individual fitness (Korschgen and Dahlgren 1992). Three species of fish-eating waterbirds (osprey, common merganser, and common loon) were found at Wisconsin lakes with low levels of human influence (i.e., absence of housing development and motorized boats), but were absent from lakes with high levels of human influence (i.e., presence of housing development and motorized boats) (Newbrey et al. 2005).

Shorebird species richness decreased by an average of 25 percent on days with higher trail use in the San Francisco Bay area (Trulio and Sokale 2008), and both species richness and abundance decreased in a similar study in Argentina (Cardoni et al. 2008). However, these studies investigated only short-term effects.

Raptors—Several studies indicate that nonmotorized summer recreation can disturb bald eagles. An experimental study along the Boise River in Idaho found that bald eagles flushed more readily in response to walkers than to bicyclists, although eagles flushed farther distances from bicyclists (Spahr 1990). Two studies on bald eagles found that humans on foot were most disturbing, followed by aquatic recreationists (including motorized and nonmotorized activities), vehicles, and aircraft (Stalmaster and Kaiser 1998, Steidl and Anthony 1996). Further detail on the latter studies is provided in chapter 5.

Mammals

The impacts of nonmotorized summer recreation on mammals has received perhaps the most attention of all taxonomic groups in the scientific literature. Larson et al. (2016) found that 42 percent of 274 articles they reviewed focused on mammals, which accounted for the highest proportion of positive effects reported in the literature. Reviews on the effects of primarily nonmotorized summer recreation on ungulates (e.g., Stankowich 2008) and carnivores (e.g., Fortin et al. 2016) have also been published. The summaries presented here indicate highly species-specific effects of nonmotorized summer recreation on mammals.

Impacts on habitat—

Habitats fragmented by human land uses can negatively affect wide-ranging mammals that require large, unfragmented habitats. Studies on the effects of habitat fragmentation on mammals typically investigate fragmentation that results from land uses such as residential areas, agriculture, or other human developments. Although the infrastructure built for outdoor recreation generally modifies the landscape less than these types of human developments, we address fragmentation here to put recreation into the context of the larger human landscape.

Large carnivores are particularly sensitive to habitat fragmentation, because they require large areas (Berger 2007, Crooks 2002, Crooks and Soule 1999, George and Crooks 2006, Lenth et al. 2008, Ordenana et al. 2010, Reed and Merenlender 2008, Reilly 2015, Sweanor et al. 2008, van der Ree and van der Grift 2015). In a study in southern California, large and medium carnivores, including cougars, badgers, mountain lions, and coyotes, were sensitive to habitat fragmentation and occurred less frequently in suburban areas (Crooks 2002). Comparatively, smaller carnivores were either tolerant of habitat fragmentation (raccoons and striped skunks) or even were associated with fragmentation (domestic cats, gray foxes, and opossums). However, small- and medium-sized carnivores can also be vulnerable to human disturbance and fragmentation. In the same southern California study, long-tailed weasels and western spotted skunks were also found less frequently in fragmented habitat and suburban landscapes (Crooks 2002). Weasels were found only in habitat patches larger than 10 ha in a study in Oregon (Murphy 2005). For small mammals, habitats can be fragmented by paved roads. White-footed mice and eastern chipmunks were significantly less likely to cross a road than cover the same distance away from roads, influenced by the structure itself rather than traffic volume and noise level. However, chipmunks in this study were found in higher densities near roads (McGregor et al. 2008).

The openness of the landscape is also an important factor in estimating how recreation will affect mammals. Mammals in areas with dense vegetative structure and closer to refuge areas are generally less easily disturbed than those in open areas. This can explain some variation between studies that have reported conflicting results, such as the use of human-made trails by mammals, and the overall effect of recreational activity on mammalian density. For example, large animals, including carnivores, have been found to use recreational trails in some studies and avoid such trails in other studies. This pattern seems to correspond with the density of vegetative structure, with trails being used by mammals in areas with dense areas such as tropical rainforests or Appalachian forest (Cusack et al. 2015; Harmsen et al. 2010; Kays et al. 2011, 2016; Miller et al. 2020b). Another example is in the contrasting results of two extensive studies on the overall effect of recreational activity on mammalian density and distribution. In relatively open oak woodland areas in California, dispersed, nonmotorized recreation led to a fivefold decline in native carnivore density (Reed and Merenlender 2008). However, in denser eastern forests, a large-scale study found that such variables as the amount of large continuous forest and local housing density were more important than recreation in predicting mammalian distribution (Kays et al. 2016). Mammals are known to flee more readily in open areas as compared with dense forests (e.g., Fairbanks and Tullous 2002, Jayakody et al. 2008). Vegetation density should be considered when predicting mammalian behavioral response to recreational activity.

Vegetation density should be considered when predicting mammalian behavioral response to recreational activity.

The opening up of dense forest areas through new trail construction can influence mammalian habitat use as well. An Appalachian study found white-tailed deer, coyotes, and eastern gray squirrels to use a forested area significantly less both during (all species) and after (squirrels only) construction of a new trail, while raccoon activity increased highly during construction (Miller et al. 2020b).

Impacts on individuals, populations, and communities—
Studies on effects of nonmotorized summer recreation on mammals fall into three primary groups: ungulates, carnivores, and small mammals.

Ungulates—Ungulates, including deer, elk, and bison, have been found to demonstrate short-term behavioral responses to nonmotorized summer recreation. Studies of deer and elk have indicated flight distances ranging from 74 to 400 m depending on the setting and intensity of disturbance (Hennings 2017, Rogala et al. 2011). During recreation treatments, elk in Oregon avoided trails and recreationists in real time. In this study, elk kept distances of between 240 and 286 m from hikers, bikers, and horseback riders (Wisdom et al. 2018). Elk in the Rocky Mountains increasingly avoided areas within 50 m of trails with increasing use (a response which leveled off at 10 to 20 users per hour) and were mildly attracted to recreation between 51 to 400 m of trails, but avoided this zone when the number of recreationists

Box 8

The behavioral response of mammals to nonmotorized summer recreation is a complex subject, but several factors emerge that can strongly influence the response:

- Openness of habitat and distance from cover
- Intensity (a combination of people per day, noise level, and speed) of human activity on trails
- Trophic category (e.g., apex predator, mesopredator, prey)
- Species within a trophic category; for example, red foxes generally are attracted to trails, while gray foxes avoid them.
- Reproductive status. For example, adult female bobcats avoided human use areas more than adult male and young female bobcats (Riley et al. 2003).
- Individual temperament

increased to one or two users per hour. Moving out to 400 to 800 m from trails, elk showed the same pattern of mild attraction, shifting to avoidance of trails at around 12 users per hour (Rogala et al. 2011). In Saskatchewan, Canada 42 percent of bison fled in response to approach by humans traveling by foot. Other responses included approaching the observer (8 percent) and being alert while remaining stationary (60 percent) (Fortin and Andruskiw 2003). However, Dumont (1993) found that the number of hikers had no impact on the behavior of caribou.

Ungulates can avoid nonmotorized summer recreation both spatially and temporally. Caribou were found to leave preferred habitats in situations of intense and persistent harassment during the fall rutting season (Bergerud 1974), and in spring and early summer they were displaced by ecotourism activities from preferred alpine tundra habitat to forested areas with higher predation rates (Dumont 1993). Deer and elk also may avoid human recreation by temporally shifting activity to nights or other periods when disturbance from recreational activity is reduced (Barrueto et al. 2014, Marchand et al. 2014, Miller et al. 2020b, Reilly et al. 2017, Schultz and Bailey 1978, Spitz et al. 2019). Cervid species’ general avoidance of recreationists appears to be consistent while their response to motorized traffic may vary (Brown et al. 2012, Pelletier 2006, Rogala et al. 2011, Rowland et al. 2004).

Nonmotorized summer recreation has also resulted in altered activity budgets and movement rates for elk. The amount of time that elk spent resting decreased when they were subjected to disturbance from mountain biking and hiking. Travel time for elk increased following exposure to mountain biking, followed by hiking and horseback riding (Naylor et al. 2009).

Herd size and composition influence responses to nonmotorized summer recreation, particularly proclivity to habituate. Larger herds of deer and elk are typically more sensitive to disturbance (Brown et al. 2012, Ciuti et al. 2012, Czech 1991, Stankowich and Blumstein 2005, Taylor and Knight 2003). Pronghorn, a species that prefers large open areas, may not habituate to recreational activity. In Utah, smaller groups of pronghorn stayed farther from trails than did larger groups (Fairbanks and Tullous 2002). Caribou have been found to habituate to the presence of a highway and to intense traffic in summer months (Johnson and Todd 1977).

Nonmotorized recreation has the potential to cause population-level effects on cervids owing to negative impacts on breeding success for elk (e.g., Shively et al. 2005) and reduced diet quality and food availability for deer, elk, and pronghorn (Fairbanks and Tullous 2002, Jayakody et al. 2008, Jayakody et al. 2011).

Carnivores—Large carnivores have been studied widely regarding the effects of recreation. Responses of carnivores to recreational activity seem to support the human-mediated predator shelter hypothesis, suggesting that prey species use areas disturbed by human activity as shelter from predators, which are more sensitive to human disturbance and avoid such areas (Berger 2007, Hebblewhite and Merrill 2008, Muhly et al. 2011, Roever et al. 2008, Shannon et al. 2014). This has been documented in large protected areas such as Grand Teton National Park (Shannon et al. 2014), the greater Yellowstone ecosystem (Berger 2007), and several Canadian national parks (Hebblewhite and Merrill 2008, Muhly et al. 2011, Roever et al. 2008, Rogala et al. 2011). In Alberta, Canada, more than 18 humans per day on trails and roads displaced predators but not prey species; cervids were more than three times more abundant on roads and trails visited by more than 32 humans per day. In Yellowstone, pregnant moose shifted toward roads to give birth, while brown bears (a moose predator) avoided roads (Berger 2007).

Large carnivores are sensitive to human-caused disturbance, and have been found to avoid trails and recreational areas with higher human usage (Crooks and Soule 1999, Erb et al. 2013, Fortin et al. 2016, George and Crooks 2006, Muhly et al. 2011, Reed and Merenlender 2008, Reilly 2015, Rogala et al. 2011). Cougars in southern California were negatively associated with bicycle use, but not equestrian use (Markovchick-Nicholls et al. 2008). In Banff National Park, Canada, cougars and black bears more frequently used underpasses that had less recreational activity and were farther from town (van der Ree and van der Grift 2015).

Large mammals, including carnivores, have also been found to use human-made trails (see previous discussion of habitat effects on mammals); however, trails with high levels of human use are generally avoided more than those with low levels of human use (George and Crooks 2006, Ordenana et al. 2010, Riley et al. 2003). These effects are species specific; e.g., red fox seem to use recreational trails and human-disturbed areas (Corlatti et al. 2009, Joslin and Youmans 1999, Lenth et al. 2008, Ordenana et al. 2010, Pouwels and van der Grift 2012) more frequently than gray fox and black bears (Erb et al. 2013, Reilly 2015). In the Appalachian Mountains, coyotes were less active within 50 m of highly active construction of a new trail as compared with before construction of the trail, but were as active in the area during the low-activity period (average of 1.4 people passing per day) following the opening of the trail (Miller et al. 2020b). Some carnivores have also shown temporal displacement, with reduced activity levels during periods with higher human activity such as daytime hours and weekends, e.g., wolves (Hebblewhite and Merrill 2008) and coyotes (Barrueto et al. 2014, Reilly 2017). However, small nocturnal carnivores such as striped skunks may not be directly affected by daytime recreational activities (Reilly 2017).

Several studies have documented varying activity from individual animals, suggesting that certain individuals' bold temperament leads to their habituation-type responses to human activity (Martin and Reale 2008, Papouchis et al. 2001, Sweanor et al. 2008).

Small mammals—Studies have found mixed effects of recreation on small mammals, and no distinct patterns regarding predator and prey species. Nest predators such as raccoons, Virginia opossums, and squirrels have sometimes been found to be more active in proximity to recreational areas such as trails, but sometimes appear to avoid these areas, especially when domestic dogs are present. Raccoons are known to be attracted to point sources of human presence such as garbage cans and often use edges (Barding and Nelson 2008). The effect of recreational trails on raccoons is unclear, with one study finding that raccoons did not disproportionately use trails compared with adjacent areas (Gompper et al. 2006), while another found that raccoons avoided trails (Miller and Hobbs 2000). Raccoon abundance was higher in urban greenway segments with wider trails (Sinclair et al. 2005). Raccoons appeared to be highly attracted to a trail construction project in the Appalachians, while no significant changes in opossum activity relative to trail construction or presence were detected (Miller et al. 2020b). In a study on nest predators along urban greenways, opossums were found to be more abundant in greenway segments with a greater percentage of trail (Sinclair et al. 2005). Eastern grey squirrels avoided humans and dogs temporally in a study that took place in 33 protected areas in the Eastern United States but did not avoid them spatially or increase vigilance in response to recreation. Humans were perceived as a greater risk than coyotes, an effect that increased when humans were with dogs (Parsons et al. 2016). Squirrels were also found to temporally avoid human activity along a newly constructed Appalachian equestrian and mixed-use trail (Miller et al. 2020b). Fox squirrels, a known predator of bird nests, were not found to avoid recreational trails in a study in riparian areas in Boulder County, Colorado (Miller and Hobbs 2000).

Marmots appear to be able to adjust their behavior to avoid negative demographic consequences in situations with heavy tourism, specifically in response to hikers. In Washington's Olympic Mountains, Olympic marmots at high-use recreation sites displayed significantly reduced responses to human approach, and looked up more often while foraging, as compared with marmots at low-use sites (Griffin et al. 2007). Alpine marmots in the Swiss Alps appear to habituate to humans during the first summer of life (Mainini et al. 1993, Neuhaus and Mainini 1998). Furthermore, Alpine marmots in high-use recreation areas were found to react more strongly to a hiker with a dog (especially one on a long leash) than to a hiker without a dog. Off-trail hikers also elicited a stronger response than on-trail hikers, especially when off-trail hikers crossed marmots' main burrows (Mainini et al. 1993). However, behavioral responses did not result in altered reproductive rates, survival rates, or body condition of Olympic marmots (Griffin et al. 2007).

We reviewed one study that indicated effects of recreation on small mammals at the community level. Endemic small mammals in chaparral ecosystems were found to have decreased species diversity near urban areas with habitat modification and proliferation of roads and trails (Sauvajot et al. 1998).

Simon Berlin

An elk herd rests on a municipal golf course fairway in Estes Park, Colorado.

Potential Effects of Emerging and Under-Researched Nonmotorized Summer Recreation

A number of types of nonmotorized summer recreation not summarized above are described below. These activities differ in speed, predictability, species present (i.e., domestic dogs), duration, time of day, and vertical location within natural spaces. Below, we apply findings from other types of recreation to hypothesize potential effects of these types of recreation.

- **Dog walking.** This activity is associated with large disturbance factors. Dogs are a domesticated subspecies of wolf, and their presence and scent (which remains after dogs are gone) repels many wildlife species and can incite antipredator responses. In Colorado, mule deer showed reduced activity within 66 m of trails where dogs were prohibited, but within 100 m of trails where dogs were allowed (Miller et al. 2001). Similar effects were also found for small mammals, including squirrels, rabbits, chipmunks, mice, prairie dogs (Bekoff and Ickes 1999, Lenth et al. 2008), and marmots (Griffin et al. 2007). However, common grassland and forest birds might not have strong responses to dogs (Miller et al. 2001). The effects of dogs on wildlife have also been reviewed extensively (see Hennings 2016).
- **Trail running and ultra-running.** The effects of a recreationist running along trails in natural areas are likely similar to those of jogging along trails, which has been found to elicit stronger responses than walking in some bird, reptile, and ungulate species (Burger 1981, Gander and Ingold 1997, Mayo et al. 2015, Stankowich and Blumstein 2005). However, the opposite effect has also been found for western snowy plovers; one study found that a smaller proportion of joggers than walkers on a California beach caused plovers to move or fly away (Lafferty 2001a).
- **Bicycling:**
  - **Fat-tire bikes.** This type of mountain bike with oversized tires, also called a fat bike, can be ridden on designated trails or off-trail. One attraction of these bikes is that they enable recreationists to access off-trail areas that are otherwise difficult to reach. However, a survey of fat-tire bike users suggested that a relatively low percentage of users are riding off-trail (Monz and Kulmatiski 2016). In another survey, 80 percent of fat-tire bikers indicated that they do not ride fat bikes when trails are muddy and sensitive to damage (Monz and Kulmatiski 2016). Fat bikes move more slowly than regular mountain bikes (estimated at 30 percent slower) (Monz and Kulmatiski 2016). However, riders do move more quickly than other recreationists and can cover larger distances in

  less time. Thus, with this type of use, we expect fat-tire bikers to have more substantial effects on behavioral and physiological responses for sensitive species compared with non-bikers, but somewhat less than mountain bikers. Because off-trail travel is less predictable than on-trail travel, in areas where fat-tire bikers travel off-trail we expect a relatively high impact on species sensitive to off-trail travel such as mule deer, desert bighorn sheep, and elk (Ciuti et al. 2012, Papouchis et al. 2001, Taylor and Knight 2003), and other species. Off-trail recreation can result in the clearing of vegetation in some cases, which might affect wildlife habitat in ways similar to those for creating new trails. Effects may include habitat fragmentation for small species that have difficulty crossing trails, creation of edges, and spread of invasive species.

  - **Night biking**. In this sport, mountain bikers take to the trails at night with the assistance of high-powered lights. Attractions of night biking include avoiding crowds, including slower moving mountain bikers, and the thrill of moving quickly through natural areas at night. The fast-paced nature of this activity will likely disturb species that are more highly disturbed by quickly moving activities such as mountain biking. Night biking may affect nocturnal animals as well as diurnal animals that have shifted activity to the night to avoid contact with recreationists, such as shorebirds (Burger and Gochfeld 1991a, McNeil et al. 1992), ungulates (Barrueto et al. 2014, Marchand et al. 2014, Schultz and Bailey 1978), and coyotes (Reilly et al. 2017).
  - **Mountain bike trail technical features**. These enhance the difficulty of the sport, with construction of a variety of jumps, logs, bridges, ditches, and other structures, from both naturally occurring and artificial materials, to make trails more rewarding for mountain bikers seeking a technical challenge. These features can be authorized by public land managers, but are sometimes built by users or user groups without authorization. Unauthorized trail technical features in a protected area in Australia were found to result in bare soil and cleared undergrowth (Pickering et al. 2010), which has implications for wildlife habitat availability. Additionally, if creating trail technical features involves the removal or addition of coarse woody debris or rocks, this might have implications for animals that use these as habitat.
- **Caving.** Also called spelunking, caving involves people visiting caves in a variety of ways. Several studies have investigated the impacts of human recreation in caves, focusing on bats. These articles indicate that bats can

be disturbed by noise from conversations (Mann et al. 2002), direct artificial light (Cardiff et al. 2012, Mann et al. 2002), and human approaches within 5 to 6 m (Cardiff et al. 2012). Although visitation is sometimes associated with negative impacts on bats at the population level, other factors such as environmental conditions within the cave are also very important to bat fitness and survival, and can be altered by human-made structures. At a cave system in Indiana, increased visitation was associated with higher overwinter weight loss in Indiana bats (Johnson et al. 1998). A study in Turkey found the total number of bats recorded in a cave system to increase significantly after it was opened for tourism (Paksuz and Özkan 2012). This could be because two entrances were gated to control visitation. Managers also considered the varying seasonal use of different parts of the caves by bats when designing the visitor schedule. In caves in southwest England, researcher visits to caves (approximately five visits per month, average duration 50 minutes) were not associated with increased activity of horseshoe bats (Park et al. 1999).

Cave-dwelling bats are susceptible to white-nose syndrome (WNS), a fungal pathogen affecting bats, which is contagious between bats and can be transferred between caves on visitors' shoes or gear which comes in contact with cave substrates. This fungal pathogen was first documented by spelunkers visiting a cave in New York. Seven North American bat species have been confirmed with WNS, and five additional species carry the disease-causing fungus (White-Nose Syndrome Response Team 2016).

This literature offered the following recommendations for managing recreation in caves:

- Designing cave tours to minimize short-term effects on bats will require careful consideration of cave lighting and tour frequency, route location, and noise levels (Mann et al. 2002).
- Maintain a minimum distance of 12 m between cave visitors and bats, do not illuminate bats directly, and avoid opening additional roost sites to tourism (Madagascar: Madagascan rousette) (Cardiff et al. 2012).
- Consider how different parts of the cave are used seasonally for activities such as hibernating and breeding/nursing when scheduling visitation to caves. Gating entrances to control visitation can also reduce negative impacts of recreation in caves (Paksuz and Özkan 2012).
- Pay attention to environmental factors within a cave, such as the thermal regime and air flow, which have been associated with local bat declines. In a case in Indiana, removing a stone wall at an entrance

changed the thermal regime within a cave, contributing to a threefold increase in its bat population (Johnson et al. 1998, Richter et al. 1993).

Recommendations from the U.S. Fish and Wildlife Service to prevent the spread of WNS include the following:

- Prevent unrestricted access to subterranean bat roosts, especially when bats are present.
- Require visitors to subterranean bat roosts to follow decontamination protocols (see https://www.whitenosesyndrome.org/).
- Designate "no entry" restriction for subterranean bat roosts when wintering bats are present, which may include fall and spring as well.
- Educate visitors and local communities about WNS and conservation of bats, caves, and subterranean habitats (White-Nose Syndrome Response Team 2016).

- **Nontrail-based activities**
  - **Geocaching**. In this activity, individuals or groups travel cross-country, often off trail, to locate points where a small cache is hidden. Because off-trail travel is less predictable than on-trail travel, we can expect a relatively high impact on species sensitive to off-trail travel such as mule deer, desert bighorn sheep, and elk (Ciuti et al. 2012, Papouchis et al. 2001, Taylor and Knight 2003). Off-trail hiking might also result in the clearing of vegetation in some cases. This might affect wildlife habitat similarly to the creation of new trails, such as creation of edges, spread of invasive species, and habitat fragmentation for species that have difficulty crossing trails.
  - **Off-route adventure races**. Participants in these events run and scramble off-trail for extended periods. In addition to the expected impacts of off-trail travel (see "Geocaching" above), the continual nature of races might have a comparatively larger effect on species sensitive to human activity. However, if responses are short term and the races are infrequent, these may be restricted to a relatively short period following the race.
  - **Stargazing**. This activity involves individuals or groups gathering in an open area to observe the night sky. Although limited research is available on stargazing as a recreational activity, one study found that participants in a night sky interpretive program valued it as an opportunity to connect with nature and experience solitude (Mace and McDaniel 2013), which suggests that this is a relatively quiet activity. In high-intensity recreation areas, some diurnal species have been found to shift toward more activity at night to avoid contact with humans,

such as shorebirds (Burger and Gochfeld 1991a, McNeil et al. 1992) and ungulates (Barrueto et al. 2014, Marchand et al. 2014, Schultz and Bailey 1978). Recreational activities that take place during the night could have substantial negative effects on these species, as well as nocturnal species sensitive to human activity.

- **Rock climbing**. The popular recreational activity of rock climbing has received relatively little attention in the scientific literature. One recent review investigated potential effects of rock climbing on biodiversity, including birds and snails as well as plants, bryophytes, and lichens (Holzschuh 2016). Rock climbing is associated with a high level of bird species richness at moderately climbed cliffs (Camp and Knight 1998). Increased nest predation by ravens has resulted in reduced breeding success, productivity (Brambilla et al. 2004), and nest abandonment by peregrine falcons during the nesting season (Olsen and Olsen 1980, Snow 1972). Negative effects have been found on the richness and abundance of snail communities (Baur et al. 2007, McMillan et al. 2003), as well as no effect on the abundance of snails (Baur et al. 2007). Further research that carefully accounts for environmental variables (see Holzschuh 2016) is needed to draw more substantial conclusions about the impacts of rock climbing on birds and snails. Rock climbers often travel off-trail to access climbing areas (see "Geocaching" above for expected impacts of off-trail travel). In some situations, climbers remain in groups at the base of a climbing area for an extended period, talking or calling to each other. This will likely incite more response from species that are sensitive to noise, and might be similar to the effects elicited by nature photographers who remain in the same place for long periods of time (e.g., Boyle and Samson 1985, Cline et al. 2007, Klein 1993).
- **Sport tree climbing and ziplining**. Both of these activities take place within the tree canopy, an area that is otherwise disturbed only by the sounds associated with recreation. We found no studies on these types of recreation. However, we hypothesize that these activities may flush animals that live in the tree canopy, lead to alterations in nest predation, and may affect nest success rates as well as locations of nests. If these activities are relatively well contained and do not substantially reduce the amount of undisturbed potential habitat area available, the effects might be minimal. However, because no research has been conducted in this area, it is difficult to make sound judgments. One study that assessed the impacts of components of the natural ecosystem on recre-


Hayk Arabaget

Zipliners take in a view of the scenic Lastiver region of Armenia.

ationists found that zipliners were positively influenced by bird sounds (Li et al. 2018). This finding emphasizes the importance of maintaining wildlife populations and habitat for the benefit of recreationists as well as biodiversity conservation.

- **Slacklining.** In this activity, a line is tethered between two points and people walk across the line. Although we found no scientific studies on the subject, slacklines have been noted to cause damage to trees, such as Joshua trees, which have a shallow root system (USDI NPS 2017), and they can alter habitat for some wildlife species. In some situations, slackliners remain in small or large groups at a slacklining area for long periods. This will likely incite more response from species that are sensitive to noise, and might be similar to the effects elicited by nature photographers who remain in the same place for long periods (e.g., Boyle and Samson 1985, Cline et al. 2007, Klein 1993).
- **Off-trail hiking**. Participation in this activity may be increasing with the use of global positioning system (GPS) devices. Along stretches of trails that pass through relatively open areas, hikers can use GPS to

navigate along a straight route instead of following the designated trail. Off-trail hiking is less predictable (e.g., Harris et al. 2014; Miller et al. 2001) and likely covers larger areas (e.g., Leung and Marion 1999) than hiking confined to designated trails. As this type of hiking typically occurs within relatively open habitat, some species might have a stronger response to this type of hiking because less cover is available (Stankowich and Blumstein 2005) and because sounds travel farther in open areas (Keyel et al. 2018).

- **Paragliding.** This activity takes place primarily in the air, but requires launch and landing zones and sometimes a trail to access the launch site. The small body of research on the environmental effects of paragliding comes primarily from the European Alps, near where this sport was developed. Researchers found that chamois (a goat species) fled from paragliders at distances up to 900 m, seeking refuge in areas with forest cover (Schnidrig-Petrig and Ingold 2001). In this study, chamois fled further when paragliders appeared above them than when paragliders appeared at the same elevation as the animals. Chamois fled shorter distances in response to paragliders when the animals were close to forest cover than when they were in open meadows above the treeline. Chamois stayed in forest cover longer as the duration of paragliding off the normal flight path increased. In an area with infrequent paragliding, chamois stayed within forest cover for up to 4 hours after a single paraglider flyover. The color of parasails, distance to rocks, and group size did not affect chamois response (Schnidrig-Petrig and Ingold 2001). Another study indicated that paragliders spatially and temporally displaced feeding chamois disproportionately more than did hikers (Enggist-Düblin and Ingold 2003). The clearing of large areas for launching and landing zones might also have implications for reduced wildlife habitat availability, most significantly, where the cleared areas remove a substantial proportion of important habitat.
- **Remote cameras.** Hunters sometimes deploy these motion-activated cameras to scout for big game. This activity may involve the use of human-built recreational trails as well as off-trail areas and wildlife-created trails (i.e., game trails). The off-trail activity involved in deploying cameras can disturb wildlife in many of the same ways that other off-trail activities disturb wildlife, such as through unpredictable human activity in areas where people are not often present. In some cases, cameras might be baited to attract animals. Unbaited remote cameras can be heard and seen by animals (Meek et al. 2014).

Motorized Summer Recreation

Motorized summer recreation is the third most popular outdoor recreation activity category on U.S. national forests, accounting for 7 percent of the main activities pursued by visitors to these areas (table 2.3) (USDA FS 2016). Most commonly, motorized recreation includes driving for pleasure or the use of off-highway vehicles (OHVs), all-terrain vehicles (ATVs), and dirt bikes or motorcyles. Other motorized activities include the use of side-by-sides (two-seat, all-terrain vehicles) and electric vehicles such as e-bikes, uniwheels (a type of self-balancing electric unicycle), and motorized skateboards, and such activities as motorized racing, blazing new trails for motorized recreation, going on helicopter tours, and flying recreational UAVs. User-made trail proliferation is a concern for public land managers as participation in these forms of recreation increases and the types of

Nick Taylor

An off-road-vehicle driver follows a streambed on the White River National Forest, Colorado.

motorized vehicles seeking specialized trail widths diversify. Driving cars, motorcycles, and other motorized vehicles associated with nonmotorized recreational activity in the summer season is also included in this type of recreation, because characteristics such as noise, pollution, and infrastructure are similar and overlapping. Motorized summer recreation such as ATV use occurs both on and off trails, and in designated OHV play areas.

Off-road motorized activity is increasing, although the scale of this increase is relatively low. Compared with nonmotorized summer activities, motorized summer recreation makes moderate economic contributions to local communities (see fig. 2.4 for comparison of economic contributions and projected increase in participation with other recreational activity categories) (White and Stynes 2010). Although participation in motorized off-road activities is expected to decrease slightly with projected climate change in some regions of the United States (i.e., the northern and southern Forest Service regions), this type of activity is not expected to be highly affected by climate change at the national level (Askew and Bowker 2018). As climate change alters wildlife distributions and activities, it is important to consider potential changes in human-wildlife interactions (Miller et al., n.d.).

Individuals and groups who participate in motorized recreation often volunteer with land management agencies to assist with trail maintenance or clean-up efforts.

Summer motorized recreation provides a wealth of benefits to participants. ATV riders report that their activity allows them to build social bonds and connect with nature, and provides mental and physical health benefits (Dennis 1987). ATV riding is accessible to people who have health conditions that prevent them from participating in other recreational activities (Mann and Leahy 2009). Individuals and groups who participate in motorized recreation often volunteer with land management agencies to assist with trail maintenance or clean-up efforts (Dennis 1987, Waight and Bath 2014).

An extensive review on the environmental effects of off-highway vehicles described socioeconomic factors of ATV riding on public lands (Ouren et al. 2007). A survey of off-highway vehicle riders in Colorado indicated a preference for riding in national forests, followed by private land (Crimmins 1999). This study also indicated that the OHV users prefer areas with no user fees, where signs indicate all activities allowed on the trail, and where locations are exclusively designated for motorized vehicle use. Patrolling by public land management agencies, restrooms, and loading ramps were not important to users (Crimmins 1999). A study in Utah found that the majority of motorcycle users engage only in motorcycle use, while more than half of other off-highway vehicle users engaged in other recreational activities during their trips, of which hiking was the most popular activity, followed by hunting, fishing, camping, and sightseeing (Fisher et al. 2001). Fisher et al. (2001) also reported that motorcycle and ATV riders in Utah preferred riding off established trails and on double track trails, while motorcycle users also preferred single-track trails and roads more than ATV users, and ATV users preferred ATV courses more than motorcycle users preferred moto-cross areas. Regarding closures for resource protection, a study in Idaho found that ATV and motorbike users were most concerned about permanent closure of frequently used areas, followed by temporary closure of such areas, inattentive motorized recreationists, litter, too many regulations, and poor communication of regulations (Achana 2005). In this study, ATV users were not concerned with inadequate facilities, vehicle impacts on water and wildlife, and lack of availability of support vehicle parking. When asked what factors they believed contributed to the creation of unauthorized trails, motorized recreationists indicated that closures of off-highway vehicle areas could result in increases in dispersed use (Achana 2005). Considering the preferences of different groups of motorized recreationists can assist in planning recreation areas that maximize the benefits received by recreationists, while minimizing negative effects on wildlife.

Recreation planning that considers the preferences of different groups of motorized recreationists may enhance the benefits to these users, while minimizing negative effects on wildlife.

Some authors have concluded that nonmotorized activity elicits stronger behavioral responses in wildlife than motorized activities (e.g., Harris 2014, Stankowich 2008); however, the extent of disturbance may be higher in motorized activities because motor vehicles can cover a larger area and their engine noise can be heard from farther away (Harris 2014).

General Impacts of Motorized Summer Recreation on Wildlife

A review found that about 45 percent of studies on motorized summer recreation demonstrated negative effects on species (Larson et al. 2016). Important characteristics are the associated noise, broad extent of activity, speeds at which recreationists travel, and expanding infrastructure (i.e., trails, parking, and staging areas). Powerful off-road vehicles can cause vegetation and soil loss, and pollution from vehicles (e.g., fuel and oil leaks) can potentially affect water quality. The ability to travel deeper into recreation areas can cause widespread impacts, especially for sensitive species and species that require large undisturbed territories. User-created trails compound these problems. This type of recreation is generally predictable when recreationists stay on designated trails, while off-trail motorized activity can be unpredictable. The frequency of motorized activity varies, likely peaking on weekends and especially during race events.

Noise created by motorized recreational vehicles can travel for miles, especially in open landscapes. Such noise has been shown to directly, negatively affect species behavior (Brattstrom and Bondello 1983, Karp and Root 2009), and can cause individuals to avoid certain areas, resulting in energetically costly displacements

Box 9

Key considerations for motorized summer recreation:

- Noise
- Extent (e.g., reaching previously undisturbed areas)
- Speed (e.g., resulting in direct mortality)
- Infrastructure (e.g., trails, staging areas)
- Impact on habitat (e.g., soil and vegetation loss, water quality)
- Predictability (e.g., on-trail vs. off-trail use)
- Frequency of activity

(Bradshaw et al. 1998). Noise can mask species communication (Lohr et al. 2003), and compensation can be costly (Brumm and Slabbekoorn 2005). Noise can also alter the use of areas for breeding, disrupt migration routes, and reduce the amount of available habitat (Barber et al. 2009, Ouren et al. 2007, Reed et al. 2012). An experimental study on the effects of trail construction using motorized equipment found that coyotes were less active along the new trail and that both white-tailed deer and coyotes were less active within the 50 m zone surrounding the trail (Miller et al. 2020b). Although trail construction is not the same as motorized recreational activity, we provide this example because some noise produced during construction (e.g., by ATVs) might be similar to motorized recreational vehicles. Additionally, the high intensity of motorized and other human activity along the trail for long periods of time might resemble that of intense motorized recreation events (e.g., ATV races) in some ways. This study also found no significant effect of motorized trail building on habitat use of eastern grey squirrels, wild turkeys, and Virginia opossums (Miller et al. 2020b).

Box 10

Noise travels farthest in open vegetative structure and areas with low topographic complexity, where it can:

- Cause individuals to avoid certain areas
- Mask species communication
- Alter breeding behavior
- Disrupt migration routes
- Reduce the amount of habitat used
- Interfere with predator avoidance or hunting behaviors

Keyel et al. (2018) used a modeling approach to predict areas in which noises from point, line, and polygon sources were audible to humans and would potentially mask species communication. This study indicated that noise sources in locations with long, unobstructed lines of sight will have a disproportionate impact on the surrounding area, and offers a method to identify sites with smaller acoustic footprints, as well as sites that would benefit from added noise control.

Motorized recreation can have a larger footprint than nonmotorized recreation, with motor vehicles covering a larger extent of wildlife habitat. Disturbances that are widespread throughout a larger portion of a population or species range likely result in greater decreases in population growth rate, compared with disturbances in a small portion of the range (Tablado and Jenni 2017).

In general, disturbance from motorized recreation (e.g., OHVs) can result in physiological changes such as reduced body mass (Bury and Luckenbach 2002, McGrann et al. 2006) and increased stress response (Blickley et al. 2012b, Tull and Brussard 2007), as well as behavioral changes such as altered movement patterns (Grant and Doherty 2009, Naylor et al. 2009, Wisdom et al. 2004), increased vigilance (Dyck and Baydack 2004, Gavin and Komers 2006), increased flight response (Gavin and Komers 2006, Naylor et al. 2009), displacement (Wisdom et al. 2018), and avoidance of road corridors (e.g., Papouchis et al. 2001, Proffitt et al. 2012, Rowland et al. 2004, Webb et al. 2011). Such avoidance can lead to displacement from preferred habitats and increased use of lower-quality habitats. OHV disturbance can lead to greater nest desertion and abandonment by songbirds (Barton and Holmes 2007). Motorized recreation can also cause direct mortality, especially when vehicles are moving quickly (see Bury and Luckenbach 2002, Knisley and Hill 2001, Laabs 2006).

Box 11

Motorized summer recreation has led to the following:

- Habitat loss
- Reduced habitat quality
- Species shift to lower quality habitat areas

Key impacts on areas used as habitat include:

- Soil loss
- Vegetation loss and changes in community composition
- Increases in numbers and abundance of invasive species

Wildlife Habitat Impacts

Motorized summer recreation has led to habitat loss, reduced habitat quality, and shifts to less-preferred habitat. ATVs can cause vegetation and soil loss, shifts to nonnative plant communities, habitat fragmentation, disruption of migration corridors, and altered use of areas for breeding.

According to Switalski (2018), habitat loss from OHV disturbance in drylands (i.e., arid or semiarid ecosystems) has been documented for beetles (Knisley and Hill 2001), bees (Wilson et al. 2009), desert tortoises (Bury and Luckenbach 2002), flat-tailed lizards (Grant and Doherty 2009), snakes (Munger et al. 2003), and deer mice (Laabs 2006). Several ungulate species have been found to avoid motorized road corridors, leading to a loss of habitat for desert bighorn sheep (Papouchis et al. 2001), Sonoran pronghorn (deVos and Miller 2005), mule deer (D'Eon and Serrouya 2005, Webb et al. 2011), and elk (Proffitt et al. 2012; Rowland et al. 2000, 2004). In non-dryland ecosystems, habitat loss resulting from motorized recreation has been

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Riders use motorcycles designed for off-road travel to reach the Colorado backcountry.

documented for birds (Mallord et al. 2007, Martinez-Abrain et al. 2010), while bison were not found to experience habitat loss (Fortin and Andruskiw 2003).

Motorized recreation can degrade the quality of resources provided by habitats, transforming areas from native to nonnative plant communities and leading to increased soil loss (Belnap et al. 2009, Bury and Luckenbach 2002). OHVs have been found to indirectly reduce food sources by facilitating the spread of invasive species (Knisley and Hill 2001, Laabs 2006, Wilson et al. 2009). Mule deer may shift their distribution to lower quality habitats farther from roads (Northrup et al. 2015, Sawyer et al. 2012, Webb et al. 2011), and grouse have been displaced from preferred habitat (Hovick et al. 2014). Roads or hardened surfaces associated with motorized recreation can negatively affect the resources provided by amphibian habitat (Guderyahn et al. 2016).

Motorized recreation can lead to habitat fragmentation, especially for small mammals (Laabs 2006, McGregor et al. 2008). Associated roads and development can isolate populations, increasing vulnerability to extinction (Wilson et al. 2016). One such example is the case of local extirpations of Mojave ground squirrels following drought events in areas with ATV activity (Laabs 2006). Riparian habitats, which often host habitat specialists, can also be affected by motorized recreation, as in the case of two threatened garter snake species (Nowak and Santana-Bendix 2002) and a flycatcher species (USDI FWS 2002).

Although motorized activity can disrupt important migration corridors, note that this disruption is more strongly influenced by highway traffic than is typical of trail-based motorized recreation (Lendrum et al. 2013, Sawyer et al. 2012). However, in open landscapes, noise from OHVs can travel for miles, potentially altering species' use of areas for breeding, reducing overall habitat quality, and contributing toward habitat loss (Barber et al. 2009, Ouren et al. 2007, Reed et al. 2012).

Impacts on Habitat, Individuals, and Populations, by Taxonomic Group

Invertebrates

There are few studies on the impacts of motorized summer recreation on invertebrates. However, invertebrates are the taxonomic group with the third most documented negative effects from recreation overall, with just over half of effects reviewed considered negative (Larson et al. 2016).

Impacts on habitat—

In dryland areas, the most commonly reported indirect impact from OHV disturbance is loss of habitat for wildlife (Switalski 2018). In the Great Basin Desert of northwestern Utah, 163 bee species experienced a loss of nesting habitat (Wilson et al. 2009) and the coral pink sand dunes tiger beetle in southwestern Utah experienced habitat loss (Knisley and Hill 2001) resulting from OHV activity.

Impacts on individuals, populations, and communities—

In semiarid lands, also referred to as dryland areas, beetles and bees have been found to be negatively affected by motorized recreation (Switalski 2018). A study in southern California found five species of beetles to have a decline in population size, diversity, and species evenness (Van Dam and Van Dam 2008). In southwestern Utah, one beetle species experienced direct mortality and reduction of prey (Knisley and Hill 2001). Bees in the Great Basin Desert of northwestern Utah had changes in species and community composition (Wilson et al. 2009). A study in California found greater ant mound densities in areas with low OHV impact (McGrann et al. 2006).

In beach and estuarine areas, motorized recreation has been found to have negative impacts on ghost crabs, while having no effect on bivalves. Beaches with OHV activity on Assateague Island in Maryland and Virginia reduced the density of ghost crabs to 1 crab per 0.1 ha on beaches with pedestrian and light OHV use and 0.3 crabs per 0.1 ha in a heavy OHV-use beach, compared with a base level of 10 crabs per 0.1 ha on undisturbed beaches (Steiner and Leatherman 1981). However, in estuaries of southeastern England, a study found no significant indications that human activity (motorized and nonmotorized), marinas, or footpaths caused variation in the density of bivalves available as prey items for shorebirds (i.e., black-tailed godwit) (Gill et al. 2001).

One study in a highly urbanized area in Russia found a relatively low impact of recreation on ground-dwelling invertebrates. In this study, carabids had lower abundance and species richness in areas with high recreation pressure, and arachnids had an increased abundance (Zolotarev and Belskaya 2015).

Motorized vehicles and roads have been associated with direct mortality for insects.

Motorized vehicles and roads have been associated with direct mortality for insects. Although not in a strictly recreational context, a study in Canada estimated that road mortality may be responsible for the death of billions of pollinating insects annually (Baxter-Gilbert et al. 2015). However, a study focusing specifically on butterflies in grassland areas indicated that areas with high conservation value for butterflies had the least road mortality. Though this was an isolated case, results of this study suggested that sowing of plant species, less frequent mowing, and maintaining a high grassland cover near roads might correspond with reduced road mortality (Skorka et al. 2013).

Amphibians

The effects of motorized recreation on amphibians is generally under-researched (Larson et al. 2016). The presence of nearby roads or hardened surfaces can negatively affect amphibian habitat (Guderyahn et al. 2016). For further discussion, see the "Impacts on habitat" section on page 50.

Reptiles

Impacts on habitat—

Most research on the impact of motorized recreation on reptiles has been conducted in dryland areas. Roads and OHV use are associated with habitat loss for reptiles, including desert tortoises in the Mojave Desert (Bury and Luckenbach 2002), flat-tailed lizards in Southern California (Grant and Doherty 2009), and 12 species of lizards and snakes in Great Basin Desert (Munger et al. 2003). Motorized recreation has also led to the listing of two native species of garter snake in southwestern riparian areas (Nowak and Santana-Bendix 2002).

Habitat loss associated with motorized recreation is a factor in the federal listing of some reptile species.

Impacts on individuals, populations, and communities—

In dryland areas, motorized recreation has been associated with negative effects on reptiles at the individual level. Roads and OHVs are associated with reduced body mass for desert tortoises and flat-tailed lizards (Bury and Luckenbach 2002, McGrann et al. 2006), increased stress in western fence lizards (Tull and Brussard 2007), reduced movement in flat-tailed lizards (Grant and Doherty 2009), and direct mortality for desert tortoises (Bury and Luckenbach 2002).

Motorized recreation in drylands also has demonstrated negative effects on reptiles at the population level. Population decline was documented for desert tortoises (Bury and Luckenbach 2002), and reduced population density for lizard and snake species (McGrann et al. 2006, Munger et al. 2003). In California, greater densities of flat-tailed horned lizards were found in areas with high OHV impact, but lizard mass was greater where OHV impacts were lower. These results suggest that OHV activity may negatively affect lizard body condition (McGrann et al. 2006).

However, in wetland areas, recreation may not negatively affect reptiles such as turtles, at least regarding individual behavior. One study on the banks of the Mississippi River in Illinois found that the intensity of human recreation had no effect on decisions by painted turtles to emerge from the water and nest, or on habitat selection by nesting turtles. This underscores the variability in wildlife responses to human recreation and the need for species-specific and population-specific studies (Bowen and Janzen 2008).

Birds

Motorized recreation can lead to reduced habitat for some bird species. At the individual level, responses can include displacement, nest abandonment, increased stress levels, direct mortality, and failed breeding attempts. Results such as reduced nest initiation suggest potential negative effects at the population level; however, no studies have documented long-term effects at the population level for birds in response to motorized recreation.

Box 12

Both ground-based and aerial motorized recreation can lead to negative effects on birds at the individual level, such as:

- Displacement
- Nest abandonment
- Increased stress levels
- Failed breeding attempts
- Direct mortality

Although most of the literature discussed in this section focuses on ground-based motorized recreation such as cars and ATVs, aircraft can also affect bird behavior. Aircraft commonly provoke alarm responses (Hockin et al. 1992, Owens 1977); however, birds have been observed to nest in marshes, cliffs, and other areas in proximity to aircraft (Altman and Grano 1984, Anderson et al. 1989, Dunnet 1977).

Although it is not within the scope of this report to cover the effects of road-based traffic on wildlife, it is worth mentioning that noise generated from such traffic can affect some bird species. A literature review indicated that (1) road noise negatively affects bird populations in a variety of species, especially during breeding; (2) for species disturbed by road noise, the distance of the effect increases with density of traffic on the road and can extend up to 3000 m from the road; (3) not all species, however, have shown this effect, and (4) some species show the opposite response, with increased numbers near roads (Kaseloo 2005).

Impacts on habitat—

Motorized recreation has been found to reduce habitat for some bird species, particularly ground-dwelling species such as woodlarks (Mallord et al. 2007) as well as tree- and cliff-dwelling birds of prey (Martinez-Abrain et al. 2010). Riparian areas, which often host habitat specialists, can also be affected by motorized recreation, such as in the case of a flycatcher species (USDI FWS 2002).

Impacts on individuals, populations, and communities—

Forest and grassland birds—Several studies found negative effects of motorized recreation on forest and grassland birds at the individual and population level; research in this area has a particular focus on ground-dwelling birds. Effects include nest abandonment, nest desertion, and lower rates of nest predation within 100 m of active OHV trails for songbirds (Barton and Holmes 2007), as well as habitat reduction for woodlarks (Mallord et al. 2007).

For grouse species, disturbance from OHVs and other recreational activity can displace grouse from preferred habitat (Hovick et al. 2014), increase stress levels, and decrease lek attendance because of noise (Blickley et al. 2012a, 2012b); and it can reduce nest initiation and increase the distance moved from leks (Lyon and Anderson 2003). Recreation associated with roads can also degrade sage-grouse habitat by facilitating the spread of invasive plants into native plant communities (Knick et al. 2011).

Waterbirds, shorebirds, and waders—Vehicular recreation (e.g., ATVs and cars) is the primary type of motorized recreation affecting waterbirds, shorebirds, and waders. Powerboats are covered separately in chapter 5. With regard to land-based motorized recreation, three studies were found.

The effects of OHVs on piping plovers is somewhat mixed. On Atlantic coast beaches, OHVs caused direct mortality to piping plovers. Dead chicks were found on beaches with relatively low vehicular use (20 or fewer passes per day). These beaches had intensive management to protect chicks from vehicles, such as people monitoring chicks, posted warning signs, and closing the beach to the public in some cases (Melvin et al. 1994). However, another study found that only one piping plover nest was destroyed by visitors during a 2-year study (Patterson et al. 1991). There was no evidence suggesting that recreational disturbance was a factor affecting productivity.

Public and vehicle access to open landscapes has been shown to negatively affect grazing geese in winter and lowland and upland waders during breeding (Hockin et al. 1992)

Raptors/birds of prey—A review of nesting birds of prey found the most frequent effect of recreation to be decreased time for nest attendance, but effects on breeding parameters were inconclusive (Martinez-Abrain et al. 2010). This study also indicated that nesting birds of prey were displaced from areas close to roads, indicating a reduction in habitat associated with infrastructure that provides recreation access. The displacement distance was larger for big raptors nesting in trees than those nesting in cliffs (Martinez-Abrain et al. 2010). Additionally, golden eagles in southwestern Idaho showed a decline in nest occupancy and reduced breeding success in areas with OHV use and parking areas (Steenhof et al. 2014). However, preliminary results from an experimental test of the effect of off-road motorcycles on northern spotted owls suggested no or low disturbance to nesting success or productivity of five nest sites tested, and only one individual was observed to flush (Delaney and Grubb 2003).

An experimental study of northern goshawks in Plumas National Forest (northeastern California) showed that females and fledglings were sensitive to nearby, intensive recreational activity during the breeding season. Continued ATV use for more than 1 hour, such as during race events, likely has a particularly high impact on northern goshawk nesting behavior. However, results from this study suggested that periodic ATV passes are unlikely to result in significant impacts on individuals; no conclusions were drawn at the population level (Dunk et al. 2010).

Scavengers—In northern Spain, recreational activities were observed to cause failures in breeding attempts by Egyptian vultures. These activities mainly consisted of climbing and hiking, but also included birdwatching, wildlife watching, collecting mushrooms, fishing, hunting, cycling, and the passing or parking of cars, motorcycles, and tractors near nests. These failures were observed for four pairs, two of which were within protected areas, and resulted in the loss of 11 clutches out of 25 breeding attempts. Two of these four pairs changed breeding sites, after which they bred successfully (Zuberogoitia et al. 2008).

Mammals

Impacts on habitat—

Motorized recreation has mixed effects on mammalian habitats. For ungulates in dryland areas, avoidance of motorized road corridors can contribute to habitat loss and has been observed in desert bighorn sheep (Papouchis et al. 2001), Sonoran pronghorn (deVos and Miller 2005), mule deer (D’Eon and Serrouya 2005, Webb et al. 2011), and elk (Proffitt et al. 2012). Sonoran pronghorn were found to avoid areas within 1 km of roads (deVos and Miller 2005).

Ungulates living in mixed forest and grassland areas have been found to have mixed responses with regard to habitat loss. Elk in Oregon were observed to avoid recreationists using ATVs in real time, which represents a form of “habitat compression,” similar to effects described for forest roads open to traffic, and which results in habitat loss for elk (Wisdom et al. 2018). However, bison use across meadows in Saskatchewan was not related to the number of human disturbances and was instead related to water availability in snow-free seasons (Fortin and Andruskiw 2003).

Roads used for recreation or access can diminish habitat connectivity for all sizes of mammals. Improved gravel roads were found to inhibit crossings by mountain lions (van Dyke et al. 1986). Documenting the effects of highways is outside the scope of this report but we acknowledge that these structures, which are used to access recreational areas, can be barriers to movement for large and small mammals, although larger mammals have been documented to cross highways (e.g., Alexander and Waters 2000, ILBT 2013). For small mammals, motorized recreation and associated infrastructure such as paved roads are associated with habitat loss. The Mojave ground squirrel had collapsed burrows, removed cover, and decreased forage availability as a result of OHV use (Laabs 2006). Both white-footed mice and eastern chipmunks were significantly less likely to cross a road than cover the same distance away from roads, owing to the presence of a paved road, as there was no influence from traffic volume and noise level (McGregor et al. 2008).

Roads used for recreation or access can diminish habitat connectivity for all sizes of mammals.

Impacts on individuals, populations, and communities—

Ungulates—At the individual level, ungulates respond to motorized recreation (i.e., ATVs) through a variety of behavioral responses. Studies have reported increased alert responses in bison (Fortin and Andruskiw 2003), increased flight in elk (Preisler et al. 2006, Wisdom et al. 2004) and bison (Fortin and Andruskiw 2003), increased vigilance in pronghorn (Gavin and Komers 2006), lower foraging time in pronghorn (Gavin and Komers 2006) and elk (Naylor et al. 2009), higher rate of movement in elk (Naylor et al. 2009, Wisdom et al. 2004), and displacement in elk (Wisdom et al. 2018). White-tailed deer shifted toward being active throughout the day in a site where motorized trail construction was occurring, as compared to peaks of activity at dawn and dusk observed in a control site (Miller et al. 2020b). Although this activity is different from motorized recreation, this response might compare to intense ATV use, as ATVs were operated throughout trail construction.

Researchers have also found ungulates to have a decreased flight response to frequent motorized traffic along roads. Elk and pronghorn demonstrated reduced antipredator responses (measured by vigilance, flight, travel, and defensive behaviors) with increasing levels of vehicular traffic, along a transportation corridor in Grand Teton National Park. However, these species showed antipredator responses to the presence of pedestrians and passing motorcycles. This could indicate that ungulates either did not associate noise with predation risk, or that continuously responding to vehicle traffic required too much energy, as this was the most frequent and predictable human disturbance (Brown et al. 2012). Elk response to traffic may vary, but their general avoidance of recreationists appears to be consistent.

In some cases, ungulates have decreased flight response to frequent motorized traffic along roads.

One study described a physiological response in ungulates, demonstrating an increasing stress level in chamois (a goat species) with increasing recreational

Bob Wick, Bureau of Land Management

A cyclist rides a battery-assisted "e-bike" through McMinnis Canyons National Conservation Area in Colorado.

activity. In this study, stress levels peaked during the busy summer season, in which recreation consisted primarily of cable cars, but did not specify if noncable-car recreation was motorized or nonmotorized (Zwijacz-Kozica et al. 2013).

At least one ungulate species was found to demonstrate habituation to motorized recreation. Based on analysis of flight distance, guanacos (a llama relative) in Spain were found to develop a tolerance to vehicles and pedestrians in tourist areas, extending about 500 m around visited areas. However, there was a significant reduction in the number of sightings on days with higher park visitation. This suggests potential negative effects at the population level paired with evidence of habituation to pedestrian and motorized activity (Malo et al. 2011). Ungulates may not habituate to disturbance from helicopters in certain situations, as seen in mountain sheep (Bleich et al. 1994) and mountain goats (Côté 1996).

Carnivores—At the individual level, carnivores respond to motorized recreation (i.e., ATVs) through a variety of responses. Although no studies were found on flight distance, responses included altered activity budgets in bobcats and coyotes

(George and Crooks 2006); spatial displacement of bobcats and coyotes (George and Crooks 2006); temporal displacement, with bobcats and coyotes becoming more active at night when recreationists are not present (George and Crooks 2006); and increased vigilance behavior in polar bears (Dyck and Baydack 2004). Panthers also experienced a small but statistically significant effect on resource selection from ATV use by hunters in Florida (McCarthy and Fletcher 2015)

One study reported on a physiological response in a carnivore species. Increased stress levels were found in wildcats in Spain in the zone of a protected area with higher tourism intensity, as well as during the spring gestation period and the autumn young dispersal period (Pineiro et al. 2012). Regarding spatial distribution, no effect of motorized recreational activity was found for Florida panthers and American martens (McCarthy and Fletcher 2015, Zielinski et al. 2008).

One carnivore species demonstrated habituation to motorized recreation. Polar bears habituated to a single vehicle that was stationary for 120 minutes during viewing activities in the fall season (Dyck and Baydack 2004).

Small mammals—At the individual level, the only study we found on small mammals reported direct mortality on mammals that burrow in roadways, such as the Mohave ground squirrel (Laabs 2006).

Some results were reported for small mammals at the population level. Deer mice showed reduced survival and reproductive probabilities during dry years in the Great Basin Desert in response to disturbance from OHV use (Previtali et al. 2010). White-footed mice and eastern chipmunks were not found in lower densities near roads, and chipmunks had higher densities near roads (McGregor et al. 2008).

Potential Effects of Emerging and Under-Researched Motorized Summer Recreation

Types of motorized summer recreation for which potential impacts have not yet been widely empirically researched include side-by-sides, motorized racing, new trail blazing by and for motorized recreation, electric bicycles and other electric vehicles, and helicopters or small aircraft. Below, we apply findings from other types of recreation to hypothesize potential effects of these types of recreation.

- **Side-by-sides** are similar to ATVs but accommodate two people sitting next to each other, giving the vehicle a wider track. Expected impacts would be similar to those of ATVs, with the additional requirement of wider trails, possibly requiring new trails where the existing trail system is too narrow for these vehicles.
- **Motorized racing** introduces a continuous stream of motorized activity during a short period. In an experimental test of the effect of ATV races,

northern goshawks were disturbed by continuous ATV activity near the nesting area, spending less time on the nest during ATV activity (Dunk et al. 2010). We also suggest the possible application of results from a study on the response of Appalachian wildlife to a motorized trail construction project, which used ATVs and other motorized equipment throughout the day. The study found white-tailed deer and coyotes to be less active during trail construction (Miller et al. 2020b). However, motor vehicles were more localized and less numerous in trail construction than they would be during an ATV race. Although the effect of motorized races is not widely studied, species that are sensitive to human activities may be negatively affected during the race. Future work is needed to investigate the long-term effects of races on wildlife populations and communities.

- **New trail blazing by and for motorized recreation** is an issue often related to current trail networks not meeting user demand, and conflicts between users. Being created by users and unregulated by planners and managers, these trails can cross through sensitive habitat, lead to increased erosion and disturbance of natural vegetation, fragment the landscape, and generally enlarge the extent of disturbance. As mentioned above, white-tailed deer and coyotes were found to be less active up to 50 m from the trail during trail construction that uses motorized equipment (Miller et al. 2020b). In this study, no significant response to trail building was found for Viriginia opossums, wild turkeys, and squirrels.
- **Electric bicycles (e-bikes)** are a relatively new form of motorized outdoor recreation. E-bikes are considered a motorized vehicle by federal land management agencies, and have access to motorized trails on these lands. State and local lands often have their own policies on where e-bike use is allowed. E-bike use is new, and some people are not familiar with restrictions on e-bike use in certain areas. Some e-bikers have been observed to use both motorized and nonmotorized trails, with some unauthorized activity in wilderness areas (which occurs with standard mountain bikes as well). E-bikes create less noise than such vehicles as ATVs and thus incur less risk of masking bird vocalizations or causing disturbance to species at long distances. Because e-bikes can reach higher speeds than traditional mountain bikes, some wildlife may show increased behavioral responses to these bikes. By moving at higher speed and requiring less physical effort, e-bikers might also move farther into recreation areas than traditional mountain bikers, potentially dispersing recreation farther from access points. E-bikes can also be used off-trail, in which case some species will likely show increased behavioral response or displacement owing to the unpredictability

of off-trail travel. E-bikes are popular for hunters, enabling them to access more remote areas and remove game species by towing them on a trailer.

- **Other electric vehicles, such as uni-wheels and motorized skateboards**, may be expected to have somewhat similar effects as e-bikes, as they likely produce a similar range of sounds. This may vary with the areas such users frequent, and other behaviors these users engage in.
- **Helicopter or small aircraft tours,** as well as helicopters used for news coverage of recreational events, can affect wildlife. Motorized airborne recreation has been found to have little or no effect on birds of prey (Grubb et al. 2010, Kochert et al. 2002), although helicopters can result in increased alert and flight behavior in osprey (Trimper et al. 1998) and displacement in gyrfalcons (Platt 1977). Red-tailed hawks and golden eagles have been found to habituate to helicopter overflights (Anderson et al. 1989, Grubb et al. 2010). Small aircraft activity was associated with increased aggressive behavior in osprey and golden eagles (Bruderer 1978, Trimper et al. 1998). Ungulate response to helicopter disturbance varies by the species, season, quality of nearby cover, level of activity, and altitude and distance of aircraft from the animal (Bleich et al. 1994, Côté 1996, Foster and Rahs 1983, Frid 2003). Mountain sheep (Bleich et al. 1994) and mountain goats (Côté 1996) may not habituate to disturbance from helicopters. Response can depend on the setting of the interaction; sheep were less likely to flee from indirect helicopter flights when on rocky slopes as opposed to when they were far from this refuge from predators (Frid and Dill 2002). Helicopter overflights were associated with a decline in mountain goat reproduction and recruitment in Montana (Joslin 1986), and disturbance of mountain goats by most flights within 500 m in Alberta, Canada (Côté 1996).
- **UAVs**, also known as drones, are increasingly being used in outdoor areas. UAVs fly at low altitudes (<500 m) in any terrain and can interact with fauna. Existing literature on this subject (Mulero-Pazmany et al. 2017) indicated that wildlife reactions depend on attributes of the UAV (e.g., flight pattern, engine type, and size of aircraft) and characteristics of the animal (i.e., type of animal, life-history stage, and level of aggregation). The strongest wildlife reactions were evoked by target-oriented flight patterns, larger UAV size, and noisier engines (those powered by gasoline). Birds were more prone to react than other taxa, and animals were more likely to show behavioral responses when they were in the nonbreeding season and in large groups, although one study found that colonial waterbirds did not increase flight behavior in response to UAVs flown in horizontal transects for surveys (Barr et al. 2020). Compared to other types of human disturbances, research suggests that UAVs evoke flight in wildlife species at distances similar to those recorded for on-foot approaches, and

smaller than for manned aircraft and car approaches (Mulero-Pazmany et al. 2017). Another recent article found that in addition to altitude, distance, and species, vegetative structure was another important factor in predicting mammalian response to UAVs, with African mammals, (elephant, giraffe, wildebeest, and zebra) more likely to avoid UAV approaches than to be vigilant in open areas (Bennitt et al. 2019).

Comparison of Summer Activity Types

Recreational activities that occur during the summer and shoulder seasons (i.e., warm weather recreation) are highly diverse. Thus, the characteristics of recreation during this time of year are wide ranging. Here we highlight the results of several studies that have compared the relative effects of warm weather recreation on wildlife. For additional general trends, refer to "Factors Influencing Wildlife Response to Recreation" in chapter 2.

Birds—

Two separate studies on bald eagles found that humans on foot were the most disturbing type of recreation, followed by aquatic recreationists (including motorized and nonmotorized activities), vehicles, and aircraft (Stalmaster and Kaiser 1998, Steidl and Anthony 1996). Thus, it appears that a similar pattern holds true as with ungulates, with humans on foot cited as the strongest source of disturbance (Harris 2014, Stankowich 2008). However, motorized activities may create a wider ranging disturbance, if birds become alert or vigilant due to the noise created by these activities.

In northern California, female goshawks were threatened by direct approaches by hikers, particularly two hikers, toward the nest, but did not respond negatively to direct approaches by ATVs (Dunk et al. 2010).

Mammals—

Ungulates—Cervid species' general avoidance of recreationists appears to be consistent, while their response to motorized traffic may vary (Brown et al. 2012; Pelletier 2006; Rowland et al. 2000, 2004). Motorized recreation has been found to have stronger effects on elk and bison (Fortin and Andruskiw 2003; Naylor 2006; Wisdom et al. 2004, 2018), with elk having the strongest response to ATVs, followed by mountain bikers, on-trail hikers, and equestrian use in a controlled experiment (Naylor 2006; Wisdom et al. 2004, 2018). However, humans on foot were found to incite more flight behavior in ungulates than stimuli from vehicles and noise (Stankowich 2008).

Small mammals—In high-use recreation areas, alpine marmots reacted least to hikers on trails, followed by off-trail hikers (especially when such hikers crossed the main burrows of animals), and had the most severe reaction to hikers with dogs, especially when dogs were on a long leash (Mainini et al. 1993).

However, making generalizations about the relative effects of different types of recreation on wildlife is difficult. A study in northern California emphasized the importance of species-specific and case-specific analyses, reporting the following results (Reilly 2015):

- Mountain lions and mule deer were negatively associated with the amount of hiking.
- Raccoons were negatively associated with the amount of mountain biking.
- Striped skunks were less abundant in the presence of hikers with dogs.
- Gray foxes and coyotes became more active at night in response to any level of recreation.
- Mule deer were sensitive to any level of human recreation.

Anna Miller

Winter visitors to Arches National Park, Utah. Wildlife in this ecosystem change their activity in winter, such as snakes and lizards, which go into a state of torpor.

Chapter 4: Winter Recreation

Nonmotorized Winter Recreation

The second most popular category of recreational activity on national forests in the United States, nonmotorized winter recreation, accounts for about 18 percent of the main activities of visitors (table 2.3) (USDA FS 2016). Recreation in this category can be divided into two groups: developed-area activities (i.e., downhill skiing, cross-country skiing, snowboarding, snowbiking), and undeveloped-area activities (i.e., snowshoeing, downhill skiing, glade skiing, cross-country skiing, snowboarding, skijoring, split-board skiing, kite skiing, and off-trail snowbiking). According to the Forest Service's National Visitor Use Monitoring (NVUM) survey, downhill skiing and snowboarding account for the bulk of this type of recreation. Cross-country skiing and snowshoeing are popular as well but may not be well documented by the NVUM survey. National forests host about 40 percent of the 56.5 million annual skier and snowboarder visits in the United States (Belin 2014, Chapagain et al. 2018), amounting to nearly 23 million annual visits to National Forest System lands. As nearly one-fourth of the 470 ski areas operating in the United States operate within national forests (Belin 2014), understanding how to manage interactions between this type of recreation and wildlife is important.

Box 13

Winter recreation has a greater impact on wildlife than summer recreation owing to some of the following factors:

- Species are under more stress energetically during the winter.
- Food availability and quality are reduced.
- As limited relocation areas are available in winter, wildlife may not be able to avoid human activity.

Participation in nonmotorized winter recreation is increasing at relatively high rates (39 percent increase in participant days for developed skiing projected for 2008–2030, 29 percent increase for undeveloped skiing, compared with 12 percent increase for motorized snow use). Both types of skiing generate relatively high economic benefits for local communities, with developed skiing having the highest per party per trip spending for non-local day and overnight trips, and local day and overnight trip spending second only to motorized snow use. Spending by parties participating in undeveloped skiing is somewhat lower than developed skiing and motorized snow use, but high relative to summer nonmotorized recreation. Combining this increase in participation with the relatively high level of spending per party per trip, nonmotorized winter recreation is lucrative for local communities and others who receive economic benefits from the outdoor recreation industry (see fig. 2.4 for comparison of economic contributions and projected increase in participation with other recreational activity categories) (White and Stynes 2010).

Undeveloped snow sports (i.e., cross-country skiing and snowshoeing), along with snowmobiling, are the recreational activities most adversely affected by climate change (Askew and Bowker 2018). Understanding interactions between recreationists and wildlife will be increasingly important in shrinking snow-covered areas and seasons (Miller et al., n.d.). Understanding recreation and wildlife vulnerabilities associated with climate change can help public land planners and managers develop adaptation strategies (Askew and Bowker 2018, Halofsky et al. 2018).

Nonmotorized winter recreation also provides health and social benefits to participants. For example, regularly participating in downhill skiing may contribute toward healthy aging, as it is associated with a healthier lifestyle with higher levels of physical activity. Downhill skiing also has emotional and social benefits, similar to other forms of outdoor recreation (Burtscher et al. 2019). Downhill skiers volunteer as patrollers to assist in rescue on ski slopes (Hawkins 2012), and both cross-country skiers and snow-based fat-tire bikers are involved or interested in volunteering to assist in trail maintenance (Neumann and Mason 2019).

In winter months, nonmotorized recreation continues in areas without snow, such as on beaches, in temperate areas, and in low-elevation areas. Although our focus in this section is primarily on snow-based recreation, we include effects of some non-snow-based winter recreation, specifically with regard to shorebirds. In some cases, we also include effects of winter recreation infrastructure, such as ski slopes, parking lots, and roads, on wildlife habitat outside of the winter season.

General Impacts of Nonmotorized Winter Recreation on Wildlife

Disturbance to wildlife is of particular concern in winter, when many species are under considerable stress.

Disturbance to wildlife is of particular concern in winter, when many species are under considerable stress (Goodrich and Berger 1994). Some species show a dampened response to human activity in the winter, likely because of energetic tradeoffs (e.g., Lafferty 2001a). Food availability and quality is lower during winter for many species, which limits their options to relocate to areas without human activity (e.g., Thiel et al. 2008). This is true for wildlife in a wide range of geographic locations, in areas with or without snow cover in winter.

Larson et al.'s (2016) literature review of recreation impacts found winter terrestrial activities to be more highly associated with effects on animals than summer terrestrial or aquatic activities. Their review also found nonmotorized snow-based activities to be less responsible for negative effects than motorized snow-based recreation, with a proportion of negative effects similar to that of other nonmotorized forms of recreation. More than half the articles on winter recreation reviewed by Larson et al. (2016) reported overall detrimental effects, especially on birds, as well as on species richness and diversity.

Many alpine and subalpine areas support endemic communities of taxa such as reptiles, birds, and invertebrates (Sato et al. 2013; Strong et al. 2002a, 2002b). These ecosystems are shrinking in extent as global temperatures rise, and snow lines are moving upslope (IPCC 2014, UNEP 2007). In response, adaptation strategies for improving and lengthening the winter recreation season are being implemented in some areas, including artificial snowmaking and concentrating ski areas at higher elevations (Steiger et al. 2019). However, these strategies may adversely affect fauna by limiting the area of undisturbed habitat available for endemic species sensitive to human disturbance (Sato et al. 2013).

Although creation or enlargement of ski areas results in the loss of natural wildlife habitats, some species have been found to habituate to human activity, such as elk (Morrison et al. 1995) and corvids (Rolando et al. 2003), and some species are attracted to recreation structures typical of ski resorts. These include sheep, reindeer, mountain hares, and several alpine bird species (e.g., black redstart, northern wheatear, snowfinch, and Alpine chough) (Rolando et al. 2007, Watson 1979).

Wildlife habitat impacts—
A meta-analysis reported that ski slope management and modification (i.e., slope and snow grooming) and winter recreational sports (i.e., snowshoeing, skiing, snowboarding, and snowmobiling) were more likely to have negative than positive impacts on wildlife (Sato et al. 2013). The presence of resort infrastructure (i.e., roads, buildings, and ski lifts) also had a predominantly negative effect on wildlife, although this was not statistically significant (Sato et al. 2013). Ski run development is similar to disturbance caused by clearcutting, with the added long-term effects of ongoing disturbance, maintenance, and snow compaction (Hadley and Wilson 2004a). Because vegetation regenerates slowly in alpine and subalpine areas, where

Box 14

Infrastructure for winter recreational sports can lead to the following:

- Habitat loss or fragmentation
- Alteration of habitat quality
- Shift in species composition from specialists to generalists
- Shift to urban bird species
- Shift to open habitat dwellers for small mammals
- Decreases in species richness and diversity

ski slopes typically are developed, habitat degradation associated with winter recreation might be more severe than that caused by recreational activities in other climates (Billings 1973, Sato et al. 2013).

Habitat modification to accommodate nonmotorized winter recreation can cause habitat loss for reptiles (Amo et al. 2007), ground-dwelling birds (Braunisch et al. 2011, Patthey et al. 2008), and mammals (Nellemann et al. 2000); habitat fragmentation for small mammals (Mansergh and Scotts 1989) and some beetle species (Strong et al. 2002b); and altered habitat quality for invertebrates (Caravello et al. 2006, Rolando et al. 2013), reptiles (Shine et al. 2002) and small mammals (Sanecki et al. 2006). Modifications can lend to a shift in species from habitat specialists to generalists in invertebrates (Haslett 1991, Kasak et al. 2013, Kessler et al. 2012), shifts toward urban bird species (Ballenger and Ortega 2001, Jokimäki et al. 2007, Watson 1979), and shifts from closed to open habitat dwellers for small mammals (Hadley and Wilson 2004b, Rolando et al. 2013). Particularly for invertebrates and birds, these shifts might represent a homogenization of biodiversity near ski areas.

Trails created for nonmotorized winter recreation can alter mammalian habitat use, with animals that have a higher footload (body mass per foot of surface area)

Greg Hayward

A backcountry skier takes in the stillness of a winter day in south-central Alaska.

(Richens and Lavigne 1978, Whiteman and Buskirk 2013) (see page 104 in "Mammals" section below). Wires and cables from ski lifts can also cause direct mortality to birds (Miquet 1990, Watson and Moss 2004).

However, research has also shown an absence of effects of habitat modification associated with ski resorts on some species, as well as attraction of some species to ski areas (Ballenger and Ortega 2001, Jokimäki et al. 2007, Ukkola et al. 2007, Watson 1979). Variation between years within one study highlights the importance of multiyear studies (Ukkola et al. 2007). Additionally, discrepancies of results between studies, sites, and species show the importance of considering case-specific environmental, human, and wildlife variables.

Community-level impacts—

A systematic review and meta-analysis conducted in 2013 investigated reported impacts of nonmotorized winter recreation on fauna in alpine and subalpine areas. This review found that richness and diversity of subalpine fauna were significantly lower in winter recreation areas compared with undisturbed areas. Studies generally reported negative effects for birds and annelids, negative or variable effects on arthropods, and negative or nonsignificant effects on mammals. The effects on reptiles, nematodes, and protozoans were variable and did not show consistent trend patterns. Regarding population and community measures, birds were more likely to have negative impacts, while impacts on mammals were almost equally likely to be positive or negative (Sato et al. 2013).

Species richness and diversity of subalpine fauna have been found to be significantly lower in winter recreation areas compared with undisturbed areas.

Impacts on Habitat, Individuals, and Populations, By Taxonomic Group

Note: No published studies on the effects of nonmotorized winter recreation on amphibians were identified.

Invertebrates

Research on the effects of nonmotorized winter recreation on invertebrates is based largely in Europe. We present that research here, as effects might be similar to those in North American ecosystems. We note the location of each study for reference.

Arthropods responded negatively to disturbance from winter recreation, but to a lesser extent than birds (Sato et al. 2013). Effects of nonmotorized winter recreation on invertebrates are reported according to their effects on habitats and communities, but not at the level of individuals and populations. Most studies reviewed here focused on arthropods and found primarily negative effects, as well as some neutral and positive effects, depending on the requirements of different species.

Impacts on habitat—

Ski trails can be a barrier to dispersal for flightless and short-winged forest-dwelling beetles, potentially leading to habitat fragmentation, as found in Vermont (Strong et al. 2002b). Poor grass cover on ski slopes can hinder the colonization of ground-dwelling arthropods, potentially affecting the functioning of high-altitude ecosystems and conservation of endemic species in the Alps mountain range in Europe (Rolando et al. 2013). Caravello et al. (2006) reported that the use of artificial snow on ski slopes in the Alps can result in temporal shifts in the renewal of biotic activity, compared with neighboring areas that do not have snow.

Impacts on individuals, populations and communities—

Arthropods—Several studies have indicated a shift from habitat specialist to generalist species, more mobile species, and herbivores, implying homogenization of biodiversity as a result of ski run management in the Austrian Alps (Haslett 1991, Kessler et al. 2012) and mountains of central Europe (Kasak et al. 2013). Fragmentation of habitats by ski trails for flightless and short-winged beetles could put isolated populations at a greater risk of local extirpation, especially when ski trails run perpendicular to the climatic gradient, as was found in Vermont (Strong et al. 2002b).

The effects of ski slopes on arthropod species diversity patterns differ by family, although the utility of this parameter is questioned. Three studies in the Alps found negative effects of ski slopes on species diversity for orthopteran species, brachypterous carabids, and spiders. Orthoptera had significantly lower species richness on ski slopes than on control plots, with further decrease in species richness associated with the use of artificial snow (Kessler et al. 2012). Brachypterous carabid diversity parameters were lower in open ski slope areas, compared with the forest interior (Negro et al. 2009). Diversity of brachypterous carabids, spiders, and grasshoppers decreased significantly from natural grasslands to ski slopes. Low grass cover of ski slopes was a hindrance to colonization by spider, grasshopper, brachypterous, and some macropterous carabid species. These results support concern about the possible disruption of local ecosystem functionality and conservation of endemic arthropod species (Negro et al. 2010).

Three studies in the Alps and Poland found positive effects of ski slopes on spiders and macropterous carabids. A study in Poland found that the use of artificial snow did not affect the species composition or abundance of spiders, and reported that many rare spiders occurred in the transition zone between forest and ski slope (Szymkowiak and Gorski 2004). At ski resorts in the Italian Alps, spider and macropterous carabid diversity parameters were higher in open ski slope areas, compared with the forest interior, and were best explained by grass cover and ski slope width (Negro et al. 2009). Another study by the same research group indicated that diversity of the macropterous carabid guild was higher in natural grasslands than in ski slopes. This group of species has contrasting ecological requirements to brachypterous carabids, spiders, and grasshoppers (Negro et al. 2010).

However, Haslett (1997) argued that species richness and other indicators of diversity are not a good way to characterize ecological communities, as such measures have been found to be consistent between ski slopes and control areas for such invertebrate species as annelids (Caravello et al. 2006), syrphid fly species (Haslett 1991), and carabid beetles (Hammelbacher and Mühlenberg 1986).

Annelids and nematodes—We identified two studies investigating the effects of ski slope management on non-arthropod invertebrates, reporting either moderately negative or neutral results for annelids and nematodes. A study on ski slopes with artificial snow in the Italian Alps found a temporal change in the renewal of biotic activity within the ski run area because snow remained longer on ski slopes than on nearby meadows. This study used earthworms (annelids) as an indicator species and found that earthworms on ski runs were in lower numbers than in control meadows in the summer, but this difference diminished by mid-fall (Caravello et al. 2006). In the Pirin Mountains of Bulgaria, no clear correlation was found between nematode assemblage characteristics and level of disturbance when areas next to and outside of ski runs were compared (Mincheva et al. 2009).

Reptiles

Impacts on habitat—

Nonmotorized winter recreation can lead to loss of optimal habitat for reptiles (Amo et al. 2007, Sato et al. 2013), and can alter existing habitat when areas are cleared for ski runs (Shine et al. 2002). Habitat alterations on ski slopes are likely to suppress local lizard abundances, especially for habitat specialists (Sato et al. 2014). However, retaining habitat structure and minimizing disturbance to native vegetation can help lizards persist in these areas (Sato et al. 2014).

Impacts on individuals, populations, and communities—

- An endemic endangered lizard had reduced body condition in ski slope areas in Spain. Habitat deterioration on ski slopes implied a loss of habitat for lizards and led to an increase in perceived risk of predation (Amo et al. 2007).
- When corridors are cleared for ski slopes, increased solar radiation on potential reptile nesting sites can enable oviparous reptiles to nest higher in montane areas and may eventually modify the genetic structure and demography of populations (Shine et al. 2002).

Birds

Ski slopes in alpine and subalpine areas are associated with a shift toward more urban bird species.

According to a meta-analysis of the effects of nonmotorized winter recreation on subalpine species, birds respond negatively to disturbance from winter recreation (Sato et al. 2013). Development and presence of ski slopes in alpine and subalpine areas are associated with a shift in species composition to higher numbers of urban bird species (particularly corvids) (Ballenger and Ortega 2001, Jokimäki et al. 2007, Watson 1979), declining forest bird diversity (Laiolo 2007), and declining grassland bird species richness (Caprio et al. 2011). This pattern suggests that nest predation by corvids could contribute toward local declines in other passerine bird species (Ballenger and Ortega 2001). Shorebirds exhibit dampened responses to humans during winter (Beale and Monaghan 2004, Lafferty 2001a, Stillman and Goss-Custard 2002).

Impacts on habitat—

Development of ski areas has been found to cause habitat reduction in black grouse. This species avoided ski lifts and areas frequented by free-ranging snow sports, reducing the amount of habitat by 10 percent (Braunisch et al. 2011). In another study, ski lift density and habitat typology had strong negative effects on the number of displaying male black grouse, and male grouse abundance was 36 percent lower in ski lift areas than in areas with no ski lifts, on average (Patthey et al. 2008).

However, other researchers found that grouse species do not appear to be affected by ski resorts, but may be more highly influenced by the landscape uses surrounding the ski resort, having positive correlation with the proportion of mixed forest (Ukkola et al. 2007, Watson 1979). In cases where richness and abundance of arthropods are reduced on ski slopes, low food availability likely reduces the attractiveness of these patches for arthropod-eating bird species (Rolando et al. 2007).

Impacts on individuals, populations, and communities—

Ground-dwelling birds—The effects of nonmotorized winter recreation on ground-dwelling birds, especially those in the grouse family, have been studied by several research groups. Grouse species have been found to flush in response to recreation (Thiel et al. 2007), avoid areas with high recreational activity (Thiel et al. 2008), and increase feeding time following disturbance (Arlettaz et al. 2007). Black grouse and capercaillies have been found to have increased stress levels following disturbance from nonmotorized winter recreation (Arlettaz et al. 2007, Thiel et al. 2008), and capercaillies have shown indications of sensitization to human disturbance (Thiel et al. 2007). However, ski tourism did not affect the location of capercaillie home ranges in the Black Forest in Germany (Thiel et al. 2008).

Brock McCormick

This ski lift has red components inside that appear to attract and entrap hummingbirds.

Ptarmigans, another member of the grouse family, are negatively affected by alterations associated with ski areas. In Scotland, ptarmigan populations in four areas were compared, three with varying levels of human activity and development and a fourth located far from a ski area. In the three ski-proximate sites, the number of carrion crows was high, and ptarmigans experienced nest predation, reared abnormally few broods, and did not exhibit their normal 10-year population cycle.

These effects decreased somewhat with distance from the main parking lot. In the site farthest from the ski area, there were few or no crows, ptarmigans bred as well as in undisturbed sites, and their population cycles were the same as in undisturbed areas (Watson and Moss 2004). Another corvid species also seemed to benefit from ski resorts, displaying reduced movement near ski resorts likely because human food scraps were available to them (Laiolo 2007).

Ski lift wires and cables can cause mortal collisions for grouse (Buffet and Dumont-Dayot 2013, Miquet 1990), ptarmigans (Watson and Moss 2004), and partridges (Buffet and Dumont-Dayot 2013). In France, black grouse and capercaillie had the highest losses, mostly associated with button lifts (also known as T-bars), which have poles spaced along a cable to pull skiers up the slope (Buffet and Dumont-Dayot 2013). A method for reducing this source of mortality might be attaching red markers on various parts of ski lifts to increase their visibility (Buffet and Dumont-Dayot 2013); for more detail, see "Guidelines for Specific Recreational Activities" in chapter 6.

At the community level, ski resorts are associated with a decline in forest bird diversity (Laiolo 2007).

Waterbirds, shorebirds, and waders—Few studies were found on the effects of nonmotorized winter recreation on waterbirds, shorebirds, and waders. These studies suggested that bird responses to humans in winter may be dampened by their need for food. On beaches near Santa Barbara, California, wintering snowy plovers reacted to human disturbance at half the distance reported for plovers during the breeding season (Lafferty 2001a). Oystercatchers in England showed decreasing reactions to human disturbance as winter progressed (Stillman and Goss-Custard 2002). A controlled experiment in Scotland found that wintering ruddy turnstones who were given food responded more to human disturbance than did those in a control site (Beale and Monaghan 2004).

Mammals

Mammals in subalpine areas generally respond negatively to disturbance from nonmotorized winter recreation, but to a lesser extent than birds.

According to a meta-analysis on the effects of nonmotorized winter recreation on subalpine species, mammals generally responded negatively to disturbance from winter recreation, but to a lesser extent than birds (Sato et al. 2013). Development of ski slopes can result in loss and fragmentation of habitat for some mammals (e.g., Hadley and Wilson 2004a, Heinemeyer et al. 2019, Nellemann et al. 2000). Nonmotorized winter recreation is sometimes associated with altered movement (e.g., Whiteman and Buskirk 2013), behavior (Reimers et al. 2003), site use (Nellemann et al. 2000), denning behavior (e.g., Goodrich and Berger 1994), and spatial and temporal displacement (e.g., Neumann et al. 2011, Olson et al. 2018). This type of recreation can affect community composition (e.g., Hadley and Wilson 2004a). Mammals have been found to habituate to predictable nonmotorized winter recreation (e.g., Schultz and Bailey 1978), but not in all cases (Neumann et al. 2011). Lack of response to nonmotorized winter recreation has also been documented (e.g., Fortin and Andruskiw 2003).

Impacts on habitat—

Development of nonmotorized winter recreation areas such as ski slopes and trails can alter movement patterns, fragment habitats for small mammals, contribute toward habitat loss for some mammals, and increase available habitat for others.

Trails created for nonmotorized winter recreation can alter the behavior of mammals. Animals with a higher footload were more likely to use trails where snow was compacted by snow-based recreation, and followed trails for somewhat longer distances than animals with lower footloads (Whiteman and Buskirk 2013). This was the case for white-tailed deer when trails were near major bedding areas (Richens and Lavigne 1978).

When forests are cleared to create ski slopes, landscapes become fragmented and the amount of forest habitat is reduced. Ski run development is similar to disturbance caused by clearcutting, with the added long-term effects of ongoing disturbance, maintenance, and snow compaction (Hadley and Wilson 2004a). Moose avoidance of a high-altitude ski resort in Norway implies reduction of habitat and may involve long-term impacts such as reductions in carrying capacity (Nellemann et al. 2000). Although some small mammals appear to avoid ski slopes, open habitat species are able to colonize these areas. Species that avoid open areas may inhabit ski areas if tree islands are retained and woody debris is incorporated (Hadley and Wilson 2004b, Rolando et al. 2013). In cases where the snowpack is shallow, super grooming of slopes, which sometimes entails burning or raking underbrush, further alters the ecosystem and can remove the subnivean region that some small mammals use during the winter (Gaines et al. 2003, Sanecki et al. 2006, Schmid 1972). These studies suggest the importance of maintaining vegetation complexity in the understory to retain habitat for small mammals.

Fragmentation is particularly important for small mammals and species with meta-population structures. In Australia, the social organization and survival rates of a rare marsupial were disrupted by habitat fragmentation associated with ski resort infrastructure. This problem was remedied by constructing a corridor leading to two tunnels beneath a road that had bisected the breeding area (Mansergh and Scotts 1989).

Changes in the proportions of small mammal populations can result from ski slope development. In a study on two 30-year-old ski slopes in Colorado, ski runs had lower densities of red-backed voles and higher densities of deer mice and least chipmunks than adjacent forest sites. Voles were captured only in forest edges of ski runs (Hadley and Wilson 2004a).

In Finland, distance from a ski resort did not have negative effects on mountain hare, pine marten, mustelids, and red fox, and densities of these species were affected more by the landscape uses surrounding the ski resort. In this study, the densities of mountain hare and mustelids were higher near ski resorts, but there was no apparent influence of proximity to ski resorts on the density of four grouse species, pine marten, and red fox. Density of most species (mountain hare, red fox, and mustelids) varied between years, highlighting the importance of multiyear studies (Ukkola et al. 2007).

Habitat alterations from ski slopes can also attract some species. Sheep, reindeer, and native mountain hares were found in higher abundance in areas disturbed by ski developments in the Scottish Hills than in undisturbed areas, concentrating on small patches treated to reduce soil erosion (Watson 1979).

Backcountry recreation in Idaho, Montana, and Wyoming was found to result in habitat loss for wolverines, especially females. Wolverines responded more strongly to off-road recreation than to road-based recreation, and responses increased with increasing levels of backcountry winter recreation. However, the effective habitat loss was greater in response to motorized recreation than nonmotorized recreation (see also “Comparison of Winter Activity Types” below) (Heinemeyer et al. 2019).

Impacts on individuals, populations and communities—

Ungulates—Nonmotorized winter recreation can have minimal effects on ungulates when sufficient habitat without human activity is available. However, if there is not sufficient disturbance-free habitat and if animals are displaced to areas with lower quality resources, such recreation can negatively affect individual health and survival during winter, potentially contributing to population decline (Harris et al. 2014). Guidelines describing situations when winter recreation is potentially detrimental to ungulates were described by Harris et al. (2014) (see “Comparison of Winter Activity Types”).

Ungulates have been found to change their behavior in response to nonmotorized winter recreation.

Ungulates have been found to change their behavior in response to nonmotorized winter recreation. Reindeer can become alert to human activity (Reimers et al. 2003), and bison and reindeer may flee from human approach (Fortin and Andruskiw 2003, Reimers et al. 2003). Woodland caribou exhibit increased vigilance at the expense of foraging and resting time, with foraging time decreasing as the number of recreationists increases (Duchesne et al. 2000). Female bison and moose have increased movement in the presence of nonmotorized winter recreation, measured in daily radius of movement for bison (Fortin and Andruskiw 2003) and rate of movement for moose (Neumann et al. 2011). Areas of daily movement of bison herds containing juveniles were also larger year-round (Fortin and Andruskiw 2003). For moose, the increased rate of movement lasted up to 2 hours (Neumann et al. 2011). Responses of both bison and moose to recreation differed by individual, with those individuals that fled human approach having a larger increase in rate of movement (Fortin and Andruskiw 2003, Neumann et al. 2011).

Ungulate distribution and site use have been altered by the development of ski resorts. In Vail, Colorado, elk nearly disappeared from the most highly developed area in the first year following ski area development. Elk used the area least when human activity was highest (Morrison et al. 1995). In Norway, reindeer distribution and site use were altered within a 10-km zone surrounding a high-altitude resort, with females and calves showing the most substantial changes and maternal reindeer avoiding the zone entirely. This avoidance implies reduced forage intake during winter and lower herd productivity. These results suggest that avoidance of human use areas by wildlife may involve long-term impacts, such as reduced carrying capacity (Nellemann et al. 2000).

Displacement of ungulates by nonmotorized winter recreation has been documented. Moose were temporarily displaced by off-trail hiking in northern Sweden (Neumann et al. 2011) and were permanently displaced by cross-country skiing in a park in Alberta, Canada (Ferguson and Keith 1982). In eastern Canada, woodland caribou were increasingly displaced (including into valleys with higher abundance of predators) by backcountry skiing as the number of recreationists increased (Lesmerises et al. 2018), but were not displaced by guided ecotourism groups (Duchesne et al. 2000). For elk, Cassirer et al. (1992) found that the frequency of use and proportion of winter range used by skiers seemed to have a greater impact than the number of skiers. Although displacement effects are generally short term, repeated displacement may result in higher energy expenditure (Neumann et al. 2011). However, ungulates have been found to habituate to predictable recreational activities (Harris et al. 2014), suggesting that repeated displacement to the extent of reducing fitness is unlikely.

For situations in which ungulates habituate to predicable recreation, repeated displacement to the extent of reducing fitness is unlikely.

Studies have indicated that ungulates can habituate to recreational activity that is visually or acoustically predictable in location and time (Cassirer et al. 1992, Epsmark and Langvatn 1985, Schultz and Bailey 1978). Indications of habituation have been documented for woodland caribou in response to winter ecotourism (Duchesne et al. 2000) and elk in response to cross-country skiing (Cassirer et al. 1992) and human use of a ski area (Morrison et al. 1995). Moose did not habituate to off-trail hiking in northern Sweden (Neumann et al. 2011). Hunted elk appear to acclimate more to physical disturbances such as ski slope development than to human disturbances such as recreational activity and human presence (Morrison et al. 1995).

Although less frequently reported, some ungulates have shown no response to nonmotorized winter recreation. In bison, frequency of disturbance from winter recreationists did not have an important impact on resource use, and the number of human disturbances was not related to variation in bison use across meadows. Bison density was instead related to environmental factors such a snow depth in winter and water availability in snow-free seasons (Fortin and Andruskiw 2003). Additionally, avoidance of human-induced disturbances by moose in good condition were thought to have negligible effects on their overall energy budget, because their response to human-induced disturbances was short in duration (Neumann et al. 2011).

Carnivores—Carnivore habitat use, daily activity, denning behavior, and population densities can be affected by nonmotorized winter recreation.

Wolverines in British Columbia responded negatively to human disturbance within their occupied habitat. Whereas male wolverine habitat use was most closely associated with food availability in both summer and winter (e.g., moose ranges), their habitat use was also negatively associated with helicopter skiing areas (see "Motorized Winter Recreation" and "Comparison of Winter Activity Types" below). Female wolverine habitat use was also influenced by food availability, as well as predation risk and human disturbance, and females were negatively associated with helicopter and backcountry skiing areas (Krebs et al. 2007). Wolverines avoided areas with nonmotorized winter recreation in a study in Idaho, Montana, and Wyoming (Heinemeyer et al. 2019).

Lynx appear to avoid direct interactions with winter recreationists by altering behavioral and temporal patterns. In areas with high-intensity backcountry skiing, lynx had decreased movement rates and were more active at night. Lynx avoided high-intensity developed ski resorts, but selected areas near nonmotorized recreation trails (Olson et al. 2018).

Several studies have found winter recreation to disrupt bear denning behavior. Black bears near ski areas in California and Nevada entered dens earlier and were more selective in their choice of den site than those farther from ski areas and winter recreation. Both populations abandoned dens and cubs in response to investigator disturbance, indicating that bears are likely sensitive to human activity from winter recreation (Goodrich and Berger 1994). In Alberta, black bears that abandoned dens lost more weight during winter than those that did not (Tietje and Ruff 1980). Disturbance of bears during their transition into hibernation may result in death from starvation and urea poisoning (Lundberg et al. 1976). Some studies have shown that bears find new dens after abandonment (Hellgren and Vaughan 1989, Kolenosky and Strathearn 1987), while others found the opposite (Goodrich and Berger 1994).

Near ski resorts in Finland, the overall density of mustelids was heightened. Considering individual species of small mammals, neither red fox nor pine marten populations were found to differ with proximity to ski resorts. Additionally, pine marten and overall mustelid density decreased with proportion of agricultural land (Ukkola et al. 2007).

Small mammals—Several studies have indicated that ski slopes are associated with negative impacts on small mammals during the winter. Mountain hares living in areas with frequent human winter recreation showed physiological and behavioral changes that have additional energy requirements in winter, when access to food resources is limited by snow (Rehnus et al. 2014). Three species of voles and shrews were found to be absent from ski slopes, although they were found in the surrounding edges and forests in a study in the Alps (Negro et al. 2009). Bank voles and pygmy shrews have been found to avoid ski slopes, but the open areas created by these slopes may attract other ground-dwelling small forest mammals such as the red-backed vole (Rolando et al. 2013). Water shrews can also be negatively affected by snow compaction resulting from skiing and snowshoeing (Gaines et al. 2003, Schmid 1972).

Potential Effects of Emerging and Under-Researched Nonmotorized Winter Recreation

Types of nonmotorized winter recreation for which potential impacts have not yet been empirically researched include fat-tire bikes, glade skiing, skijoring, kite skiing, and splitboard skiing. These are primarily backcountry activities and can often occur outside of designated trails and recreation areas, sometimes involving the unauthorized clearing of vegetation. Below, we apply findings from other types of recreation to hypothesize potential effects of these types of recreation.

- **Fat-tire bikes**, also called snowbikes or fat bikes, can be ridden on designated trails or off trail, and they enable cyclists to access areas that are otherwise difficult to reach. Snow compaction caused by riding and snow-grooming equipment can potentially reduce the habitability of subnivean spaces (Gaines et al. 2003, Sanecki et al. 2006, Sato et al. 2013) and enhance movement for animals with high footloads (Whiteman and Buskirk 2013). Snow compaction can also contribute to trail widening if spring trail users move to the edges of trails to avoid persistent snow (Monz and Kulmatiski 2016). Because fat-tire bikes can move more quickly than other snow-based recreation (estimated to be 10 percent faster than Nordic skate skiers) (Monz and Kulmatiski 2016) and cover larger distances in less time, we would expect them to have more substantial effects on behavioral and physiological responses for sensitive species. In particular, ungulates generally respond more strongly to recreation that is unpredictable, spans large areas, has a large spatial footprint, and is nonmotorized (Harris et al. 2014), four characteristics of fat-tire biking. It is possible that off-trail biking could result in the collapse of subnivean spaces, reducing habitat for species that occupy these spaces. Species particularly sensitive to the presence of people might also experience habitat loss if they are displaced by fat-tire bike activity in new areas. Recreationists have used these bikes on glaciers in Alaska, and their potential to decrease the number of oversnow vehicles such as snowmobiles has been noted (Caldwell 2017).

- **Glade skiing** is backcountry downhill skiing on cleared mountain slopes with trees left standing for skiers to maneuver around. Although some public lands have designated glade skiing areas, demand for this backcountry experience is not always met by the areas provided for it. For example, in New Hampshire's White Mountain National Forest, interest groups asked for a half-mile wide area to be cleared of understory vegetation to form a network of trails for downhill glade skiing. Where such public demands have not been met by forest managers, some unauthorized preparation of mountain slopes for glade skiing has occurred. Based on the previous literature, we hypothesize that glade skiing is relatively unpredictable and thus would have a somewhat higher effect on ungulates than skiing confined to more narrow trails. Clearing understory vegetation will also remove protective cover for many species throughout the year, effectively resulting in reduced quality of habitat resources for some species and habitat loss for others. In particular, species such as invertebrates, reptiles, small mammals, and ground-dwelling birds that are sensitive to disturbance typical of ski slopes would likely experience habitat loss from the clearing of underbrush. Clearing can also result in higher flush responses for birds and other species that use vegetative cover as protection from predators. Applying the guidelines for environmentally friendly ski slopes (outlined in the "Guidelines for Specific Recreational Activities" section in chapter 6) can contribute to minimizing negative impacts of glade skiing areas on wildlife.
- **Kite skiing** is the use of kite-surfing equipment and skis or snowboards in large open snowfields. This type of recreation is largely unpredictable, except that recreationists stay within the open space. Species that rely on resources in open areas used by kite skiers during the day will likely be displaced by this type of recreation.

- **Skijoring** consists of a skier being pulled cross country by dogs or horses. This activity moves relatively quickly and likely covers a larger spatial area than typical cross-country skiing, and thus may incur more negative impacts on ungulates (Harris et al. 2014). The use of dogs might also incur antipredator responses in some species, as is common in summer recreation (e.g., Hennings 2016, 2017; Miller et al. 2001), but these effects are not widely researched in the winter season (however, see MacArthur et al. 2010). The use of horses in skijoring may have less negative effects on wildlife than the use of dogs, as people on horseback may elicit relatively weak responses from wildlife (e.g., Stankowich 2008). However, if skijoring, especially the horse-pulled variety, leads to additional compaction of subnivean spaces, animals that use those spaces may be negatively affected (Gaines et al. 2003, Sanecki et al. 2006).
- **Splitboard skiing** enables recreationists to use a board as two skis to ski to the top of a backcountry run, then bind the skis together to form a snowboard for descending a mountain slope. Recreationists using splitboard skis might disperse into backcountry areas that are inaccessible on conventional skis. Species that rely on large unfragmented territories and are sensitive to human activity might be negatively affected by splitboard skiers.

Xavier Caré

Skijoring at a ski resort in France.

Jacob W. Frank, National Park Service

A bison crosses in front of two snowmobilers in Yellowstone National Park.

Motorized Winter Recreation

Included in this category are snowmobiling, heli-skiing, motorized skijoring, and cat-skiing. Of these activities, the National Visitor Use Monitoring (NVUM) survey captures the use of snowmobiles (also known as "snow machines"), which accounted for 1.4 percent of the main activities pursued by national forest visitors in 2016 (table 2.3) (USDA FS 2016).

Snowmobiling consists of riding a snowmobile on designated groomed trails, in the backcountry, or in unofficial areas. Heli-skiing allows skiers to access remote locations by helicopter, which drops them off at a landing site and is allowed on some federal lands by special permits held by private guides. Motorized skijoring and cat-skiing, which use snowmobiles or snowcats, respectively, to access backcountry skiing areas, are considered emerging recreation types. Results from studies on the impacts of snowmobiles and heli-skiing are applied to potential impacts of motorized skijoring and cat-skiing at the end of this section.

Although motorized snow-based activities provide important economic benefits to local communities, participation is expected to grow at a lower rate than other types of recreation, especially when compared with the high rates of increase projected for nonmotorized snow-based activities (White and Stynes 2010) (fig. 2.4). However, motorized snow use has the second highest overall economic contributions per trip, second to developed skiing in dollars spent per trip (see fig. 2.4 for comparison of economic contributions and projected increase in participation with other recreational activity categories) (White and Stynes 2010). Snowmobiling and undeveloped skiing are the recreational activities most likely to be adversely affected by climate change (Askew and Bowker 2018). As snow-covered areas and seasons shrink, it is increasingly important to understand changing interactions between recreationists and wildlife (Miller et al., n.d.).

Through snowmobiling, participants gain both physical and mental benefits and are active outdoors and enjoy sunlight during a period when many people suffer from seasonal affect disorder. This activity is a way to form connections with natural environments and build social relationships (Canadian Council of Snowmobile Organizations 2019). Snowmobilers are also viewed as an “emergency lifeline” for backcountry skiers, and can help police all-terrain vehicle trespassing (Vail and Heldt 2004). Snowmobile trails can benefit local landowners and recreationists by providing infrastructure for both transportation and recreation (Anttila and Stern 2005). Snowmobilers also act as environmental stewards, volunteering to create and maintain trails (Andrews 2014, Anttila and Stern 2005).

Through snowmobiling, participants gain both physical and mental benefits and are active outdoors and enjoy sunlight during a period when many people suffer from seasonal affect disorder.

According to an extensive review on the impacts of recreation on wildlife, winter terrestrial activities were more highly associated with effects on animals than summer terrestrial or aquatic activities (Larson et al. 2016). Although non-snow-based motorized recreation does occur in the winter, we did not find peer-reviewed literature on this subject, thus it is not included here.

General Impacts of Motorized Winter Recreation on Wildlife

As noted in the discussion of nonmotorized winter recreation above, disturbance to wildlife is of particular concern in winter, when many species are under increased stress. Food availability and quality are lower during winter for many species, limiting these species’ options for moving to areas without human activity (e.g., Krebs et al. 2007). A recent review of recreational impacts on wildlife found that about 80 percent of studies of snow-based motorized winter recreation demonstrated negative effects on species (Larson et al. 2016).

About 80 percent of studies in a recent review of recreational impacts on wildlife found that snow-based motorized winter recreation demonstrated negative effects on species.

Two primary concerns regarding the effects of motorized winter recreation on wildlife are the noise produced and the spatial footprint. Both snowmobiles and helicopters emit loud sounds that are different from naturally occurring sounds on the landscape. However, some of these sounds may not be detectable by wildlife. For example, a study on the impacts of helicopters on nesting golden eagles observed that the sound of helicopters was at a lower frequency than golden eagles may readily hear

(Grubb et al. 2010). However, as this study was carried out in April, results might not represent whether helicopter noise affects golden eagles during winter months.

Both snowmobiling and heli-skiing allow recreationists to reach geographic regions otherwise difficult or impossible to reach. Propelled by a motorized vehicle, recreationists can cover more ground in less time and thus have a larger spatial footprint that nonmotorized winter recreation in the same areas. Heli-skiing brings skiers into backcountry settings with no designated trail, making this type of recreation less predictable than trail-based recreation.

Generally, unpredictable recreation with a larger spatial footprint and louder noise has comparatively higher potential to negatively impact wildlife species (e.g., Harris et al. 2014). It is important to consider these specific aspects of recreation and their potential impacts on the species present in the area.

Box 15

Primary concerns for motorized winter recreation include the following:

- Noise
- Extent (e.g., reaching previously undisturbed areas)

Wildlife habitat impacts—

Compaction of snow by snowmobiles can affect mammalian mobility on the surface (Bunnell et al. 2006, Dowd et al. 2014, Gese et al. 2013, Richens and Lavigne 1978), and use of subnivean space (Sanecki et al. 2006, Schmid 1972). Ideal snowmobile areas sometimes overlap with important mammal habitats, including denning habitat for grizzly bears (Goldstein et al. 2010, Linnell et al. 2000) and wolverines (USDI NPS 2013). Where the density of snowmobile trails is high, moose may experience habitat loss (Harris et al. 2014). Songbirds are also likely to have negative effects in high-use areas, as their vocalizations can be masked by snowmobile noise (Keyel et al. 2018). Habitat specialists are particularly susceptible to the effects of disturbance (Canfield et al. 1999). However, not all mammals are affected by motorized winter recreation (Fortin and Andruskiw 2003, Kolbe et al. 2005).

Impacts on Habitat, Individuals, and Populations, By Taxonomic Group

Note: No studies on the impacts of motorized winter recreation on invertebrates, amphibians, or reptiles were identified.

Birds

Few studies were identified that investigated the impacts of motorized winter recreation on birds. In general, impacts were small for raptors, but noise emitted from snowmobiles can mask vocalizations for songbirds.

Impacts on habitat—

Motorized recreation may contribute toward effective habitat loss for some bird species, although the effects specific to winter activity are unclear. A meta-analysis investigating the impacts of roads and other human infrastructure indicated that bird populations avoid infrastructure over distances up to approximately 1 km (Benitez-Lopez et al. 2010). However, this analysis was not specific to winter months, and focused on motorized activity at a larger scale than that typical of motorized recreation.

Impacts on individuals, populations, and communities—

Forest birds—One study was found on the effect of snowmobiles on a songbird species, indicating that noise from snowmobiles can mask bird vocalizations. On the Stanislaus National Forest, California, the listening area for white-breasted nuthatches was reduced by more than 90 percent within the zone exposed to snowmobile noise. The extent of this zone varied spatially, with noise travelling farther in flatter sites. The amount of noise emitted by snowmobiles and the number of snowmobiles were also important factors. For example, the zone extended 64 to 137 m beyond the location of an older, noisier model of snowmobile (i.e., a “standard” model), while the zone extended only 13 to 86 m from the location of a newer model of snowmobile that emits less noise. Eight standard snowmobiles had a zone extending 158 to 286 m, compared to 83 to 210 m for eight newer snowmobiles (Keyel et al. 2018). The newest generation of snowmobiles had smaller noise footprints and produced lower sound levels than did standard machines in the 2.5 kHz one-third octave band, which is the band used by white-breasted nuthatches (Keyel et al. 2018).

Snowmobile noise can mask bird calls; newer models emit less noise and are heard over a smaller area than older models.

Raptors—Research on raptors within this category focused on helicopters and small aircraft. Overall, motorized airborne recreation had little or no effect on birds of prey (Grubb et al. 2010, Kochert et al. 2002). Helicopters seemed to have a larger impact on raptors, resulting in increased alert and flight behavior in osprey (Trimper et al. 1998), and displacement in gyrfalcons (Platt 1977). Golden eagles appeared to become habituated to helicopter activity (Grubb et al. 2010). Small aircraft activity was associated with increased aggressive behavior in osprey and golden eagles (Bruderer 1978, Trimper et al. 1998), and displacement in gyrfalcons (Platt 1977). However, low-level jet overflights (0 to 1.4 km) did not displace, startle, or flush osprey (Trimper et al. 1998).

Implications for impacts of aircraft activity on raptors at the population level are minimal. No reduction in nesting success was found for golden eagles, and no reduction in productivity was found for golden eagles and Mexican spotted owls (Delaney et al. 1999, Grubb et al. 2010).

Mammals

Impacts on habitat—

Although responses of mammals to motorized winter recreation are mixed, it is important to make sure that sufficient overwintering habitat is maintained. Habitat specialists such as bighorn sheep and mountain goats are particularly susceptible to the effects of disturbance because they are limited to relatively small areas with very steep and rocky slopes (Canfield et al. 1999), although they often winter on gentler slopes at lower elevations.

Preferred snowmobile areas often overlap with important habitat for mountain caribou (Seip et al. 2007). For grizzly bears (Goldstein et al. 2010, Linnell et al. 2000) and wolverines (Switalski 2016), snowmobiles commonly overlap with important denning habitat. Snowmobiles can also reach farther into denning habitat than nonmotorized winter recreationists, resulting in a larger extent of this overlap. High-density snowmobile trails can result in habitat loss for moose, which avoid areas with snowmobile trails (Harris et al. 2014).

Box 16

Motorized winter recreation can have greater negative impacts on some of these mammal groups:

- Habitat specialists
- Subnivean species
- Some carnivores (e.g., wolverines and bears)

Compaction of snow by snowmobiles can affect mammalian use of areas both on the surface and in the subnivean space. A study in Idaho and Wyoming indicated that animals with a higher footload (thus less adapted to snow travel) were more likely to follow compacted trails and used such trails for longer distances (Whiteman and Buskirk 2013). White-tailed deer, coyotes, and other species with a high footload have been observed to use compacted trails on some landscapes (Bunnell et al. 2006, Dowd et al. 2014, Gese et al. 2013, Richens and Lavigne 1978), but did not follow trails in other studies (Kolbe et al. 2005). Snow compaction and clearing of ground areas in preparation for winter recreation can potentially restrict overwintering habitat of subnivean mammals (Sanecki et al. 2006, Schmid 1972).

For bison, snow depth was important in predicting habitat use, while disturbance by motorized winter recreation did not affect resource use (Fortin and Andruskiw 2003).

A study in Idaho, Montana, and Wyoming indicated that motorized backcountry recreation resulted in habitat loss for wolverines, especially for females (for further detail, see corresponding "Nonmotorized Winter Recreation" section above and "Comparison of Winter Activity Types" below) (Heinemeyer et al. 2019).

Impacts on individuals, populations, and communities—

Ungulates—A recent research synthesis of the effects of winter recreation on northern ungulates (Harris et al. 2014) formulated guidelines for situations in which winter recreation (both motorized and nonmotorized) is potentially detrimental to ungulates (see also "Comparison of Winter Activity Types" below).

Snowmobiles have been found to disturb ungulates in numerous cases, often more than nonmotorized winter recreation. Behavioral responses to motorized winter recreation include bison becoming alert and fleeing the area (Fortin and Andruskiw 2003), moose avoiding areas with a high density of snowmobile trails and that are close to roads (Harris et al. 2014), and increased vigilance in elk, bison (to a lesser extent than elk), and white-tailed deer (Borkowski et al. 2006, Eckstein et al. 1979). Moose in Wyoming remained bedded and fed less frequently in response to snowmobile activity (Colescott and Gillingham 1998). Several ungulate species had increased movement rates in the presence of motorized recreation during winter, including elk, bison (Borkowski et al. 2006), and white-tailed deer (Eckstein et al. 1979). This was particularly noted for females, including bison (Fortin and Andruskiw 2003) and moose (Neumann et al. 2011).

Snowmobiles have been found to disturb ungulates in numerous cases, often more than nonmotorized winter recreation.

Ungulates have been displaced by snowmobiles, including white-tailed deer in Minnesota (Dorrance et al. 1975) and woodland caribou in British Columbia (Seip et al. 2007). However, white-tailed deer in Maine were not displaced by snowmobiles (Richens and Lavigne 1978). Moose were temporarily displaced when exposed to unpredictable activity by snowmobiles (Harris et al. 2014).

Alterations in the use of space and resources have been found for female moose, whose diurnal activity ranges were spaced farther apart and had less spatial overlap in areas with snowmobile activity (Neumann et al. 2011). Most white-tailed deer in a study in Maine followed snowmobile trails for short distances when near major bedding areas (Richens and Lavigne 1978). However, another study found that white-tailed deer home range size was not altered by snowmobiles (Eckstein et al. 1979). Additionally, bison distribution across meadows and density were not influenced by human activity (including travel by foot and snowmobile), but were related to environmental factors such as snow depth (Fortin and Andruskiw 2003).

Habituation of ungluates to snowmobiles has been documented, and is case specific.

Several ungulate species appear to habituate to snowmobile activity, but this is case specific. Bison and elk were found to become somewhat habituated to oversnow vehicles in Yellowstone National Park (Borkowski et al. 2006); caribou habituated to snowmobiles in a park in Newfoundland, Canada (Mahoney et al. 2001); and white-tailed deer appeared to habituate to snowmobiling in a wildlife area in Minnesota (Dorrance et al. 1975), but did not habituate to snowmobiles in Maine (Richens and Lavigne 1978).

Regarding physiological responses, elk had increased glucocorticoid levels when approached by snowmobiles (Creel et al. 2002). Glucocorticoid secretion is commonly used as an indicator of stress, but is not necessarily linked to a state of distress or deleterious responses (Romero 2004). No effect of snowmobile activity was found on the overall activity budget for moose (Neumann et al. 2011).

Although research on the effects of heli-skiing on ungulates is sparse, studies indicate that ungulate response to helicopter disturbance varies with the level of activity, species, season, quality of cover nearby and the altitude and distance of aircraft from the animal (Bleich et al. 1994, Côté 1996, Foster and Rahs 1983, Frid 2003). Helicopter disturbance related to oil exploration activities (from which responses can be inferred for heli-skiing) were associated with a decline in mountain goat reproduction or recruitment of kids in Montana (Joslin 1986), and disturbance of mountain goats by 85 percent of all flights within 500 m in Alberta, Canada (Côté 1996). The potential for heli-skiers to affect ungulate habitat is limited by the steep terrain preferred by heli-skiing, and the narrow runs to which this type of recreation is generally limited. However, heli-ski operations required 700 to 3000 km^2, making the extent of localized impacts widespread (Simpson and Terry 2000).

Very few studies drew conclusions regarding the effect of motorized winter recreation on ungulates at the population or community level. However, one study did indicate a lack of evidence that 35 years of snowmobile use affected the Yellowstone bison or elk population dynamics or demography (Borkowski et al. 2006).

Carnivores—Snowmobile activity and presence of compacted snowmobile trails have been found to affect the movement rates of wolverines and coyotes. Denning female wolverines moved more frequently and at higher rates in spaces and periods with higher intensity recreation, requiring extra energy from wolverines during the critical winter and denning periods (Heinemeyer and Squires 2013).

However, recreation-related variables did not predict overall wolverine use of winter habitat (Krebs et al. 2007). Coyotes have been documented to use compacted snowmobile trails extensively in Utah and Wyoming (Bunnell et al. 2006, Dowd et al. 2014, Gese et al. 2013), but exhibited limited use of such trails for movement and foraging in Montana (Kolbe et al. 2005). Facilitation of coyote movement via snowmobile trails implies potential competition with and displacement of Canada lynx, and the mixed effects documented by these studies is likely due to distinct regional snow characteristics, predator communities, and snowmobile use (Bunnell et al. 2006).

Snowmobile activity and presence of compacted snowmobile trails have been found to affect the movement rates of wolverines and coyotes.

In polar regions, male polar bears were found to have increased vigilance in the presence of snowmobiles during the fall (Dyck and Baydack 2004), and arctic foxes shifted toward more nocturnal activities in some polar regions, but not others, in early spring (Fuglei et al. 2017). Polar bears were also found to habituate to the presence of stationary wildlife-watching vehicles in fall (Dyck and Baydack 2004).

Direct mortality is possible for grizzly bears, specifically if snowmobile noise triggers an avalanche on a slope with bear dens (Hilderbrand 2000). Grizzly bears and wolverines also have a risk of increased den abandonment. Grizzly bears are more likely to abandon a den when human disturbance is within 1 km of a den site, especially early in the denning season as bears are particularly susceptible to abandoning their dens early in the denning period. However, if a bear can find an alternative denning area within the home range, human disturbance that leads to den abandonment might not result in increased cub mortality (Linnell et al. 2000). Wolverines are sensitive to noise, and snowmobile activity that reaches into their habitat may result in reduced reproductive success (Switalski 2016). In one study, wolverines avoided areas with motorized winter recreation (Heinemeyer et al. 2019).

Lynx appear to avoid direct interactions with motorized winter recreationists by altering behavioral and temporal patterns. In Colorado, Lynx avoided areas with motorized recreation and high-intensity developed ski resorts. Lynx also had decreased movement rates and were active more at night in areas with high-intensity snowmobiling (Olson et al. 2018).

Small mammals—The compaction of snow for and by snowmobiles, as well as preparation of areas for winter recreation, can have negative effects on small mammals that overwinter in subnivean spaces. A study in southern Australia found subnivean spaces to be small or absent in ski areas, while this space averaged 8 to 20 cm in unmodified areas. Snow cover was also denser in ski areas than unmodified areas. Experimental snow compaction resulted in declines of two small mammal species by 75 to 80 percent (Sanecki et al. 2006). In North America, the water shrew was found to be susceptible to snow compaction from snowmobiling (Gaines et al. 2003, Schmid 1972). Snow compaction can cause small mammals to be suffocated, or their subnivean movements can be altered, potentially altering dynamics between predators and prey (Gaines et al. 2003). Additionally, cascading effects on species that hunt for animals negatively affected by snow compaction are likely.

Potential Effects of Emerging and Under-Researched Motorized Winter Recreation

Types of motorized winter recreation for which potential impacts have not yet been empirically researched include motorized skijoring and cat-skiing. Below, we apply findings from other types of recreation to hypothesize potential effects of these types of recreation.

Motorized skijoring and cat-skiing are types of motorized winter recreation gaining in popularity. Motorized skijoring involves a vehicle such as a snowmobile towing one or more skiers. In cat-skiing, skiers are transported to the tops of runs by snowcats (caterpillar-tracked vehicles). This type of activity targets open-bowl areas with deep fresh powder and gladed tree skiing, otherwise difficult or impossible to access. A study in British Columbia, Canada, found that mountain caribou populations were likely to overlap with potential cat-skiing areas (Simpson and Terry 2000). Snowcat skiing may have less overall impact than heli-skiing because it occurs less frequently, involves less vertical skiing (typically 5 to 10 runs per day), and requires less area to operate (30 to 80 km^2 for cat-skiing, compared with 700 to 3000 km^2 for heli-skiing). Local impacts may be more intense because snowcats or snowmobiles create compacted access trails, which may be used by predator species such as coyotes in some situations (Bunnell et al. 2006, Dowd et al. 2014, Gese et al. 2013). Snow compression from snowcats and snowmobiles may also negatively affect species that use the subnivean space (Sanecki et al. 2006). As both snowcats and snowmobiles are motorized vehicles, they would be expected to have similar effects regarding noise, such as masking songbird vocalizations (Keyel et al. 2018), potentially triggering an avalanche and resulting in direct mortality for animals on affected slopes (Hilderbrand 2000), and disturbing bear and wolverine denning behavior (Switalski 2016). As for snowmobiles, the disturbance to bear denning activity may be particularly high toward the beginning of the season, as bears are particularly susceptible to abandoning their dens early in the denning period. However, if a bear can find an alternative denning area within the home range, human disturbance that results in den abandonment might not lead to increased cub mortality (Linnell et al. 2000).

Comparison of Winter Activity Types

Disturbance to wildlife is of particular concern during winter when many species are under increased stress (Goodrich and Berger 1994), face energetic tradeoffs (e.g., Lafferty 2001a), and have limited options for relocating to areas without human activity (Krebs et al. 2007, Thiel et al. 2008). Although this is true for wildlife in a wide range of geographic locations, most of the literature investigating the effects of winter recreation on wildlife takes place in areas that are snow-covered in winter. Thus, we focus only on snow-based winter recreation in this comparison of recreational activity types.

Birds—

Bird vocalizations can be masked by loud sounds emitted by snowmobiles (Keyel et al. 2018), suggesting that motorized recreation might have a larger effect on songbirds than nonmotorized recreation.

Mammals—

In general, species living in the subnivean layer and those with a high footload might be affected by the compaction of snow by snow-based recreation (see “Motorized Winter Recreation” section above). Compaction of snow and increases in snow density are similar between different types of snow sports (Whiteman and Buskirk 2013).

Ungulates—

Many studies have compared the impacts of different attributes of recreational activity on ungulate species. Harris et al. (2014) reviewed these studies and presented a set of guidelines describing when winter recreation is potentially detrimental to ungulates. Further detail is provided below:

- **When winter recreation is unpredictable:** When it is predictable, animals can habituate (Cassirer et al. 1992, Dorrance et al. 1975, Epsmark and Langvatn 1985, Schultz and Bailey 1978), but displacement can result when winter recreation is unpredictable in location or time (Cassirer et al. 1992, Freddy et al. 1986), although this displacement is often temporary (Cassirer et al. 1992, Dorrance et al. 1975, Richens and Lavigne 1978, Tyler 1991). These effects are small for white-tailed deer.
- **Spanning large areas**: Winter recreation occurring in small areas has less impact relative to that spanning large areas.

- **Long duration:** Winter recreation activities occurring over short periods (e.g., days or hours) have less impact than those occurring over longer periods (e.g., months).
- **Nonmotorized:** When not considering its spatial extent, nonmotorized winter recreation causes greater disturbance to ungulates than motorized winter users (e.g., Canfield et al. 1999, Eckstein et al. 1979, Freddy et al. 1986, Reimers et al. 2003, Richens and Lavigne 1978). Nonmotorized activities cause fewer, stronger disturbance effects in relatively smaller areas, while motorized winter recreation generates more, weaker disturbances across larger areas. Ungulates flee sooner and move farther in response to nonmotorized winter recreation (e.g., moose) (Andersen et al. 1996). However some ungulates are aware of snowmobiles at farther distances than skiers (e.g., reindeer) (Reimers et al. 2003).
- **When animals are displaced to poor-quality habitats:** Several researchers have hypothesized that individuals are less likely to move permanently from high-quality habitat to lower quality habitat, if equally good habitat without recreational activity is also nearby. At least two studies documented ungulates being displaced from high-quality habitat areas by snowmobile activity, although these displacements were temporary, e.g. moose (Colescott and Gillingham 1998) and caribou (Seip et al. 2007).

Box 17

Winter recreation is potentially detrimental to ungulates when it is:

- Unpredictable
- Spanning large areas
- Long in duration
- Nonmotorized[3]
- Displacing animals to poor-quality habitats

Source: Harris et al. 2014.

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[3] Because motorized use has a larger spatial footprint than nonmotorized use, the number of disturbance events is typically greater. However, nonmotorized recreation may have greater effects than motorized recreation at a single place and time.

Carnivores—

Four studies reviewed compared the impacts of different winter recreation activity types on carnivores, showing mixed effects:

Wolverines—Wolverines may be more negatively affected by helicopter skiing (both males and females negatively associated) than by backcountry skiing (only females negatively associated) (Krebs et al. 2007). In a separate study, wolverines avoided areas with both motorized and nonmotorized backcountry winter recreation, with a stronger response to off-road than road-based recreation. Wolverine responses increased with increasing levels of backcountry winter recreation. Because motorized recreation had a higher intensity and larger footprint than nonmotorized recreation in most wolverine home ranges, motorized backcountry recreation resulted in more substantial wolverine habitat loss than did nonmotorized recreation (Heinemeyer et al. 2019).

Bears—Backcountry skiing might have more negative impacts than snowmobile use on denning brown bears, as backcountry skiing overlapped more with denning habitat than snowmobile riding at the landscape level (Goldstein et al. 2010).

Lynx—Lynx might avoid direct interactions with winter recreationists by altering their behavioral and temporal patterns (Olson et al. 2018) (see pages 108 and 118).

Dave Menke, U.S. Fish and Wildlife Service

A bald eagle approaches its nest in the Kodiak National Wildlife Refuge, Alaska.

Chapter 5: Aquatic Recreation

Aquatic recreation accounts for about 8 percent of the main activities of visitors to national forests (table 2.3) (USDA FS 2016). In this chapter, we discuss recreation that occurs in both freshwater and estuarine environments. The most popular aquatic recreational activity is fishing, followed by nonmotorized water activities (i.e., kayaking, canoeing, stand-up paddleboarding, rafting, swimming, windsurfing, kite surfing, and freshwater scuba diving), and motorized water activities (i.e., powerboats, jet skis, and motorized wakeboards). The effects of launching watercraft are also important considerations associated with aquatic recreation.

Overall, participation in aquatic recreation is expected to increase at a rate similar to those of other recreational activities, and its economic benefits to local communities are generally moderate (White and Stynes 2010) (fig. 2.4). Swimming and motorized water use have relatively high projected rates of increase in participation (32 percent and 31 percent, respectively), while floating and fishing have lower projected rates of increase (22 percent and 21 percent, respectively) (White and Stynes 2010). Figure 2.4 shows a comparison of economic contributions and projected rates of increase in participation with other recreational activity categories.

Participation in aquatic recreation is expected to be affected by climate change, differing by region. For example, participation in motorized aquatic activities and fishing are expected to increase in the Northern United States, while decreasing in the Rocky Mountain region. However, swimming participation is expected to increase in the Rockies (Askew and Bowker 2018). Considering expected shifts in recreational activities alongside wildlife activity and distribution shifts will be important as climatic conditions change (Miller et al., n.d).

Water-based recreation provides physical and mental benefits to human health and well-being.

Water-based recreation provides physical and mental benefits to human health and well-being (Venohr 2018). The visibility of surface waters is particularly attractive to people, enough to raise shoreline property values more than other landscape features (Luttik 2000). There are many examples of aquatic recreationists participating in stewardship activities. For example, recreational fishers sometimes pick up litter or contact government or media to improve fish habitat (Copeland et al. 2017), and they collect data for fisheries monitoring programs (Clemens 2015). Recreational anglers and boaters sometimes participate in behaviors that reduce the spread of aquatic invasive species (van Riper et al. 2019). Water-based recreationists are influenced by recreational communities at boat ramps and tend to conform to the expected behaviors within these communities (Seekamp et al. 2016).

Although there are potential impacts of recreation on saltwater marine ecosystems, those ecosystems are outside the scope of this report.

General Impacts of Aquatic Summer Recreation on Wildlife

Aquatic recreational activity is restricted to bodies of water and the terrestrial areas immediately surrounding them. A diversity of activity types, wildlife groups, and environmental factors, such as season contribute to the variability of potential impacts on wildlife. Primary concerns include the effect of recreational activities to populations in the long term; however, a low proportion of studies address this directly, and even fewer studies provide empirical data on such impacts.

Larson et al. (2016) reported that, proportionately, aquatic recreation has somewhat fewer negative effects than terrestrial recreation. However, this analysis included recreation in marine areas and effects on species such as coral and marine fish, which are not included here. The literature covering the impacts of aquatic recreation on wildlife is not as rich as some other areas, but effects likely overlap substantially with those described in chapters 3 and 4.

A recent article (Venohr et al. 2018) provided a review of the effects of aquatic recreation on invertebrates, reptiles, fish, and birds, summarizing effects at the individual, population, community, and ecosystem levels. These authors built these results into a social-ecological systems framework, reviewing the effects that freshwater ecosystems have on aquatic recreationists to better understand interactions between recreation, ecology, and management loops.

Effects on habitat—

On beaches, the tourism infrastructure that provides access for recreationists can contribute toward beach erosion, altered dune vegetation, and other factors affecting the resources within these areas (e.g., Comor et al. 2008, Schierding et al. 2011, Yasue and Dearden 2006). One study investigated the impact of human-made structures on waterbirds, finding that birds were positively associated with such structures (Bright et al. 2004). However, activities that displace birds may result in reduction of habitat, such as with bald eagles on narrow river channels with recreation (Stalmaster and Kaiser 1998).

Effects on individuals and populations—

The literature reviewed here indicates both increased (Lima et al. 2014) and decreased (Addessi 1994, Cardoni et al. 2008, Schlacher and Thompson 2012, Veloso et al. 2006) species richness, diversity, and density associated with nonmotorized summer aquatic recreation. Some species appear to be sensitive to human influence while others are not (e.g., piscivorous birds) (Newbrey et al. 2005).

Short-term responses include increased flight and alert response, and temporary displacement in waterbirds (Cardoni et al. 2008, Madsen 1998, Schummer and

Box 18

Aquatic recreation has led to the following:

- Short-term behavioral responses (e.g., temporary displacement)
- Long-term behavioral responses (e.g., habituation)
- Reduced breeding success
- Reduction in shoreline habitat

Eddleman 2003); shorebirds (Burger et al. 2010, Lafferty 2001b, Thomas et al. 2003, Yalden 1992); forest birds (van der Zande and Vos 1984); raptors (Stalmaster and Kaiser 1998, Steidl and Anthony 1996); and mammals (Elmeligi and Shultis 2015, King and Heinen 2004, Leighton et al. 2010). Some waterbirds, shorebirds, and manatees reduced the amount of time spent feeding in the presence of aquatic recreation (Kaiser and Fritzell 1984, Keller 1991, King and Heinen 2004, Lafferty 2001a, Martin et al. 2015, Stalmaster and Kaiser 1998, Thomas et al. 2003). Reduced fitness was found in fish and reptiles (Lima et al. 2014, Selman et al. 2013).

Some species show longer term effects from aquatic recreation. Some shorebirds and waterbirds can habituate to recreation (Baudains and Lloyd 2007, Bright et al. 2004, Titus and VanDruff 1981). Shorebirds showed reduced productivity (Yasue and Dearden 2006), reduced breeding success at the population level (Lafferty et al. 2006), negative impacts on resident species in the long term or year-round (Cornelius et al. 2001, Martin et al. 2015), increased annual fecundity (Baudains and Lloyd 2007), and potential long-term effects resulting from reduced feeding activity (Kaiser and Fritzell 1984, Martin et al. 2015). Eider ducklings experienced a slight increase in nest predation because of aquatic recreation (Keller 1991), while sea turtles experienced decreased rates of nest predation (Leighton et al. 2010).

In some studies, species were not disturbed by aquatic recreation. In the short term, those species included crabs (Murph and Faulkes 2013, Steiner and Leatherman 1981) and waterbirds (Bright et al. 2003, 2004, Cardoni et al. 2008, Gill et al. 2001, Hulbert 1990, Madsen 1998, Schummer and Eddleman 2003, Yalden 1992). One study also concluded that loons were not disturbed by aquatic recreation in the long term (Titus and VanDruff 1981). In Wisconsin, several species of piscivorous bird showed indications of habituation to humans through their presence on lakes with and without housing developments and motorized boats, while three piscivorous bird species appeared only on lakes without these types of human influence (Newbrey et al. 2005).

Impacts on Habitat, Individuals, and Populations, By Taxonomic Group

Note that no literature was found on the effects of aquatic recreation on amphibians. For some taxonomic groups, results are reported only regarding their effects on habitats and communities (i.e., invertebrates) or their effects on individuals and populations (i.e., fish, reptiles, and mammals) based on results in the available literature.

Invertebrates

Effects of aquatic recreation on invertebrates is species-specific and varies by ecosystem, which include (1) riparian and estuarine areas and (2) coastal marine areas, including dunes, beaches, and intertidal zones. Studies reviewed reported effects primarily at the habitat level.

Impacts on riparian and estuarine habitats and communities—

Although occasional stream crossings by recreationists may not cause widespread and lasting impacts, long-term negative effects have been found for instream invertebrate communities.

Although occasional stream crossings by recreationists may not cause widespread and lasting impacts, long-term negative effects have been found for instream invertebrate communities, an indication of lower water quality. This has been found in southwestern Virginia (Kidd et al. 2014), Yosemite National Park in California (Holmquist et al. 2015), and Zion National Park in Utah (Caires et al. 2010). Long-term effects were detected in Yosemite but not in Zion, suggesting that higher densities of crossings may cause lasting negative impacts on aquatic invertebrates and water quality, but that some aquatic systems are resilient to recreational disturbance. Additionally, recreation along a riverbank in Belarus was associated with a reduction in the number of ground beetles (Halinouski and Krytskaya 2014).

However, in estuaries in southeastern England, a study found no significant indications that human activity, marinas, or footpaths caused variation in the density of bivalves available as prey items for shorebirds (i.e., black-tailed godwit) (Gill et al. 2001).

Impacts on individuals, populations, and communities—

Benthic invertebrates are structurally and functionally important in beach ecosystems (Schlacher and Thompson 2012). Recreational activity can alter these communities and their habitats. Beyond the presence of recreationists on beaches, the tourism infrastructure that provides access to beaches can affect dune ecosystems, altering plant cover and plant species richness (e.g., Comor et al. 2008, Schierding et al. 2011). Ten studies on the impacts of aquatic recreation on invertebrates reviewed by Larson et al. (2016) focused on coastal ecosystems, including dunes, beaches, and the intertidal zone. We did not consider articles addressing impacts on marine invertebrates such as corals. Here we summarize impacts found in these communities.

Dune insect and spider community**—**Recreational activities in dunes and on beaches can alter dune invertebrate communities by altering dune vegetation, cover, and species richness. Two studies in Europe, in the Baltic Sea and the Mediterranean Sea, found that nonmotorized recreational beach use was associated with altered beetle and spider communities, although beetles were still found to be abundant in highly disturbed sites. Both studies emphasized the importance of dune vegetation for beetle or spider abundance (Comor et al. 2008, Schierding et al. 2011). If an increasing spatial extent of beach recreation leads to reduction of dune patch size, isolation of specialized sand beetles will be a concern for their conservation (Comor et al. 2008).

Recreational activities in dunes and on beaches can alter dune invertebrate communities by altering dune vegetation, cover, and species richness.

Intertidal zone benthic community—In the intertidal zone, recreation and associated anthropogenic pressures have mixed effects on the benthic community. In Texas, neither the density nor size of sand crabs differed between two sites with different levels of human development and proximity to an urban area (Murph and Faulkes 2013). Nonmotorized beach use in Australia resulted in significantly lower abundance and species richness in the intertidal benthic invertebrate community structure on the lower part of the beach, while upper-shore assemblages were structurally similar between nonmotorized use and control areas (Schlacher and Thompson 2012). In Brazil, the intertidal macroinfauna had lower density in sandy beach sites with high nonmotorized use than those with low and medium use (Veloso et al. 2006).

Ghost crabs have been used as an indicator species for assessing human impacts on exposed sandy beaches (Barros 2001). Two studies, one in the Eastern United States and one in eastern Australia, showed results differing by proximity to urban areas and type of recreational activity present (Barros 2001, Steiner and Leatherman 1981). On Assateague Island in Maryland and Virginia, pedestrians did not appear to have harmful effects on ghost crabs, and increased crab density associated with pedestrian beaches compared with an undisturbed beach may indicate that crabs were attracted by food scraps left by beach users (Steiner and Leatherman 1981). However, a study in Sydney, Australia, found the opposite effect, with significantly fewer ghost crab burrows found in three urban beaches than on nearby non-urban beaches (Barros 2001).

Motorized beach activity (i.e., off-highway vehicles [OHVs]) on Assateague Island was associated with reduced density of ghost crabs. OHVs might directly affect ghost crabs by crushing or burying them, or indirectly by interfering with their reproductive cycle or altering their environment (Steiner and Leatherman 1981). On pedestrian beaches in both studies, crabs or their burrows were observed in the foredunes, but were concentrated near the beach berm on the OHV-use beach (Barros 2001, Steiner and Leatherman 1981).

Rocky intertidal community—A study near San Diego, California, investigated the impact of recreational activity, with a focus on people collecting species, in the rocky intertidal zone. Addessi (1994) found that the density of species deemed susceptible to collection by humans for food, bait, or aquaria was reduced in a more heavily visited intertidal area. The under-rock community at the most heavily visited site changed substantially over the course of 20 years (Addessi 1994).

Fish

Impacts on individuals, populations, and communities—

A recent article summarized the effects of aquatic recreation on freshwater ecosystems, indicating effects at the individual, population, community, and ecosystem level (Venohr et al. 2018). At the individual level, swimmers were found to cause estrogenic effects on physiology and reproduction (Weisbrod et al. 2007). Motorized boating altered behavior, communication, and habitat structure (Whitfield and Becker 2014) as well as swimming speed and fish habitat use (Jacobsen et al. 2014), and disrupted biological functions in rainbow trout (Tjärnlund et al. 1996). Nonmotorized boating was associated with increased fish diseases and mortality (Gozlan et al. 2006). The noise produced by both motorized and nonmotorized boats was found to cause sublethal physiological disturbances to largemouth bass (Graham and Cooke 2008). Littering caused toxic effects, and changed behavior and development of fish (Lee and Lee 2015, Lewin et al. 2006, Stewart et al. 2015).

Box 19

Aquatic recreation can affect fish through:

- Changes in physiology and reproduction
- Short-term behavioral responses (e.g., increased swimming speed)
- Increased diseases and mortality
- Changes in habitat structure

At the population level, motorized boating was associated with increased fish mortality by predation (Simpson et al. 2016). At the community level, motorized boating was associated with increased drift densities of young-of-the-year fish (Schludermann et al. 2014). Although we do not explicitly cover consumptive recreation in this report, we note that angling has been found to affect fish demography, abundance, and evolutionary trajectories (Lewin et al. 2006) as well as fish biodiversity (Cooke and Cowx 2006, Freyhof and Brooks 2011).

Two studies in Brazil investigated the impacts of ecotourism activities (i.e., snorkeling) on fish fauna in rivers in southern Brazil. Lima et al. (2014) found a significant increase in species richness, density, and diversity at the site with ecotourism as compared with a control site. However, behavior patterns of two indicator fish species at the tourism site suggested a higher stress level for both species, and higher cortisol levels for one of the two study species. These contrasting results led researchers to conclude that behavioral and physiological results may be early indications of negative impact caused by ecotourism, prior to community-level changes (Lima et al. 2014). A separate study found that snorkeling affected the activity patterns of freshwater fish, which changed the promptness with which they began and ended activities. However, fish did not alter microhabitat use or become more cryptic because of tourism (Bessa et al. 2017).

Reptiles

Impacts on individuals, populations and communities—

Three articles on the effects of aquatic recreation on reptiles indicated reduced body condition in the presence of motorized aquatic recreation (Bulte et al. 2009, Lester et al. 2013, Selman et al. 2013). Yellow-blotched sawback turtles at sites with a higher level of motorized recreation had a compromised body condition (i.e., higher stress level and a higher proportion of individuals with an infection). Basking behavior was also affected, with fewer individuals observed basking at the high-recreation site, and females basking longer at the low-recreation site (Selman et al. 2013). On Lake Ontario, Canada, propeller injuries to northern map turtles were two to nine times higher in adult females than in adult males and juvenile females, corresponding with higher exposure to collisions with boats owing to female movement patterns, habitat use, and basking. This could lead to rapid local extinction if the risk of boat-induced mortality is greater than 10 percent (Bulte et al. 2009). In New Jersey, diamondback terrapins taken from a population typically exposed to recreational boats did not significantly change their behavior in response to playback recordings of boat engines of varying sizes. This lack of behavioral response to boat sounds may explain the high rates of injury and mortality of terrapins, which might threaten terrapin population viability (Lester et al. 2013).

Motorized aquatic recreation is associated with reduced body condition in reptiles.

Birds

We found 24 empirical articles and 4 review articles that included effects of aquatic recreation on birds (i.e., Bateman and Fleming 2017, Buckley 2004, Larson et al. 2016, Steven et al. 2011). These papers focused on short-term behavioral responses, changes in activity budget, and (less frequently) impacts on reproductive success.

Tom Koerner, U.S. Fish and Wildlife Service

A green-winged teal takes flight in the Seedskadee National Wildlife Refuge, Wyoming.

Some studies reported long-term population-level impacts or drew conclusions regarding what short-term results might imply in the long term. Only one study reviewed focused on habitat-level impacts of aquatic recreation. These studies are summarized below, according to the primary ecosystem in which the study was conducted. In general, although there were many negative impacts of aquatic recreation documented, they were primarily short term, and authors often indicated that the long-term implications at the population level are expected to be neutral or sometimes slightly negative. As Gill et al. (2001) pointed out, it is important to distinguish critically important conservation issues from trivial ones, to prevent unnecessary restrictions on recreational access to areas in which human presence does not have substantial negative effects on wildlife populations.

According to a review on the impacts of multiple types of ecotourist activities on birds, their noise, speed, and suddenness all seem to be factors determining the extent to which birds are affected by recreation (Buckley 2004).

Box 20

Studies investigating the effects of aquatic recreation on birds indicate:

- Short-term negative effects, including flight responses and changes to roosting activity.
- Long-term effects that may be neutral or slightly negative.

Impacts on habitat—

One study investigated the impact of human-made structures on wetland birds, finding that birds were positively associated with such structures (Bright et al. 2004). However, tourism structures such as resorts can result in habitat reduction for some species (Yasue and Dearden 2006). Activities that displace birds may also result in habitat reduction, such as in the case of bald eagles on narrow river channels with recreation (Stalmaster and Kaiser 1998).

Impacts on individuals, populations, and communities—

Shorebirds—Shorebird responses to recreational activities on beaches differ with species and type of recreation. Many species become alert and fly away from approaching humans at varying distances, such as 20 m for crows and gulls (Lafferty 2001b), 27 m for common sandpipers (Yalden 1992), 30 m for sanderlings (Thomas et al. 2003), and from boats at 72 to 110 m for black skimmers (Burger et al. 2010). However, these effects are generally temporary and do not alter large-scale patterns of beach use by birds in the long term (Burger et al. 2010, Lafferty 2001b, Thomas et al. 2003). This type of response is more concerning when recreation displaces individuals to areas with lower quality resources, such as in the case of a cormorant species (Velando and Murilla 2011). Recreation that moves quickly and unpredictably likely causes larger behavioral responses from shorebirds. For example, no shorebirds were observed on study beaches in California on one occasion when a kite buggy (wind-powered three-wheeled vehicle) was present (Thomas et al. 2003). Some shorebirds have reduced foraging time in the presence of aquatic recreation (Lafferty 2001a, Thomas et al. 2003, Velando and Murilla 2011).

Beach recreation can affect roosting activity for some shorebirds.

Beach recreation can affect roosting activity for some but not all shorebirds. A study in coastal South Carolina investigated high-tide roost-site selection for eight species of non-breeding shorebird at two temporal scales at a stopover and wintering refuge areas. Results indicated that, among years, only red knots avoided roosts that had high average motorized boat activity within 1000 m. Considering daily roost use, only dowitchers appeared to track daily disturbance, avoiding prospective roosts when motorized boat activity within 100 m was high. Other species in the study (American oystercatcher, dunlin, whimbrel, and ruddy turnstone) did not show significant effects of human recreational activity at the daily or yearly time frame (Peters and Otis 2007). For the coastal marine bird assemblage in central Chile, a reserve played an important role in providing safe roosting sites without human interference. This study indicated year-round effects of recreation on shorebird distribution (Cornelius et al. 2001).

Evidence of habituation of shorebirds to recreation is rare. In southern Spain, no evidence of habituation was found in any of the five migratory shorebirds studied (Martin et al. 2015). However, white-fronted plovers in South Africa showed evidence of habituation to human presence at a site with higher experimental disturbance levels. At this site, plovers allowed closer human approach before leaving the nest, and returned to the nest more quickly after a disturbance event (Baudains and Lloyd 2007).

Few studies reported an overall lack of effect of recreation on shorebirds. At a beach in southern California, shorebird density varied mostly with season and tide rather than human activity, and distributions were determined mainly by ecosystem type rather than human presence (Lafferty 2001b). In this study, access to urban refuse increased crow and western gull abundance. Displacement of birds by humans was short lived and did not alter large-scale patterns of beach use by birds (Lafferty 2001b). In eastern England, there was no evidence that the number of black-tailed godwits supported by food resources in coastal areas was affected by human presence (Gill et al. 2001).

In our review, two studies drew conclusions that might have implications at the population level, both indicating limited long-term effects at the population level. For white-fronted plovers in South Africa, nest mortality was significantly lower at the site with high recreational activity, but chick mortality was significantly higher at the more disturbed site, likely from domestic dogs. However, annual fecundity was higher at the more disturbed site (Baudains and Lloyd 2007). In common sandpipers breeding around a reservoir in central England, the size of the breeding population was reduced by anglers and other visitors, but breeding success was unaffected (Yalden 1992).

Wetland birds have shown short-term responses to aquatic recreational activity, although these are often not expected to have long-term effects at the population level.

Waterbirds and waders—Wetland birds have shown short-term responses to aquatic recreational activity, although these are often not expected to have long-term effects at the population level. The studies reviewed were primarily short-term studies. Vigilance responses reported include alertness with escape activities in American coots and no escape activities in American white pelicans (Schummer and Eddleman 2003). Two species showed an altered activity budget, with less time spent feeding by flamingos (Galicia and Baldassarre 1997) and eider ducklings (Keller 1991). Three species, including green-backed herons (Kaiser and Fritzell 1984), mute swans, and wigeons (Madsen 1998), were reported to be spatially displaced by aquatic recreation.

Results on the responses of waders and divers to human disturbance are mixed. Some studies found that waders are particularly vulnerable to human disturbance (Cardoni et al. 2008), while coots and grebes have relatively low response to aquatic recreational activities and associated infrastructure (Bright et al. 2004, Cardoni et al. 2008, Madsen 1998, Schummer and Eddleman 2003, Titus and VanDruff 1981). However, two divers (common merganser and common loon) were observed only on Wisconsin lakes without human housing developments and motorized boats, while many other pisicvorous species were present on lakes both with and without these types of human influence (Newbrey et al. 2005). Additionally, one New Zealand grebe species showed evidence of habituation to motorized boat traffic in high-use recreational sites (Bright et al. 2003).

Ruddy shelducks were not affected by recreational canoe activity on a river in Nepal, with birds disturbed for an average of 11 minutes per day (Hulbert 1990). However, this species did appear to be disturbed by the lengthy return of canoes from upriver, indicating that this species would not be disturbed by recreational activity at the given level if canoes were returned to their starting location by land.

Studies reporting results with population-level implications were sparse and suggested little long-term effects of aquatic recreation on wildlife populations. In a Scotland estuary, eider ducklings experienced slightly increased predation rates by gulls, with an estimated loss of one duckling per 200 human disturbances (Keller 1991). A slight reduction in nesting and brood rearing success of individual pairs of common loons was found in a wilderness area in Minnesota with high human impact, but the size of the adult breeding population did not decline during a 25-year period over which recreation increased enormously (Titus and VanDruff 1981).

At the community level, a study in Argentina found that wetland bird species richness and abundance in high disturbance areas was higher on days without recreational activity (Cardoni et al. 2008). Waterbird assemblages and structure changed in relation to presence of people on the shoreline, suggesting direct effects of recreational activities on waterbirds' habitat use. However, these effects were short term, and waterbirds returned to a high disturbance area when recreationists were not present (Cardoni et al. 2008).

Forest birds—In a study in the Netherlands, 11 of the 12 most abundant species along a lake shore showed effects of disturbance from increased recreation following the opening of a nearby parking lot, with significant negative correlations found between densities of two warbler species and between the number of recreationists and bird density (van der Zande and Vos 1984).

Bald eagles are particularly sensitive to disturbance from recreation in narrow river channels; studies suggest that temporal recreation restrictions can decrease negative impacts to bald eagles.

Raptors—Two studies by different researchers covered winter and summer seasons for bald eagles, both indicating that bald eagles are particularly sensitive to disturbance from recreation in narrow river channels, and recommending temporal restrictions on recreational activities. In northwest Washington, the number of wintering bald eagles decreased, and feeding activity declined exponentially, as the number of daily recreational events increased (considering nonmotorized boats, motorized boats, and foot traffic). This population showed a weekend effect, with fewer eagles using the river and feeding less on weekends compared with weekdays (Stalmaster and Kaiser 1998). During the summer in interior Alaska, bald eagle flush response rate and distance were governed by the context within which encounters with nonmotorized boats occurred. This population showed that both flush rates and distance increased as the summer progressed (Steidl and Anthony 1996). Both studies indicated that eagle locations relative to human disturbance was important in their responses, with eagles on the ground (Stalmaster and Kaiser 1998), near the river's edge, and lower in trees (Steidl and Anthony 1996) having a higher response.

It is not clear whether bald eagles habituate to human disturbance. In the summer in Alaska, eagle flush response rate varied with the existing level of human activity in a geographic location, suggesting that eagles either habituate to human disturbance or that individuals sensitive to human activity relocate (Steidl and Anthony 1996). The wintering population in Washington exhibited sensitization to disturbances through their feeding behavior; authors recommended restricting recreational activity during the first 5 hours of daylight, as this was an important feeding period for this bald eagle population (Stalmaster and Kaiser 1998).

Mammals

Four articles were found on the effects of aquatic recreation on mammals, three focusing on carnivores and one on manatees. Collectively, these studies found alterations in activity such as time spent feeding (King and Heinen 2004), use of habitat (Elmeligi and Shultis 2015, King and Heinen 2004, Leighton et al. 2010), and evidence of using human areas as refuge (Elmeligi and Shultis 2015).

Impacts on individuals, populations and communities—

Carnivores—Some grizzly bears in British Columbia, Canada, and Alaska were tolerant of boat-based wildlife viewing activities while others were not. Females (especially those with cubs) may have used viewing areas as refuges from males, because males were rarely observed outside of the mating season. Reaction distances of bears varied greatly by individual (Elmeligi and Shultis 2015). Brown bears were also found to flee from motorized watercraft in Alaska (Wilker and Barnes 1998).

David King

Whitewater canoeing on the Deerfield River, Massachusetts. The Deerfield is heavily used by canoeists and tubers and is an important cold-water fishery.

Mongooses, a species introduced from Southeast Asia, are known diurnal predators of Hawskbill sea turtles in the Caribbean. Researchers estimated that human activity on beaches would deter mongooses from accessing nests on open beach and has the potential to reduce predation on nests in vegetation by up to 56 percent at the study site. The greatest per capita impact was found when fewer than 50 people were on the beach at one time. This study documented a positive impact of human activity on sea turtles (Leighton et al. 2010). Although mongooses are not known to be present in the continental United States, they are found in Hawaii and general lessons on nest predation may be derived from this study.

Other mammal species—Manatee overwintering behaviors were altered by recreational swimming and boating in central Florida. When the number of swimmers and boats increased, manatee use of protected sanctuaries (i.e., no human entry) was significantly greater if water temperatures were also lower in surrounding areas. Manatees also spent less time bottom-resting and nursing and more time milling and swimming when swimmers were present, compared to absent. Researchers concluded that the use of no-entry sanctuaries is important for the conservation of manatees and suggested expanding the sanctuary network (King and Heinen 2004).

Potential Effects of Emerging and Under-Researched Aquatic Recreation

Types of aquatic recreation not extensively covered in the summaries presented here include the use of stand-up paddleboards (SUPs) and packrafts (small inflatable rafts), windsurfing, kitesurfing, freshwater scuba diving and snorkeling, and motorized wakeboarding. Below, we apply findings from other types of recreation to hypothesize potential effects of these types of recreation.

- **SUPs and packrafts** can be compared to kayaks and canoes, which seem to have relatively low impacts on waterbirds and bald eagles (Keller 1991, Stalmaster and Kaiser 1998). This type of recreation can have implications for erosion on the banks of water bodies at access points, especially if access is widely distributed and not hardened with a designated boat ramp. In that case, we could expect trampling of vegetation and potentially compromised water quality and invertebrate communities in streams similar to those found at stream crossings (see Caires et al. 2010, Halinouski and Krytskaya 2014, Holmquist et al. 2015, Kidd et al. 2014). We might expect low or no effect of access to dispersed boat launching points in estuaries to bivalve densities (Gill et al. 2001).
- **Windsurfing and kitesurfing** are both fast-paced aquatic activities that require windy conditions. One study reviewed here indicated that mute swans and wigeons responded to windsurfing at the greatest distances, compared to other recreational activities (Keller 1991). No studies were found on the effects of kitesurfing on wildlife or habitat, but as these types of recreation require similar conditions, we might expect their effects to be similar.
- **Scuba diving and snorkeling** in freshwater may have effects on animals that live within the water column. Manatees are known to have reduced foraging time in response to swimmers and snorkelers (King and Heinen 2004).
- **Motorized wakeboards** are similar to SUPs but are propelled by an electric motor. We might expect similar effects as with SUPs and packrafts for access to water bodies. The sounds generated by the motor may also have some effect on wildlife living in the water and potentially on land. At this writing, no research was found regarding the effects of motorized wakeboards on wildlife.

Comparison of Aquatic Activity Types

Few studies compared the effects of different types of aquatic recreational activity on wildlife. Similar to non-aquatic recreation, birds showed higher sensitivity to quickly moving (Madsen 1998) and unpredictable types of activity (Stalmaster and Kaiser 1998), and possible sensitivity to loud noises, though this showed mixed results.

On beaches, dogs were more disturbing than humans on foot for western snowy plovers. However, these birds were also more likely to fly from horses than from humans (Lafferty 2001a), contrary to other studies finding that horses were less disturbing than humans (see Hennings 2017). Motorized traffic was more disturbing to the ghost crab population as well, with crab density highest at beaches with only nonmotorized activity, and decreasing with increasing intensity of motorized recreation on Assateague Island (Steiner and Leatherman 1981).

Shore-based activity produced more short-term disturbance than water-based activity for eider ducklings and bald eagles (Keller 1991, Stalmaster and Kaiser 1998). However, motorized boats disturbed a greater portion of the bald eagle population than did foot traffic (Stalmaster and Kaiser 1998). Overall, running

USDA Forest Service

A boy tries his hand at fishing on the Clackamas River, Mount Hood National Forest, Oregon.

motorboats were the most disturbing type of aquatic recreation activity to bald eagles, owing to the repetitious pattern of upstream running followed by downstream drifting by the same motorboats. Bank anglers and hikers had less overall impact on bald eagles because they traveled short distances along the river (Stalmaster and Kaiser 1998).

Considering water-based activities only, hunting (especially from nonmotorized mobile boats without decoys as compared with stationary anchored boats with decoys) was the most disturbing aquatic recreation for autumn-staging waterfowl compared with nonmotorized activities (fishing, sailing, and windsurfing). However, waterfowl fled from windsurfers at the farthest distance, compared to fishing, sailing, and hunting (Madsen 1998). Bald eagles had the highest flushing rate in response to (1) dories (small, shallow-draft boats), research boats, and drifting motorboats, followed by (2) running motorboats and rafts, and finally (3) canoes and kayaks, but flushed at farther distances from running motorboats than from drifting motorboats (Stalmaster and Kaiser 1998).

Conclusion: Impacts of Recreation on Wildlife and Habitat

In this report, we synthesized research on the impacts of recreation on wildlife that reveal patterns of response at the individual, population, and community level. In addition to these overall effects, we describe variability in wildlife responses among different forms of recreation, season, and taxonomic groups to enable managers to more precisely incorporate wildlife concerns into their planning and management activities. These can be found in the preceding sections under the appropriate headings; below we summarize some general findings:

- Impacts of recreation on wildlife are highly variable among species. In general, habitat specialists and migratory species are less adaptable to recreational activities and associated habitat modifications than are habitat generalists and resident species. Predator, mesopredator, and prey species can also be differentially affected by recreation. These dynamics can lead to altered wildlife community composition.
- The majority of studies conducted focus on the behavioral response of individuals to recreational activity. However, studies on invertebrates are more often conducted at the population and sometimes community level.
- Habitat modifications from recreational infrastructure can have substantial impacts on wildlife. One important example is landscapes cleared for ski trails and resorts, where altered habitat structure can affect distribution of small mammals year-round.

- The responses of wildlife to recreation in winter months often appear dampened compared to those in warmer seasons, with energetic impacts to wildlife a critical consideration during winter.
- Effects of aquatic recreation are less well-studied than terrestrial activities; however, types and intensities of responses by wildlife to aquatic recreation are presumed to be similar.
- Evidence of habituation has been documented for a range of species, as has attraction to points of human activity.
- A lack of effect of recreational activity and infrastructure has also been documented for a range of species. Owing to the difficulty of publishing studies of "no effect," a lack of wildlife response to recreation may be more widespread than is represented in the published scientific literature.

By presenting wildlife responses and habitat alterations associated with recreation in this way, we aim to provide a reference for wildlife and recreation managers for making decisions specific to present or proposed recreational activites on lands that provide habitat for a range of wildlife species. Many of the studies reviewed in these chapters present strategies for managing both humans and wildlife to benefit wildlife populations and their habitats, and to provide quality visitor experiences. Those strategies are described in chapter 6.

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Signs can be an important component of managing wildlife in areas with recreation. Framing instructions in a positive way, such as in the signs pictured here, is often more effective than negative phrasing.

Chapter 6: Management Principles for Recreation and Wildlife on Public Lands

Introduction

To address problems stemming from human-wildlife interactions, both human and wildlife systems need to be considered (see chapter 1). Some wildlife management issues related to recreation can pertain to recreation demands not being met (such as when new snowmobile trails are forged by users), conflicts among different user types in a shared setting, or other social issues.

Several land management agencies have developed management plans for sustainable recreation. For example, the U.S. Forest Service released the national Framework for Sustainable Recreation in 2010 (USDA FS 2010), outlining the broad challenges and opportunities within the agency's managed recreation program, as well as a vision, guiding principles, and goals and focus areas for National Forest System recreation. Subsequently, Forest Service regions developed "sustainable recreation strategies" further describing local issues, opportunities, goals, and visions for sustainable recreation. The contents of six of these regional strategies were analyzed and compared by Selin (2017). Wildlife and recreation staff would benefit from working with regional counterparts to develop criteria for measuring sustainability for both recreation and wildlife.

Below we suggest ways to minimize the impacts of recreation on wildlife through (1) using social science methods and data to more fully consider human aspects of human-wildlife interactions, (2) planning new recreation programs and infrastructure, and (3) managing existing recreational programs and infrastructure. We also provide several lists of guidelines for managing specific activities in wildlife-friendly and environmentally sound ways, informed by literature on these subjects.

Note that the management practices guidelines presented here should be treated as hypotheses based on previous findings and recommendations from the scientific literature and land management documents, but that they have not been empirically tested.

Understanding Human Aspects of Human-Wildlife Interactions

Integrating lessons learned through social science research is essential in effective visitor management. Some key proposals for better management of human-wildlife interactions include the following:

- **Consult with user groups** to identify demands that are not being met in the current management of recreation areas and public lands in general. Applying methods such as human ecology mapping with user groups can highlight routes and areas of particularly high value or demand for different types of recreational use (e.g., Cerveny et al. 2017).

- **Learn from data provided by users** such as are found in social media websites, global positioning system (GPS)-tagged photos, blogs, and trip reports. Crowdsourced data from GPS-enabled applications, GPS-tagged photos, and other sources can help us understand the spatiotemporal distribution of visitors on landscapes (e.g., Fisher et al. 2018, Walden-Schreiner et al. 2018). User-provided data from websites to which recreationists upload their routes, such as the Strava® application[2] used by mountain bikers, can also help show what areas are receiving the most use (e.g., Campelo and Mendes 2016). Information from blogs, trip reports, and photography sites can help provide better understanding of how people value public lands, interact with wildlife, and make recreation choices (e.g., Richards and Tunçer 2018, Sachdeva 2020, van Zanten et al. 2016). However, caution should be used to account for possible biases in the profiles of visitors who post on social media sites (e.g., people may be less likely to upload posts about certain types of recreation, or about a trip that was less valued, or if they live near the area and visit often) (Wood et al. 2013).
- **Map social-ecological systems** to better understand management challenges at relevant scales. Combining human values and use (based on information gained through consulting with user groups or through social media data) with known and potential wildlife habitat and movement can highlight areas with low tradeoffs between recreation and wildlife, in situations where wildlife and recreation might not coexist well. An example of this mapping technique is shown in figure 1.3.
- **Clearly mark recreational designations** such as trails, camping areas, wilderness areas, and play areas using signs and other markers to help visitors use different zones as intended. In some cases, users might leave designated recreation areas without realizing it if their boundaries are not clearly marked. If speed limits are implemented, these should also be clearly marked. When GPS is used for navigation, providing files that can be viewed on handheld GPS units or smartphones, such as through the Avenza Maps® mobile application, can promote awareness of boundary locations.
- **Work with communication scientists to craft and distribute effective messages.** Communication experts have found that framing instructions in a positive way is more effective than a negative way. For example, "Please

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

park in designated areas" is more likely to be effective than "Please do not park outside designated areas." This was found to be true in both urban and wildland settings (Winter et al. 2000). Managers are encouraged to promote alternative behaviors (such as Leave No Trace principles) rather than trying to prevent current behaviors considered problematic (Marzano and Dandy 2012). Communication strategies that emphasize the visitor experience gained by participating in wildlife viewing can be more effective than those only highlighting the importance of wildlife protection. Additionally, strategies that make desired behaviors easy, convenient, and enjoyable can be more effective than fear appeals (Abrams et al. 2020). These suggestions take a positive approach, encouraging environmentally friendly behaviors rather than penalizing behaviors that, in some cases, recreationists might not realize are detrimental to the environment. Additionally, delivering messages through multiple methods (e.g., personal contact, posters or brochures at trailheads, signs along trails, volunteers or staff delivering messages at critical sites) increases their effectiveness (Hockett et al. 2017, Marion and Reid 2007), and multilingual signs targeting surrounding communities and expected visitors can also help a diversity of audiences receive the message (Winter 2006). Communication scientists can be consulted to effectively distribute messages to the intended audience (Mackenzie et al. 2017, Wilkins et al. 2018). See also "Education and Outreach" below.

- **Ensure that trails are easily accessible** in areas with the least overlap with important wildlife habitat. Making recreation in these zones easily accessible might result in decreased recreation in spaces where negative impacts on sensitive species are more likely.

Planning New Recreation Programs and Infrastructure

Minimize Overlap With Important Habitat for Species Sensitive to Recreation

- Combining maps of known or potential key habitat, such as core undisturbed habitat for species of concern (e.g., McCormick et al. 2018), with maps of current and potential recreation areas can improve our spatial understanding of tradeoffs between recreation and wildlife. These combined maps can be used, for example, to encourage high-intensity recreation in more ecologically tolerant areas with high user demand, while setting aside the most ecologically important and sensitive areas with low user demand as low-recreation reserves. Figure 1.3 demonstrates an example of this concept.

- For motorized summer recreation, avoid fragmenting important habitat for small mammals (Laabs 2006, McGregor et al. 2008) and for lizards, which are affected even by moderate amounts of off-highway vehicle (OHV) use (McGrann et al. 2006). In dryland areas, desert bighorn sheep, desert tortoise, sage-grouse, and Sonoran pronghorn are particularly sensitive to OHV use (Switalski 2018). For managing OHVs in drylands, Switalski (2018) suggested mapping the entire OHV trail network, including user-created trails, then overlaying this with environmental and cultural resources to be protected. A method for planning and conducting route inventories on Bureau of Land Management lands is outlined by Graves et al. (2006).
- Other areas of importance include key wildlife corridors, foraging areas, riparian areas, washes, and floodplains; critical wintering habitat and winter concentration areas for ungulates (Manier et al. 2013, Switalski 2018); and forest wetlands for Florida panthers (McCarthy and Fletcher 2015). Developing methods similar to those used to identify and monitor potential overlaps of recreation with wildlife habitat (Wisdom et al. 2013) can contribute toward this aim. For example, researchers have modelled potential overlaps of winter recreation with grizzly bear denning habitat (Goldstein et al. 2010, Podruzny et al. 2002).
- Consider important winter habitat (e.g., Patthey et al. 2008), such as denning habitat for bears (Goodrich and Berger 1994, Lundberg et al. 1976) and wolverines (Heinemeyer et al. 2019), and important winter habitat for ungulates (Harris et al. 2014) and Canada lynx (Olson et al. 2018). Bighorn sheep and mountain goat habitat should also be considered, as these species are limited to relatively small areas with very steep and rocky slopes (Canfield et al. 1999).
- In caves with bat species sensitive to white-nose syndrome, recreation should be avoided if strict regulation of recreational activity (such as tour-only access) cannot be achieved (White-Nose Syndrome Response Team 2016).

Implement Buffer Zones for Sensitive Species

Restricting recreational activity within a predetermined distance from sensitive species might decrease disturbance to these species. Some researchers suggest requiring visitors to keep a minimum distance from animals in reproductive periods, such as nesting birds and other sensitive species (e.g., Burger and Gochfeld 1991b, Rodgers and Smith 1997; see also Hennings 2017). A starting point for establishing buffer zones is identifying the distance at which species of concern respond to human activity (e.g., flight initiation distance, alert distance, etc.). A graphic representation of a literature review of reported flight initiation and alert distances by species grouping was compiled by Hennings (2017), summarized in table 5.1.

Table 5.1—Flight initiation distance (FID) and alert distance (AD) for wildlife species groups, as reported in the literature reviewed by Hennings (2017)

Species grouping	Mean reported FID or AD	Minimum reported FID or AD	Maximum reported FID or AD	Number of studies reviewed
	- - - - - - - - - - - *Meters*	- - - - - - - - - - - -		
Amphibians	194	125	287	5
Reptiles	216	205	236	3
Waterfowl (ducks)	71	40	103	7
Waterbirds (herons, egrets, cormorants)	67	9	201	28
Shorebirds	35	7	201	39
Terns/gulls	24	7	38	7
Songbirds (excluding grassland species)	10	4	63	47
Grassland songbirds	40	26	67	6
Raptors	195	38	476	24
Cervids (deer, elk, sheep)	215	74	400	21

Mean, minimum, and maximum FID and AD are provided, along with the number of studies reviewed to compile these numbers.

Further recommendations include the following:

- To reduce disturbance of frogs using streambanks in Spain, researchers recommended setting up buffer areas of more than 2.5 m from streams, or reducing visitor rates to fewer than five visits per hour (Rodríguez-Prieto and Fernández-Juricic 2005).
- For woodland and grassland bird species in Colorado, the zone of influence (i.e., where individuals were alert or flushed) was approximately 75 m from trails for most species (Miller et al. 1998).
- Some authors have suggested that a buffer of 100 m surrounding shorebird and wetland bird habitat in Florida would minimize disturbance to most species (Burger and Gochfeld 1991a, Rodgers and Smith 1997).
- One study suggested limiting motorized recreation to a distance of at least 50 m from the boundaries of nesting colonial waterbirds (Hillman et al. 2015).
- A 400 m distance of recreationists from bald eagles was suggested to minimize disturbance to bald eagle feeding behavior (Stalmaster and Kaiser 1998).
- Flush distances of some species are longer in response to vehicular traffic than foot traffic, e.g., bighorn sheep (Papouchis et al. 2001); white-tailed deer (Kucera 1976); reindeer (Reimers et al. 2003); mule deer (Freddy et al. 1986), and moose (Harris et al. 2014). Research on flush responses of a wide range of ungulates to varying human activities were synthesized by Harris et al. (2014) and Stankowich (2008).

- Reaction distances from grizzly bears being viewed from boats varied greatly, suggesting that an appropriate management option may be to ensure that boat captains can recognize potential displacement behavior in bears to avoid affecting subject animals (Elmeligi and Shultis 2015).

The process for making decisions on implementing buffer distances involves selecting the behavioral response and reproductive stage of highest concern, and an appropriate level of response at which to establish the buffer area (Burger et al. 2010). Implementing buffer zones is the highest priority for species at risk of long-term population changes resulting from human activity, which may not be a concern for all species that become alert to, or flush in response to, human activity. Implementing and enforcing buffer zones can be difficult. Clearly marking the buffer zone and using clear and memorable communication might aid in implementation (Winter 2006). Infographics using commonly understood measures of distance, such as the length of a bus, can help visitors visualize buffer distances better than the same distance written only in text (Abrams et al. 2020). See also "Understanding Human Aspects of Human-Wildlife Interactions" above.

Maintain Existing Large Unfragmented Landscapes

To the extent possible, large unfragmented areas should be maintained for species that rely on such territories and are sensitive to human visitors. Depending on the level of sensitivity of the species of concern, these areas should host limited or no recreation (Cornelius et al. 2001). Recreation and transportation routes should be planned to avoid areas important to migration and population connectivity.

Maintain Connectivity Between Habitat Patches

Building underpasses can help mitigate negative impacts on habitat and improve connectivity within and between habitat patches for amphibians (Guderyahn et al. 2016, Schmidt and Zumbach 2008), reptiles (Woltz et al. 2008), and small mammals (McGregor et al. 2008). Where highways or other barriers are in place, crossing structures can be important to maintain habitat connectivity for larger animals as well (Alexander and Waters 2000). See Woltz et al. (2008) for a comparison of the efficacy of different materials and crossing structure arrangements for reptiles and amphibians.

Enhancing habitat by adding rock piles and logs to trail borders can improve habitat connectivity for amphibians (Davis 2007, Fleming et al. 2011). Additionally, maintaining clearings on south-facing slopes is important for reptile populations (Woltz et al. 2008).

Reduce Noise and Visual Disturbance

Maintaining natural vegetative cover for motorized recreation routes and play areas, and building these in topographically complex areas, can reduce the extent of disturbance from motorized use. This practice can reduce the distance that sound travels and provide a visual barrier. Because the newest generation of snowmobiles is quieter than older models, requiring or incentivizing the use of newer models can reduce the level of noise disturbance (see Keyel et al. 2018). Models of sound propagation by snowmobiles have been developed separately by three research groups (Keyel et al. 2018, Reed et al. 2012, USDI NPS 2013). Reed et al. (2009) also modeled the overlap of noise with wolverine denning habitat. To minimize the effect of heli-skiing on mountain goats, researchers suggested restricting helicopter flights within 2 km of alpine areas and cliffs that support mountain goat populations (Côté 1996).

Time Recreation to Minimize Negative Impacts for Wildlife

Some researchers suggest restricting recreational activity by time of day or season of the year. For wintering bald eagles, restricting recreation during the first 5 hours of daylight, when a population studied in the Pacific Northwest was most sensitive to aquatic recreation, might minimize disturbance to feeding behavior (Stalmaster and Kaiser 1998). On beaches, restricting the use of kite buggies during peak migration season might decrease disturbance to migratory shorebirds; however, this was observed on only one occasion in one study (Thomas et al. 2003). Encouraging winter recreation to avoid bear denning season (Lundberg et al. 1976) and emergence time (Switalski 2016) may reduce potential impacts on bears. However, one source suggested that winter recreation in potential denning areas should begin around the time that bears naturally enter dens, allowing them to choose den sites away from disturbed areas (Linnell et al. 2000). Sensitive and biologically important periods differ by location, population, and species. Consolidating use (see below) might be a more effective method for minimizing negative impacts if seasonal restrictions cannot be enforced.

Managing Existing Recreation Programs and Infrastructure

Consolidate Use to Durable Zones

The decision to concentrate or disperse use is best made on a case-by-case basis. However, concentrating use in zones with higher ecological tolerance (i.e., ecosystems which are better able to withstand a cycle of disturbance and recover; Cole 1995) or durability while permitting dispersed use in other areas, and retaining some no-entry sanctuaries, has been implemented and suggested in numerous cases. By using tools such as user-created maps of important recreation areas, recreational areas might be consolidated to a core network in some areas. Easy access to trails in durable spaces should be maintained, including infrastructure such as parking, camping, and staging areas and restrooms, to encourage recreation in these spaces and minimize the dispersal of recreational activity. One recommendation is to avoid building new infrastructure in otherwise high-quality habitat for sensitive species (e.g., McGrann et al. 2006).

Several sources suggest reducing impacts of recreation by making it as predictable as possible and consolidating use to designated trails, routes, and play areas. Examples include the following:

- Nonmotorized summer recreation: Research addresses ungulates (e.g., Wisdom et al. 2018), brown bears (Fortin et al. 2016), marmots (Neuhaus and Mainini 1998), and birds (e.g., Burger 1995, Klein 1993, see also Hennings 2017).
- Winter recreation: Research addresses ungulates, grizzly bears, wolverines, and lynx (Canfield et al. 1999, 1992; Harris et al. 2014; Heinemeyer et al. 2019; ILBT 2013; Krebs et al. 2007; MDNRC 2011; Olson et al. 2018; USDA FS 2011). Studies on the effects of motorized and nonmotorized winter recreation on ungulates suggest that these species (i.e., elk and moose) respond to the initial recreation event, and that the amount of time and area covered by the recreation event are the most important factors (Cassirer et al. 1992, Harris et al. 2014), while the frequency of visitation has little influence (Cassirer et al. 1992, Ferguson and Keith 1982). Wolverines were found to avoid off-road recreation to a greater extent than vehicles on designated roads (Heinemeyer et al. 2019).
- Aquatic recreation: Research indicates the importance of no-entry sanctuaries for manatees (King and Heinen 2004). However, to protect seabirds, limiting the number of boats using a reserve was suggested to be a better management option than establishing boat-free zones in marine protected areas near islands in northern Spain (Velando and Murilla 2011).

Closures and restrictions should be case specific and justified by evidence of negative impacts at the population level—

It is important that recreational closures and other restrictions on public lands be justified by considering the biology and ecological requirements of species of concern when setting seasonal dates for recreation restrictions. As Schummer and Eddleman (2003) highlighted, such closures may trade human benefits for ecological benefits, and would best be justified through evidence of associated negative impacts at the population level, on a case-by-case basis. Working with managers of neighboring landscapes might help reveal the tradeoffs of closures for both people and wildlife at the larger landscape scale. Permitting systems can reduce negative social effects (e.g., safety, conflict between users) as well as negative ecological effects (e.g., be a detriment to wildlife populations and habitat), but they should also be justified by evidence that they will reduce negative impacts at the population level. Positive examples of permitting systems can be found in wilderness management (e.g., Boundary Waters Canoe Area Wilderness) and river permit lottery systems. Permitting systems come with tradeoffs, as they limit the number of people who can benefit from outdoor recreation at a particular site (e.g., Pettebone et al. 2013), but may improve the quality of the experience for those who do receive permits.

Apply adaptive management—

Regularly monitor populations in areas open and closed to recreation and establish an adaptive management framework to measure the efficacy of current management on populations. Adjust management to continue minimizing impacts of motorized and nonmotorized summer and winter recreation to wildlife (Switalski 2016, 2018).

Guidelines for New and Existing Recreational Programs and Infrastructure

Consider Managing the Activities and Numbers of Winter Recreationists to Minimize Impacts on Mammals

Management suggestions based on empirical results are summarized below. However, these guidelines will differ by species and setting.

Wolverines—

Wolverines are sensitive to winter recreation, both motorized and nonmotorized (Heinemeyer et al. 2019) (see "Comparison of Winter Activity Types" in chapter 4).

Bison—

Remaining at least 260 m from bison herds and being discrete when near large herds with young can minimize recreationist impacts on bison, according to a study in Yellowstone National Park (Fortin and Andruskiw 2003). A method for effectively communicating this type of distance is discussed in "Planning New Recreation Programs and Infrastructure" above (see also Abrams et al. 2020).

Elk—

In winter, hunted elk will often avoid areas with disturbed ground (e.g., that associated with expanding a ski area) and areas with increased human activity (associated with existing ski areas) more than elk that are not hunted, but they may


Korkeasaari Uusijani

A wolverine in Finland. Wolverines are particularly sensitive to off-road winter recreation.

habituate to disturbance in some instances. Disturbance to elk can be reduced by minimizing human activities where elk are concentrated on winter ranges (Morrison et al. 1995).

Mountain goats—

Goats avoid winter recreation associated with ski areas in Canada, and development of these areas should be avoided in habitats used by these sensitive species (Richard and Côté 2016).

Caribou—

In a biosphere reserve in eastern Canada, limiting groups of ecotourists to approximately nine people, and using only caribou trails to reduce the disturbance of snow cover, were suggested to minimize impacts on caribou (Duchesne et al. 2000).

Reindeer—

A maximum of three daily encounters with recreationists throughout the winter was estimated to not have substantial energy costs for reindeer (Reimers et al. 2003).

Avoid Intensive Motorized Use Near Sensitive Species

Some species are particularly sensitive to intensive human activity. A study on goshawk chick survival suggested benefits to delaying opening forest roads that have intensive all-terrain vehicle (ATV) use, and especially those that pass near nests during the first few weeks after chicks have hatched (Dunk et al. 2010). Intensive ATV use in this case refers to race events.

Follow Best Practices for Use of Artificial Light

Artificial light can alter the behavior, movement, and breeding success for some species, with some species attracted to light while others avoid it (see chapter 2 for further detail). When artificial lighting in recreational areas is deemed necessary, the effects can be reduced by following best practices, such as those suggested by the Illuminating Engineering Society of North America (Jacobson 2005) and the Audubon Society (Audubon Society of Portland 2012). The International Dark-Sky Association is another source for information on reducing and mitigating light pollution.

Education and Outreach

Encourage Guides to Foster Environmentally Friendly Tours

Guided recreation programs offer opportunities for information to be delivered to visitors by knowledgable guides. Encouraging guides to practice techniques that result in minimal disturbance to wildlife can improve the experience for recreationists, enabling them to see more wildlife and potentially reducing the long-term effects of recreation on wildlife and habitat. This approach can be particularly useful when applied to cases in which wildlife responses vary greatly by recreational situation or by individual. Two examples include (1) guides who reduce tour group disturbance of flamingos in Mexico (Galicia and Baldassarre 1997) and (2) boat captains who recognize potential displacement behaviors in bears to avoid affecting animals that are the subject of their tour (Elmeligi and Shultis 2015). For grizzly bears, responses to boats varied too highly to establish a distinct buffer distance, so the knowledge and experience of guides was essential for recognizing warning signs, allowing boats to move away before flushing a bear from the area.

Implement Effective Educational Programs for Recreationists

In certain situations, educational programs can help reach goals of (1) improving visitor experiences by providing useful or interesting information and (2) influencing certain visitor behaviors during or after their trip. If an educational program is used, identifying specific goals before developing and implementing the program is crucial to its success. Note that visitor behaviors are linked closely to factors such as personal norms and morals, internal motivations, past experiences, and habits (Steg and Vlek 2008). Behaviors are also related to contextual factors, such as how easy it is to carry out a desired action. Thus, some behaviors are more effectively influenced by educational programs than others. Research in environmental psychology suggests that promoting behavior change becomes more effective when designers follow this process:

- Select which behaviors one seeks to change to improve environmental quality.
- Investigate what factors cause those undesirable behaviors.
- Apply targeted interventions to change those behaviors and their antecedents.
- Systematically evaluate the effects of interventions on behaviors and their antecedents on environmental quality and human quality of life (Steg and Vlek 2008).

Specific guidelines for using information and education in visitor management were compiled by Manning and Anderson (2011). Those guidelines are summarized as follows:

- Target messages at specific audiences. Particularly important audiences for educational messaging include the following:
    - Those who request information in advance.
    - Those who are least knowledgeable about the issue being communicated.
    - Young visitors.
- Deliver messages at an appropriate time and place:
    - Some messages may be more effective when delivered close to the time or place where problem behaviors occur. For example, hikers may be less likely to hike off-trail if information is provided where they would move off trail (Hockett et al. 2017).
    - Some messages may be more effective when delivered during trip planning. For example, campers may be more likely to use a camp stove instead of building a fire if information about a fire ban and appropriate alternatives to campfires are provided in advance, allowing campers to plan accordingly (Christensen and Cole 2000).
- Delivery methods and sources are important:
    - Use multiple media to reach wider audiences.
    - Deliver messages from sources judged to be highly credible by the target audience.
    - Provide simple, interesting, consistent, and useful messages in educational programs.

  - Limit messages at trailheads and bulletin boards to very few issues.
  - Use strongly worded language to communicate high-priority messages such as visitor safety or protection of critical resources.
- The type of information to provide depends on the goals of the education program and its target audience. The following types of information may be particularly effective:
  - Information on the impacts, costs, and consequences of problem behaviors.
  - Information targeted toward problem behaviors that are regarded as careless, unskilled, uninformed, or of most importance to managers.
  - Programs designed to connect with or modify visitor attitudes, beliefs, or norms.
- Giving ecological reasons for appropriate behavior may be more effective than experiential reasons.
- Educational programs are not a simple approach to management and require important planning steps as outlined above. One important way that educational programs can be used is to complement more direct management approaches by explaining the need for such management.

Engage With Recreationists Through Outreach Programs

Outreach programs such as environmental stewardship, citizen science, and other volunteer programs can be educational for participants while supporting conservation goals. Working with existing groups such as those formed around particular outdoor recreation activities or locations can build trust between land management agencies and the public and can increase management capacity in some cases. In a recent review article on environmental stewardship, Bennett et al. (2018) discussed leverage points for promoting and supporting local stewardship programs, such as introducing new actors, providing incentives, increasing capacity, promoting certain actions, or monitoring outcomes to facilitate adaptive management. The role of outdoor recreationists as environmental stewards was also discussed by Miller et al. (2020a).

Guidelines for Specific Recreational Activities

Based on the literature, we compiled guidelines for managing specific recreational activities in ways that are intended to minimize negative impacts on wildlife and wildlife habitat. These guidelines are summarized below.

Unmanned Aerial Vehicles or Drones

Recreational use of unmanned aerial vehicles (UAVs, commonly referred to as drones) on public lands began relatively recently and is becoming more popular. UAVs are also used by both wildlife and recreation managers and researchers for data collection and monitoring (Merkert and Bushell 2020). At the time of publication, few researchers had addressed the impacts of recreational UAV use on wildlife and other recreationists. A brief survey conducted at public spaces around Missoula, Montana, investigated concerns about recreational UAV use and support for a variety of management options. Results indicated that fines for misuse of UAVs was the most highly supported management option, while banning UAVs on public lands received little support (Allen 2018). A study using scientific literature complemented by YouTube™ videos to assess the impacts of recreational UAVs on wildlife found many species to show behavioral responses to UAVs, with those using aerial and terrestrial habitats more likely to respond than aquatic species. These authors called for educational programs for recreationists using UAVs, and additional research and regulation on UAV use in sensitive wildlife areas (Rebolo-Ifrán et al. 2019).

Several studies have investigated the impact of UAVs on wildlife when used for research and management. Although this type of use is different from recreational use, we provide information here because research is sparse on recreational UAV use, and aspects of this information are relevant to recreation management. One study found that using UAVs for surveying colonial waterbirds did not increase colony-wide flight behavior at nesting sites, but responses differed among species and increased at the lowest flight path (Barr et al. 2020). In a review article, Mulero-Pazmany et al. (2017) recommended that, while using UAVs, researchers and managers observe the following guidelines to reduce their effect on wildlife:

- Favor low-noise or small UAVs over noisier or larger ones.
- Mount the ground control station 100 ± 300 m away from the study area.
- Conduct missions as short as possible.
- Fly at the highest altitude possible, while remaining below 400 feet, as required by the Federal Aviation Administration (FAA 2020).
- Avoid maneuvers above animals.
- Favor consistent back-and-forth flight patterns rather than less predictable movement.
- Minimize flights over sensitive species or during the breeding period.
- Avoid UAV silhouettes that resemble predator shapes.
- Avoid direct approaches at close distances and favor indirect approaches.
- Monitor target animals before, during, and after the flight.

- For nest inspections, fly at times in which eggs/chicks are out of risk.
- If the flights are around aggressive raptor's territories, schedule them during times when the temperature is low when birds are less prone to fly due to lack of thermal lift.

Caving

Recommendations to prevent the spread of white-nose syndrome (WNS) in cave-dwelling bats include the following:

- Prevent unrestricted access to subterranean bat roosts, especially when bats are present.
- Require visitors to subterranean bat roosts to follow decontamination protocols.
- Designate no-entry restrictions for subterranean bat roosts when wintering bats are present, which may include fall and spring.
- Educate visitors and local communities about WNS and conservation of bats, caves, and subterranean habitats (USDI FWS 2016)

Ski Slope Development

The guidelines below summarize management recommendations made by researchers to develop environmentally friendly ski slopes, reducing negative impacts of ski slopes on wildlife. Although ski areas generally choose how ski slopes will be engineered, these guidelines can inform requirements built into the permitting system.

- Avoid removing rocks and leveling ground surfaces as much as possible, to preserve soil and natural vegetation for arthropods (Negro et al. 2010, Rolando et al. 2013).
- Create a gradual transition from forest to open area of the ski slope, reducing stark edges between forest and grassland areas (Patthey et al. 2008, Rolando et al. 2013).
- Maintain or create tree islands and incorporate woody debris into ski slopes to improve these areas as habitats for small mammals (Hadley and Wilson 2004b, Patthey et al. 2008, Rolando et al. 2013).
- Reduce the visibility between wildlife habitat and recreationists by planting or preserving native vegetation (Thiel et al. 2007).
- Improve connectivity between habitat patches within ski resort areas where species with social metapopulations are present by creating wildlife underpasses under roads (Mansergh and Scotts 1989).
- Install marking devices on sections of ski lift cables where the number of bird collisions is likely to be high (Buffet and Dumont-Dayot 2013).

- Promote the recovery and maintenance of local vegetation to enhance invertebrate and bird assemblages. Pruning or grazing might be necessary to control encroaching shrubs and maintain safety standards (Rolando et al. 2007).
- Retain vegetative structure and minimize disturbance to native vegetation to help lizards persist in ski slope areas (Sato et al. 2014).

Note that although these steps will likely increase the provision of habitat and reduce costly behavioral responses for wildlife in general, negative effects on some species may still be detected. For example, a study in the Czech Republic found that even ski areas that employed environmentally friendly management had negative effects on beetle species. In this study, direct disturbance to vegetation and soil was prevented by not using machine grading and artificial snow in winter as well as not grazing, mowing, or conducting other management in summer, and by opening the slope for skiing only with a minimum snow depth of 80 cm (Kasak et al. 2013). Also worth noting is that low-intensity farming systems in valley bottoms near ski resorts can provide a food supply alternative to human food scraps, to address overabundance of urban-adapted species such as crows (Laiolo 2007).

Guidelines for Snowmobile Trail Density and Use Intensity

Some agencies have limited snowmobile route density in areas or seasons if species sensitive to motorized activity are present (Switalski 2016). For example, the Forest Service recommended limiting open motorized route density to less than 0.6 km of trail per km^2 (1 mi of trail per mi^2) to increase grizzly bear habitat security in parts of the Cabinet-Yaak Recovery Area, Montana (USDA FS 2011). Montana state management plans also call for minimizing motorized road miles in important grizzly bear habitat and seasons (MDNRC 2011). A study on interactions between over-snow vehicles (snowmobiles and tourist vans fitted with snow tires) with bison and elk in Yellowstone recommended that managers maintain over-snow vehicle traffic levels at or below those observed during the study (ranging maximum daily numbers of 330 to 1,874, and yearly average daily numbers from 178 ± 59 to 593 ± 269 across as 27 000 ha area) (Borkowski et al. 2006). In Yellowstone National Park, the number of snowmobiles allowed was limited to reduce impacts on wildlife (USDI NPS 2013). However, the ideal trail density and use intensity will vary widely with location-specific factors. Wolverines remain active through the winter, requiring large territories, and are particularly susceptible to habitat loss (Heinemeyer et al. 2019) (see “Comparison of Winter Activity Types” in chapter 4). With snow-covered areas diminishing in winter because of the effects of climate change, both snow-based recreation and potential snow-covered habitat are becoming more concentrated (Halofsky et al. 2018, Miller et al., n.d), presenting important conflicts to consider in these areas.

Further Resources

- Multiple sets of guidelines are available for managing visitor use in protected areas, such as the recent best management practices published by the International Union for Conservation of Nature (Leung et al. 2018).
- Tools to help manage negative effects of some nonmotorized summer recreation are further described by Hennings (2017).
- Switalski (2018) presented a set of best management practices regarding ATV use on drylands. This article also cites other resources for managing factors such conflicts among users and the creation of additional user-created routes (Ouren and Coffin 2013, USDA FS 2012, USDI BLM 2012).
- Switalski (2016) presented a set of best management practices regarding snowmobile use for three species of special concern (grizzly bear, wolverine, and Canada lynx), and ungulates managed as game species. An overview of snowmobile impacts on water quality, soils, and vegetation and associated best management practices are also provided by Switalski (2016).
- Wisdom et al. (2013) provided methods for monitoring impacts of human disturbance, including recreation, on wildlife habitat.

Christopher Monz

Understanding interactions between wildlife and recreationists can be aided by surveys that reveal support and preferences of recreationists for management practices, recreational activities they participate in, and areas they visit for different recreation experiences, as seen here in a survey conducted in Rocky Mountain National Park.

Chapter 7: Priority Administrative Studies on Wildlife-Recreation Interactions

The development of this report was a collaboration between U.S. Forest Service researchers and managers with expertise in wildlife and recreation. We solicited information needs widely from recreation and wildlife managers within the National Forest System (NFS) across the United States, which shaped the topics covered within this report. Through the process of searching for responses to these information needs identified by wildlife and recreation managers, we identified areas for priority administrative studies for the NFS and partners in the future, described below.

Contextualizing Research Within a Social-Ecological Systems Framework

Understanding human-wildlife interactions requires an understanding of both the social and ecological aspects of these interactions. In chapter 1, we described four quadrants of human-wildlife interactions (see fig. 1.1). Research investigating the positive effects of humans on wildlife, positive effects of wildlife on humans, and negative effects of wildlife on humans is sparse, in comparison to the vast body of literature investigating the negative effects of humans on wildlife and habitats. Building our understanding of these sparsely researched areas will be critical in the successful management of human-wildlife interactions within a social-ecological systems framework. To build this knowledge base, priority research will:

- **Seek to understand what visitors desire in their experiences with wildlife.** What types of encounters do visitors enjoy or not enjoy? What settings or conditions do visitors prefer? Framing this research within a social-ecological systems framework will foster connections between humans and nature to promote goals of providing recreational opportunities and conserving ecosystems.
- **Investigate public responses to management actions** intended to benefit wildlife populations. Research within this area will seek to understand how recreationists substitute activities, locations, and timing of recreation in response to the closure of an area or a season to recreation; how recreationists respond in their actions and mental well-being when an area or trail is closed or rerouted to avoid sensitive wildlife habitat; and how educational programs effect visitor experiences and behaviors.
- **Use social science to evaluate the efficacy of management practices**. Management actions that have both a low tradeoff with the supply of recreation opportunities (e.g., education, site hardening) and those with a high

tradeoff (e.g., spatial or temporal restrictions or closures) should be empirically studied regarding their ultimate effects on recreationist behavior and the status of sensitive wildlife populations. This research can be informed by a comprehensive literature review investigating the efficacy of management actions and priority gaps to address. Research in this area can be designed to directly inform visitor management decisions.

Developing a Decision Support Tool for Recreation-Wildlife Interactions

Although hundreds of studies have investigated the effects of recreation on wildlife and habitat, results are conflicting at times, and few true patterns emerge that can be confidently applied across the wide diversity of situations in which wildlife and recreation interact on public lands and protected areas. Many factors contribute to the outcome of human-wildlife interactions, as described in detail in chapter 2. This range of factors essentially creates a limitless array of possible ways that wildlife might respond to recreation, with the complexity of responses increasing from the level of individuals to populations (Tablado and Jenni 2017). As it is impossible to conduct scientific studies of wildlife responses to recreation in every situation, and because management decisions typically must be made before research results are available, it is critical to be able to use existing science to inform management decisions in a timely and case-specific manner.

Several frameworks for contextualizing and conceptualizing recreation-wildlife interactions exist, two of which are presented in chapter 1 (i.e., Lischka et al. 2018, Tablado and Jenni 2017). These frameworks highlight important factors contributing to the complexity of recreation-wildlife interactions. While Lischka et al. (2018) demonstrated the importance of framing these interactions within a social-ecological system, Tablado and Jenni (2017) organized these interactions into distinct categories of factors that influence four hierarchical levels of human-wildlife interactions in the recreation context.

Framing research to contribute toward a central theory or framework can help identify population-level implications and trends that are not obvious at the levels typically analyzed, such as individuals or species. Development of standardized methods for studies might also aid in the potential to compare results across studies. The development of a decision support tool through which to organize results of existing and future research will be useful to those faced with decisions regarding managing recreation and wildlife in the same space. Such a tool would help enable frequent updates to be made to management as new research is published.

Pursuing Research With Implications at the Landscape Scale, Population Level, and in the Long Term

With home ranges and populations spanning large areas, many species are influenced by conditions at multiple spatial extents. This makes it crucial to understand landscape-scale effects of recreation on wildlife (Gutzwiller et al. 2017). However, few studies have considered landscape-scale effects, and studies on the effects of recreation on other aspects of the ecosystem have mostly been conducted within relatively small areas (Buckley 2013, Gutzwiller et al. 2017, Hammitt et al. 2015). Research is needed to understand the impacts of recreational activities at landscape scales, especially for species that have large territories or home ranges (see Gutzwiller et al. 2017). Studies are especially needed at a scale large enough to document effects of habitat fragmentation associated with recreation at a landscape level (Switalski 2018).

Also needed is further research that focuses on the long-term and population-level impacts of recreation on wildlife. Many studies have investigated short-term impacts such as flight from a disturbance, but few have either (1) empirically investigated long-term population-level impacts, or (2) drawn conclusions regarding how short-term impacts on individuals likely translate to the population level and the long term. The lack of research within these areas is likely due to the high level of complexity at the population level (Tablado and Jenni 2017), paired with the long-term commitments and funding required for long-term studies. However, this aim should be an overarching goal of future studies.

Further Administrative Studies

Furthermore, we recommend additional research on recreation and wildlife that:

- **Uses an experimental design** to draw causal inferences on the effects of recreation on wildlife. Studies are also needed that use baseline data on wildlife presence, occupancy, density, or other metrics before a recreational activity or infrastructure is introduced to an area (as suggested by Hennings 2017, Switalski 2018, and others).
- **Addresses lesser studied taxonomic groups**. Most research about impacts of recreation on wildlife focuses on mammals and birds, and most mammalian research is primarily on ungulates and carnivores (Hennings 2017, Larson et al. 2016). Taxonomic bias, such as described here, is widespread in conservation literature (Clark and May 2002). More research is needed on small mammals, reptiles, amphibians, and invertebrates to better understand how recreation affects different taxonomic groups and trophic levels.

- **Documents instances of “no effect” results**, which are likely difficult to publish or not submitted for publication. However, this information would be especially important in determining what species or ecosystems are not particularly sensitive to human activities such as recreation, to better allocate resources to protect highly sensitive species and ecosystems while allowing development of recreation in areas where little ecological impact is anticipated and thus providing social and economic benefits.

Wildlife Species Identified in This Report

Common name	Scientific name
Alpine chough	*Pyrrhocorax graculus*
American marten	*Martes americana*
American coot	*Fulica americana*
American oystercatcher	*Haematopus palliatus*
American white pelican	*Pelecanus erythrorhynchos*
Arctic fox	*Vulpes lagopus*
Badger	*Taxidea taxus*
Bald eagle	*Haliaeetus leucocephalus*
Bank vole	*Myodes glareolus*
Bison	*Bison bison*
Black bear	*Ursus americanus*
Black grouse	*Tetrao tetrix*
Black redstart	*Phoenicurus ochruros*
Black skimmer	*Rynchops niger*
Black-tailed godwit	*Limosa limosa*
Bobcat	*Lynx rufus*
Brown bear	*Ursus arctos*
Brown-headed cowbird	*Molothrus ater*
Capercaillie	*Tetrao urogallus*
Caribou	*Rangifer tarandus*
Carrion crow	*Corvus corone*
Cave myotis	*Myotis velifer*
Chamois	*Rupicapra rupicapra* spp.
Chipmunk	*Tamias* spp.
Clark's nutcracker	*Nucifraga columbiana*
Columbian black-tailed deer	*Odocoileus hemionus columbianus*
Common loon	*Gavia immer*
Common merganser	*Mergus merganser*
Common raven	*Corvus corax*
Common redshank	*Tringa totanus*
Common sandpiper	*Actitis hypoleucos*
Coral pink sand dunes tiger beetle	*Cicindela limbata albissima*
Cougar	*Puma concolor*
Coyote	*Canis latrans*
Crow	*Corvus* spp.
Curlew	*Numenius arquata*
Deer	*Odocoileus* spp.
Deer mice	*Peromyscus maniculatus*
Desert bighorn sheep	*Ovis canadensis nelsoni*
Desert tortoise	*Gopherus agassizii*
Domestic cat	*Felis catus*
Domestic dog	*Canis lupus familiaris*
Domestic horse	*Equus caballus*
Dowitcher	*Limnodromus griseu, L. scolopaceus*
Dunlin	*Calidris alpina*
Eastern chipmunk	*Tamias striatus*
Eastern garter snake	*Thamnophis sirtalis*
Eastern garter snake	*Thamnophis sirtalis*
Eastern grey squirrel	*Sciurus carolinensis*
Egyptian vulture	*Neophron percnopterus*
Eider duck	*Somateria mollissima*
Elk	*Cervus canadensis*
Elephant	*Loxodonta africana*
Flamingo (American)	*Phoenicopterus ruber ruber*
Flat-tailed lizard	*Phrynosoma mcallii*
Florida panther	*Puma concolor coryi*
Fox squirrel	*Scuirus niger*
Ghost crab	*Ocypode quadrata*
Giraffe	*Giraffa camelopardalis*
Golden eagle	*Aquila chrysaetos*
Golden-cheeked warbler	*Dendroica chrysoparia*
Gray fox	*Urocyon cinereoargenteus*
Gray jay	*Perisoreus canadensis*
Green-backed heron	*Butorides striatus*
Grizzly bear	*Ursus arctos*
Grouse	*many species*
Guanaco	*Lama guanicoe*
Gulls	*Larus* spp.
Gyrfalcon	*Falco rusticolus*
Hamster	*Phodopus sungorus*
Hawk	*Buteo* spp.
Hawskbill sea turtle	*Eretmochelys imbricate*
Hector's dolphin	*Cephalorhynchus hectori*
Horseshoe bat	*Rhinolophus ferrumequinum*
Indiana bat	*Myotis sodalis*
Lapwing	*Vanellus* spp.
Largemouth bass	*Micropterus salmoides*

Common name	Scientific name
Least chipmunk	*Tamias minimus*
Lizards	*many species*
Long-tailed weasel	*Mustela frenata*
Lynx	*Lynx canadensis*
Madagascan rousette	*Rousettus madagascariensis*
Manatee (West Indian)	*Trichechus manatus latirostris*
Marmot (Olympic Mountains)	*Marmota olympus*
Marmot (Swiss Alps)	*Marmota marmota*
Mexican spotted owl	*Strix occidentalis*
Mongoose	*Herpestes javanicus*
Moose	*Alces americanus*
Moose (Eurasian elk)	*Alces alces*
Mountain goat	*Oreamnos americanus*
Mountain hare	*Lepus timidus*
Mountain sheep	*Ovis canadensis*
Mule deer	*Odocoileus hemionus*
Mustelids	*Mustelidae*
Mute swan	*Cygnus olor*
Northern goshawk	*Accipiter gentilis*
Northern map turtle	*Graptemys geographica*
Northern water snake	*Nerodia sipedon*
Northern spotted owl	*Strix occidentalis caurina*
Northwestern salamander	*Ambystoma gracile*
Ohlone tiger beetle	*Cicindela ohlone*
Orb-weaving spider	*Larinioides sclopetarius*
Osprey	*Pandion haliaetus*
Oystercatcher	*Haematopus ostralegus*
Pacific chorus frog	*Pseudacris regilla*
Painted turtle	*Chrysemys picta*
Pelican (spot-billed)	*Pelecanus philippensis*
Peregrine falcon	*Falco peregrinus*
Pine marten	*Martes martes*
Piping plover	*Charadrius melodus*
Plovers	*Charadrius* spp.
Polar bears	*Ursus maritimus*
Prairie dog (black-tailed)	*Cynomys ludovicianus*
Pronghorn	*Antilocapra americana*
Ptarmigan	*Lagopus mutus*
Pygmy shrew	*Sorex minutus*
Rabbit	*Sylviagus* spp.

Common name	Scientific name
Raccoon	*Procyon lotor*
Rainbow trout	*Oncorhynchus mykiss*
Red fox	*Vulpes vulpes*
Red knot	*Calidris canutus*
Red-backed vole	*Clethrionomis gapperi*
Red-tailed hawk	*Buteo jamaicensis*
Reindeer	*Rangifer tarandus*
Rodent	Rodentia (order)
Ruddy shelduck	*Tadorna ferruginea*
Ruddy turnstone	*Arenaria interpres*
Sage-grouse	*Centrocercus* spp.
Salamander	*Salamandidae*
Sand crab	*Lepidopa benedicti*
Sanderling	*Calidris alba*
Sheep	*Ovis* spp.
Snowfinch	*Montifringilla nivalis*
Sonoran pronghorn	*Antilocapra americana sonoriensis*
Spotted salamander	*Ambystoma maculatum*
Steller's jay	*Cyanocitta stelleri*
Striped skunk	*Mephitis mephitis*
Swan	*Cygnus* spp.
Tern	*Sterna* spp.
Virginia opossum	*Didelphis virginiana*
Wall lizard	*Podarcis muralis*
Water shrew	*Sorex palustris*
Weasel	*Mustela* spp.
Western fence lizard	*Sceloporus occidentalis*
Western pond turtle	*Actinemys marmorata*
Western snowy plover	*Charadrius alexandrinus nivosus*
Western spotted skunk	*Spilogale gracilis*
Western whip snake	*Hierophis viridiflavus*
Whimbrel	*Numenius phaeopus*
White-breasted nuthatch	*Sitta carolinensis*
White-footed mouse	*Peromyscus leucopus*
White-fronted plover	*Charadrius marginatus*
White-tailed deer	*Odocoileus virginianu*s
Wigeon	*Anas penelope*
Wild sheep	*Ovis* spp.
Wild turkey	*Meleagris gallopavo*

Common name	Scientific name
Wildcat	*Felis silvestris*
Wildebeest	*Connochaetes taurinus*
Wolf	*Canis* spp.
Wolverine	*Gulo gulo*
Wood frog	*Rana sylvatica*
Wood turtle	*Clemmys insculpta*
Woodland caribou	*Rangifer tarandus caribou*
Woodlark	*Lullula arborea*
Yellow-blotched sawback turtle	*Graptemys flavimaculata*
Zebra	*Equus quagga*

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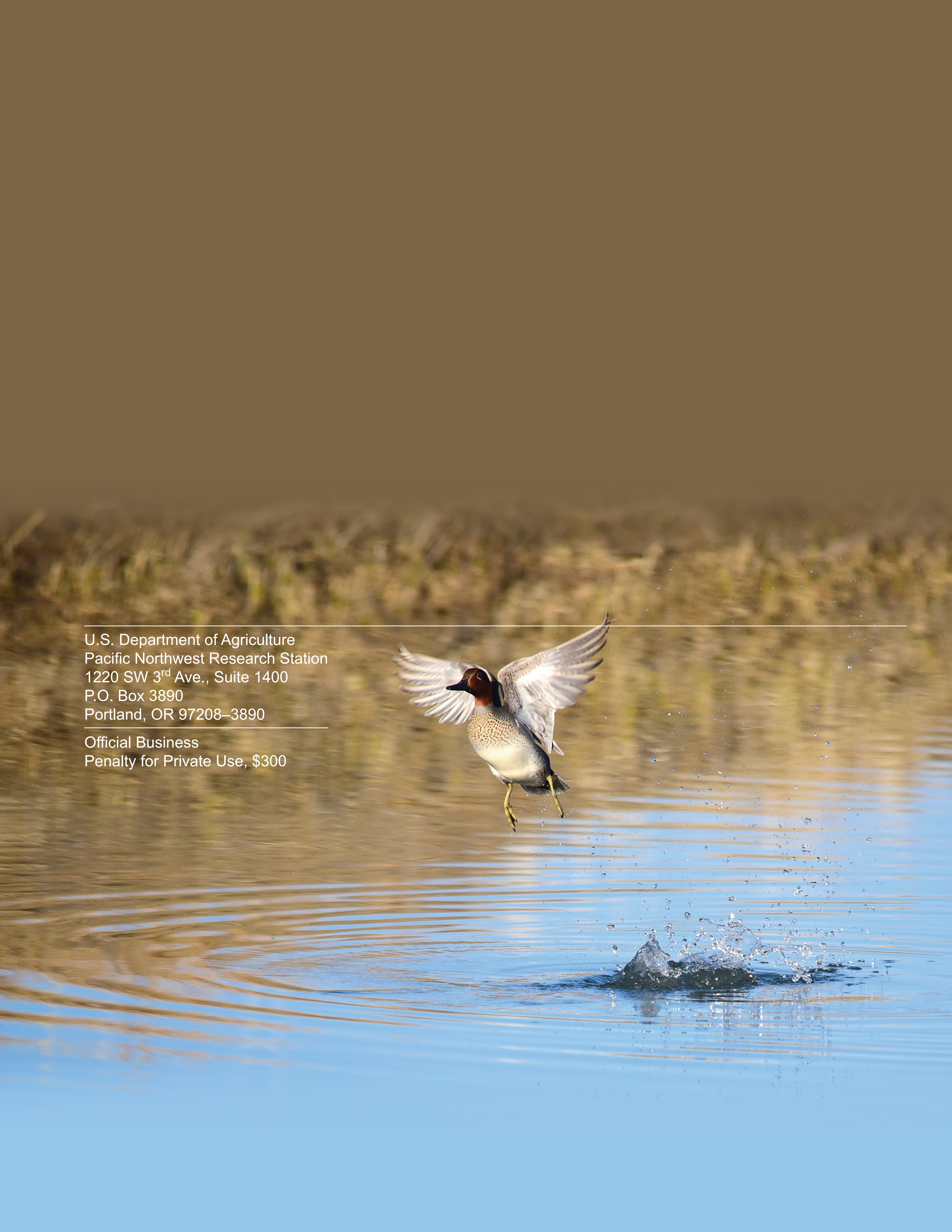

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