ATTACHMENT 1

Russian Ridge Open Space Preserve. (Photo by Karl Gohl, courtesy of Midpeninsula Regional Open Space District)

An Examination of the Benefits and Trade-offs of Visitation and Recreational Use of Public Open Space

PREPARED BY
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with support from Point Blue Conservation Science

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SAN FRANCISCO ESTUARY INSTITUTE PUBLICATION #1020
DECEMBER 2021

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ACKNOWLEDGEMENTS

Funding for this work was provided by the Midpeninsula Regional Open Space District.We are grateful to Mary Ann Bonnell, Peter Cowan, Natalie Dayal, Mia Monroe, Jennifer Thomsen, Lynne Trulio, Letitia Grenier, Megan Wheeler, Lynn Huntsinger, and Tom Gardali for their input and review. We also thank Crissy Pickett and Erik Ndayishimiye for their contributions to the literature review. We also thank Ruth Askevold and Ellen Plane for design and production of this report.

Wildflowers. (Photo by Steve Jurvetson, courtesy of CC BY 2.0)

EXECUTIVE SUMMARY

The Midpeninsula Regional Open Space District (hereafter "Midpen") has preserved approximately 65,000 acres of land in Santa Clara, San Mateo, and Santa Cruz counties. A little more than half of the 60,000 acres currently managed by Midpen, 31,000 acres across 26 open space preserves, is open for public recreation. Midpen's mission for the management and protection of these lands is: *"To acquire and preserve a regional greenbelt of open space land in perpetuity, protect and restore the natural environment, and provide opportunities for ecologically sensitive public enjoyment and education."* Within the Coastside Protection Area, Midpen has an expanded mission to "acquire and preserve agricultural land of regional significance, preserve rural character and encourage viable agricultural uses of land resources." Midpen's braided mission necessitates a balance between public use and natural resource protection that is not unique to Midpen; many agencies struggle with this issue.

The Midpeninsula Regional Open Space District (hereafter "Midpen") has preserved approximately 65,000 acres of land in Santa Clara, San Mateo, and Santa Cruz counties. Slightly less than half of this land, 31,000 acres across 26 open space preserves, is open for public recreation. Midpen's mission for the management and protection of these lands is: "To acquire and preserve a regional greenbelt of open space land in perpetuity, protect and restore the natural environment, and provide opportunities for ecologically sensitive public enjoyment and education." Within the Coastside Protection Area, Midpen has an expanded mission to "acquire and preserve agricultural land of regional significance, preserve rural character and encourage viable agricultural uses of land resources." Midpen's braided mission necessitates a balance between public use and natural resource protection that is not unique to Midpen; many agencies struggle with this issue.

To make science-based management decisions that accomplish both goals of public enjoyment and natural resource protection, Midpen and other open space agencies must weigh the many benefits and tradeoffs of public access and recreation. This report presents a synthesis of scientific research on open space recreation to support future management decisions. For this science synthesis, over 180 papers were reviewed, and a committee of advisors (see Introduction) lended their knowledge and expert opinions during workshops with Midpen staff. The objectives of this report are:

- To understand how public access to open space benefits visitors,
- To understand how public access can engender support for conservation efforts,
- To understand the negative effects of recreation in open space on wildlife, vegetation, soil and water,
- To understand recreation-related impacts to visitor experience,
- To explore existing decision-support tools that can help land managers find a balance between public enjoyment of open space and natural resource protection, and
- To provide management recommendations based on the scientific literature.

The summary of open space recreation benefits to human health and well-being revealed several key themes:

1. **Midpen's preserves likely play a crucial function for local people by providing substantial regional benefits: expansive views of nature, relief from urban heat islands, and venues for higher levels of physical activity and mental restoration.** Nature, whether in a smaller urban park or in a larger open space, provides benefits to health behavior, physical health, mental health, and social health. Larger natural areas tend to impart benefits for a number of reasons: (1) natural areas are a refuge from air and noise pollution in cities, (2) their large size encourages more physical activity and promotes feelings of escape and solitude, (3) they tend to be biodiverse, which supports mental health, and (4) they provide views of special natural resources that promote a sense of awe and general well-being. Accessibility and moderating factors (e.g., income level, race, gender) influence the magnitude of benefit an individual may receive.

2. **Each recreational opportunity in natural areas is linked to a suite of benefits.** A subset of the nature-health literature is specifically focused on recreation in large open spaces, referred to as wildland recreation. Each type of recreational activity (e.g., hiking, biking, horseback riding) is associated with its own set of health outcomes, generally pertaining to increased physical

activity, improved physical health, and improved mental health. Some examples of the specific outcomes include lower diabetes risk, lower risk of being overweight, improved muscular fitness, improved self-esteem, lower levels of anxiety and depression, and stress relief.

3. **Experiences in nature can play a critical role in sustaining public support for conservation efforts.** Direct experiences with nature foster feelings of connection with nature, which then can lead to pro-environmental behavior. Outdoor recreationists tend to have higher levels of environmental concern than non-recreationists, greater likelihood of engaging in conservation behaviors like participating in local environmental groups, and greater likelihood of financially supporting conservation.

The summary of negative recreational impacts to wildlife, ecosystems, and visitor experience revealed several key themes:

1. **Wildlife behavioral responses to human presence are well researched. Other recreation impacts to wildlife include reduced abundance and fitness.** Protected area effectiveness can be diminished if public access results in the exclusion of wildlife from using available habitat. Wildlife may respond to human presence by being on alert or moving away. Such responses can be energetically costly and stressful to wildlife. Wildlife species that are disturbed by human presence may decrease in abundance at a site, or a species may no longer occupy the site at all. Factors influencing wildlife response are categorized into recreation characteristics, environmental characteristics, and characteristics of the particular species or individual animal. In addition, noise pollution results in several documented effects to wildlife, ranging from altered behaviors to reduced abundance and reproductive success.

2. **Human trampling of vegetation is associated with damage to plants and subsequent changes to vegetation structure and community composition.** As trampling increases, researchers have observed a progression of vegetation changes of height reduction, loss of vigor and flowering, cover loss, compositional change, and eventually loss of regeneration. Trampling also compacts soil which limits water availability for plants and inhibits root growth. Vegetation structure and composition changes can in turn significantly impact species richness and abundance of small mammals. In cases of heavy trampling, vegetation cover could disappear entirely. Other impacts to vegetation include the potential human-mediated dispersal of non-native species and pathogens.

3. **Unsustainable trail design and creation of informal trails cause resource degradation.** When well designed and constructed for sustainability, most natural-surface trails are resilient to degradation. Wet conditions may lead people to move off trail in wet conditions, causing trails to widen. The key factors that influence trail degradation are trail grade and trail-slope alignment. Informal trails, also called social trails or unplanned trails, tend to be more susceptible to degradation than trails planned and constructed by land management staff. Informal trails can also contribute significantly to habitat fragmentation.

4. **Recreation can lead to fecal contamination of waterways and soil erosion that in turn reduces water quality and degrades aquatic habitat.** Human and dog waste deposited on surface soils can make its way into water bodies (e.g., after rain events). People and animals (including domestic dogs and livestock) that are directly exposed to contaminated water are at risk of contracting parasites and diseases. Water quality can also be altered through recreation impacts on vegetation and soils. High visitation can lead to soil erosion, and excessive sediment

inputs to water bodies is well known to degrade fish habitat, including for salmonids. Excessive sedimentation can also trigger algal blooms, some of which can produce harmful toxins that make water unsafe for recreation or drinking.

5. **Increased use levels and the negative outcomes of recreation can have negative impacts to visitor experience.** Every open space visitor brings their unique set of motivations, norms, and expectations; therefore visitor satisfaction is highly subjective. Issues may arise when a visitor encounters activities, behaviors, or conditions that are not in alignment with their values. For example, a visitor may perceive a trail to be crowded when they encounter more people than they expect to see or deem acceptable. In addition to use levels, sound level can play a significant role in acceptability.

Following the summaries of positive and negative impacts, this report then examines the Visitor Use Management Framework (the framework), a proactive adaptive management approach and decision-support tool. A group of federal agencies developed the framework to help managers navigate complex decisions with no obvious correct choice or blanket solution. The framework is a flexible process, designed to help managers collect information about a given project and its potential benefits and trade-offs, analyze this information, make a decision, and monitor for success following implementation. Since Midpen and the federal agencies that use the Visitor Use Framework have similarities in their missions (namely that they provide public enjoyment and protect natural resources), Midpen could adopt the framework as is, or a version best suited to Midpen's preserves, management and needs. The adoption of a structured decision-making approach provides benefits to agencies by standardizing the process, building a defensible justification for decisions, and providing transparency about management decisions.

When it comes to visitor use management, it may seem intuitive to conclude that reducing use would be the most effective tool for reducing impacts. Yet, research shows that other management strategies for reducing impacts are more effective, such as modifying visitor behavior, changing where use happens, and changing how use is managed. To positively modify visitor behavior to lessen impact, education and outreach programs can be a powerful tool, as recreationists tend to underestimate their impact and may make the change if they understand the significance of their role and how wildlife and ecosystems will benefit. Subdivision of protected areas into management units enables land managers to determine the appropriate amounts and types of use to allow based on the presence of sensitive species or habitats. Other recommendations in the scientific literature for minimizing negative impacts of recreation include practicing sustainable trail design and consistently enforcing trail use regulations.

Finding the right balance between public access and natural resource protection is complex; there will be unique challenges given the particular characteristics of each preserve. However, Midpen has a growing body of scientific research, decision-support tools, and other resources to bring to this management challenge. With these assets and additional resources, Midpen can steer management of its preserves to achieve its braided mission.

Mindego Hill. (Photo by T. Hugg, courtesy of Midpeninsula Regional Open Space District)

INTRODUCTION

In recent decades, there has been rapid growth in the popularity of outdoor recreation. In 2020, outdoor recreation saw a sharp increase in participation driven by the COVID-19 global pandemic, as open spaces became one of the few locations to safely socialize and exercise (Outdoor Foundation, 2021). As participation has increased over time, so has scientific research to understand the effects, both positive and negative, of outdoor recreation on people, wildlife, and the environment. Much of this research is being conducted in the United States, with a significant amount coming from Australia as well (Larson et al., 2016). Rigorous scientific studies provide a foundation of evidence that can guide and support land managers' decisions.

The Midpeninsula Regional Open Space District ("Midpen") has preserved approximately 65,000 acres of land in Santa Clara, San Mateo, and Santa Cruz counties. A little more than half of the 60,000 acres currently managed by Midpen, 31,000 acres across 26 open space preserves, is open to the public. Many people in the region visit Midpen's preserves to participate in various recreational activities, such as hiking, running, mountain biking, horseback riding, birdwatching, dog-walking, geo-caching and nature photography. Part of Midpen's mission for these preserved lands is: "protect and restore the natural environment, and provide opportunities for ecologically sensitive public enjoyment and education." As more and more people visit the preserves, Midpen and other open space agencies share a valid concern that natural areas may be "loved to death." It is increasingly important to utilize the best available science to develop effective strategies and thoughtful management decisions.

Effective management to both provide public enjoyment and protect natural resources is complicated, and Midpen's land managers want their decisions to be guided by the best available science. This report presents a synthesis of scientific evidence of the effects of open space visitation and recreation. The chapter on positive effects explores the many benefits to mental health, physical health and public support for conservation. The chapter on negative effects summarizes the impacts to wildlife, vegetation, soil, water, and visitor experience. The numerous benefits and tradeoffs present a challenge to land managers, and this report also contains an overview of an existing management framework used by some federal agencies to make standardized, science-based decisions for open space management. Finally, this report presents a compilation of management recommendations from the scientific literature.

For this report, over 180 papers were reviewed to understand the current state of the scientific literature on the negative impacts of recreation. A committee of six advisors, representing a range of relevant areas of expertise, contributed their knowledge and insights during two workshop meetings with Midpen staff and through review of this report. The advisors were Mary Ann Bonnell (Jefferson County Open Space), Peter Cowan (Peninsula Open Space Trust), Natalie Dayal (National Park Service, Golden Gate National Recreation Area), Mia Monroe (National Park Service, Golden Gate National Recreation Area), Jennifer Thomsen (University of Montana), and Lynne Trulio (San Jose State University).

Bicyclists on Midpeninsula trails. (Photo by John Shalamskas, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)

Fog over Midpeninsula lands. (Photo courtesy of Midpeninsula Regional Open Space District)

BENEFITS OF EXPERIENCES IN NATURE

Spending time in nature, whether in a smaller urban park or in a large preserve, provides numerous benefits to people. For many urban residents living on the peninsula and in Silicon Valley, Midpen lands provide the closest opportunity to visit a natural space that is biodiverse, large, and relatively undeveloped. Such settings present a healthier environment in which to recreate, exercise and generally spend time, thus supporting physical, mental, and social health. Each recreational activity is associated with its own set of health outcomes, from lower diabetes risk to stress relief. Furthermore, direct experiences with nature can foster feelings of connectedness to nature and support for conservation.

Human health outcomes from nature experience

Over the past two decades, there has been a growing interest in the fields of public health, epidemiology, medicine, and psychology in the various ways experiences with nature improve human health and well-being. This science has grown rapidly, and there are now thousands of scientific papers on the topic (Bratman et al., 2019; Hartig et al., 2014; Kondo et al., 2018; Kuo, 2015). To some extent, nature appears to deliver health benefits no matter in what form people experience it, though we will discuss the nuances to this. While the majority of nature-health research focused on benefits gained by urban residents, studies focused on rural areas show that the results are similar for rural populations (Dennis and James, 2017; Mitchell and Popham, 2007), and therefore many of the findings from urban landscapes can reliably be assumed to be transferable to non-urban contexts. There is also a small subset of studies on expansive natural areas similar in form and context to Midpen's preserves. Given the great volume of literature, we conducted a review of some of the available studies and review articles across the broader nature-health field, then focused on the subset of studies and review articles specific to recreation in large natural areas as the most similar comparison available to Midpen's preserves.

As evidence of nature's benefits to human health has accumulated, researchers have pursued an understanding of how and why benefits are conferred. In a comprehensive review, Shanahan et al. (2016a) identified four broad categories of human health outcomes from nature according to the current literature: mental health, physical health, health behavior, and social health (described in detail below). These four categories are not mutually exclusive. They can overlap and influence each other through feedback processes, i.e., enhancement in one category can elicit positive change in another category.

MENTAL HEALTH BENEFITS OF NATURE EXPERIENCE

A growing body of empirical evidence reveals the value of nature experience for mental health (Bratman et al., 2019). The scientific evidence has reached a consensus that: (1) nature experience is associated with psychological well-being; (2) nature experience is associated with reduced risk and lower burdens of some types of mental illness; and (3) opportunities for some types of nature experience are decreasing in quality and quantity for many people around the globe (Bratman et al., 2019). The "extinction of experience" due to urbanization, whereby urban residents grow removed from personal contact with nature, is a growing concern as the consequences include loss of health and well-being benefits of nature and a decline in pro-environmental attitudes and behavior (Cox et al., 2017a; Soga and Gaston, 2016). One of the most well studied pathways from nature experience to human health outcomes is attention restoration, or the recovery from stress and attention fatigue (Mayer et al., 2008). Mental health benefits of nature experience are numerous, for example:

- Walking in nature is restorative and improves mood and cognitive function (Gidlow et al., 2016)
- Walking in nature reduces symptoms related to depression (Bratman et al., 2015)
- More nearby nature leads to reductions in depression, anxiety and stress (Cox et al., 2017b)

HEALTH BEHAVIOR AND PHYSICAL HEALTH BENEFITS OF NATURE EXPERIENCE

Studies indicate that natural areas encourage health behavior, i.e., natural areas provide a venue and a motivation to engage in physical activity (Shanahan et al., 2016b). In part as a result of engaging in health behavior, people improve their physical health, and may also see benefits in the mental and social health categories. The natural environment also appears to enhance the benefits of physical activity, compared to the benefits if the same activity were conducted in an urban environment (Shanahan et al., 2016b). The following are examples of positive health behavior and physical health outcomes:

- Children with more nearby greenspace spend more time being physically active (de Vries et al., 2007).
- Parks and natural resource areas are associated with more time spent being physically active (Cohen et al., 2006).
- Park users have better cardiovascular health (Grazuleviciene et al., 2015; Paquet et al., 2013)
- Higher neighborhood greenness is associated with higher survival rates after a stroke (Wilker et al., 2014)

SOCIAL HEALTH BENEFITS OF NATURE EXPERIENCE

Studies show that greenspaces facilitate social interactions, thereby fostering community attachment (i.e., the emotional connection between residents and to their place of residence) and neighborhood satisfaction (Larson et al., 2016; Lee and Maheswaran, 2011). Studies specific to recreational experiences in nature have found a range of social health benefits, including an increased sense of community, group cohesion, teamwork, empathy, and cooperation (Holland et al., 2018). The following are examples of positive social health outcomes:

- Greenspaces can strengthen sense of community among residents (Maas et al., 2009)
- Park quantity contributes to physical and social health, as well as overall well-being (Larson et al., 2016)
- Perceived greenspace quality and quantity can foster community attachment (Arnberger and Eder, 2012)

MODERATING FACTORS

While there is consensus in the literature that nature benefits mental, physical, and social well-being, the impact is not equal for all individuals. A suite of potential moderating factors influence the ways in which people interact with nature and whether people benefit from nature (Hartig et al., 2014; Shanahan et al., 2015). These factors include socioeconomic status, gender, ethnicity, age, and physical ability.

Moderating factors also include the physical accessibility of the public open space. As an individual must be able to get there in order to experience and benefit from nature, distant locations, lack of public transportation, and lack of parking are prominent physical access barriers to use of parks (Gibson et al., 2019). Other barriers to access include the perceived safety of a park, which has variable impact on park use across genders and ethnicities (Carlson et al., 2010; Lapham et al., 2015); and how appealing or welcoming a park seems to the community (Gibson et al., 2019). During a visit, conventional trail design can be a physical access barrier, e.g. to persons with mobility differences, and new design strategies for "all persons trails" or "universally designed interpretive trails" can help to reduce this barrier (Gertz et al., 2016).

Unique benefits of natural areas

Natural spaces found in parks and preserves adjacent to urban areas can provide unique resources to urban residents. For many urban residents living on the peninsula and in Silicon Valley, Midpen lands provide the closest opportunity to visit a natural space that is biodiverse, large, and relatively undeveloped. While much of the research connecting nature to human health has been conducted in urban areas, a subset of research specific to wildland areas highlights the unique health benefits that larger, more natural open spaces can provide. In this section, we identify the health benefits specific to natural areas, including escape from unhealthy environments found in cities, access to biodiversity, expansive views, and other natural features, and opportunities for recreation which can provide their own set of health benefits.

NATURAL AREAS PRESENT A HEALTHIER ENVIRONMENT

Natural spaces present a healthier environment in which to recreate, exercise and generally spend time (Markevych et al., 2017; Shanahan et al., 2016b). The scientific literature describes multiple pathways, one of which is that natural spaces are a refuge from various stressors found in urban environments. Air temperatures tend to be higher within cities, a phenomenon known as the urban heat island (Voogt and Oke, 2003), and natural environments provide a respite from excessive heat, due to the higher albedo (the reflection of sunlight) of vegetation and the cooling effect of evapotranspiration. Air pollutant concentrations tend to be lower in and around greenspaces, in part due to the absence of most emissions sources within greenspace, i.e., vehicular traffic (Markevych et al., 2017). Open spaces are also quieter than more developed areas, due to buffering effects of vegetation (Markevych et al., 2017).

Simply being in nature, even without participating in activities such as hiking, horseback riding, or mountain biking, has a therapeutic effect. Compared to an experience in an urban setting, an experience in forest environments leads to significantly improved attention capacity, as well as lowered heart

Horseback riding. (Photo by Randy Weber, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)

rate, lower blood pressure, and better mood (Sonntag-Öström et al., 2014). Some studies also show that passively experiencing natural elements near to an individual's home affects human health. More greenness around one's home is associated with higher birth weights (Dzhambov et al., 2014), lower risk of myocardial infarction (Yitshak-Sade et al., 2017), and reduced levels of depression and anxiety (Beyer et al., 2014). A classic study by Ulrich (1984) found that views of nature from hospital windows may influence post-surgery recovery times. Furthermore, environmental biodiversity has been associated with immune function via support of beneficial microorganisms living on skin and in the gut (Kuo, 2015). For instance, a study in Finland found species richness of uncommon native flowering plants to be associated with reduced allergy response, by means of supporting higher diversity of bacterial floral on a person's skin (Hanski et al., 2012). Nearby habitat diversity has been associated with good general health (Wheeler et al., 2015), and a lower risk of asthma in children (Donovan et al., 2018).

NATURAL AREAS ARE LARGE

While the nature-health literature has grown to a vast body of work, there is only a small subset of these papers focused specifically on the experience of wildland recreation and its health outcomes (as opposed to more general urban greening and city park recreation). Hammitt et al. (2015) described the key characteristics of wildlands as:

- dispersed over large areas, and often having low use density compared to designed recreation areas;
- those in which the environment for activities is of greater importance than in developed recreation situations;
- largely natural, where management strives to maintain a natural appearance; and
- limited in facility development extent and function.

Compared to studies on health and urban nature, the subset of studies on health and wildland experiences may be of elevated interest, given the size and expansiveness of Midpen's network of preserves. In a recent review of 113 wildland recreation studies, 33% of studies focused on physical health impacts and 84% focused on mental health impacts (Thomsen et al., 2018). A complementary review of 235 studies explored trends of psychological, social and educational outcomes associated with wildland recreation (Holland et al., 2018). The vast majority of wildland recreation and health studies were published in the last 20 years (Thomsen et al., 2018). Our understanding of the potential unique benefits of experiences in wildlands compared to urban nature will continue to deepen as more research continues to emerge.

The large size of natural areas likely plays a role in enhancing health outcomes. The lack of interruptions (e.g., road intersections) to walking in larger parks allows visitors to sustain both a higher level of physical activity and a longer duration of physical activity (Sellers et al., 2012), supporting better cardiometabolic health (Paquet et al., 2013). While these findings were derived from examination of size variation among urban parks, we expect this trend to translate and be true of wildland settings as well. Furthermore, wildlands can provide unique opportunities for solitude and nature immersion (Holland et al., 2018), possibly due to their large size. Wildland settings make it possible for visitors to perceive escape and solitude, which appears to have an important influence on a variety of health outcomes (Holland et al., 2018; Thomsen et al., 2018).

NATURAL AREAS TEND TO BE BIODIVERSE

Visiting more highly biodiverse parks can confer greater mental health benefits. Studies have found that greater species richness (among birds, bees, butterflies, and plants) is positively correlated with better attention restoration among visitors to parks (Wood et al., 2018; Fuller et al., 2007). Meanwhile Dallimer et al. (2012) found that, regardless of a park's actual species richness, people achieve better attention restoration in parks they perceive as biodiverse.

Parks with high native biodiversity may also encourage physical health by drawing more visitors, although ecological knowledge mediates this effect. Shanahan et al. (2015) found that people with stronger connections to nature are more likely to travel to visit parks with high canopy cover and large areas of remnant native vegetation. Meanwhile, parks with visible ecological deterioration, such as forests invaded by pine beetles in Colorado and Minnesota, may be less appealing as sites for recreation (Arnberger et al., 2018). However, where ecological deterioration occurs without visible damage, such as when a non-native ecosystem displaces a native one, visitor perceptions of the area can vary depending on their knowledge of local ecology (Barendse et al., 2016; Bravo-Vargas et al., 2019).

NATURAL AREAS OFFER VIEWS AND AND EXPERIENCES WITH UNIQUE NATURAL FEATURES

Natural areas provide visitors with views and experiences with unique natural features, such as bodies of water and geological formations. Unique natural features can foster a sense of place, which in turn provides diverse benefits to health and well-being, including recovery from stress and lower risk of mental illness (Hausmann et al., 2016).

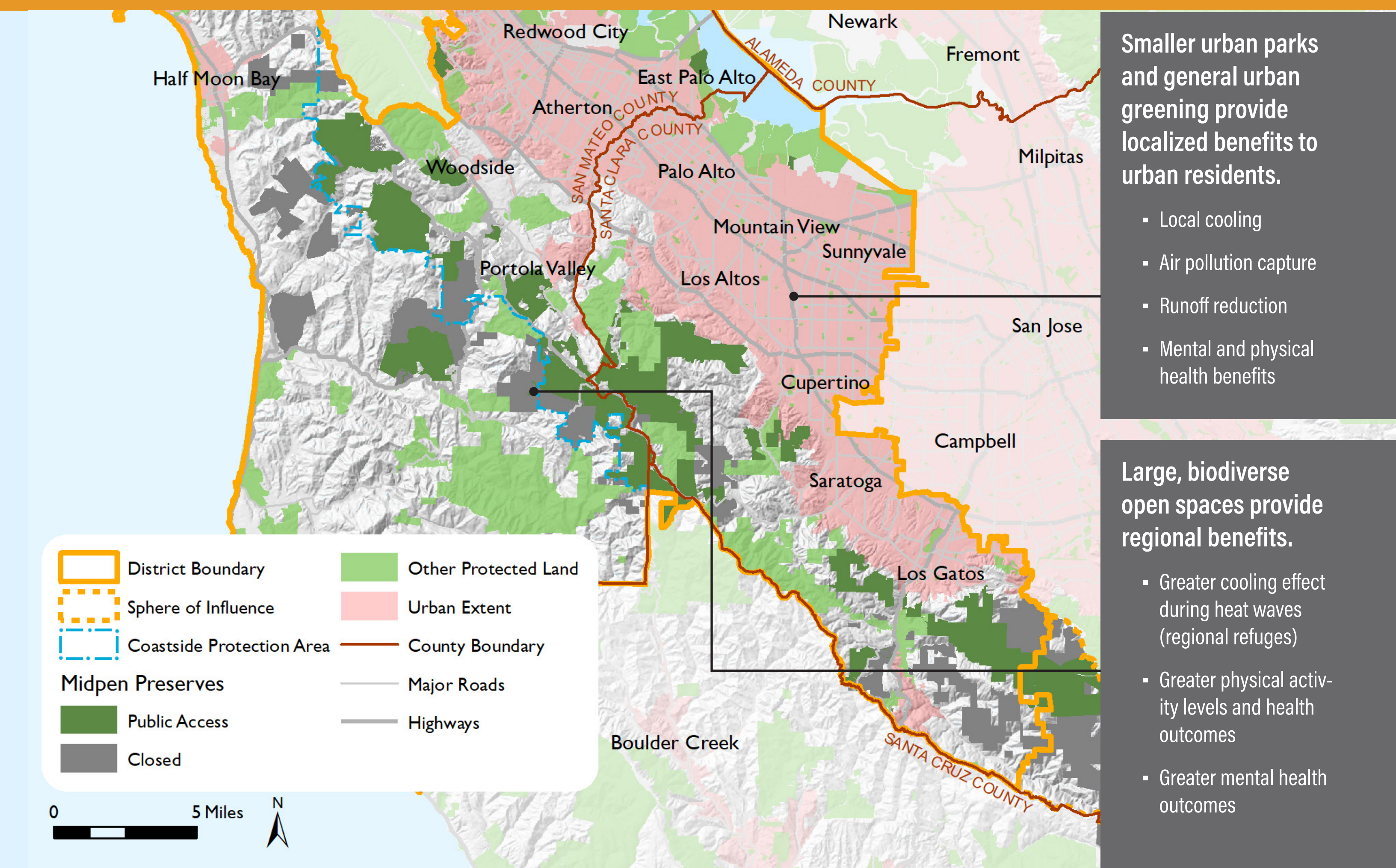
In a systematic review, Gascon et al. (2017) found consistent evidence that exposure to blue space (including lakes, coastlines, rivers, and other bodies of water) is associated with improved mental health and increased physical activity. Some studies also suggested correlations between blue space exposure and cardiovascular health, general health, and obesity rates, but these results were not consistently demonstrated across publications (Gascon et al., 2017). While most studies within this review largely used remote sensing to correlate health outcomes with the amount of blue space near one's home (Gascon et al., 2017), several demonstrated health benefits from spending time recreating near blue spaces (e.g., Amoly et al., 2014; Elliott et al., 2015; MacKerron and Mourato, 2013).

California newt. (Photo by Ron Wolf, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0) District)

THE UNIQUE ROLE OF MIDPEN'S PRESERVES

Midpen's preserves offer a large urban population access to expansive, biodiverse, and relatively undeveloped areas for a variety of recreational activities. Due to these characteristics, the preserves play a role that is complementary to local, smaller urban parks (Figure 2). The preserves provide access to unique natural features and expansive views, regional relief from urban heat islands, and likely support higher levels of physical activity and mental restoration. Therefore, the preserves are serving a crucial function for local people by providing these substantial regional benefits. Additionally, providing public access likely contributes to cultivating public support for conservation efforts.

The accessibility of Midpen's preserves has an impact on what proportion of the population can use the preserves. The health benefits a person can gain from nature depends on their ability to get there in the first place. A lack of public transportation options is a known limitation to access. Accessibility also includes informational resources at the preserve to help guide visitors (e.g., brochures in languages spoken by the community, directional signage, natural and historical resources information). While recent surveys conducted by Midpen gathered important information about visitor experiences, future surveys can help Midpen to better understand who in the service area is not visiting the preserves, and therefore who is not receiving the health benefits of nature experiences. There is a growing body of scientific literature on equity in nature access, which is an area of research Midpen may wish to pursue to better understand which communities are underserved and how better to engage as part of Midpen's diversity, equity, and inclusion efforts.



Recreation opportunities in natural areas are linked to their own set of benefits

Each type of recreational activity is associated with its own suite of health outcomes. Our understanding of these health outcomes is limited by the popularity of each recreation type as a focus of study, and the most commonly studied activity is hiking (Thomsen et al., 2018).

BENEFITS OF HIKING AND RECREATIONAL WALKING

In the wildland recreation and health literature, the most commonly studied activity is hiking, possibly due to its popularity (Thomsen et al., 2018). Many studies have also found significant mental health benefits of hiking or walking in nature. Hiking is associated with benefits such as improved self-esteem, reduced diabetes risk, connectedness to nature, and physical fitness (Barton et al., 2016; Freidt et al., 2010). Relative to walking in an urban environment, walking in nature is linked with reduced symptoms of depression (Bratman et al., 2015), lower heart rate and anxiety levels (Song et al., 2014), and better cardiac function among coronary artery disease patients (Grazuleviciene et al., 2015). These studies indicate that for the same activity, a natural venue enhances the health outcome.

Dog-walking is a popular activity on Midpen lands. Dog ownership has an important influence on whether a person gets regular exercise, and access to public open space is positively associated with dog walking (Westgarth et al., 2014). Dog walking can help people increase physical activity levels, and the proximity of parks influences an owner's dog walking behavior (Christian et al., 2016). Through interviews with dog owners who have long-term health conditions (e.g., multiple sclerosis, diabetes, asthma, stroke), one study in New Zealand found that dog walking can alleviate feelings of social isolation and enhance well-being by relieving stress and requiring adequate exercise (Smith et al., 2017).

BENEFITS OF OBSERVING WILDLIFE

Relatively few studies have quantified the health benefits of observing wildlife in natural settings, but the existing literature highlights the potential psychological benefits of human-wildlife encounters. Cobar et al. (2017) assessed the mental health impacts of bird-watching among high school students and found that, compared to those students who took walks without observing birds, students who engaged in bird-watching experienced significantly more reductions in tension, fatigue, and confusion. Curtin (2009) documented feelings of awe, wonder, and well-being among tourists on wildlife tours in Spain and California. Follow-up surveys revealed that such feelings are not necessarily limited to experiences with charismatic megafauna in exotic locations, but can also occur when visitors encounter local wildlife near their homes (Curtin, 2009). The value that people derive from encounters with wildlife depends on a variety of personal factors, particularly their perceptions of and past experiences with the species they encounter. People with greater familiarity with animal diversity may be poised to garner greater benefits from wildlife encounters (Bell et al., 2018). When people perceive animals as a threat to their health or safety, they are unlikely to derive mental health benefits from viewing them (Barua et al., 2013; Soulsbury and White, 2016).

BENEFITS OF MOUNTAIN BIKING

There is a lack of data on the health impacts of mountain biking; in the wildland recreation and health literature, only six papers studied mountain biking (Thomsen et al., 2018). However, Dillard (2017) contends that mountain biking is as healthful an activity as road cycling, for which there is vastly more evidence available. The health benefits of road cycling include cardiorespiratory fitness, lower risk of heart disease, lower risk of stroke, improved muscular fitness, and reduced depression (Oja et al., 2011).

Some studies explored the perceived benefits of mountain biking using survey methods. Mountain bikers engage in the activity for a variety of reasons, including the perception that mountain biking makes them feel more connected to nature (Roberts et al., 2018). The feeling of connection with nature is thought to be of great benefit to human well-being (Mayer and Frantz, 2004; Shanahan et al., 2016a). Other motivations for mountain bikers included the beliefs that the activity helps them to de-stress, improves their self-esteem and helps them deal with negative thoughts or feelings (Roberts et al., 2018). Another study found that some benefits varied by gender; women perceived mental health benefits of mountain biking (e.g., self-reliance, self-esteem, life satisfaction) more strongly than men (Hill and Gómez, 2020).

In recent years, electric pedal-assist bikes (e-bikes) have emerged, and may make it more feasible for some to engage in biking activities (Hall et al., 2019). Following suit, new research is emerging to understand the health benefit from e-bike use, but current studies are very few in number. In the case of electric pedal-assist mountain bikes (eMTB) specifically, the literature is extremely limited. One study found that eMTB use helps individuals meet physical activity guidelines and supports cardiovascular fitness nearly as much as conventional mountain bike use (Hall et al., 2019).

Mountain biking in the forest. (Photo by TJ N, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)

BENEFITS OF ORGANIZED ACTIVITIES

Midpen hosts a wide variety of docent-led activities year-round, including guided hikes, educational programs, and equestrian activities. Midpen also partners with schools and various community groups such as Latino Outdoors to provide guided nature experiences for diverse youth, and conservation groups such as the Sierra Club hold outings for their members in Midpen preserves. As most wildland recreationists travel in social groups, the social aspect of wildland recreation is a key driver of positive health outcomes (Thomsen et al., 2018; Holland et al., 2018). Studies have found that organized activities in the outdoors are important for both children and adults. Among children, access to recreational programs can significantly promote physical activity and lower the risk of being overweight (Wolch et al., 2011). Beyond mental and physical health, the social aspects of wildland recreation also contribute to pro-social behaviors, sense of place, environmental stewardship, and even academic performance (Holland et al., 2018).

Some researchers are beginning to evaluate the potential role of new nature-based therapeutic programs in managing and supporting recovery from mental illness. In the U.K., a nature-based program consisting of weekly countryside and urban park walks resulted in significantly greater self-esteem and mood improvements than other existing programs (Barton et al., 2012). Also in the U.K., a novel 6-week treatment based on visits to a wetland reserve was found to be an effective therapy option for anxiety and/or depression (Maund et al., 2019). The visits included guided walks, watching wildlife and canoeing. Such novel treatment programs are nascent, yet there is growing evidence for the benefits of including nature-based treatment in the management of and recovery from mental illness.

BENEFITS OF OTHER ACTIVITIES

In the wildland recreation and health literature, there are very few studies related to other activities available on Midpen lands. On Midpen lands, one campsite is provided at Monte Bello Open Space Preserve, and in the limited number of studies relating to backpacking and camping, there is evidence of these activities' positive contributions to self-esteem (e.g., Autry, 2001; Kiernan et al., 2004). 21 of Midpen's preserves are open to horseback riding, providing approximately 215 miles of trail. There are very few studies available that examine horseback riding and health outcomes, and most of these studies focus on therapeutic horseback riding as opposed to recreational. A study conducted in Austria found that recreational horseback riding is associated with a greater sense of nature relatedness, greater overall well-being, and better mood (Schwarzmüller-Erber et al., 2020). As research continues to emerge, there may be more to learn about the potential health benefits of these activities.

Broader implications for public support for conservation

While experiences in nature can significantly support human health, they can also play a critical role in sustaining public support for biodiversity conservation. Feelings of connection with nature can lead to pro-environmental behavior (Mackay and Schmitt, 2019). A primary way that both children and adults develop feelings of connection to nature is having direct experiences with nature (Cleary et al., 2020). For children, having an adult role model whom the child perceives to be knowledgeable about the environment and active in trying to maintain environmental quality is another way to foster nature connection (Chawla, 2015; Sivek, 2002).

In adulthood, direct recreational experiences with nature can have a significant impact on public support for conservation. Some characteristics of wildland recreation that influence the outcome of environmental stewardship include examining the natural environment, wilderness as a source of adversity, social interactions, trip leader's interpretation amount and quality, and duration of experience (Holland et al., 2018). Overall, outdoor recreationists — especially those participating in wildlife watching and nature photography — have been found to have higher levels of environmental concern than non-recreationists (Teisl and O'Brien, 2003), and 4-5 times more likely to engage in conservation behaviors like participating in local environmental groups and enhancing wildlife habitat on public lands (Cooper et al., 2015).

Nature experiences also significantly impact willingness to financially support conservation. Bird-watchers are more likely than non-recreationists to donate to local conservation efforts (Cooper et al., 2015). A study in the U.S. found that each hiker or backpacker may contribute $200–$300 annually in the future to conservation NGOs (Zaradic et al., 2009). On a related note, San Mateo County Parks conducted a study to determine willingness to pay through taxes or fees for parks, trails and other amenities at the parks (San Mateo County Parks Department, 2016), an approach which Midpen could also adapt and implement to better understand the connection between nature experiences in Midpen's preserves and willingness to pay for continued conservation efforts. Efforts to educate the public can also be influential, as Buttke et al. (2014) suggested that having an increased understanding of biodiversity's value and benefits to human health and well-being may lead to greater support for conservation. Overall, these studies indicate that encouraging participation in hiking, backpacking, bird-watching, and nature photography should be considered in strategies to secure long-term support for conservation.

Great egrets. (Photo by Axel Sudhausen, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)

Russian Ridge Open Space Preserve. (Photo by B.T. Washburn, courtesy of Midpeninsula Regional Open Space District)

TRADE-OFFS
OF OPEN SPACE RECREATION

Human modification and recreation can negatively impact wildlife, vegetation, soil, and water. Human presence can cause stress and behavioral changes in wildlife, which can be energetically costly to wildlife. Whether by foot, bicycle or horse, trampling of soils and vegetation can lead to degradation and losses of both resources. Additionally, recreation has been linked with water quality degradation and damage to critical aquatic habitat (e.g., nesting areas for salmonids). Unsustainable trail design is a major driver of damage to resources. Some negative recreational impacts (e.g., damage to plants, litter) can have a secondary impact of diminishing visitor experience.

Negative impacts of recreation

This chapter explores the various types of negative recreation-related impacts to wildlife, vegetation, soil and water. These are the four major landscape components that are affected by recreation (Cole, 1993). These four components are all interconnected, and a change in one can lead to a change in the others. This chapter also addresses the secondary impacts of recreation-related degradation on visitor experience. Wherever possible given the available literature, the negative impact is discussed in terms of its magnitude, temporal scale (i.e., short- to long-term effects) and spatial scale (i.e., persistence or attenuation across space).

While the focus of this chapter is on the impacts of recreational activities such as hiking, mountain biking, horseback riding, and wildlife viewing, it is important to note that the presence of the recreational trail network itself can have ecological impacts not directly associated with human use. Depending on trail density and configuration, trail networks can be important contributors to habitat fragmentation in otherwise intact natural areas (Ballantyne et al., 2014). Like other forms of habitat fragmentation, trails may create barriers to wildlife movement and plant dispersal, and edge effects associated with trail corridors may result in altered species composition and vegetation structure (Fischer and Lindenmayer, 2007; Lucas, 2020; Pickering and Norman, 2017). Recent studies have also demonstrated that habitat fragmentation can reduce plant community diversity within habitat patches (Damschen et al., 2019). Further research is needed to better understand the degree to which habitat fragmentation from trail networks alters plant and animal communities (regardless of human use of the trails) relative to other sources of habitat fragmentation such as roads or urban development, but in areas with extensive trail networks, even minor effects may have a sizable cumulative impact.

The relationship between use and impact is not linear, but rather sigmoidal (Figure 1; Cole, 2019). As the amount of use increases from low to medium, the impact increases greatly. As the amount of use continues to increase, there is an inflection point, after which further increases in use do not make as great a difference and the magnitude of impact plateaus. The use-impact relationship is influenced by various use characteristics (e.g., amount of use, type of recreation activity, behavior of recreationists, spatial distribution of use, and temporal distribution of use) and environmental characteristics (e.g., characteristics of the soils, vegetation, animals, water, and topography of the area) (Cole, 1993).

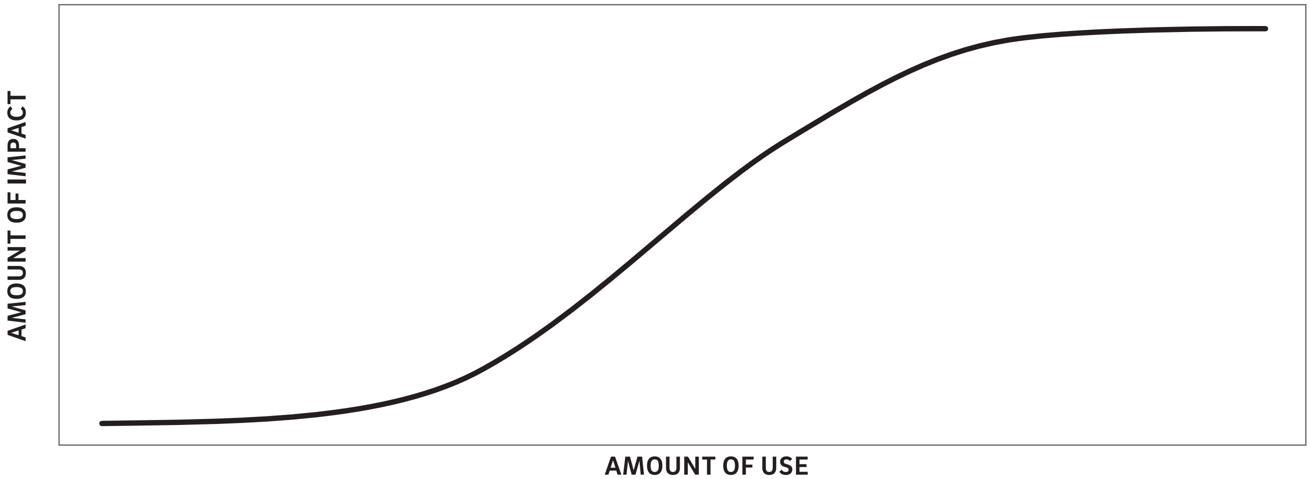


Figure 1. The sigmoidal use-impact curve shows the relationship between amount of recreation use and the intensity of environmental impact (Cole, 2019).

Disturbance to wildlife

A recent review found that most recreation studies have focused primarily on the responses of birds and mammals; more studies are needed to understand the responses of other taxa like reptiles, amphibians and invertebrates (Larson et al., 2016). Recreation studies also focused more heavily on hiking impacts than other activities. In sum, there remains a gap in knowledge across many taxa and many activity types.

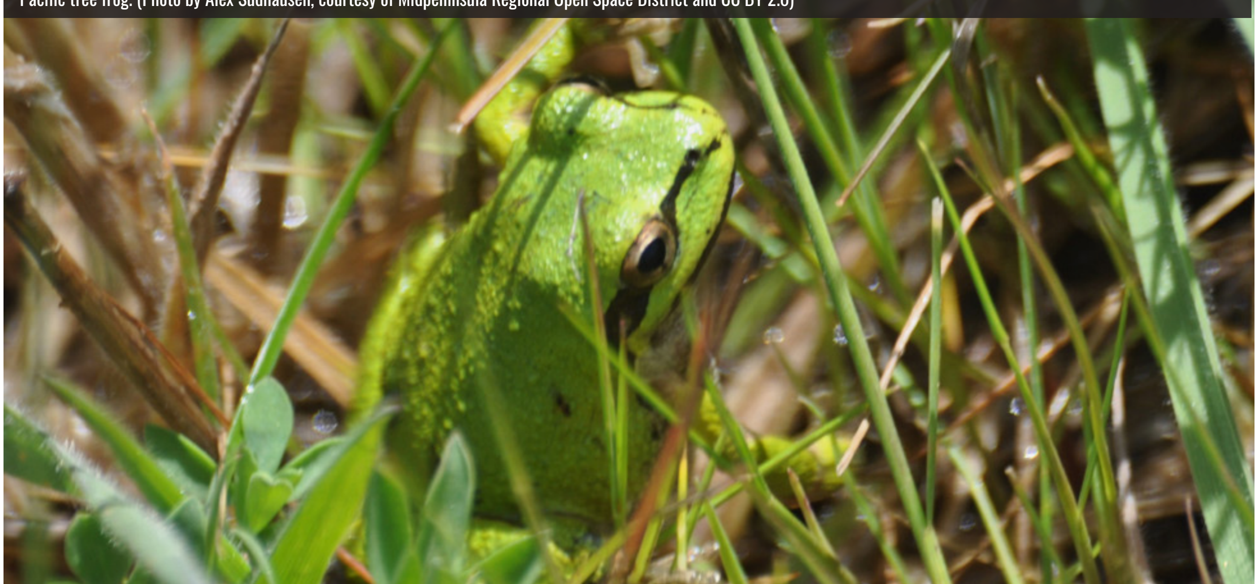
Based on the scientific literature that is available, there are many factors that influence wildlife responses to recreation. This complexity contributes to the challenge scientists and land managers face in interpreting animal behavior responses to humans, which in turn leads to challenges in decision-making (Baas et al., 2020). Factors influencing wildlife response are categorized into recreation characteristics, environmental characteristics, and characteristics of the particular species or individual animal. Marion (2019) identified five main recreation characteristics:

- Type of recreation activity
- Recreationist's behavior
- Impact predictability (e.g., consistent non-threatening behavior, which wildlife can predict and tolerate)
- Impact frequency and magnitude (e.g., infrequent disturbance, which is likely to cause a greater behavior response, or more frequent disturbance, to which wildlife is more able to habituate)
- Impact timing and location (e.g., wildlife may be more reactive in nesting areas or during breeding season)

Environmental characteristics may indicate the natural environment's resilience or resistance to damage from recreation. These include soil type, vegetation type, and topography of the area. The important influencing characteristics of a species or an individual animal include body size, group size, sex, age, niche (specialized versus generalized), and breeding status (Knight and Cole, 1995; L. Trulio pers.comm.).

When measuring the wildlife response itself, studies have focused on both immediate and long-term effects (Figure 2; Cole, 2019). Behavioral responses of wildlife are by far the most studied recreation-related impacts to wildlife, followed by changes in abundance of wildlife (Larson et al., 2016). While most studies have focused on the behavioral response of individual animals, these responses can have cascading effects at the population and community levels; however, more research is needed to understand impacts at these levels.

Pacific tree frog. (Photo by Alex Sudhausen, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)



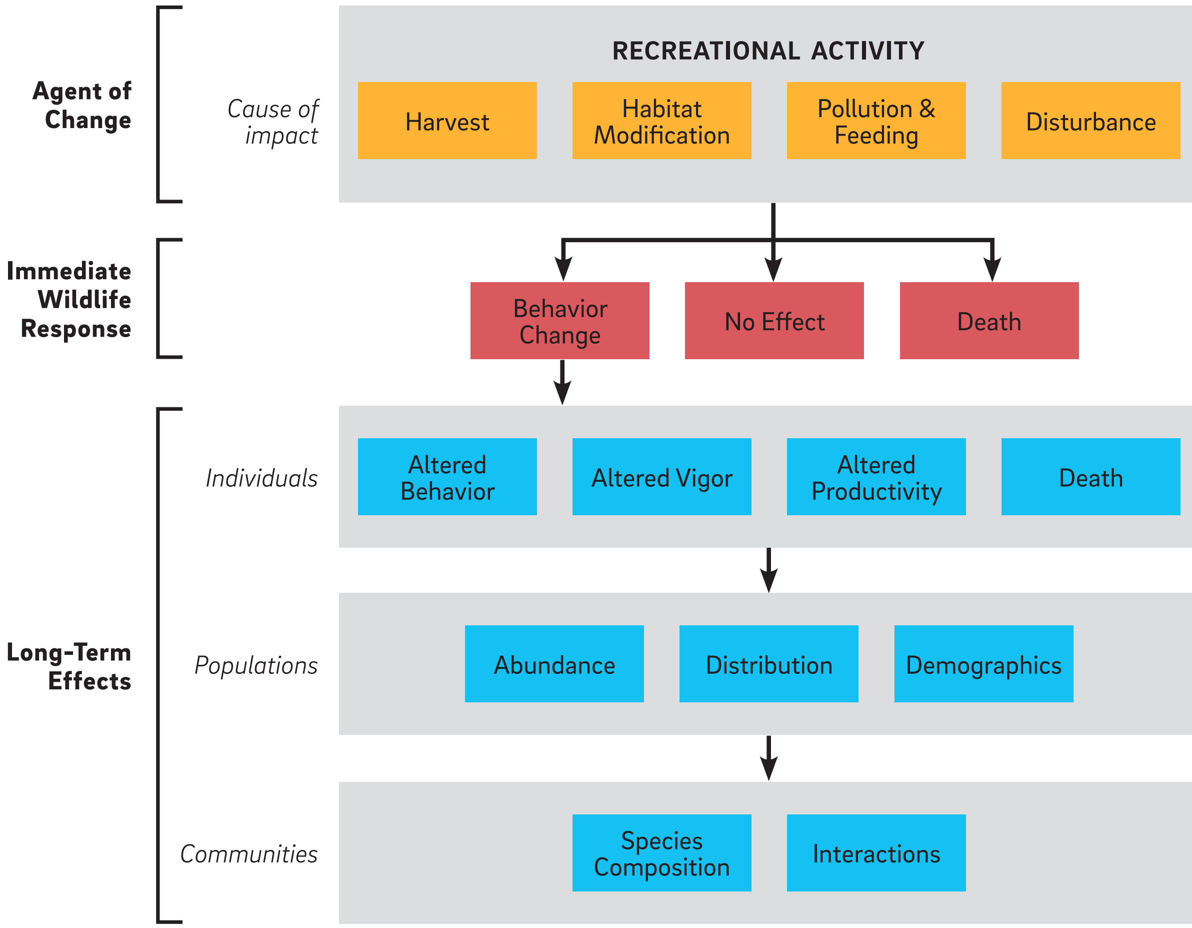


Figure 2. This conceptual model depicts wildlife responses to recreational activity (Cole, 1993).

This section focuses on the following categories of wildlife response to recreation: displacement of wildlife, changes in occupancy and abundance, responses to noise pollution, and impacts of pathogen translocation by humans. While these categories don't align perfectly with the framework presented in Figure 2, they were chosen because they effectively summarize the main areas of relevant scientific research pertaining to recreation impacts on wildlife.

DISPLACEMENT OF WILDLIFE

Protected area effectiveness can be diminished if public access results in the exclusion of wildlife from using the available habitat. Both formal and informal trails impact wildlife habitat around the trail, and many wildlife species will avoid that area of influence even if it is otherwise good quality habitat. Once an animal detects human presence, it will be on alert and may eventually flee. The disturbance to and displacement of wildlife is commonly studied using four indicators: alert distance, flush or flight initiation distance, distance moved, and area of influence (Table 1). Such responses can be energetically costly and stressful to wildlife.

The distance at which an animal will flee from a human varies by species (Lucas, 2020), and is subject to a wide suite of influencing factors, such as age, sex or breeding status of the individual animal, or even

Table 1. Research on wildlife response to recreation is often focused on four indicators (Cole, 2019).

Indicator	Definition
Alert Distance	Distance at which an animal detects and pays attention to an approaching human
Flush or Flight Initiation Distance	Distance at which an animal flees an approaching human
Distance Moved	Distance that wildlife move when flushed
Area of Influence	A measure of habitat area from which wildlife are displaced because of recreational disturbance

the size of the group of animals. Another factor is the availability of alternative sites to flee to, which, if limited, could restrict the range of responses wildlife can choose (Stankowich, 2008), highlighting the importance of habitat connectivity and preservation of undisturbed habitat areas.

Researchers have looked for differences in animal response across recreational activities with mixed results. A study in Utah, for instance, found no difference in the response of mule deer, pronghorn antelope, and bison to hiking or mountain biking; either recreation type caused a 70% probability of flushing when the animal was within 100 m of the trail (Taylor and Knight, 2003). However, the potential for mountain bikers to disturb more wildlife within a given time period due to greater distance traveled was not examined. On the other hand, a study in British Columbia found that several wildlife species (e.g., coyote, mule deer) avoided humans on trails, with avoidance strongest for mountain biking and motorized vehicles (Naidoo and Burton, 2020). Little information is available on the effect of newer technologies; however, the existing evidence indicates that drones pose a threat to wildlife and elicit escape behavior (Barr et al., 2020; Rebolo-Ifrán et al., 2019).

Recreationists sometimes go off-trail or use informal trails, causing negative impacts to wildlife. Off-trail hikers and bicyclists elicit a greater flushing response from animals compared to on-trail visitors, and the area of influence from off-trail visitors is larger than from on-trail visitors (Miller et al., 2001; Taylor and Knight, 2003; Westekemper et al., 2018). In addition, off-trail hikers in areas with low trail density, where wildlife is less habituated to human presence, may elicit a stronger reaction than off-trail hikers in areas with high trail density (Westekemper et al., 2018).

The presence of a dog exacerbates some wildlife responses. Depending on the species, wildlife may react to the presence of a dog through increased vigilance, distraction, reduced foraging, flight, aggression, or other responses (Weston and Stankowich, 2013). In areas where dogs are permitted, wildlife presence and activity around trails tends to be reduced (Lenth et al., 2008). Also, the distance that wildlife move away to escape is greater in response to hikers with dogs than hikers without dogs (Miller et al., 2001). Leashed dogs are less likely to disturb wildlife than unleashed dogs (Lafferty, 2001; Weston and Stankowich, 2013), though lack of compliance in some cases may reduce the effectiveness of leash laws (Forrest and St. Clair, 2006).

The literature contains mixed results as to whether wildlife responses intensify or decline with repeated exposure to human activity. A study in Santa Barbara found that shorebirds sensitized to human activity (walking, jogging, sitting, dog-walking, horseback riding): more human activity led to greater response to the disturbance (Lafferty, 2001). On the other hand, some shorebird studies report lessened responses to human activity over time (Ikuta and Blumstein, 2003; Miller et al., 2001; Trulio et al., 2013), indicating habituation or desensitization to humans. Habituation may be more likely with greater predictability of human activity (e.g., humans stay on trail, humans do not cross the fenceline) and greater frequency of visitors (Miller et al., 2001; Trulio et al., 2013; Westekemper et al., 2018).

CHANGES IN ABUNDANCE AND OCCUPANCY

Humans recreating in open space can lead to changes in species abundance and occupancy. The observed change (positive, neutral or negative) varies across species and likely across sites and individuals as well.

Wildlife species that are disturbed by human presence may decrease in abundance at a site, or a species may no longer occupy the site at all. Some studies have reported reduced abundance of coyotes, bobcats and small mammals in response to human-caused disturbance in open space (Reed and Merenlender, 2008, 2011; Sauvajot et al., 1998), while other studies have found little relationship between mesocarnivore habitat occupancy and recreational use (Reilly et al., 2017; Townsend et al., 2020). These contradictory findings may be explained in part by different methodologies, such as the use of scat as a proxy for occupancy (Townsend et al., 2020). Mountain lions are especially sensitive to humans, and have been observed in the Santa Cruz Mountains using GPS trackers to avoid areas where they perceive human presence by sound (Suraci et al., 2019). Their reduced occupancy led to a secondary effect of small mammals using more habitat area. After the opening of a new multi-use trail in Sonoma County, mountain lions disappeared from the site and nine months of surveys post-opening did not observe any individuals returning to the site (Townsend et al., 2020). In some contexts, some wildlife species may habituate to recreational use and rebound to occupancy levels observed prior to the introduction of recreation (Townsend et al., 2020). For example, Townsend et al., 2020 found that detection of black-tailed deer around trails in North Sonoma Mountain Regional Park and Open Space Preserve decreased for two years after trail opening but then returned to pre-opening levels.

While many wildlife species avoid areas of human-influence, some species are tolerant of human recreation or even benefit from trail systems, anthropogenic food sources, or other factors associated with recreational use (Lewis et al., 2021). For instance, West et al. (2016) found that human food contributes substantially to the diet of Steller's jays in open spaces in the Santa Cruz Mountains, which may negatively impact species such as the federally endangered marbled murrelet, as Steller's jays predate murrelet eggs and young. Human recreational use may also influence wildlife community composition directly through the intentional release of domestic animals and pest captured near homes; this has been observed in Midpen's preserves (S. Christel pers. comm.; A. Verbrugge pers. comm.).

RESPONSES TO NOISE POLLUTION

Elevated noise is a widespread problem among protected areas in the U.S. Anthropogenic noise (from transportation, development, and/or extractive land use) doubled background sound levels in 63% of US protected areas, and 14% of critical habitat for endangered species experiences greatly elevated sound levels (Buxton, McKenna, et al., 2017).

Noise pollution results in several documented effects to wildlife, ranging from altered behaviors to reduced abundance and fitness. The particular effects depend both on the species and the characteristics of the noise (e.g., its frequency, intensity, predictability; Shannon et al., 2016). Infrequent or unpredictable noises may be more likely to elicit a flight response, while chronic noises may be more likely to interfere with predator or prey detection, communication, and other behaviors (Barber et al., 2010; Francis and Barber, 2013; Siemers and Schaub, 2011). Among vertebrate groups, birds or other species that depend heavily on acoustic communication may be particularly sensitive to noise; studies have found that anthropogenic noise can result in decreased species richness among nesting birds (Francis et al., 2009), as well as decreased abundance and diversity of migratory birds (McClure et al., 2013).

At the request of Midpen, H.T. Harvey and Associates (2021) measured the noise output from both traditional bikes and e-bikes in Midpen preserves to predict impacts of e-bike noise on bats and birds. Bats and birds hear in the high and low frequency range, respectively, and therefore both ranges were measured. In general, terrestrial wildlife responds to sound levels of 40dB (the approximate level of bird song or the inside of a library; IAC Acoustics, 2021) and greater (Shannon et al., 2016). The loudest measurements in the study were 90-96 dB (approximately as loud as a motorcycle at 25 feet; IAC Acoustics, 2021). (Note that decibels are a logarithmic scale, meaning for ever 10 dB increase, the sound intensity is 10 times greater.) The researchers also calculated the distance at which the noise output would attenuate to ambient noise levels of 20 decibels: 45 ft for low frequency noise and 100-231 ft for high frequency noise (depending on the frequency). Given this new evidence, it is plausible that e-bike motor and braking noise can disturb wildlife that have audible ranges in either low or high frequencies.

IMPACTS OF PATHOGENS

A recent review found the human modification of landscapes often leads to increases in wildlife disease prevalence (Brearly et al., 2012). In human-modified landscapes, wildlife face multiple stressors and restricted dispersal ability, which can reduce immune response and in turn affect disease transmission and prevalence (Brearly et al., 2012). Additionally, humans can contribute to the dispersal of some pathogens. For example, chytridiomycosis, an infectious fungal disease driving global declines in amphibian populations, is likely translocated through contaminated footwear of researchers and eco-tourists spreading viable propagules between sites (Kolby and Daszak, 2016).

It is important to identify the mode of disease transmission (direct contact, fomites, aerosol (airborne), oral (ingestion), and vector-borne) when assessing and deciding upon mitigation approaches. For example, a study in the Golden Gate National Recreation Area found that bobcats and gray foxes are vulnerable to a number of pathogens carried by domestic pets, and that pathogen transmission occurs through direct contact with domestic pets or with pet feces (Riley et al., 2004).

A SAMPLING OF SPECIES-SPECIFIC RESPONSES TO RECREATION

Because wildlife responses to recreation vary across species, there is value in better understanding the responses of some individual wildlife species. The amount of available research per species varies. The following summaries highlight responses of some species that inhabit Midpen lands.

Mountain Lion *(Puma concolor):* Mountain lions have demonstrated a strong aversion to human presence, significantly altering their movements in response to detection of human sounds (Baker and Leberg, 2018; Suraci et al., 2019). They are also averse to the presence of domestic dogs (Reilly et al., 2016) and human modifications, including trails, roads, and the edges of their protected habitats (Baker and Leberg, 2018; Townsend et al., 2020; Lewis et al., 2021).

Mule deer *(Odocoileus hemionus):* Mule deer have demonstrated behavioral responses to people on trail. When a person on trail comes within 100 meters of a deer, there is a 70% probability of flushing (Taylor and Knight, 2003). Greater behavioral responses of mule deer are associated with the presence of a domestic dog and hikers going off-trail (Miller et al., 2001). Studies comparing deer response to hiking and mountain biking have mixed results, with some studies finding greater avoidance for mountain biking than hiking (Naidoo and Burton, 2020), and others finding no difference (Taylor and Knight, 2003). Some research indicates that mule deer may switch to a more nocturnal lifestyle to avoid humans (Lewis et al., 2021).

California red-legged frog, Pacifica. (Photo by KQED Quest, courtesy of CC BY 2.0)

California red-legged frog *(Rana draytonii)*: A federally listed species, the California red-legged frog has experienced significant population declines, primarily driven by habitat loss (Barry and Fellers, 2013), and additional threats such as reduced water quality and modification of water flows have been identified (Allen and Tennant, 2000). Research suggests that California red-legged frogs are highly sensitive to human presence. A recent study conducted in central California, for instance, found that human activity (i.e., proximity to hiking trails and roads) was a strong predictor of frog absence, even compared to the presence of predatory invasive species (Anderson, 2019).

Impacts to vegetation

Research has shown that recreation has significant impacts on vegetation. One of the best studied impacts is vegetation trampling, which is associated with subsequent changes in vegetation structure and community composition. In cases of heavy trampling, vegetation cover can disappear entirely. Soil compaction associated with recreational activities can indirectly affect vegetation by altering water availability, rates of seed germination, and other factors. In addition to the direct loss of habitat associated with recreation-related vegetation trampling and soil compaction in the immediate vicinity of formal or informal trails, trail networks can have wider-ranging impacts on vegetation communities by increasing habitat fragmentation at the landscape scale (see page 22). Other impacts to vegetation include the potential human-mediated dispersal of non-native species and pathogens.

TRAMPLING AND SOIL COMPACTION

Vegetation trampling is perhaps the best studied impact of recreation to vegetation. Even at low use levels, trampling causes damage and removal of leaves and stems (Marion, 2016). Plant species vary widely in their resistance to damage and their ability to recover from trampling. Generally speaking, woodier, taller, more rigid plants are more prone to breakage. In contrast, more flexible lower stature plants (especially grasses, which evolved in the presence of large native herbivores) are more resistant to damage from trampling, and in fact grasslands may benefit from periodic disturbance from grazing under certain conditions (Stahlheber and D'Antonio, 2013; SFEI 2020). Site-specific characteristics that influence the magnitude of impact of trampling on vegetation include slope, soil characteristics, and presence of rocks (Havlick et al., 2016).

As trampling increases, researchers have observed a progression of vegetation changes of height reduction, loss of vigor and flowering, cover loss, compositional change, and eventually loss of regeneration (Figure 3; Marion, 2016). For example, a study in the Santa Monica Mountains recorded several structural and compositional changes from trampling, including reduced woody vegetation cover, lower woody species richness, more forb and grass cover and lower average vegetation height (Sauvajot et al., 1998). These vegetation changes in turn had a significant impact on the species richness and abundance of small mammals. The degree and rate of vegetation recovery following trampling varies by vegetation type; for instance, Cole (1995) found that plants with perennating buds above the soil surface were less resilient following trampling than plants with buds at or below the soil surface.

The amount of impact also depends on the type of recreation activity. Ranking impacts to vegetation cover, Havlick et al. (2016) identified mountain biking as the most detrimental, followed by hiking and then running. Mountain bikers move faster and thus cannot avoid all obstacles, and may actually seek out obstacles for fun. In contrast, hikers and runners move more slowly than mountain bikers and are more careful about foot placement, though hikers appeared to spread out more and thus trample a greater area of vegetation than runners.

In addition to direct effects of vegetation trampling, soil compaction resulting from recreation can indirectly impact vegetation. Soil compaction reduces the porosity of the soil, which can limit water availability and inhibit root growth. The loss of organic matter and microtopographic heterogeneity associated with soil compaction can also result in lower rates of seed germination and growth (Harper et al., 1965; Pickering and Hill, 2007). See page 31 for additional discussion of soil compaction and other soil impacts from recreation.

IMPACTS OF TRAMPLING ON VEGETATION

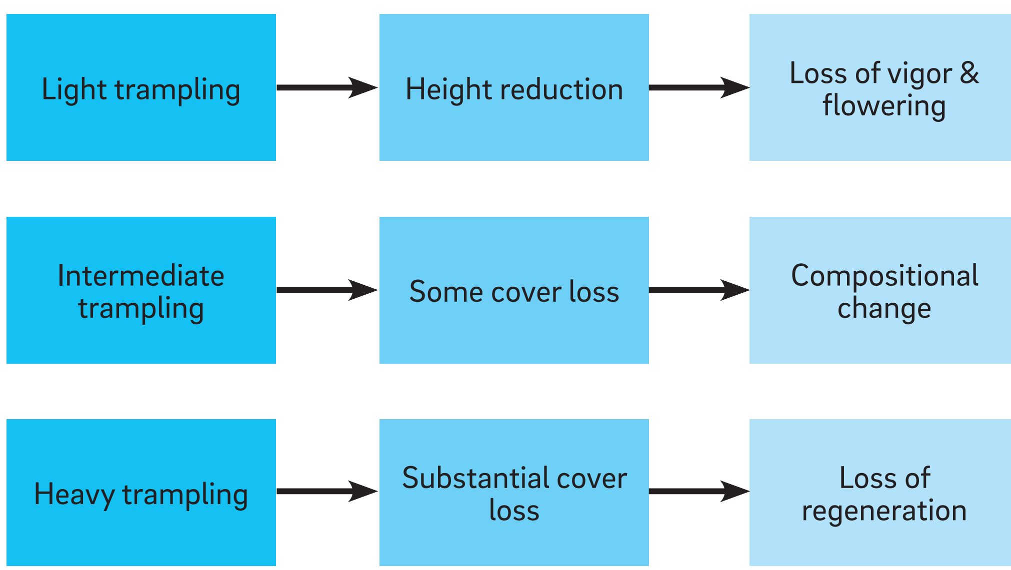


Figure 3. Various vegetation impacts result from trampling (Marion, 2016).

IMPACTS OF NON-NATIVE PLANTS

Recreation contributes to the spread of non-native plant species, some of which may have the ability to become invasive. Once an invasive species has been introduced to a new area, it can continue spreading through self-propagation (Pickering and Hill, 2007). There is evidence that hiking, mountain biking, and horseback riding can all be associated with dispersal or abundance of non-native species. Viable plant seeds can attach to recreationists, horses and bicycles and travel great distances. Hikers can carry seeds up to 13 km (Ansong and Pickering, 2014) (Ansong and Pickering, 2014), and mountain bike tires can disperse seeds up to 500m (Weiss et al., 2016). Factors that influence the seed dispersal distance and amount include visitor behavior (e.g., walking off trail), the clothing type and material, the number of seeds of the plant and their ability to come into contact with the clothing, seed traits such as adhesive and attachment structures, and environmental conditions affecting seed attachment to clothing (Ansong and Pickering, 2014).

In general, horseback riding has been associated with an elevated abundance of non-native species (Anderson et al., 2015). After ingesting plants, horses have the potential to spread viable seeds through their manure (Landsberg et al., 2001). Where riders go off trail, horses have been found to create disturbed terrain that enables non-native plants to establish (Landsberg et al., 2001).

IMPACTS OF PATHOGEN TRANSLOCATION BY HUMANS

As with pathogens that affect wildlife (see page 27), it is also highly plausible that humans may contribute to dispersal of plant pathogens. Fomites are non-living objects that can carry pathogens (Kolby and Daszak, 2016). Examples of fomites include contaminated footwear or clothing. For example, recreationists may inadvertently contribute to dispersal of the oomycete *Phytophthora ramorum,* which causes sudden oak death, when soil containing *P. ramorum* sticks to vehicle tires, bike tires or shoes (Davidson et al., 2005).

Evidence of likely sudden oak death in tanoak tree, Sonoma County. (Photo by KQED Quest, courtesy of CC BY 2.0)

IMPACTS OF TRAMPLING ON SOILS

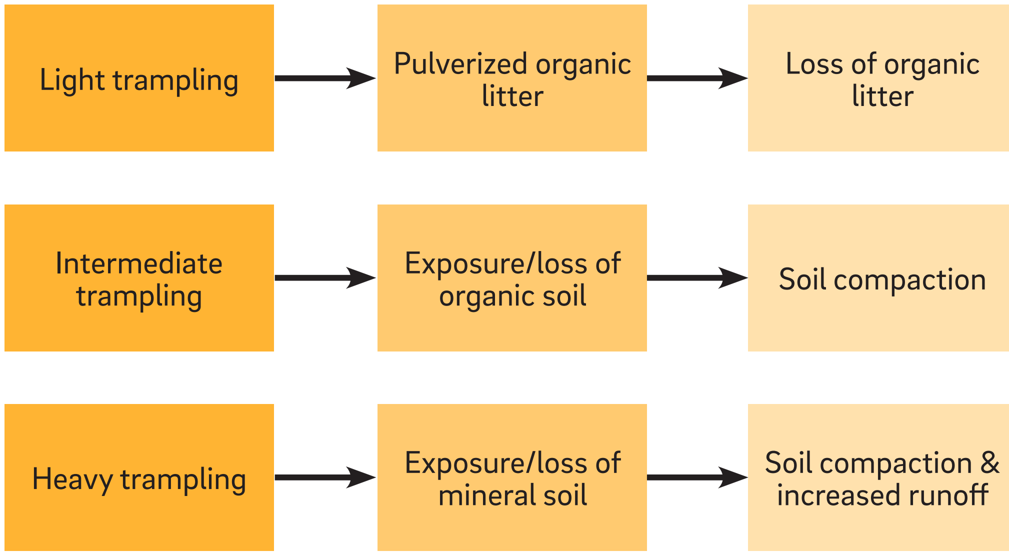


Figure 4. Various soil impacts result from trampling (Marion, 2016).

Impacts to soil

In association with soil trampling by humans, researchers have observed loss of organic litter, loss of organic and mineral soils, soil compaction and increased runoff (Figure 4; Marion, 2016). While much of the research has focused on impacts to formal trails, the changes observed on trails are likely relevant to other places where trampling occurs, like informal trails or picnic areas. Trail degradation generally falls within the categories of trail widening and trail incision, as well as informal trail creation.

Trail degradation is driven by multiple factors: grade, elevation, surface type, trail slope alignment, volume of use and types of use (Svajda et al., 2016). While there is a lack of research that directly compares the magnitude of impact across different recreational activities, hiking, mountain biking, and horseback riding all have the potential to cause trail degradation (Evju et al., 2021; Landsberg et al., 2001). Hiking and biking have similar soil impacts, although the effects of biking are slightly greater. Other environmental factors, like soil type and soil moisture levels, affect the rate of impact, and managers can expect an increase in impact as trail use increases (Evju et al., 2021; Martin et al., 2018).

Marion and Wimpey (2017) developed a Trail Sustainability Rating system using two factors—trail slope alignment and trail grade—to evaluate the sustainability of new and existing trails (Table 2). Trail slope alignment (TSA) is the angle between the direction of travel along the trail and hill slope. Generally, trails are resilient to widening, incision and compaction when they are well designed and constructed for sustainability, and there are numerous resources on best practices for sustainable trails. As the Trail Sustainability Rating system indicates, low trail slope alignment and low trail grade are key characteristics of sustainable trails. While low trail grade is important, completely flat trails are less sustainable because water requires at least a small grade to drain off the trail, and soil moisture makes trails more prone to degradation.

Table 2. The Trail Sustainability Rating system recently proposed by Marion and Wimpey (2017) is consistent with scientific literature and supported by testing using data from three protected areas.

Trail sustainability rating	Trail grade and trail slope alignment (TSA) criteria
Good	Trail grade of 3-10% and TSA>30°
Neutral	Trail grade of 0-2%
Poor	Trail grade of 3-10% and TSA of 0-30°, trail grade of 11-20% and TSA>30°
Very poor	Trail grade of 11-20% and TSA of 0-30°, and trail grade of >20%

TRAIL WIDENING

In comparisons across use types, mountain biking has been found to have a comparable (White et al., 2006) or slightly greater (Evju et al., 2021) impact on trail width than hiking. Still greater impacts on trail width can be attributed to horseback riding (White et al., 2006).

The degree of trail widening is strongly influenced by use level, trail roughness (which may itself be influenced by management factors like livestock grazing; C. Barresi pers. comm.), soil moisture, and other factors (Wimpey and Marion, 2010). Consistent with the use-impact curve paradigm (see Figure 1), a study of the Appalachian Trail found that an increase from low to medium trail use resulted in increased trail width, while an increase from medium to high trail use resulted in insignificant width differences (Wimpey and Marion, 2010; use levels were defined based on staff rankings as well as use counts). Where trail is more rough, visitors may move off trail to more appealing terrain, thereby trampling the adjacent vegetation and widening the trail over time (Wimpey and Marion, 2010).

Most natural-surface trails are resilient to degradation except in wet conditions, which can exacerbate the deterioration caused by hikers, mountain bikers, and horses (Evju et al., 2021; Landsberg et al., 2001). Trails on flat terrain are more susceptible to soil compaction and drain less easily compared to trails on steep terrain. As a result, flat trails become muddy in wet conditions, leading visitors to walk or ride off trail to avoid the mud, widening the trail in the process (Wimpey and Marion, 2010). Evju et al. (2021) found that mountain biking caused more degradation under wet trail conditions than hiking.

TRAIL INCISION

Trail incision occurs when soil is being moved and lost from the trail. Incision can be measured as trail depth, or the depth of the trail relative to its outer boundaries. Steeper trails are more likely to become incised (Meadema et al., 2020; White et al., 2006). Some researchers suggest increasing the durability of the trail surface (e.g., by adding crushed gravel) to avoid incision and other forms of deterioration (Marion and Wimpey, 2017). Where natural surface trails have not received rockwork, managers should note the compaction of the soil, as high soil compaction can limit soil movement or loss from the compacted trail section (Evju et al., 2021).

INFORMAL TRAILS

Informal trails, also called social trails or unplanned trails, are created by the public over time for various reasons, including bathroom stops, activity locations, shortcuts, and access to attractions (Van Winkle, 2014; Wimpey and Marion, 2011). One study also found park access from private property to be an important driver of informal trails (Van Winkle, 2014). The creation of informal trails has been observed in a number of Midpen's preserves (A. Verbrugge pers. comm.).

Compared to trails carefully planned and constructed by land management staff, the unplanned nature of informal trails typically means that sustainability is not factored into their creation. Informal trails are more susceptible to degradation because they tend to feature higher trail grade and greater trail slope alignment (Wimpey and Marion, 2011). Informal trails can also contribute significantly to habitat fragmentation (Barros and Pickering, 2017).

Water quality and aquatic habitat degradation

Water quality impacts from recreation are not as well studied as wildlife, vegetation, and soil impacts (Marion, 2016); however, the disposal of human waste in recreation areas has the potential to contaminate waterways and increase disease transmission (Cilimburg, 2000). Dog waste is also a significant source of fecal pollution in waterways, as was found in a study in Santa Clara County (Tu et al., 2017). For decades, scientists have used coliform bacteria (e.g., *Escherichia coli*) as an indicator to assess fecal contamination in water (Bohn and Buckhouse, 1985). Testing for *E. coli* in waters upstream and downstream of a decommissioned dog park in Jefferson County Open Space in Colorado has shown a significant negative impact of dog use on water quality, as well as vegetation loss and bank cutting (M. Bonnell pers. comm.) People who are directly exposed to contaminated water are at risk of contracting parasites and diseases (Rose et al., 2001). Aside from fecal contamination, recreationists may introduce other forms of pollution into water bodies, including soap, sunscreen, and food particles (Ursem et al., 2009).

Water quality can also be altered through recreation impacts on vegetation and soils. High visitation is associated with vegetation trampling and soil compaction, which can lead to reduced water infiltration (and thus less water available for plants) and increased runoff (Marion, 2016). The effects of increased runoff depend on the slope. It can exacerbate soil erosion in sloped terrain, whereas increased runoff that arrives on flat terrain collects, creating muddy conditions that lead to trail widening as people move off trail to avoid mud (Marion, 2016). Soil erosion may be higher where trails cross streams, especially where best management practices for trails are not implemented, and the resultant extra sediment input can lower the water quality (Kidd et al., 2014). Excessive sedimentation is well known to degrade fish habitat, reducing the quality of salmonid spawning gravels and reducing egg survival rates (Wood and Armitage, 1997). Juvenile salmonids also experience decreased growth and survival rates as a result of fine sediment deposition according to a study in Northern California (Suttle et al., 2004). The entry of extra soil and nutrients into water bodies can also lead to turbidity, reduced dissolved oxygen, and algal blooms (Hammitt et al., 2015). Some algae produce toxins, and these harmful algal blooms (often referred to as "HABs") can make water unsafe for recreation or drinking (Wurtsbaugh et al., 2019).

Visitor experience declines

Across user groups and across individuals, expectations for visitor experience range widely. Every open space visitor brings their unique set of motivations, norms, and expectations (Dorwart et al., 2009). Each has expectations regarding acceptability of components of their experience (e.g., the level of natural resource protection perceived, the activity types encountered, the level of interaction with others, and observed behaviors from others; Dorwart et al., 2009). Furthermore, each of the many types of activities available to visitors tends to be associated with certain expectations. For instance, birdwatchers move relatively quietly and slowly along the trail; picnickers may gather in larger numbers and require certain amenities (e.g., tables, bathrooms); and mountain bikers move faster and may seek thrills during their ride. Where these expectations differ or when the actual experience is not compatible with expectations, visitor conflicts may arise and visitor experience may degrade. These negative impacts can manifest as complaints filed with rangers and negative responses provided during surveys of visitors.

Issues may arise when a visitor perceives activities, behaviors, or conditions that are not in alignment with their own suite of values. For instance, the experience of visitors who care about environmental protection is negatively affected when they observe the negative environmental impacts of recreation. A survey of 82 hikers conducted in Toronto, Canada, evaluated the most common recreation impacts and found that litter had the greatest negative effect on those hikers' overall experience on the trail (Lynn and Brown, 2003). Tree and plant damage and fire rings also had strong negative effects, while trail degradation (extension, widening and erosion) had moderate negative effects. Aside from visible damage, the perception or belief that a certain user group will cause more damage to the environment can create tension among users. For example, in some surveys non-cyclists cited the predicted environmental damage from mountain bikes as part of the basis for their concerns or disapproval toward mountain bikes (Carothers et al., 2001; Rossi et al., 2014).

Furthermore, the visitor experience can be negatively affected by certain interpersonal interactions that are perceived as unacceptable by at least one party. Interpersonal conflict is often asymmetrical, with one user group frequently reporting conflict with another group and the other group reporting little to no conflict (Dorwart et al., 2009). For example, a study of mountain bikers and hikers in Colorado found that hikers were far more likely to report unacceptable behaviors from mountain bikers (e.g., passing too closely, no warning on approach, and excessive speed) than vice versa (Carothers et al., 2001). High speeds of mountain bikers can also startle horses, leading some equestrians to report conflict (Napp and Longsdorf, 2005). Electric bicycles (e-bikes), an emerging technology, may generate some unique conflicts between recreationists. For example, a visitor intercept survey assessing perceptions of e-bikes in Jefferson County, Colorado, found that a number of visitors viewed e-bikes as similar to other motorized forms of transportation, and thus an unacceptable activity type for open space trails (Jefferson County Open Space, 2017).

The visitor experience is also influenced by the level of concurrent use at a site. Acceptability of concurrent use levels is highly subjective, varying across individuals, and generally decreases as the number of people increases (Grau and Freimund, 2016). Sound level plays a significant role in acceptability as well. A study of perceived crowding in Zion National Park, for instance, found higher sound levels were less acceptable than lower sound levels, even if the number of people was unchanged (Grau and Freimund, 2016). Perception that a site is crowded is a negative response to use levels (Fefer et al., 2021). There is some evidence that sensitivity to crowding may differ across cultures, as one study has found nationality to be a moderating factor in crowding perception and response to crowding (Sun and Budruk, 2017). When an individual begins to perceive crowding, they may respond in different ways (Fefer et al., 2021). A person may choose to cope with the crowd cognitively (e.g., reframing the situation more positively) or behaviorally, by trying to amend the situation (e.g., by reporting to a ranger) or by changing location or activity. While crowd size may prevent some visitors from enjoying their preferred recreation spots and/or activities, attitudes tend to shift in a positive direction after the location or activity change (Fefer et al., 2021). However, if crowding results in a person's temporal displacement (i.e., avoiding recreation on popular days), negative feelings tend to persist (Fefer et al., 2021).

Trailhead at Russian Ridge Open Space Preserve. (Photo by Dipika Bhattacharya courtesy CC BY 2.0)

LIMITATIONS
OF THE CURRENT BODY OF LITERATURE

While there is currently a substantial amount of research on which practitioners can base land management and visitor use management decisions, there are still gaps in the current state of knowledge. Among studies on wildlife responses to recreation, reptiles, amphibians, and invertebrates are greatly under-researched compared with birds and mammals (Larson et al., 2016). Wildlife studies typically measure short-term responses of individuals; however, the long-term impacts of such responses on individuals, populations, and communities are not well understood (Snetsinger and White, 2009). Furthermore, the various recreation activities are studied at unequal rates (Larson et al., 2016; Thomsen et al., 2018). In particular, very little has been published about newly emerged technologies, such as drones and e-bikes. Although mountain bikes are not novel, research on mountain biking impacts is far behind research on hiking impacts. As researchers continue to publish their findings, land managers can keep abreast of the new literature and incorporate the latest information into their management decisions.

(Photo courtesy of Midpeninsula Regional Open Space District)

MANAGEMENT RECOMMENDATIONS

Recreation in large open spaces brings benefits to people and sometimes negative impacts to ecosystems. People who visit and experience nature benefit from improved health and well-being, and experiences in nature also tend to engender public support for conservation. On the other hand, the negative impacts of recreation on wildlife, vegetation, soils, and water must be managed for protected areas to effectively conserve natural resources. The numerous outcomes and influencing factors pose a challenge to land managers, who must weigh all the risks and benefits and make decisions about visitor use.

For a long time, the concept of carrying capacity—which assumed a linear relationship between use and negative impact—was the paradigm in management decision-making. Over time, researchers have come to understand that the use-impact relationship is more complex and non-linear (Cole, 2019). While limiting use is still an option, studies show that there are effective methods to reduce negative impacts of recreation other than limiting use, such as modifying visitor behavior, changing where use occurs, and changing use management (Cole, 2019). It is possible for outdoor recreation to be done sustainably, providing opportunities to enjoy nature while generating economic and political support for protected areas (Leung et al., 2018).

This chapter first explores the Visitor Use Management Framework, which is used by six federal agencies, as a model for standardized decision-making regarding open space recreation. Then it takes a deeper dive into important components of an adaptive management approach and the many strategies for visitor use management.

The Visitor Use Management Framework

The Visitor Use Management Framework ("the framework") is used by six federal agencies that collaborate on the Interagency Visitor Use Management Council (IVUMC). The agencies are the Bureau of Land Management, U.S. Forest Service, National Oceanic and Atmospheric Administration, National Park Service, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service. The framework is a proactive and adaptive management process that enables managers to make informed decisions on which strategies and tools to use to achieve and maintain desired conditions and experiences.

Since the agencies that use the framework and Midpen are similarly tasked with providing both natural resource protection and opportunities for public enjoyment, the framework includes a number of elements that may be valuable for Midpen. Midpen could adopt the framework as is or adopt a version that is tailored to the specific needs of Midpen. A decision support framework can benefit Midpen by standardizing the process, building a defensible justification for decisions, and providing transparency about management decisions.

According to the IVUMC, managers must do the following to implement responsive and effective visitor use management:

- Identify desired conditions for resources, visitor experiences and opportunities, and facilities and services;
- Gain an understanding of how visitor use influences achievement of those goals; and
- Commit to active / adaptive management and monitoring of visitor use to meet those goals.

The Visitor Use Management Framework was designed with flexibility so that managers may apply the framework to a wide range of projects or decisions. The iterative nature of the framework allows managers to make decisions with some amount of uncertainty and adjust management as new information becomes available. The framework can support decision-making at various scales, from relatively minor decisions (e.g., whether to add a picnic table) to much larger considerations (e.g., whether to allow public access in a new preserve). The time commitment required depends on the size and complexity of a given project.

Trailhead, Russian Ridge Open Space Preserve. (Photo by Dipika Bhattacharya courtesy CC BY 2.0)

The Visitor Use Management Framework outlines four elements in the decision-making process: 1) build the foundation; 2) define visitor use management direction; 3) identify management strategies; and 4) implement, monitor, evaluate, and adjust (Figure 5). A sliding scale decision support tool (see Appendix B) is used in each element of the framework. It asks the decision maker to respond to a series of questions about the likelihood of various risks using a high, moderate, or low rating. Based on the ratings, this system helps to identify how much further analysis is required to make a confident and defensible decision.

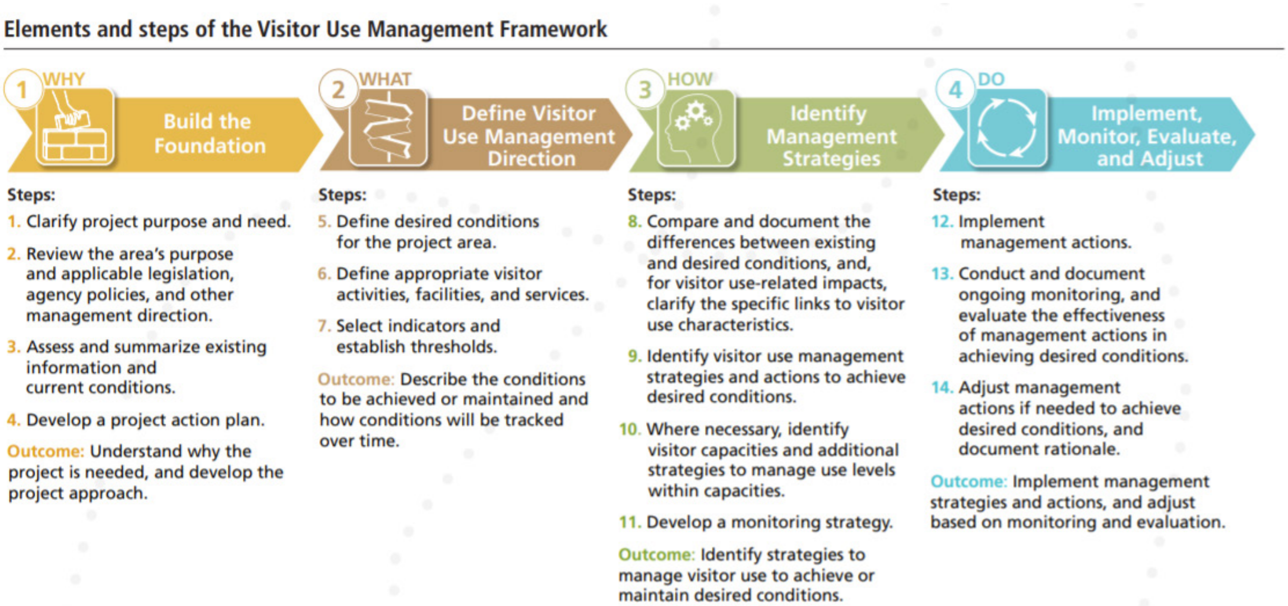


Figure 5. Elements, steps, and outcomes of the Visitor Use Management Framework, from IVUMC (2016).

Impact monitoring program and adaptive management

The fourth element of the Visitor Use Management Framework is to implement, monitor, evaluate, and adjust. This element makes the framework an adaptive management approach, in which the land manager observes and learns from the successes and shortcomings of implemented practices in order to improve those practices to achieve the desired results. Whether or not Midpen adopts the framework, a monitoring program is important for accountability and adaptive management makes it possible to adjust practices.

In addition, a monitoring program will enable Midpen to collect the data that will be most relevant to future management decisions, and quantify and understand impacts within the unique context of each preserve. While the scientific literature provides helpful information for management decisions, research findings from other locations will have varying degrees of applicability to Midpen's preserves. In other words, the patterns of cause and effect summarized in this report are likely to hold true, but concerns related to a specific site or species may require the collection of new data.

Establishing a baseline is an important element of a new monitoring program. A baseline is a starting point that is used for future comparisons. The exact approach to establishing a baseline depends on the current status of the preserve (i.e., whether the area is already open to recreation, and whether the recreation in the area is already deemed acceptable or unacceptable in some way for ecology and/or experience; J. Thomsen pers. comm.). Once the status is determined, goals may be set in relation to the baseline. For example, if the baseline is deemed acceptable, the goal may be to maintain current conditions, and if the baseline is not acceptable, the goal may be to first improve and then maintain conditions.

Next, it is crucial to select measurable indicators for each goal to enable land managers to monitor and track progress. Appendix A provides a compilation of indicators and methods used in the existing body of research. Monitoring at regular intervals can provide new information on a regular basis. It enables managers to evaluate whether strategies are working and to decide upon additional changes that could improve results and reduce the impact to an acceptable level.

The most appropriate study design will depend on the indicators and other factors. If possible to plan sufficiently in advance, the preferred approach is generally to use a long-term before-after-control-impact (BACI) design with a sufficient number of replicates (Christie et al., 2019) to directly measure effects associated with a change in policy or management, such as the opening of a trail (Larson et al., 2020; Townsend et al., 2020). The baseline serves as the comparison for future conditions. If it is not possible to collect monitoring data prior to the policy or management change, a paired-site (or control-impact) design (again, with a sufficient number of replicates; e.g., Reed and Merenlender, 2008) may be used to compare sites with variable policy or management. Midpen can consult a local scientist for guidance on study design and other components of the monitoring program.

Midpen might consider partnering with scientists at local colleges and universities to initiate a cost-effective and scientifically rigorous program. Undergraduates and masters students would be able to run a 1-year project, and doctoral students could run multi-year studies, all under the supervision and guidance of their professor. In such a partnership, Midpen would typically share the cost with the college or university. Ultimately, Midpen would receive site-specific information to help inform decision-making, and the research may be peer reviewed and published to affirm rigor and contribute to overall understanding of recreation impacts in open space.

Visitor use management strategies

As mentioned earlier in this chapter, it may seem intuitive to draw the conclusion that use must be reduced in order to reduce impacts; however, studies have shown that there are other effective ways to reduce impact (Cole, 2019). While reducing use remains an option, Midpen can consider additional approaches to reducing recreation-related impacts. The following compilation of strategies from the scientific literature and from the technical advisors pertain to changing user behavior, where use occurs, and how use is managed. Where applicable, current visitor use management strategies employed by Midpen are noted, though a comprehensive review or assessment of Midpen's existing policies was beyond the scope of this study.

For several of the potential strategies described herein, enforcement may be difficult for various reasons. Despite a land manager's best efforts to post regulations and educate the public about environmental stewardship, a visitor may still choose not to comply and participate in activities or behaviors that are not allowed (e.g., hiking with an off-leash dog, bicycling off trail, improper disposal of dog feces). It may also be difficult to recognize non-compliance regarding e-bike use. At the time of writing, Midpen has not yet established a policy on e-bikes. If the future policy allows certain classes of e-bikes, rangers may have difficulty distinguishing between the classes or between e-bikes and traditional bicycles. Surveys conducted in Colorado found that people are often unable to differentiate between e-bikes and traditional bicycles (Jefferson County Open Space, 2017). Finally, any changes to visitor use management may require changes to staff resources, though making recommendations regarding staffing was beyond the scope of this study.

INTERPRETATION, EDUCATION, PUBLIC OUTREACH, AND SIGNAGE

Interpretive engagement and public outreach programs can be powerful tools for positively changing recreationist behavior. While recreationists tend to underestimate their own impact on the places they visit, they can lessen their impact if they understand how wildlife will benefit (Miller et al., 2001). To positively influence visitor behavior to reduce impact, Midpen can provide clear, consistent, and straightforward messaging through trusted communication channels combined with provision of practical resources (Hall et al., 2020). Visitor interactions with a uniformed ranger or volunteer may lead to greater improvements in trail behavior than signage (Kidd et al., 2014). Furthermore, organized group activities can foster a sense of community and the social aspect of these nature experiences supports physical and mental health outcomes (Holland et al., 2018; Thomsen et al., 2018). Public programming could emphasize hiking, bird-watching, and nature photography, as these activities in particular are linked with elevated pro-environmental behaviors like participation in environmental stewardship and donating to local conservation efforts. Midpen works to educate and engage visitors in a variety of ways, including messaging on the website, social media, newsletters and public-facing programs, such as docent naturalist-led activities.

Communication to the public is important in advance of implementing temporary or permanent policy decisions. The messaging should make clear why the decision was made and how it is going to benefit nature and people. Afterwards, messaging can share positive outcomes of the decision (e.g., how much habitat was reclaimed) and express gratitude to visitors for contributing to resource protection.

CLEANING EQUIPMENT

Providing cleaning equipment for hiking shoes and mountain bikes at the trailhead can encourage visitors to clean at the end of each visit, which can help to limit the spread of invasive species and pathogens (Weiss et al., 2016). Examples of equipment include scrub brushes, a tub of soapy water, and sanitizing solution to destroy fungal and viral pathogens (http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/wildlife-wetland-sanitation.pdf). Midpen currently provides boot and wheel brushes at some trailheads for hikers and bikers to remove dirt both before and after recreating (S. Christel pers. comm.).

PROHIBIT OFF-TRAIL USE

Midpen currently prohibits the construction and maintenance of informal trails, as well as off-trail use by bicyclists and equestrians throughout Midpen lands and by all users in sensitive areas (e.g., seasonal closures in wildflower areas), though other off-trail hiking is not generally prohibited (with the exception of El Corte de Madera Preserve; A. Verbrugge pers. comm., S. Christel pers. comm., C. Barresi pers. comm.). Midpen policy could expand this prohibition to restrict all off-trail use to avoid informal trail creation and reduce impacts to vegetation and wildlife. If visitors stay on trail, wildlife can better predict visitor behavior and are less disturbed, whereas off-trail use effectively reduces the amount of habitat accessible to wildlife. As mentioned above, any policy change should be accompanied by plenty of advance education and outreach about the change.

REDUCING USE

Part of Midpen's management strategy may include limiting the amount of site use, which can promote healthier wildlife communities and habitats (Grooms and Urbanek, 2018). There are several approaches to managing use levels, including setting use quotas, creating use schedules on high-traffic trails, using a permit system, or collecting entrance fees. However, Midpen should consider the implications of any of these approaches in terms of equitable access of the preserves; cost in particular is a well-recognized barrier to entry for marginalized groups (Gibson et al., 2019). Midpen currently does not charge a fee to enter open space preserves and use trails (J. Mark pers. comm.). Staff time for enforcement may also be a consideration.

MANAGEMENT UNITS AND BUFFER ZONES

Protected areas can be subdivided into management units, which can vary in the permitted types of activities as appropriate to the habitat and wildlife species present. Permitted uses may also vary by the time of year. Recreation can be entirely excluded from certain management units to protect sensitive areas and to provide a refuge for wildlife away from humans. For example, Midpen currently designates Conservation Management Units (CMUs) in its preserves with restrictions for public access and/or internal resource protection protocols (S. Christel pers. comm.).

As a general guideline, experts advise an intensification approach over an extensification approach to providing more recreation, although this may not always be the case (J. Thomsen pers. comm.). In other words, when increasing opportunities for recreation, it is better to concentrate use in a smaller area than to spread it across a greater portion of the preserve.

Buffer zones can also be designated for sensitive wildlife based on the species' alert distance and flight-initiation distance. Such zones can be delineated using a buffer distance around sensitive habitat or breeding areas. Implementing quiet zones (e.g., near nesting areas) offers a cost-effective method of reducing disturbance to wildlife without having to entirely close a trail (Buxton, Galvan, et al., 2017). In Acadia National Park, humans were found to be the primary source of noise and quiet zones (indicated using educational signage) were highly effective, reducing human noise by 26% (Abad et al., 2017).

PARKING GUIDANCE

Visitors may choose to go to a less crowded entrance if they know that a given parking area is already (or likely) crowded. While traditionally there is no way to get this information to visitors until they arrive at the parking lot, Jefferson County Open Space in Colorado has begun using an application called Lot Spot (https://lotspot.co) to provide parking guidance to potential visitors (M. Bonnell pers. comm.). With Lot Spot, a smart camera is installed to monitor a parking lot and the mobile app allows users to see the current status of available spaces within a parking lot on a scale from green (available), to yellow, to red (lot full). This information sets realistic expectations for visitors, potentially enhancing visitor satisfaction. This approach can help redistribute use during peak times and manage use levels per preserve. Along similar lines, the "Know Before You Go" page of Midpen's website provides guidance to potential visitors about the popular days, times, and locations, as well as provides instructions to check the "Popular Times" feature in Google Maps.

Midpen recently completed the Rancho San Antonio Multimodal Access Study which evaluated a number of transportation demand management (TDM) measures, including use of a mobile app or messaging system to collect and monitoring real-time data about parking availability (J. Mark pers. comm.).

TEMPORARY AND PERMANENT CLOSURES

Experts advise that it is very difficult to permanently close trails to public access, due to visitor connection and routine associated with certain trails or locations (L. Trulio pers. comm.). This is especially true for trails that are heavily used, though it may be more feasible to close less visited remote trails.

Temporary closures can enable Midpen to protect natural resources during conditions when they are most vulnerable to negative impacts. Seasonal closures of certain trails and other use areas can serve to protect breeding areas (M. Bonnell pers. comm.). Trails can be closed during wet conditions to prevent erosion of the trail. Mountain bikers tend to be more accustomed to and abide by temporary wet trail closures, whereas hikers and runners may be less likely to heed the closure and still enter the trail (M. Bonnell pers. comm.).

Midpen's existing policy is to seasonally close some trails to mountain bikers and equestrians during the rainy season, when soil moisture is higher (S. Christel pers. comm.; A. Verbrugge pers. comm.). In addition, after constructing a new trail system, Midpen's policy is to test compaction, actively compact the trail to a minimum level if needed, and allow the trail to self-compact through one rainy season before opening it to the public to minimize the risk of soil degradation (S. Christel pers. comm.). Midpen also rocks trails that are seasonally muddy, especially in grazing areas and where erosion risk is high either due to expected usage or underlying, less stable soil types (S. Christel pers. comm.).

SUSTAINABLE TRAIL DESIGN

Land managers can use sustainable design to enhance the resistance of trails to negative impacts. A well-designed sustainable trail can withstand high traffic, easily drains water off the tread, and requires minimal maintenance. Some of the key characteristics of a sustainable trail are side-hill trails with low trail-slope alignment, low trail grade, drainage features and an out-sloping tread (Marion and Wimpey, 2017). In areas of very high traffic, some land managers also consider modifying the trail surface to be more durable by adding crushed gravel or rockwork to prevent erosion. There is an abundance of sustainable trail design guidance available for Midpen to draw from for future management of existing trails and planning of future trails. Midpen has 30 staff dedicated to constructing and maintaining roads and trails. New trails are constructed with sustainability as the goal, even when conditions in the field preclude strictly following general sustainability guidance (D. Mackessy pers. comm.). Midpen's trail system features grade reversals that direct water off trails and the average trail grade is generally 10% and below. Midpen also avoids building trails with high trail-slope alignment unless necessary to avoid sensitive resources. When a new property is purchased, pre-existing roads and trails are inventoried and assessed. When they do not meet sustainability goals, Midpen evaluates whether to decommission them, rebuild them, or maintain them as is, based on operational needs and feasibility for repairs, upgrades, or alternative realignments.

WILDLIFE-FRIENDLY TRAIL DESIGN

In addition to designing trails to prevent erosion or widening, trail systems can also be planned carefully to minimize negative impacts to wildlife. Managers should strongly avoid placing new recreational trails or roads through previously unfragmented habitats (Snetsinger and White, 2009). Many studies indicate that once trails or roads are present, human impacts begin to multiply. Midpen seeks to identify locations of sensitive habitats, such as nesting sites and foraging areas, and site trails far enough away to reduce the likelihood of visitors disturbing sensitive habitat and the wildlife using it (S. Christel pers. comm.). An appropriate minimum distance may be informed by regulatory recommendations as well as studies that measure direct disturbance (e.g., alert distance) from recreationists to wildlife, keeping in mind that non-visual cues like scent or sounds may indirectly disturb wildlife from greater distances. For instance, noise pollution from certain recreation activities can be a disturbance trigger for some wildlife even when the sound is not of a frequency audible to humans (H.T. Harvey and Associates, 2021). For waterbirds,

Hikers, Russian Ridge Open Space Preserve. (Photo by J. Kehoe courtesy CC BY 2.0) orienting the trail to steer humans to approach indirectly rather than head-on can help to reduce disturbances (Trulio and Sokale, 2008). Protective barriers like fences can also help prevent visitors from entering a sensitive area.

DRONES

While there are a limited number of studies on wildlife response to drones, there is enough evidence to indicate that drones frequently elicit an escape response, and can provoke an attack response, depending on the species and individual animal. Such responses can be energetically costly and stressful to wildlife. Some researchers recommend prohibiting drone flights by recreationists (Mulero-Pázmány et al., 2017). The piloting team should be able to demonstrate the requisite skill, knowledge, and experience, to ensure no harm in the course of ecological study or other necessary operations.

Midpen's current policy prohibits drone use by recreationists. Limited use of drones is reviewed and permitted on a case-by-case basis for capturing aerial photography or for research purposes (S. Christel pers. comm.; Karine Tokatlian pers. comm.). Electric remote controlled aircraft are currently permitted at Rancho San Antonio County Park, though drones, gas-powered aircraft, and helicopters are not permitted at the airfield (J. Mark pers. comm.; S. Christel pers. comm.).

DOMESTIC DOGS

Land managers must consider the risks of wildlife displacement and infectious disease when deciding to limit or ban domestic pets from the preserves. Compared to unleashed dogs, leashed dogs cause less disturbance to wildlife (Lafferty, 2001; Weston and Stankowich, 2013), and a hiker without a dog causes less disturbance than a hiker with a dog (Miller et al., 2001). Midpen currently requires dogs to be leashed and owners to collect their pet's feces (S. Christel pers. comm.). Although providing garbage cans may require additional staff resources to collect the trash, providing garbage cans may encourage proper disposal of feces (J. Thomsen pers. comm.). Midpen has installed dog waste receptacles at its most heavily used dog areas, which has been effective in greatly reducing dog waste in those areas (B. Malone pers. comm.).

PLANNING MANAGEMENT OF NEW PRESERVES

When planning the management of new preserves, land managers can use a phased approach to opening sections of the new preserve for public access. As mentioned earlier, experts advise that it is very difficult to permanently close trails (especially heavily used trails), due to visitor connection and routine associated with certain trails or locations (L. Trulio pers. comm.). Management of new preserves should err on the side of fewer trails, since it is relatively easier to add additional trails later but very challenging to close an existing trail if it is later determined to be problematic (L. Trulio pers. comm.). Because there is a greater likelihood of wildlife habituating to more frequent disturbance than less frequent disturbance, the amount and type of public access may be restricted to a portion of the preserve as designated by management zones. Exclusion zones and buffer zones can be designated to protect highly sensitive species and habitats, such as breeding areas. Midpen typically uses a phased approach in new preserves, corresponding to internal capacity for opening and managing new areas and trails for public access (S. Christel pers. comm.).

La Honda Creek Preserve. (Photo courtesy of Midpeninsula Regional Open Space District)

CONCLUSION

Public enjoyment of Midpen's preserves has the potential to cause numerous benefits and negative impacts. Due to their expansive size and natural character, Midpen's preserves likely play a significant role in public health for the large population in the region. Midpen's docent naturalist-led activities and volunteer opportunities are important for helping people connect with nature, grow in support for conservation, and meet physical activity guidelines. However, public access in Midpen preserves may cause habitat fragmentation; disturbance to wildlife; and damage to vegetation, soils and water.

The numerous outcomes and influencing factors pose a challenge to land managers, who must weigh all the risks and benefits and make decisions about visitor use. Fortunately, there are numerous resources and experts available to help inform and guide future land management decisions. The scientific literature and shared wisdom from other land managers provides a toolkit containing many management strategies, supporting some that Midpen already uses and offering others that Midpen may consider implementing or expanding. These strategies can be tailored to the unique context and characteristics of each preserve. Midpen may also adopt a decision support framework, such as the Visitor Use Management Framework or a modified version of it, in order to develop a standardized process for decision making, build justification for a decision, identify risks and vulnerabilities of a project, and be transparent about the process and result. Finally, there are many local experts who can help implement an adaptive management approach that includes regular monitoring and research to inform future decisions.

Although the many influencing factors and outcomes makes for a complicated decision-making process, Midpen's braided mission to provide both public enjoyment and natural resource protection is possible to achieve. There will be unique challenges given the particular characteristics of each preserve. The growing body of scientific research, decision-support tools, local experts, and other resources will enable Midpen to meet this management challenge with the information and strategies it needs to steer decisions toward positive solutions.

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APPENDIX A.
MONITORING TECHNIQUES

This appendix provides technical information about the various methods that can be used to measure recreation-related impacts to wildlife, vegetation, soil, water, and visitor experience. This information is not exhaustive, as there is sometimes more than one method to measure an indicator, and more than one indicator can be used to assess an impact.

While there is a growing body of scientific literature on which to base future land management decisions, there may be certain decisions for which site-specific information is more valuable than applying findings from other locations. Midpen may use this addendum to identify high priority impacts and metrics for future land management decisions. Midpen may consider reaching out to local colleges and universities to partner on monitoring and research. Developing a relationship with a recreation-impacts focused laboratory and allowing students to conduct these research projects within Midpen preserves can also result in some cost savings, while still benefiting from the production of scientifically rigorous information.

Category	Negative Impact	Measurable Indicator	Measurement Techniques and Example Studies
Wildlife	Human Presence as a Disturbance to Wildlife	Alert Distance	Measure the distance at which animals become alert to an approaching pedestrian (Miller, Knight and Miller, 2001; Taylor and Knight, 2003)
Wildlife	Human Presence as a Disturbance to Wildlife	Flush or Flight Initiation Distance	Measure the distance at which animals flee from an approaching pedestrian (Ikuta and Blumstein, 2003; Carrete and Tella, 2010; Westekemper et al., 2018; Taylor and Knight, 2003)
Wildlife	Human Presence as a Disturbance to Wildlife	Distance moved	Measure the distance traveled by the fleeing animals from their initial position to where they stopped fleeing (Miller, Knight and Miller, 2001; Ikuta and Blumstein, 2003; Taylor and Knight, 2003)
Wildlife	Human Presence as a Disturbance to Wildlife	Area of Influence	Calculate the area surrounding a trail or transect (using the flush distance perpendicular to the trail) within which wildlife will flush from a particular activity with a certain probability (Taylor and Knight, 2003)
Wildlife	Human Presence as a Disturbance to Wildlife	Change in wildlife activity	Measure changes in human and wildlife activity in association with the opening of a recreational trail with wildlife cameras (Larson et al., 2020)
Wildlife	Noise pollution	Loudness (decibels), frequency (kHz)	Install microphone arrays along trails to measure sound levels (Newman-Johnson and Schomer, 2013) Use microphones to measure low and high frequency sound levels (H.T. Harvey and Associates, 2021)
Wildlife	Noise pollution	Modeled noise propagation	Use a combination of public datasets and measured sound level data to model noise propagation with SPreAD-GIS software developed by The Wilderness Society (Barber et al., 2011)

Category	Negative Impact	Measurable Indicator	Measurement Techniques and Example Studies
Wildlife / Vegetation	Translocation of invasive species and pathogens	Number of invasive species seeds carried by visitors	Collect seeds from clothing, either through an experimental design or in an unsystematic way (Ansong and Pickering, 2014) Place seed traps inside road tunnels to capture seeds falling from passing vehicles and germinate captured seeds to identify invasive species (Von Der Lippe and Kowarik, 2006)
Vegetation	Trampling	Vegetation damage	Observation through aerial imagery of vegetation damage resulting from experimental trampling (Martin, Butler and Klier, 2018)
Vegetation	Vegetation Structure	Vegetation loss or reduction	Statistical assessments of relationships between areas with loss or reduction of vegetation and distances from urban development and road edges (Sauvajot et al., 1998)
Soil	Erosion / soil loss	Soil movement and soil loss	Measure the extent of soil movement along trails resulting from the use of heavy machinery for trail construction and/or maintenance (Barros and Pickering, 2017)
Soil	Erosion / soil loss	Soil movement and soil loss	Measure soil loss with the Cross-Sectional Area (CSA) method (Olive and Marion, 2009)
Soil	Compaction	Soil's compressive strength	Measure the compressive strength of soils following trampling using a pocket penetrometer (Martin, Butler and Klier, 2018)
Soil	Incision	Maximum trail incision	Measure the maximum depth of the trail surface compared to the level of its outer boundaries (White et al., 2006)
Soil	Trail sustainability	Trail sustainability rating	Evaluate or improve existing or planned trails with the Trail Sustainability Rating system (Marion and Wimpey, 2017)
Water	Waste pollution	Coliform bacteria	Detect presence and/or measure concentration of coliform bacteria in water sample as an indicator of fecal contamination (Roche et al., 2013)
Water	Water quality	Alkalinity, pH, etc.	Analyze water samples downstream of recreation areas and at discharge points to receiving streams (Flack, Medine and Hansen-Bristow,1988)
Water	Water quality	Benthic macroin-vertebrates	Survey for benthic macroinvertebrates to assess water quality, as they are highly sensitive to water quality degradation and often used as indicators (Kidd, Aust and Copenheaver, 2014)
Visitor experience	Crowding	Trail use	Use camera traps to document how many people are using the trail and for which activities (Naidoo and Burton, 2020).
Visitor experience	Visitor satisfaction	Visitor satisfaction	Conduct surveys to understand perceptions of crowding, other user types -- impact of seeing environmental degradation (e.g. waste, litter) during their visit. (Allen, 2019)
Visitor experience	Crowding	Displacement	Conduct surveys and semi-structured interviews to assess the occurrences and extent of displacement (Fefer et al., 2021)
Visitor experience	Conflict	Conflicts between user groups	Conduct survey to assess the visitors' perceived or actual tensions and/or conflicts (Schachinger, 2020)
Visitor experience	Conflict	Secondary impacts of rec-reational use im-pacts on visitors' experience	Conduct survey assessing secondary impacts on visitor experience of recreational use impacts (e.g., trail damage, tree and plant damage, fire rings, and litter) (Lynn and Brown, 2003)

APPENDIX B.
SLIDING SCALE DECISION-SUPPORT TOOL FROM THE VISITOR USE MANAGEMENT FRAMEWORK

The Interagency Visitor Use Management Council (IVUMC) provides a framework and support tool for making decisions on how best to manage visitors while protecting natural resources.

The tool can be accessed from: https://visitorusemanagement.nps.gov/Content/documents/VUM_Framework_Edition%201_508%20Compliant_IVUMC.pdf

Description from the IVUMC (2016):

> "The decision support tool is a simple high, moderate, or low rating system that can help inform the level of analysis needed for a project. If the overall responses to the questions are "high," then the level of analysis is likely high. If the overall responses are "low," then the level of analysis is likely low. However, if some of the responses are high, some are low, and some are moderate, the level of analysis is likely somewhere in the middle. When only one guideline rates out as high, carefully decide the overall level of analysis. For example, a high risk of controversy may mean that the level of analysis is also high or that the level of analysis is moderate and accompanied by a robust public involvement process. Document the rationale for any determination, regardless of the level of analysis.
>
> The decision support tool's list of questions is undoubtedly incomplete; the decisionmaker must consider other factors and variables in cases in which regulatory standards must be met. While the decision support tool can help determine where the project falls on the sliding scale, the decisionmaker ultimately decides the necessary level of analysis."

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Sliding Scale Decision Support Tool

Decision Support Tool	RATING QUESTIONS	RATIONALE	HIGH MODERATE LOW
Project:			
1	What is the likelihood that the situation involves sensitive, rare, or irreplaceable **natural** resources?		
2	What is the likelihood that the situation involves sensitive, rare, or irreplaceable **cultural** resources?		
3	What is the likelihood of imminent and significant changes to the natural or cultural resources?		
4	What is the likelihood of imminent and significant changes to **visitor experience?**		
5	How will the issue affect other aspects of land management in the area or surrounding areas?		
6	What is the geographic extent of the issue's impacts? Scales of impacts include: national, regional, state, local/county, and site or project.		

Decision Support Tool

	RATING QUESTIONS	RATIONALE	HIGH MODERATE LOW
7	What is the relative interest of stakeholders affected by the action? Stakeholders may include: local communities, general public, special interest groups, recreational visitors, commercial users, traditional-subsistence users, tribes, and others.		
8	Is the impact temporary (low) or long lasting (high)?		

CRITERIA - Use the ratings assigned to questions 1-8 to evaluate the following 4 sliding scale criteria. Combine those criteria into a single qualitative rating (high, moderate, or low) of the project's appropriate location on the sliding scale.

	CRITERIA	RATIONALE	HIGH MODERATE LOW
A	**Issue Uncertainty**		
B	**Impact Risk**		
C	**Stakeholder Involvement**		
D	**Level of Controversy**		
	Location on the Sliding Scale		