Photo by Karl Gohl, courtesy of Midpeninsula Regional Open Space District

E-BIKES AND OPEN SPACE:
THE CURRENT STATE OF RESEARCH AND MANAGEMENT RECOMMENDATIONS

PREPARED BY
San Francisco Estuary Institute

PREPARED FOR
Midpeninsula Regional Open Space District

AUTHORS
Stephanie Panlasigui, SFEI
Sean Baumgarten, SFEI
Erica Spotswood, SFEI

SAN FRANCISCO ESTUARY INSTITUTE PUBLICATION #1064

DECEMBER 2021

CONTENTS

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, and Letitia Grenier for their input and review. We also thank Ruth Askevold for design and production of this report.

E-bikes and open space: the current state of research and management recommendations

Prepared for Midpeninsula Open Space District by the San Francisco Estuary Institute

Executive Summary

Electric bikes (hereafter "e-bikes") are a new technology that is growing in popularity. There are three classes of e-bike, all of which have a battery-powered motor that assists the rider. Classes 1 and 3 require the rider to pedal to engage the motor, while class 2 can use the motor exclusively to propel the bike.

As e-bikes have risen in popularity and other land managers have begun allowing e-bikes on trails and roads within parks and preserves, the Midpeninsula Regional Open Space District (hereafter "Midpen") has received many public comments expressing interest in riding e-bikes in its preserves. Currently, two-thirds of Midpen's trail system allows traditional non-motorized bicycles, but their regulations prohibit e-bikes. Little information is available to predict whether e-bikes, relative to traditional bikes, would have different ecological and social impacts. Like many other agencies, Midpen is looking to emerging scientific studies to better understand the potential impacts of e-bikes on the natural resources and ecosystem functions in public open space. This information will help Midpen evaluate whether e-bike use is compatible with its mission for the management of the preserves, part of which is to "protect and restore the natural environment, and provide opportunities for ecologically sensitive public enjoyment and education." If Midpen determines that e-bikes are compatible with its goals, the science will also help in crafting a policy that allows for e-bike use in a way that serves the interests of both users and the environment.

This report is part of Midpen's effort to gain a deeper understanding of the range of possible outcomes of allowing e-bike use in the preserves. For this science synthesis, over 75 papers were reviewed, and a committee of advisors (see Introduction) contributed their knowledge and expert opinions. The goals of this report are to summarize the impacts of traditional mountain bikes, identify how e-bike impacts are likely to be similar or different, and provide recommendations for managing e-bike use if Midpen decides to allow it. The literature review revealed a number of key themes:

1. **Very few studies have been published about e-bike use in public open space.**

   Most studies are about e-bikes for commuter use. Much of this information will be relevant only to urban settings, though some portion may translate to open space settings. In addition, among the few studies conducted in open space settings, some did not yield statistically meaningful results due to small sample sizes. More research is needed to understand e-bike use in open space and its potential impacts to trails, wildlife, and other visitors. Regular reviews of new research and ongoing collaboration between Midpen and other recreation land managers would help ensure that Midpen's e-bike policy continues to be guided by the most recent science and expertise.

2. **Noise pollution is likely to be an important impact of e-bikes, leading to disturbances to some wildlife species.**

   Noise emitted by the motor has the potential to disturb some wildlife species. E-bikes emit both high- and low- frequency sounds in the audible range of many bird and bat species. Other species that hear in these frequencies are likely to experience some disturbance as well when using trail-adjacent habitat. Continued research on sounds from e-bike motors and wildlife disturbance will be valuable. If allowing e-bikes, Midpen should use buffer distances based on the best available research to separate trails from sensitive nesting and roosting sites.

3. **Potential areas of difference between e-bikes and traditional bikes include uphill speed, trail degradation, distance traveled and number of users.**

   At this time, the limited amount of available research is insufficient for drawing general conclusions about the trends or impacts related to e-bike use in open space settings. Surveys of e-bike users highlight their motivations to use e-bikes, including extending their ability to ride into older age (thus increasing the number of users) and being able to travel longer distances. Surveys of other visitors identified speed of e-bikes to be a major concern, for reasons related to safety and environmental degradation. More quantitative research is needed to understand whether these motivations and concerns are reflected in reality in open space settings where e-bikes are allowed.

4. **As more e-bike research becomes available, an adaptive management strategy would facilitate future adjustments to management practices. Many of the management strategies used for mountain bikes are likely to apply to e-bikes as well.**

   Education and outreach, including signage and education programs, are key tools for promoting responsible cyclist behavior as well as reducing conflicts between visitors. Sustainable trail design and other on-trail management strategies can help to minimize traditional mountain bike impacts to natural resources while maintaining high quality recreation experiences. These strategies are likely to continue to be effective for managing potential trail impacts of e-bikes, but continued monitoring and research will be critical to increasing knowledge and improving management of e-bikes in Midpen preserves over time.

Finally, many agencies that manage open space face a challenge in developing a policy for e-bikes based on a very limited amount of information. For instance, a 2016 survey of land management agencies found that the vast majority of land managers (91%) are concerned about possible environmental impacts of e-bikes and would find more research to be useful *(Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results,* 2016). Given the lack of information, if Midpen proceeds with a policy allowing e-bikes, an adaptive management approach is highly recommended. As new studies are published and as e-bikes continue to evolve, Midpen should be prepared to review the new information and potentially integrate it into a revised policy to ensure that e-bike use will remain compatible with its mission.

Introduction

Electric bicycles, hereafter "e-bikes," are a relatively new technology that is growing in popularity in the United States (MacArthur et al., 2018). E-bikes are equipped with a battery-powered motor that assists the rider in propelling the bike forward. Around the world, urban residents are rapidly adopting e-bikes for their commutes, and therefore most scientific research on e-bikes focuses on urban settings and outcomes like greenhouse gas emissions, urban noise pollution, and traffic collisions (e.g., McQueen et al., 2020; Schepers et al., 2014; Weiss et al., 2015). However, e-bikes are becoming increasingly popular in natural areas as well. For instance, a survey of Colorado e-bike users found that most (93%) intend to use their e-bikes on public lands and a substantial portion of e-bike users (34%) are interested in using their e-bikes for mountain biking (Perry and Casey, 2020). Given that e-bikes are fairly new technology, available studies on e-bikes are limited. Nonetheless, many open space agencies are pressed to establish an e-bike policy as public interest in e-bike use grows. By default, California Vehicle Code Section 21207.5 allows some types of e-bikes on unpaved trails unless the managing agency's policy specifically prohibits them. A survey of land managers found that the vast majority (91%) are concerned about possible environmental impacts of electric mountain bikes and would find studies on these and other impacts useful (*Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results*, 2016).

The Midpeninsula Regional Open Space District (hereafter "Midpen") is one of many agencies seeking to establish an e-bike policy. In Santa Clara, San Mateo and Santa Cruz counties, Midpen has preserved approximately 65,000 acres of land, more than half of which is open to the public. Many people in the region visit Midpen's preserves to participate in various activities, such as hiking, mountain biking, horseback riding, and other more leisurely activities like bird-watching and nature photography. Approximately two-thirds of Midpen's trail system is multi-use and allows bicyclists. Currently, Midpen does not allow e-bike use on preserves except under an e-bike pilot program at two preserves and primarily on paved trails, as well as for people with mobility disabilities under the Other Power-Driven Mobility Devices policy in conformity with federal land management laws and regulations. Recently, Midpen has received many public comments expressing interest in riding e-bikes in the preserves, prompting this literature review and other efforts to evaluate the feasibility and potential impacts of introducing e-bike use on trails.

Like many other agencies, Midpen is looking to existing scientific studies to better understand the potential impacts of e-bikes on natural resources in public open space. This information will help Midpen evaluate whether e-bike use is compatible with its mission to "protect and restore the natural environment, and provide opportunities for ecologically sensitive public enjoyment and education." This report presents a synthesis of the current body of scientific literature and aims to achieve the following:

- Summarize the impacts of traditional mountain bikes
- Identify potential impacts that may be unique to e-bikes
- Identify which traditional mountain bike impacts are likely to also be true of e-bikes
- Provide management recommendations to reduce potential negative impacts of e-bikes

In addition to this study, Midpen has collaborated with partners on a study of motor noise emissions and the potential to disturb wildlife (discussed in this report), and an ongoing study of visitor perceptions of e-bikes. The broader literature on e-bikes includes several other topics that this report will not address, because these topics are likely to not be relevant to public open space settings. Such topics are more relevant to urban areas and include greenhouse gas emissions reductions (i.e., when replacing a gas-powered vehicle with an e-bike), urban noise pollution reduction, and traffic collisions.

Additionally, this report has benefited from the involvement of a committee of six advisors, representing a range of relevant areas of expertise. They contributed their knowledge and expert opinion during two workshop meetings 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).

Electric bicycle near trail. (photo by Fabrice Florin, courtesy of CC BY 2.0)

CLASSES OF E-BIKES

California Vehicle Code Section 312.5(a) defines an "electric bicycle" as "a bicycle equipped with fully operable pedals and an electric motor of less than 750 watts." The section also defines the three classes of electric bicycle as follows:

- "A "class 1 electric bicycle," or "low-speed pedal-assisted electric bicycle," is a bicycle equipped with a motor that provides assistance only when the rider is pedaling, and that ceases to provide assistance when the bicycle reaches the speed of 20 miles per hour."
- "A "class 2 electric bicycle," or "low-speed throttle-assisted electric bicycle," is a bicycle equipped with a motor that may be used exclusively to propel the bicycle, and that is not capable of providing assistance when the bicycle reaches the speed of 20 miles per hour."
- "A "class 3 electric bicycle," or "speed pedal-assisted electric bicycle," is a bicycle equipped with a motor that provides assistance only when the rider is pedaling, and that ceases to provide assistance when the bicycle reaches the speed of 28 miles per hour, and is equipped with a speedometer."

At the time of writing, Midpen is only considering allowing class 1 e-bikes on unpaved trails and classes 1 and 2 e-bikes on limited paved trails.

ABOUT THE LITERATURE

This literature review primarily focused on peer-reviewed studies. The peer review system among academic journals gives other scientists a chance to critique the paper to ensure the research is of high quality before it is accepted for publication. Because peer-reviewed studies on both traditional mountain bikes and e-bikes are limited in number, to gather as much evidence as possible this review also includes studies that have not been peer reviewed. Whether or not a resource is peer-reviewed, when very few studies are available on a particular topic, it is important to note that additional research is necessary to build more evidence before broad conclusions may be drawn.

Studies that are not peer-reviewed fall into two categories: student research and white papers. Student research (e.g., master's theses and Ph.D. dissertations) is overseen by university faculty to ensure that the student develops a rigorous study design and produces a high quality report. A white paper is a report or guide that is independently produced by a company or organization. Some white papers in this report were produced by government agencies (e.g., Boulder County Parks and Open Space) and others by non-profit organizations (e.g., PeopleForBikes and International Mountain Biking Association). Some caution regarding literature that has not been peer reviewed is warranted. Non-peer-reviewed works were included as long as the authors provided clearly stated methods and results, and their interpretation did not overstate the results. The latter is particularly important when the sample size is too low to yield a statistically powerful result.

Impacts of traditional mountain bikes

Because traditional mountain bikes have been around since the 1970s, more is known about the ecological impacts of mountain bikes in open space than e-bikes. In the broader body of literature on recreation outcomes, mountain biking has received less attention than hiking, which is by far the most studied activity (Larson et al., 2016; Thomsen et al., 2018).

This chapter summarizes the impacts of mountain biking on the four major landscape components that are affected by recreation: wildlife, soil, vegetation and water (Cole, 1993). A brief section on visitor experience addresses the benefits received by participants in the sport and the potential for negative interactions between user groups on multi-use trails.

WILDLIFE

Mountain biking, as with other forms of recreation, can cause both short term and longer term disturbance to wildlife. Wildlife may respond to the presence of bicyclists through increased alertness or fleeing, as well as longer term avoidance of areas around trails. A recent review indicates that the level of disturbance varies widely depending on taxonomic group, frequency of recreational use, environmental characteristics, and other factors, making it difficult to draw generalizations (Marion, 2019).

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 small mammals and mesocarnivores (small to medium sized predators), such as coyotes and bobcats, in response to recreational use (biking, hiking, and horseback riding) and human-modification in open space (Reed

Bobcat near Mount Hamilton. (photo by Don DeBold, courtesy by CC BY 2.0)

and Merenlender, 2011, 2008; 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, which can be less accurate due to domestic dogs consuming scat and humans having low visual detection ability for scat (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 (biking, hiking, and horseback riding) 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.

Literature regarding the impacts of mountain biking on wildlife relative to other forms of recreation is limited, and findings are mixed. In addition, much of the research has been conducted in other regions and is not focused on local species of interest in Santa Clara and San Mateo counties. (Taylor and Knight, 2003) found that bison, pronghorn antelope, and mule deer on Antelope Island, UT, responded similarly to hiking and mountain biking, and exhibited a 70% probability of flushing from on-trail visitors within 100 m of trails regardless of the type of activity. However, the potential for mountain bikers to disturb more wildlife within a given time period due to greater distance traveled was not examined. (Papouchis et al., 2001) found that desert bighorn sheep in Canyonlands National Park, UT, were much more likely to respond behaviorally to hikers than to mountain bikers; the authors hypothesize that this was due to the less predictable activity of hikers. In contrast, a study by (Naidoo and Burton, 2020) in British Columbia found that the timing of wildlife activity was affected more by mountain biking and motorized recreation than by hikers or horse riders. Townsend et al. (2020) found in Sonoma County that in the same four seasons post-trail opening, some wildlife species' occupancy levels rebounded and mountain biking rates decreased, both to pre-trail opening levels; the authors suggest that some wildlife may tolerate high hiking levels but low rates of bicycle use.

SOIL

Studies on soil-related impacts of recreation typically focus on forms of trail degradation. While type of use does influence trail degradation (Svajda et al., 2016), it is not as significant as certain aspects of trail design. The two primary drivers of trail sustainability are low trail slope alignment and low trail grade (Marion and Wimpey, 2017). Trail slope alignment (TSA) is the difference between the trail and the slope of the land. On more sustainable “side-hill” trails, TSA is low and the trail ascends more gradually, whereas a less sustainable “fall-line” trail is highly aligned with the slope and ascends the slope more directly. Studies conducted in the Southwestern US and on the Appalachian Trail have found that the steepest trail sections experienced the most soil loss, as measured by the amount of trail incision or change in trail depth (Meadema et al., 2020; White et al., 2006).

Mountain bikes can cause trail degradation through skidding and the construction of informal trails, jumps and bridges (Pickering et al., 2010). The riding style (speed, control) and trail conditions (grade and moisture) influence the severity of mountain bike impacts (Pickering et al., 2010). Another factor is the bike’s contact patch (the area of the tire that touches a surface) which is determined by tire width and pressure. In comparison to a cyclocross bike with 35mm wide tires inflated to higher pressure, a mountain bike with 60mm wide tires inflated to lower pressure had less impact on soil compaction (Martin et al., 2018).

Generally, impacts of mountain biking are mostly confined to the main tread (the surface of the trail where people walk or ride; (White et al., 2006). Mountain biking causes a very similar but slightly higher rate of soil loss compared to hiking (Evju et al., 2021; Olive and Marion, 2009). Mountain biking can cause soil compaction at similar rates as hiking (Martin et al., 2018). Studies of trail width expansion have found mountain bikes to have a relatively low effect that is comparable or greater relative to hiking (Evju et al., 2021; White et al., 2006). Wet conditions on natural-surface trails can exacerbate degradation caused

Mountain biking in the forest. (photo by TJ N, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0) by mountain bikers and other recreationists (Evju et al., 2021; Landsberg et al., 2001). The contribution of mountain bikes to trail widening is relatively small compared to horse riding and off-highway vehicles (White et al., 2006).

Mountain bikers cause negative impacts through the unauthorized construction of trails (Pickering et al., 2010). 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).

VEGETATION

As with soil, vegetation impacts of mountain bikes stem from skidding, creation of informal trails, and addition of other unauthorized features like jumps (Pickering et al., 2010). Vegetation trampling is a well-studied impact of recreation, and is particularly problematic where users go off trail and create informal trails. In previously untrampled areas, after just 400 passes by a mountain bike (or a hiker), at least 50% of vegetation cover may be lost (Martin et al., 2018). Compared across recreational activities, mountain biking has a greater impact on vegetation cover than either hiking or running (Havlick et al., 2016). Within mountain biking, more vegetation loss occurs when riding uphill than downhill (Havlick et al., 2016). As mentioned earlier, wet trail conditions can lead mountain bikers and hikers to move around the muddy section, contributing to trail widening (Evju et al., 2021), which results from the trampling of trail-adjacent vegetation. Vegetation trampling also occurs when bikers move off trail to yield to hikers on multi-use trails where equestrians yield to bikers, who yield to hikers.

Mountain biking may also lead to human-mediated dispersal of pathogens. Pathogens may be accidentally spread on contaminated footwear, clothing, bike tires, or other objects (Kolby and Daszak, 2016). In the case of sudden oak death, a disease that affects oak trees in coastal California, spores of the fungus that causes the disease can stick to bike tires and thus travel between recreation sites (Davidson et al., 2005).

Similarly, mountain biking can also facilitate the dispersal of non-native plants. Especially in wet conditions, mountain biking can disperse plant seeds up to 500m (Weiss et al., 2016).

WATER

Mountain biking impacts to water quality have not been a major focus of scientific research. A review in 2010 found no published studies specific to mountain bike impacts on water (Quinn and Chernoff, 2010); more recent reviews have confirmed the lack of studies (Claussen, 2021). Potential impacts of mountain biking may be inferred from the broader body of literature on recreation impacts to water quality, although water quality impacts from recreation are not as well studied as wildlife, vegetation and soil impacts (Marion et al., 2016).

Recreation impacts to water quality often occur via impacts to soil. Except during wet conditions, well-designed trails are rather resilient to recreation impacts like soil compaction, widening and soil loss (Evju et al., 2021; Landsberg et al., 2001). Soil erosion may be higher where trails cross streams, especially where best management practices for trails are not implemented, and the soil enters the water (Kidd et al., 2014). The extra input of sediment and nutrients increases turbidity, reduces dissolved oxygen, and may promote 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). Deaths as a result of algal toxins have been recorded for livestock and birds (Wurtsbaugh et al., 2019). Extra input of sediment also reduces habitat quality for protected salmonids, which are present in several of the watersheds on Midpen lands. Excessive sedimentation reduces the quality of salmonid spawning gravels and 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).

VISITOR EXPERIENCE

People who participate in mountain biking receive physical and mental health benefits. Studies have found that mountain biking can be as healthful an activity as road cycling (Dillard, 2017), which imparts many health benefits like cardiorespiratory fitness, lower risk of heart disease, lower risk of stroke, improved muscular fitness, and reduced depression (Oja et al., 2011). Beyond physical fitness benefits, participation in mountain biking helps people feel more connected to nature, which plays a significant role in supporting general well-being (Mayer and Frantz, 2004; Roberts et al., 2018; Shanahan et al., 2016). Mountain bikers also report stress reduction, improved self-esteem, and greater life satisfaction as a result of participation (Hill and Gómez, 2020; Roberts et al., 2018).

When different types of recreationists interact on the trail, there is a possibility for a negative experience or conflict. One study conducted in Montana received survey responses from 161 recreationists who were a mix of bicyclists and non-bicyclists to understand their perspectives of each other (Watson et al., 1991). The survey revealed that the perceived conflict was asymmetrical, with about 60% of hikers reporting issues with mountain bikers ("Bicycles traveling too fast or too many bicycles"), whereas 25-30% of bicyclists reported issues with hikers. Conflict can manifest in the form of negative interpersonal interactions, such as mountain bikers traveling too fast or passing too closely from the perspective of hikers (Carothers et al., 2001). High speeds of mountain bikers can also startle horses, leading some equestrians to report conflict (Napp and Longsdorf, 2005). Hikers may also perceive mountain biking as in conflict with their social values (e.g., causing more environmental degradation or increasing safety concerns; Carothers et al., 2001). A survey of 270 people living within 4 km of two national parks in Australia found that primary concerns about mountain bikes include the potential for collisions and environmental impacts (e.g., damage to plants and animals; (Rossi et al., 2014).

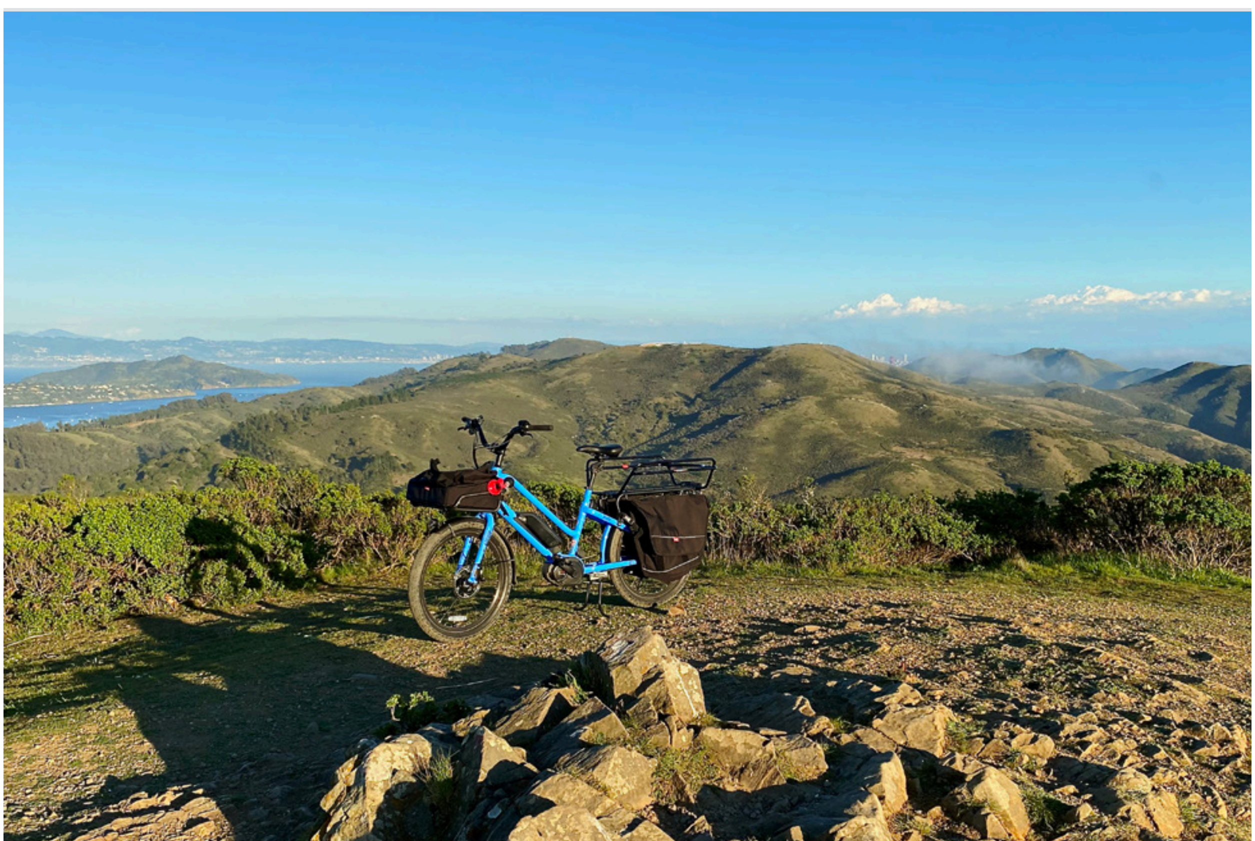
Mountain biking in the forest. (photo by TJ N, courtesy of Midpeninsula Regional Open Space District and CC BY 2.0)

Unique considerations of e-bikes

While many of the impacts from the use of e-bikes in natural areas are likely to be similar to the impacts from traditional mountain bikes discussed above, there are some areas in which the impacts from e-bikes may differ. Some of these potential differences are associated with the technology itself, such as noise produced by the e-bike motor. Other potential differences are associated with changes in visitor behavior or perceptions — such as increased number of unique visitors or distance traveled — that might result from land managers establishing a policy allowing the use of e-bikes. Very little empirical research has been conducted directly comparing the impacts of e-bikes and traditional mountain bikes in natural areas, and thus the focus of this chapter is on identifying the ways in which e-bike impacts are most likely to be similar to or different from traditional mountain bike impacts and summarizing the minimal amount of literature currently available on e-bike impacts in natural areas.

DEMOGRAPHICS

One of the potential effects of allowing e-bikes in open space is an increase in the total number of bicycles on trails. If riders are switching to e-bikes to extend their mountain biking careers as they reach older age, this would increase the overall number of mountain bikers, assuming new people continue to take up mountain biking at similar rates. This concept is supported by recent surveys conducted among bicycle riders on public lands in Colorado: the average age of e-bike riders (58 years old) is higher than that of traditional mountain bike riders (32 years old), and the average e-bike user had ridden bicycles on public lands for over 18 years (Perry and Casey, 2020).



Electric bicycle on trail. (photo by Fabrice Florin, courtesy of CC BY 2.0)

The attraction of new users to the sport due specifically to e-bikes may also increase the total number of bicycles on trails. Recent surveys in North America have found that demographic trends among e-bike users (predominantly older, highly educated, higher-income white males) are similar to trends among traditional bicycle users (Ling et al., 2017; MacArthur et al., 2018, 2014). These surveys have focused on early adopters (Ling et al., 2017), and therefore the demographics among e-bike users may change over time as technology becomes more broadly adopted. The current socioeconomic disparity among e-bike users may be in part due to the high cost of e-bikes, which has been identified as a significant barrier to e-bike adoption (Ling et al., 2017; Perry and Casey, 2020). Furthermore, new users may join the sport because e-bikes lower the physical fitness level necessary to participate. In North America, the use of e-bikes for recreation and exercise (as opposed to utilitarian purposes) is particularly common not only among older riders, but also among those with physical limitations (e.g., limitations related to mobility, respiratory disease, weight, or dexterity; MacArthur et al., 2018). These survey results are supported by other studies that found that study participants perceive their exertion to be lower on an e-bike than a traditional bike (Hall et al., 2019). Despite this perception and the pedal assistance, a comparison of measured heart rates found e-bike riding to provide many of the same health benefits as traditional bike use (Hall et al., 2019; Hoj et al., 2018).

Another potential effect of allowing e-bikes in open space is an increase in the frequency of bicycle use. Survey responses from 553 e-bike users across North America found that e-bikes can result in more frequent participation, increasing from only 31% to 89% of users riding weekly or daily after the purchase of an e-bike (MacArthur et al., 2018). This survey was more focused on urban and suburban settings, and could feasibly translate to the open space setting; however, more research is needed to determine whether this trend of increasing frequency of bicycle use will hold true in open space.

UPHILL SPEED

The electric assistance provided by e-bike motors may allow them to travel faster than traditional bicycles, particularly when traveling uphill. Surveys have shown that visitors may have safety concerns related to speed, especially on narrow trails or around blind corners (Chaney et al., 2019; Schachinger, 2020). However, very few studies have quantified e-bike speeds in open space settings, and the limited data are insufficient for drawing general conclusions. A pilot study in Boulder County conducted by Boulder County Parks & Open Space (Nielsen et al., 2019b) observed the speeds of 492 conventional bikes and 12 e-bikes on open space trails, and found that on average e-bike speed (13.8 mph) was slightly lower than conventional bike speed (14.9 mph). E-bikes traveled faster than conventional bikes in uphill settings (13.8 vs. 12.9 mph) and slower in downhill settings (13.5 vs. 15 mph). Statistical tests were not conducted due to the low number of e-bike observations. An undergraduate project from the Worcester Polytechnic Institute, which used trail cameras to compare the speeds of 152 conventional bikes and 3 e-bikes in Acadia National Park, similarly found that e-bikes traveled faster on average than conventional bikes in uphill settings (7 mph vs. 4.5 mph; Williams et al., 2020). In this study the maximum speed observed was 16 mph, but the authors did not state which type of bicycle achieved this speed.

The small sample size of e-bikes in both studies limits the utility of these findings, and further study is needed. If new research provides sufficient evidence of significant differences in speed between e-bikes and traditional bikes, then negative impacts to the trail may become a concern. This may be especially true in combination with the heavier weight of e-bikes; although the combined weight of a rider and their bike ranges widely, the additional weight of the motor and battery will shift the average weight, and thus cumulative impacts could be greater. Faster speeds may also contribute to increased safety concerns or conflicts with other visitors. For example, Pickering et al. (2010) state that impacts from mountain biking "are likely to be greater when riding is faster, less controlled, occurs on steeper slopes and in wetter conditions."

SOIL IMPACTS

There is a lack of data about the specific impacts of e-bikes on trails and soils. To date, only one study, conducted by the International Mountain Bicycling Association in 2015, has directly measured the trail impacts of electric mountain bikes compared with traditional mountain bikes (IMBA (International Mountain Bicycling Association), 2016). This study, conducted on a test trail in northwestern Oregon, measured soil displacement from class 1 electric mountain bikes, traditional mountain bikes, and off-road motorcycles, controlling for variables such as trail grade, tread texture, and soil moisture. Soil displacement was quantified by measuring trail cross sectional area following a set number of laps by each bicycle type. The study found no significant difference between the impacts of electric mountain bikes and traditional mountain bikes on trail cross sectional area, while motorcycles resulted in significantly more soil displacement than either electric or traditional mountain bikes. (Midpen does not allow visitors to ride motorcycles on trails, and is not considering doing so.) The study authors caution against drawing general conclusions from this limited study, as similar research has not yet been conducted in other study locations.

CONFLICTS BETWEEN VISITORS

The presence of e-bikes in preserves may cause concern among other user groups for similar reasons as traditional mountain bikes. Surveys have shown that visitors may have safety concerns related to speed, and may disapprove of perceived increased environmental damage or heightened noise pollution from e-bikes (Chaney et al., 2019; Schachinger, 2020). General disapproval is directed at all riders, whether on an e-bike or traditional bike, as some participants indicated in a Jefferson County, Colorado survey (Jefferson County Open Space, 2017).

In addition, e-bikes may spark new concerns. A common perception among traditional mountain bikers is that electric mountain bikers are "cheating" (Chaney et al. 2019, Jefferson County 2017, Nielsen et al.), and potential e-bike users have indicated that shaming, especially from other cyclists, poses a barrier to use (Mayer, 2020). The motorized aspect of e-bikes is a great concern (Baechle and Kressler, 2020), and has led participants in two surveys to raise the idea of a "slippery slope," meaning that if motorized e-bikes are allowed on trails not previously open to motorized recreational vehicles, then other uses that conflict with visitors' values and expectations for open space recreation may be allowed as well (Baechle and Kressler, 2020; Jefferson County Open Space, 2017). Despite these concerns, surveys have found that in practice the ability of trail users to distinguish e-bikes from traditional mountain bikes is relatively low (Jefferson County Open Space, 2017). In addition, trail users may be more likely to approve of e-bikes if they have experience with them. A study in which participants shared their perceptions before and after test riding an e-bike revealed the experience led to an increase in approval of e-bikes (Jefferson County Open Space, 2017).

Currently, Midpen is collaborating with Santa Clara County Parks (SCCP), which allows e-bike classes 1 and 2 where traditional bikes are allowed, on a study of perceptions of e-bikes among other user groups. The results (anticipated for release in 2022) will be a valuable addition to the literature on e-bikes.

NOISE POLLUTION

In the first study of its kind, 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 40 dB and greater (Shannon et al., 2016), and the loudest measurements in the study were 90-96 dB, generated by pedaling uphill (when the motor is engaged for pedal-assist) and braking. (Note that decibels are a logarithmic scale. For comparison, the sound level of a motorcycle 25 ft away is about 90 dB, and bird calls are around 44 dB (IAC Acoustics, 2021).) The researchers calculated the distance at which the noise output would attenuate to ambient noise levels of 20 decibels. Low and high frequency noise from e-bikes sufficiently attenuated around 45 ft and 100-231 ft, respectively. The attenuation distance for sounds in the high frequency range depends on the exact frequency. To protect known locations of nesting birds and roosting bats, land managers can use these attenuation distances as the minimum buffer distance required to prevent human-generated noise disturbance. Other wildlife species with similar auditory ranges may also be affected by e-bike noise output when using trail-adjacent habitat.

A recent literature review found no other studies of noise output from e-bikes, and in lieu reviewed wildlife impacts of drones as a proxy for e-bike motor noise (Nielsen et al., 2019a). Like e-bikes, drones are an emerging technology, and therefore the scientific literature is also emerging and limited. Drones can cause disturbance to wildlife when they are visibly and audibly detected by wildlife. Evidence indicates that drones can elicit behavioral changes including alertness, escape or attack (Barr et al., 2020; Rebolo-Ifrán et al., 2019). Therefore, it is plausible given the evidence from drone research and the new evidence from H.T. Harvey that e-bike motor noise can disturb and elicit behavioral responses from wildlife.

LONGER DISTANCE TRAVELED

E-bikes enable riders to travel longer distances. Surveys conducted in Sacramento and across North America have found that traveling longer distances is a motivation for e-bike users, and that e-bikes enable users to travel longer distances that might not have been possible for them on a traditional bike (MacArthur et al., 2014; Perry and Casey, 2020). These surveys were broadly focused on e-bike use, including urban and suburban settings. The findings could feasibly translate to open space settings; however, more research is needed to determine whether this trend of increasing distance traveled will hold true in open space.

The ability to travel longer distances may have implications for wildlife. If e-bike use results in increased traffic on more remote trails, wildlife may encounter more frequent disturbance. Depending on the frequency, as well as the wildlife species, wildlife response may intensify or wildlife may habituate. With infrequent disturbance, wildlife tend to have greater behavior response (e.g., alert distance, flight; (Marion, 2019). The habituation of wildlife may be more likely with greater predictability and greater frequency of visitors (Miller et al., 2001; Trulio et al., 2013; Westekemper et al., 2018).

FIRE RISK

While not common, there are a number of documented cases of the lithium-ion batteries used on e-bikes catching fire or exploding. Most of the reported incidents involved damaged batteries that caught fire while being charged or stored; fires may also be more likely to occur in aftermarket batteries (NBC New York, 2021; Roe, 2019). Fires that ignite mid-ride appear to be much less common, although there are documented cases (Pagones and Meyer, 2019; Tremblay, 2019).

Management recommendations

Similar to many other agencies who manage open space areas, Midpen will need to establish a policy on e-bikes in response to growing interest from the public. (At the time of writing, Midpen is only considering e-bikes of classes 1 and 2. Midpen is not considering class 3 e-bikes, which can travel at speeds up to 28 mph.) The decision depends on careful consideration of both the health and accessibility benefits to e-bike users and the potential negative impacts to natural resources and other visitors. Many agencies have already created policies on e-bikes (Table 1), and Midpen has interviewed staff at local agencies to understand their decision-making process, justifications, approach to rolling out the policy, and enforcement of the policy. Agencies interviewed by Midpen staff did not report major management challenges unique to e-bikes beyond those associated with traditional mountain bikes (B. Malone pers. comm.). Most local agencies that allow e-bikes did so after a classification system was adopted by the state and after California Vehicle Code was amended to allow e-bike trail use unless specifically prohibited. Similar action followed at the Federal level for land management agencies under the U.S. Department of the Interior. The existing policies represent a range of approaches across the three class types of e-bike and types of trail (paved or unpaved). Notably, only Marin Municipal Water District mentioned aftermarket kits (which are used to retrofit a traditional bike with a motor and battery), banning their use while allowing class 1 e-bikes with a special use permit. Given the potential fire hazard associated with aftermarket kits, Midpen may consider a similar stipulation in its future e-bike policy.

Short of allowing e-bikes on all trails currently open to traditional bikes, there are a number of intermediate policies that Midpen could consider. Midpen could establish a temporary pilot program in which e-bikes are allowed for a finite time period on a subset of trails. During this trial period, information about e-bike use, environmental impacts, impacts to visitor experience, and noise output can be collected. If findings from the pilot program are favorable, Midpen could permit e-bikes on a subset of trails where impacts are expected to be minimal, based on a review of ecological conditions that would inform the resiliency and durability of the vegetation, soil and wildlife (see sections on sustainable trail design and on-trail management below). Alternatively, Midpen could require e-bike riders to obtain a special use permit. A fee to obtain a special use permit (or any other approach to gain access) may have implications to equitable access, which should be considered because cost is often recognized as a barrier to participation (Gibson et al., 2019).

One factor to consider is the potential difficulty in enforcing a given e-bike policy that separates e-bikes from traditional bikes or divides use by area, trail type, or requires a greater level of oversight, such as a permit system. Detection may pose another challenge to policy enforcement. To the casual observer, e-bikes may be difficult to differentiate from traditional, and surveys have found that other recreationists in open spaces are often unable to distinguish e-bikes from traditional bikes (Jefferson County Open Space, 2017). E-bikes may be more easily identifiable to trained rangers; education and training of Midpen Rangers should be continued as new models are introduced.

In the event that Midpen decides to proceed with a policy that allows e-bikes, this chapter presents a compilation of management strategies and recommendations drawn from the scientific literature, guidance documents and advisors to this project. Management recommendations are grouped under education and outreach, sustainable trail design, on-trail management, and monitoring and research.

Table 1. E-bike policies at various agencies in the U.S. This table is not an exhaustive list of agencies with existing e-bike policies or policies in development.

AGENCY	POLICY
Agencies in California	
California State Parks	**"State recreation areas:** Except for public roadways, only class 1 e-bikes shall be allowed by Superintendent's Order on controlled-access roads and trails. Except for public roadways, class 2 or 3 e-bikes are not allowed. Class 1 e-bikes may be designated for use only on trails and controlled-access roads that already allow traditional (non-electric) bicycles. **State vehicular recreation areas:** Class 1, 2 and 3 e-bikes may be allowed by Superintendent's Order for use on trails and controlled-access roads. **All other park unit classifications:** Class 1 e-bikes may be temporarily allowed by Superintendent's Order for use on trails and nonpublic, controlled-access roads for research and demonstration purposes. Except for public roadways, class 2 or 3 e-bikes are not allowed."
City of East Palo Alto	In the process of amending their municipal code to allow e-bikes on paved bicycle paths, which includes a section of the Bay Trail south of Bay Rd which is managed by the City of Palo Alto.
City of Menlo Park	All e-bikes are allowed on paved trails, including Bay Trail.
City of Palo Alto	E-bikes are allowed under ADA, but the City will consider amending ordinance to be consistent with neighboring agencies for Bay Trail management.
City of San Jose	Class 1 and 2 only are allowed where bikes are permitted.
East Bay Regional Parks District	"Class I and II eBikes are allowed on select park trails"
Golden Gate National Recreation Area	"Allow e-bikes on all routes open to traditional bicycles" "The motor may not be used to propel an e-bike without the rider also pedaling. Motorbikes with a throttle are not e-bikes. The operator of an e-bike must also comply with speed limits that apply to traditional bikes (15 mph in most places and 5 mph in high-congestion areas) and obey state traffic laws."
Marin County	"Marin's updated ordinance allows Class 1 and Class 2 e-bikes on public roads and parking lots within Marin County Parks facilities, and on County paved bicycle and multiuse pathways. Class 1 and Class 2 e-bikes also would be allowed in other areas when specifically signed to permit them. Class 3 e-bikes are prohibited within Parks facilities except upon public roadways and parking lots or when specifically signed to permit them."
Marin Municipal Water District	E-bikes are currently prohibited. A Community Advisory Committee (CAC) was assembled to investigate and develop recommendations. The recommendation is to allow riders with class 1 e-bikes to apply for a special use permit (good for 3 years) and prohibit classes 2 and 3 and after market e-bike kits.

AGENCY	POLICY
Pt. Reyes National Seashore	"E-bike usage is limited to Class I e-bikes where traditional bikes are allowed and as listed below, except as noted (Abbotts Lagoon Trail). Only class I e-bikes are permitted; class II and class III e-bikes are prohibited. E-bikes are prohibited where traditional bikes are prohibited. Except where uswe of motor vehicles by the public is allowed, using the electric motor to move an e-bike without pedaling is prohibited."
San Mateo County Parks	Class 1 and 2 only where bikes are allowed. However, allowed bicycle use is limited.
Santa Clara County Parks	Class 1 and 2 only where bikes are permitted, paved and unpaved.
Santa Clara Valley OSA	Gathering more information, no formal policy for or against ebikes.
Sonoma County Parks	Class 1 and 2 only where bikes are permitted.
Soquel State Demonstration Forest (CalFire)	"Electric bicycles (including all classes) are not allowed."
Tahoe Donner	"Class 1 ebikes (pedal assist bikes) are allowed on Tahoe Donner fire access roads and doubletrack trails"
Town of Mammoth Lakes	"All e-bikes are allowed on roads and streets" "Class 1 e-bikes are allowed on all paved multi-use pathways and in the Mammoth Mountain Bike Park" "E-bikes are not allowed on any trail designated as non-motorized"
Agencies nation-wide	
Jefferson County Open Space (Colorado)	“Class 1 e-bikes are allowed on natural surface trails within the parks. Class 1 and Class 2 e-bikes are allowed on paved trails within the parks.”
Oregon Parks and Recreation Department	"A person may operate an electric assisted bicycle on roads and trails eight feet or wider unless otherwise posted to restrict or permit such activity."
Washington State Parks	Class 1 and 3 e-bikes are allowed on natural surface trails.
King County Parks	E-bikes are prohibited.
U.S. National Park Service	Superintendents may establish their own e-bike policy for their park.
Cuyahoga Valley National Park	"Allow class 1 and class 2 e-bikes on all routes open to traditional bicycles"
Arches National Park	"You can ride your bike or e-bike on all paved and unpaved roads in the park. You may not ride your bike on trails or anywhere off a road."
Acadia National Park	"Only Class-1 e-Bikes are allowed on park Carriage Roads." "Class 2 & 3 e-Bikes are prohibited."
U.S. Bureau of Reclamation	E-bikes are allowed only where traditional bicycles are allowed.
U.S. Fish and Wildlife Service	E-bikes are allowed only where traditional bicycles are allowed.
U.S. Bureau of Land Management	E-bikes are allowed only where traditional bicycles are allowed.
U.S. Forest Service	“Class 1, 2, and 3 e-bikes and electric mountain bicycles (eMTBs) are allowed on approximately 60,000 miles or nearly 40 percent of trails on national forests and grasslands. These vehicles are also allowed on thousands of miles of roads on national forests and grasslands at maintenance level 2, 3, or 4.”

EDUCATION AND OUTREACH

As with any policy change, efforts to educate and inform visitors about the reasons for, and the effects of, allowing e-bikes on trails are likely to increase both behavioral compliance and levels of acceptance, and thus ultimately reduce both environmental impacts and visitor conflicts. For instance, a number of studies have found that education is an effective tool for reducing conflict between hikers and mountain bikers (e.g., Carothers et al., 2001; Watson et al., 1991), and the same is likely to be true for e-bikes as well.

Education and outreach can help promote responsible, lower-impact behavior among e-bike riders, such as staying on trails, slowing down in crowded areas or at trail intersections, wearing bright colored or reflective clothing to increase visibility, and cleaning bicycle equipment before and after rides to reduce the spread of pathogens or invasive species. Signage or education programs could be paired with the tools to enact behavior changes, such as shoe brushes and bike cleaning supplies at the trailhead. Midpen currently provides boot and wheel brushes at trailheads for hikers and bikers to remove dirt both before and after recreating (S. Christel pers. comm.).

Education can also help visitors understand what e-bikes are, and what to expect if they encounter them on trails. Studies have found that there is a general lack of understanding — and some prevalent misconceptions — about the nature of e-bikes among other trail users, and in particular among traditional mountain bikers (Chaney et al., 2019). This lack of familiarity can sometimes lead to conflicts or negative perceptions. Concerns about e-bikes tend to decrease once visitors become more familiar with the technology (Nielsen et al., 2019a), and thus education and outreach is likely to be a critical tool for reducing visitor conflict.

SUSTAINABLE TRAIL DESIGN

As with other recreational activities such as hiking and traditional mountain biking, a number of the impacts from e-bikes — such as soil erosion or vegetation trampling — can be partially mitigated through sustainable trail design. While further research is needed to better understand the potential for unique soil impacts associated with e-bikes, such as increased erosion resulting from greater uphill speeds, overall the recommendations and best management practices pertaining to traditional mountain bikes are also likely to be appropriate for e-bikes on trails.

The scientific literature, as well as existing guidance documents from land management agencies and bicycling industry/advocacy groups, identify a number of best practices for sustainable trail design. Midpen's existing trail design best practices are similar to those of other agencies including California State Parks. Additionally, Midpen made improvements to 24 miles of trail in El Corte de Madera Creek Preserve, which is a popular preserve for mountain bikers, and a study showed a 63% reduction in sedimentation in the creek as a result (Midpeninsula Regional Open Space District, 2020). While an exhaustive treatment of trail design is beyond the scope of this study, several key considerations are provided below:

- **Trail grade.** In general, lower grade trails are less susceptible to erosion (Meadema et al., 2020; White et al., 2006), though very flat trails are prone to muddiness, which can result in trail widening if users go off-trail to avoid muddy sections (Marion and Wimpey, 2017). Marion and Wimpey (2017) recommend trail grades of 3-10% with periodic grade reversals (or dips) that promote the drainage of water off of the trail.
- **Trail slope alignment.** "Side-hill" trails (i.e., trails aligned more closely with local topography) tend to drain water more effectively than "fall-line" trails that ascend slopes more directly, and thus are more resistant to soil erosion and trail degradation (Marion and Wimpey, 2017).

- **Water diversion structures.** Where sufficient drainage cannot be achieved through trail grade and trail slope alignment, water diversion structures may be useful in reducing soil loss (Salesa and Cerdà, 2020).
- **Armoring substrate.** High traffic trails can be hardened, or armored, with embedded rock or crushed gravel to reduce trail degradation. Armoring may be particularly effective on steep trail segments or in wet areas (Marion and Wimpey, 2017). Land managers should consider the siting of armor, as armoring may have tradeoffs (e.g., downhill displacement problems, extra maintenance required) where the trail grade is too steep and receives heavy traffic.
- **Trail siting.** Where possible, trails should be sited in areas with dense and resistant vegetation cover and stable, well-drained soils. Trail creation should be avoided around streams, wetlands, and waterbodies; in large patches of unfragmented habitat; and in areas with sensitive soils, flora or fauna (Salesa and Cerdà, 2020).
- **Barriers.** Physical barriers or borders like boulders can be used to indicate the trail location and prevent trail widening (PeopleForBikes et al., 2017).
- **Maintenance.** Regular trail maintenance is important to ensure that features like water diversion structures continue to function properly and that trail degradation does not occur over time (Salesa and Cerdà, 2020).

Existing and planned trails should be evaluated using the Trail Sustainability Rating system (Marion and Wimpey, 2017) or other standardized methods, and unsustainable trails should be closed or rerouted if suitable alternatives exist (Evju et al., 2021). Midpen works with consultants to evaluate trails and roads that are not built to Midpen's specifications (e.g. ranch or logging roads inherited when Midpen purchases a new property) and determine if treatment, rerouting, or closure is necessary (S. Christel pers. comm.). When assessing trails and implementing sustainable trail design, if necessary, certain trail segments can be prioritized based on need and/or level of use. For trails specifically intended for mountain biking, principles of sustainable trail design may also need to be balanced with incorporation of features and experiences desired by mountain bike users (PeopleForBikes et al., 2017). Additionally, Midpen should assess its current trail network to identify more remote trail segments that may be most likely to experience a substantial increase in bicycle use if e-bikes are permitted (given the potential for e-bikes to travel longer distances than traditional mountain bikes).

ON-TRAIL MANAGEMENT

In combination with sustainable trail design, a variety of on-trail management strategies can be employed to reduce impacts from both e-bikes and traditional mountain bikes, improve on-trail safety for all visitors, and minimize the potential for conflicts between visitors:

- Post speed limits at the trailhead and at the top and bottom of hills. Use a lower speed limit (e.g., 5 mph) on trail sections with greater use or limited line of sight. Current practice at Midpen is to post the speed limit (15 mph) at all trailheads. The speed limit is reduced to 5 mph on blind curves and when passing. Trails with steep slopes where bicycle accidents or speed issues have occurred have the speed limit posted.
- Encourage positive trail behavior by posting yield signs on multi-use trails, especially at intersections (Figure 1). Signage specifically targeting e-bike riders or other user groups is not recommended, as singling out certain user groups can foster resentment or conflict between groups. Midpen has limited use of yield signs to a few locations where conflicts have occurred.

- Close trails during wet and semi-wet conditions to prevent trail degradation and potential spread of non-native plant seeds and pathogens (Weiss et al., 2016). Midpen's existing policy is to seasonally close some trails to mountain bikers and equestrians during the rainy season, when soil moisture is higher.
- Restrict bicycle use around waterbodies and streams (if trails are permitted at all), particularly during amphibian migration season. Midpen closes sensitive areas, such as habitat for endangered species, to all use. Creek fords are changed to culvert or bridge crossings when feasible.
- Take measures to prevent informal trail creation, such as posting signage, developing educational programs, creating physical or visual barriers along trail margins, and monitoring off-trail usage (Barros and Pickering, 2017). Midpen currently prohibits the construction of informal trails, as well as off-trail use by bicyclists and equestrians. Pedestrians are allowed off-trail except for specific closure areas. Midpen monitors and closes informal trails if impacts like erosion are apparent.
- Consider zoning or designating certain trails as single-use. The single-use approach may be particularly appropriate for trails where more visitor conflict has been reported or trails that are too narrow to accommodate both hiking and mountain biking. Deciding where and which user groups share trails depends on the local context, as well as conflicts reported to and observed by management staff. For example, some researchers have reported conflict when horses and bikers share trails (Koemle and Morawetz, 2016; Napp and Longsdorf, 2005), or when hikers and bikers share trails (Carothers et al., 2001). Separating e-bike and traditional mountain bike users is unlikely to be necessary or effective. Midpen currently designates about 60% of trails as multi-use, including equestrians, bicyclists and hikers. Trade-offs of shifting toward more single-use trails may include restriction of access or an increase in negative impacts if new trails are built to accommodate separate user groups.
- Similarly, consider designating certain trails as uni-directional. Directional trails reduce the frequency of visitor interactions, and can thus reduce the potential for conflict among or between user groups (PeopleForBikes et al., 2017).
- Caution signs in advance of rough terrain can inform riders and remind them not to exceed their ability level (Napp and Longsdorf, 2005).

Right-of-way signs (Forest Service sign (left) and Bureau of Land Management sign (right) courtesy of CC BY 2.0)

MONITORING AND RESEARCH

Given the lack of information about e-bike use and impacts, a key element of any policy change allowing e-bikes in Midpen's preserves will be a robust monitoring and research program to evaluate how e-bikes are being used and the impacts of e-bike use over time. Some of the high priority areas for further research on e-bike use and impacts may include soil displacement and loss in different settings (uphill, downhill, different trail grades), speed, rates of e-bike use, distance traveled within preserves, demographic make-up of e-bike users, and visitor conflicts related to e-bike use. Sharing research findings would be a benefit to other land management agencies considering policy changes or seeking to assess the impacts of e-bike use.

A report prepared for Midpen by the (San Francisco Estuary Institute, 2021), titled *An Examination of the Costs and Benefits of Visitation and Recreational Use of Public Open Space*, summarizes monitoring techniques and metrics to measure the impacts from mountain biking and other recreational activities. There are a number of established techniques for measuring mountain bike use and impacts that can be applied to e-bikes as well. For example, trail cams can be deployed to document rates of e-bike use and measure speed. Soil incision and erosion can be measured by systematically sampling trail depth or cross-sectional area. In many cases, it may not be possible to separate e-bike impacts from the impacts of other forms of trail use. Partnering with researchers to run a designed experiment would enable Midpen to isolate and measure impacts from each type of trail use and to compare across use types. Partnerships with local scientists and students could be a mutually beneficial, cost-effective way to conduct monitoring and research on e-bike impacts. Certain collaborators may be willing to share research costs. Whether studies are conducted by university research groups or even by volunteer community scientists, proper training and oversight by expert scientists or university faculty would help to ensure high quality of data to inform decisions.

Conclusion

As Midpen evaluates whether e-bike use is compatible with its mission for the management of its preserves, factors to consider include challenges to policy enforcement, potential physical and ecological impacts, the potential for visitor conflicts or changes to the visitor experience, as well as the health benefits of recreational e-bike use. While the scientific literature pertaining to e-bike impacts in open space is quite limited, insights from research on traditional mountain bike impacts provide an important foundation for decision making. Survey-based research shows that land managers and other visitors suspect there are a number of areas in which e-bike use and impacts may differ from those of traditional mountain bikes, including demographics, uphill speed, soil displacement, conflicts between visitors, noise, and distance traveled. At this time, the very limited research on e-bikes provides a basis for drawing tentative conclusions about some of these impacts, but further research is needed to provide a more robust understanding and address unresolved questions. Until additional information becomes available, the existing research seems to indicate that many of the same management strategies used for traditional mountain bikes will apply to e-bikes as well. If Midpen decides to establish a policy allowing e-bikes on some of its trails, there are a number of practical management strategies Midpen can use, and others already in place that can be continued, to educate e-bike riders and other visitors, ensure sustainable trail design, manage on-trail use, and contribute to the knowledge base around e-bike use through monitoring and research.

References

Baechle, T.J., Kressler, K.M., 2020. Perceptions of conflict surrounding future e-bike use on the Arizona Trail. Arizona Trail Association, Tucson.

Barr, J.R., Green, M.C., DeMaso, S.J., Hardy, T.B., 2020. Drone surveys do not increase colony-wide flight behaviour at waterbird nesting sites, but sensitivity varies among species. Scientific reports 10, 1–10.

Barros, A., Pickering, C., 2017. How Networks of Informal Trails Cause Landscape Level Damage to Vegetation. Environmental Management 60, 57–68. https://doi.org/10.1007/s00267-017-0865-9

Carothers, P., Vaske, J., Donnelly, M., 2001. Social Values versus Interpersonal Conflict among Hikers and Mountain Bikers. Leisure Sciences 23, 47–61. https://doi.org/10.1080/01490400150502243

Chaney, R., Hall, P., Crowder, A., Crookston, B., West, J., 2019. Mountain biker attitudes and perceptions of eMTBs (electric-mountain bikes). Sport Sciences for Health 15. https://doi.org/10.1007/s11332-019-00555-z

Claussen, L.N., 2021. Recreational mountain biking: A case study of sustainable trail development at Boggs Demonstration State Forest, Cobb, California. (Master's Thesis). Oregon State University, Corvallis.

Cole, D., 1993. Minimizing conflict between recreation and nature conservation, in: Ecology of Greenways: Design and Function of Linear Conservation Areas. University of Minnesota Press, Minneapolis, pp. 105–122.

Davidson, J.M., Wickland, A.C., Patterson, H.A., Falk, K.R., Rizzo, D.M., 2005. Transmission of Phytophthora ramorum in Mixed-Evergreen Forest in California. Phytopathology® 95, 587–596. https://doi.org/10.1094/PHYTO-95-0587

Dillard, S.C., 2017. Mountain Biking as a Means to Encourage Public Health and Wellbeing. Wright State University, Dayton, Ohio.

Evju, M., Hagen, D., Jokerud, M., Olsen, S.L., Selvaag, S.K., Vistad, O.I., 2021. Effects of mountain biking versus hiking on trails under different environmental conditions. Journal of Environmental Management 278, 111554. https://doi.org/10.1016/j.jenvman.2020.111554

Gibson, S., Loukaitou-Sideris, A., Mukhija, V., 2019. Ensuring park equity: a California case study. Journal of Urban Design 24, 385–405. https://doi.org/10.1080/13574809.2018.1497927

Hall, C., Hoj, T.H., Julian, C., Wright, G., Chaney, R.A., Crookston, B., West, J., 2019. Pedal-Assist Mountain Bikes: A Pilot Study Comparison of the Exercise Response, Perceptions, and Beliefs of Experienced Mountain Bikers. JMIR Formative Research 3, e13643. https://doi.org/10.2196/13643

Havlick, D.G., Billmeyer, E., Huber, T., Vogt, B., Rodman, K., 2016. Informal trail creation: hiking, trail running, and mountain bicycling in shortgrass prairie. Journal of Sustainable Tourism 24, 1041–1058. https://doi.org/10.1080/09669582.2015.1101127

Hill, E., Gómez, E., 2020. Perceived Health Outcomes of Mountain Bikers: A National Demographic Inquiry. The Journal of Park and Recreation Administration. https://doi.org/10.18666/JPRA-2019-9492

Hoj, T.H., Bramwell, J.J., Lister, C., Grant, E., Crookston, B.T., Hall, C., West, J.H., 2018. Increasing Active Transportation Through E-Bike Use: Pilot Study Comparing the Health Benefits, Attitudes, and Beliefs Surrounding E-Bikes and Conventional Bikes. JMIR Public Health Surveill 4, e10461. https://doi.org/10.2196/10461

IAC Acoustics, 2021. Comparative Examples of Noise Levels [WWW Document]. URL https://www.iacacoustics.com/blog-full/comparative-examples-of-noise-levels.html (accessed 11.12.21).

IMBA (International Mountain Bicycling Association), 2016. A Comparison of Environmental Impacts from Mountain Bicycles, Class 1 Electric Mountain Bicycles, and Motorcycles: Soil Displacement and Erosion on Bike-Optimized Trails in a Western Oregon Forest.

Jefferson County Open Space, 2017. E-bikes and trails: Measuring impact and acceptance of Class 1 e-bikes on trails.

Kidd, K.R., Aust, W.M., Copenheaver, C.A., 2014. Recreational Stream Crossing Effects on Sediment Delivery and Macroinvertebrates in Southwestern Virginia, USA. Environmental Management 54, 505–516. https://doi.org/10.1007/s00267-014-0328-5

Koemle, D.B.A., Morawetz, U.B., 2016. Improving mountain bike trails in Austria: An assessment of trail preferences and benefits from trail features using choice experiments. Journal of Outdoor Recreation and Tourism 15, 55–65. https://doi.org/10.1016/j.jort.2016.04.003

Kolby, J.E., Daszak, P., 2016. The Emerging Amphibian Fungal Disease, Chytridiomycosis: A Key Example of the Global Phenomenon of Wildlife Emerging Infectious Diseases. Microbiology Spectrum 4, 4.3.11. https://doi.org/10.1128/microbiolspec.EI10-0004-2015

Landsberg, J., Logan, B., Shorthouse, D., 2001. Horse riding in urban conservation areas: Reviewing scientific evidence to guide management. Ecological Management & Restoration 2, 36–46. https://doi.org/10.1046/j.1442-8903.2001.00067.x

Larson, C.L., Reed, S.E., Merenlender, A.M., Crooks, K.R., 2016. Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review. PLOS ONE 11, e0167259. https://doi.org/10.1371/journal.pone.0167259

Ling, Z., Cherry, C.R., MacArthur, J.H., Weinert, J.X., 2017. Differences of Cycling Experiences and Perceptions between E-Bike and Bicycle Users in the United States. Sustainability 9, 1662. https://doi.org/10.3390/su9091662

MacArthur, J., Cherry, C., Harpool, M., Scheppke, D., 2018. A North American Survey of Electric Bicycle Owners. Transportation Research and Education Center, Portland. https://doi.org/10.15760/trec.197

MacArthur, J., Dill, J., Person, M., 2014. Electric bikes in North America: Results of an online survey. Transportation Research Record 2468, 123–130.

Marion, J.L., 2019. Impacts to wildlife: Managing visitors and resources to protect wildlife. Interagency Visitor Use Management Council.

Marion, J.L., Leung, Y.-F., Eagleston, H., Burroughs, K., 2016. A Review and Synthesis of Recreation Ecology Research Findings on Visitor Impacts to Wilderness and Protected Natural Areas. Journal of Forestry 114, 352–362. https://doi.org/10.5849/jof.15-498

Marion, J.L., Wimpey, J., 2017. Assessing the influence of sustainable trail design and maintenance on soil loss. Journal of Environmental Management 189, 46–57. https://doi.org/10.1016/j.jenvman.2016.11.074

Martin, R.H., Butler, D.R., Klier, J., 2018. The influence of tire size on bicycle impacts to soil and vegetation. Journal of Outdoor Recreation and Tourism 24, 52–58. https://doi.org/10.1016/j.jort.2018.08.002

Mayer, A., 2020. Motivations and barriers to electric bike use in the U.S.: views from online forum participants. International Journal of Urban Sustainable Development 12, 160–168. https://doi.org/10.1080/19463138.2019.1672696

Mayer, F.S., Frantz, C.M., 2004. The connectedness to nature scale: A measure of individuals' feeling in community with nature. Journal of environmental psychology 24, 503–515.

McQueen, M., MacArthur, J., Cherry, C., 2020. The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. Transportation Research Part D: Transport and Environment 87, 102482. https://doi.org/10.1016/j.trd.2020.102482

Meadema, F., Marion, J.L., Arredondo, J., Wimpey, J., 2020. The influence of layout on Appalachian Trail soil loss, widening, and muddiness: Implications for sustainable trail design and management. Journal of environmental management 257, 109986.

Midpeninsula Regional Open Space District, 2020. El Corte de Madera Watershed Protection Program [WWW Document]. Midpeninsula Regional Open Space District. URL https://www.openspace.org/what-we-do/projects/el-corte-de-madera-watershed-protection-program

Miller, S.G., Knight, R.L., Miller, C.K., 2001. Wildlife responses to pedestrians and dogs. Wildlife Society Bulletin 124–132.

Naidoo, R., Burton, A.C., 2020. Relative effects of recreational activities on a temperate terrestrial wildlife assemblage. Conservation Science and Practice 2, e271. https://doi.org/10.1111/csp2.271

Napp, J., Longsdorf, E.L., 2005. Mountain Biking Access and Issues in USDA Eastern Region Forests. University of Toledo.

NBC New York, 2021. FDNY Issues Warning in Wake of E-Bike Battery Fires.

Nielsen, T., Palmatier, S.M., Proffitt, A., 2019a. Recreation Conflicts Focused on Emerging E-bike Technology. Boulder County Parks & Open Space, Boulder.

Nielsen, T., Palmatier, S.M., Proffitt, A., Marotti, M., 2019b. Boulder County E-bike Pilot Study Results. Boulder County Parks & Open Space.

Oja, P., Titze, S., Bauman, A., De Geus, B., Krenn, P., Reger- Nash, B., Kohlberger, T., 2011. Health benefits of cycling: a systematic review. Scandinavian journal of medicine & science in sports 21, 496–509.

Olive, N.D., Marion, J.L., 2009. The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. Journal of Environmental Management 90, 1483–1493. https://doi.org/10.1016/j.jenvman.2008.10.004

Pagones, S., Meyer, D., 2019. Lime bike apparently explodes, injuring rider in Queens. New York Post.

Papouchis, C.M., Singer, F.J., Sloan, W.B., 2001. Responses of Desert Bighorn Sheep to Increased Human Recreation. The Journal of Wildlife Management 65, 573. https://doi.org/10.2307/3803110

PeopleForBikes, Bicycle Product Suppliers Association, Bureau of Land Management, 2017. eMTB Land Manager Handbook. PeopleForBikes.

Perry, N., Casey, T., 2020. E-bikes on public lands. Colorado Mesa University.

Pickering, C.M., Hill, W., Newsome, D., Leung, Y.-F., 2010. Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. Journal of Environmental Management 91, 551–562. https://doi.org/10.1016/j.jenvman.2009.09.025

Quinn, M., Chernoff, G., 2010. Mountain Biking: A Review of the Ecological Effects. A Literature Review for Parks Canada - National Office (Visitor Experience Branch). Miistakis Institute.

Rebolo-Ifrán, N., Grilli, M.G., Lambertucci, S.A., 2019. Drones as a Threat to Wildlife: YouTube Complements Science in Providing Evidence about Their Effect. Environmental Conservation 46, 205–210. https://doi.org/10.1017/S0376892919000080

Reed, S.E., Merenlender, A.M., 2011. Effects of Management of Domestic Dogs and Recreation on Carnivores in Protected Areas in Northern California. Conservation Biology 25, 504–513. https://doi.org/10.1111/j.1523-1739.2010.01641.x

Reed, S.E., Merenlender, A.M., 2008. Quiet, Nonconsumptive Recreation Reduces Protected Area Effectiveness. Conservation Letters 1, 146–154. https://doi.org/10.1111/j.1755-263X.2008.00019.x

Reilly, M.L., Tobler, M.W., Sonderegger, D.L., Beier, P., 2017. Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion. Biological Conservation 207, 117–126. https://doi.org/10.1016/j.biocon.2016.11.003

Roberts, L., Jones, G., Brooks, R., 2018. Why Do You Ride?: A Characterization of Mountain Bikers, Their Engagement Methods, and Perceived Links to Mental Health and Well-Being. Front. Psychol. 9. https://doi.org/10.3389/fpsyg.2018.01642

Roe, D., 2019. Why Do E-Bikes Catch Fire? [WWW Document]. Bicycling. URL https://www.bicycling.com/bikes-gear/a28778383/electric-bike-explosion/

Rossi, S.D., Pickering, C.M., Byrne, J.A., 2014. Local community perceptions about mountain bike riding in peri-urban national parks. Presented at the The 7th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas, Local Community and Outdoor Recreation, Tallinn University Tallinn, pp. 69–71.

Salesa, D., Cerdà, A., 2020. Soil erosion on mountain trails as a consequence of recreational activities. A comprehensive review of the scientific literature. Journal of Environmental Management 271, 110990. https://doi.org/10.1016/j.jenvman.2020.110990

San Francisco Estuary Institute, 2021. An examination of the costs and benefits of visitation and recreational use of public open space (No. 1020). Richmond, CA.

Sauvajot, R.M., Buechner, M., Kamradt, D.A., Schonewald, C.M., 1998. Patterns of human disturbance and response by small mammals and birds in chaparral near urban development. Urban Ecosystems 2, 279–297. https://doi.org/10.1023/A:1009588723665

Schachinger, S., 2020. Mountain bikers vs. E-mountain bikers: New conflicts in outdoor recreation? (Ph.D. Dissertation). University of Innsbruck, Innsbruck.

Schepers, J.P., Fishman, E., Den Hertog, P., Wolt, K.K., Schwab, A.L., 2014. The safety of electrically assisted bicycles compared to classic bicycles. Accident Analysis & Prevention 73, 174–180.

Shanahan, D.F., Bush, R., Gaston, K.J., Lin, B.B., Dean, J., Barber, E., Fuller, R.A., 2016. Health Benefits from Nature Experiences Depend on Dose. Sci Rep 6, 28551. https://doi.org/10.1038/srep28551

Shannon, G., McKenna, M.F., Angeloni, L.M., Crooks, K.R., Fristrup, K.M., Brown, E., Warner, K.A., Nelson, M.D., White, C., Briggs, J., McFarland, S., Wittemyer, G., 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews 91, 982–1005. https://doi.org/10.1111/brv.12207

Suraci, J.P., Clinchy, M., Zanette, L.Y., Wilmers, C.C., 2019. Fear of humans as apex predators has landscape-scale impacts from mountain lions to mice. Ecology Letters 22, 1578–1586. https://doi.org/10.1111/ele.13344

Suttle, K.B., Power, M.E., Levine, J.M., McNeely, C., 2004. How Fine Sediment in Riverbeds Impairs Growth and Survival of Juvenile Salmonids. Ecological Applications 14, 969–974. https://doi.org/10.1890/03-5190

Svajda, J., Korony, S., Brighton, I., Esser, S., Ciapala, S., 2016. Trail impact monitoring in Rocky Mountain National Park, USA. Solid Earth 7, 115–128.

Taylor, A.R., Knight, R.L., 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13, 951–963. https://doi.org/10.1890/1051-0761(2003)13[951:WRTRAA]2.0.CO;2

Thomsen, J.M., Powell, R.B., Monz, C., 2018. A Systematic Review of the Physical and Mental Health Benefits of Wildland Recreation. Journal of Park & Recreation Administration 36.

Townsend, S.E., Hammerich, S., Halbur, M., 2020. Wildlife occupancy and trail use before and after a park opens to the public. California Fish and Wildlife, Recreation Special Issue 74–94.

Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results, 2016. . The International Mountain Bicycling Association, Boulder.

Tremblay, P., 2019. E-bike explodes into flames causing bush fire on Tour Down Under climb [WWW Document]. Canadian Cycling Magazine. URL https://cyclingmagazine.ca/sections/news/e-bike-explodes-into-flames-causing-bush-fire-on-tour-down-under-climb/

Trulio, L., Sokale, J., Chromczak, D., 2013. Experimental study of shorebird response to new trail use in the South Bay salt pond restoration project.

U.S. Forest Service, n.d. Sharing the Trails [WWW Document]. URL https://www.fs.usda.gov/detail/btnf/recreation/?cid=fseprd509212

Watson, A., Williams, D., Daigle, J., 1991. Sources of conflict between hikers and mountain bike riders in the Rattlesnake NRA. Journal of Park and Recreation Administration 9, 59–71.

Weiss, F., Brummer, T.J., Pufal, G., 2016. Mountain bikes as seed dispersers and their potential socio-ecological consequences. Journal of Environmental Management 181, 326–332. https://doi.org/10.1016/j.jenvman.2016.06.037

Weiss, M., Dekker, P., Moro, A., Scholz, H., Patel, M.K., 2015. On the electrification of road transportation–a review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D: Transport and Environment 41, 348–366.

Westekemper, K., Reinecke, H., Signer, J., Meißner, M., Herzog, S., Balkenhol, N., 2018. Stay on trails – effects of human recreation on the spatiotemporal behavior of red deer *Cervus elaphus* in a German national park. wbio 2018. https://doi.org/10.2981/wlb.00403

White, D.D., Waskey, M.T., Brodehl, G.P., Foti, P.E., 2006. A comparative study of impacts to mountain bike trails in five common ecological regions of the southwestern U.S. Journal of Parks and Recreation Administration 21–41.

Williams, C., DeFranco, C., Alhejaili, A., Wang, B., 2020. Exploring Electric Bicycle and Bicycle Use in Acadia National Park. Worcester Polytechnic Institute.

Wimpey, J., Marion, J.L., 2011. A spatial exploration of informal trail networks within Great Falls Park, VA. Journal of Environmental Management 92, 1012–1022. https://doi.org/10.1016/j.jenvman.2010.11.015

Wood, P., Armitage, P., 1997. Biological Effects of Fine Sediment in the Lotic Environment. Environmental management 21, 203–17.

Wurtsbaugh, W.A., Paerl, H.W., Dodds, W.K., 2019. Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. WIREs Water 6, e1373. https://doi.org/10.1002/wat2.1373