E-Bikes Literature Review

National Park Service
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Contents

1. Executive Summary

The National Park Service (NPS) electric bicycle (e-bike) regulation, which became effective in December 2020, defines the term "electric bicycle" and authorizes superintendents to allow e-bikes, where appropriate, on roads and trails where traditional bicycles are also allowed. This literature review is an internal resource for the NPS intended to assist superintendents with management decisions related to e-bikes; it does not provide recommendations about what decisions should be made. The information in this literature review identifies both beneficial and adverse effects from e-bike use. Superintendents can apply this information, along with any observed effects, to the specific site conditions of the park they manage to inform their decisions regarding e-bike use on trails and administrative roads and to support compliance with the National Environmental Policy Act (NEPA).

This document highlights key findings as they relate to concerns and considerations that may be relevant to park management needs, based on a review of nearly 60 studies that have been conducted on e-bikes. The findings are organized around the common themes of health and wellness, accessibility, equity, environment and natural resources, safety, and user conflict. Below are summaries the key findings for each theme. These key findings highlight both the potential for beneficial and adverse effects from e-bikes, as verified within the research. Areas for further research are identified where formal research was not available to address certain concerns and considerations that may be of interest to parks. Identifying these areas for further research can help superintendents avoid inaccurate assumptions about e-bikes based on anecdotal or subjective information.

Health and Wellness

Key Findings	Areas for Further Research
• Riding an e-bike has similar positive results for a rider's overall health and wellness as a traditional bicycle. • Although e-bikes require less physical exertion than traditional bicycles, e-bikes help users achieve enough physical activity to reduce the chance of sedentary lifestyle diseases. • E-bikes provide mobility to those with physical limitations that may otherwise prevent them from bicycling. • Electric mountain bike (eMTB) users achieved similar levels of physical exertion as traditional mountain bike riders.	• Longer term observational studies could clarify the health effects of riding an e-bike in comparison to other methods of exercise, including traditional bicycles, and micromobility modes. • Additional research could be done to explore the health effects on specific demographic, especially for older adults. • Additional research could be focused on the health impacts related to mode shift due to the easier mobility of e-bikes.

Accessibility

Key Findings	Areas for Further Research
• E-bikes are commonly used by older adults and people with physical limitations that make riding a traditional bicycle difficult. • People with physical limitations are more likely to use e-bikes for recreation and exercise than for commutes. • Design characteristics, including lightweight construction, step-through frame, and tricycle style bikes can help make e-bikes accessible.	• The accessibility key findings are based on survey data; research using empirical and observational methods is necessary to confirm them. • Research could investigate strategies to better integrate adaptive e-bikes into bike share fleets, including understanding the needs of users with disabilities and how to design, finance, and operate programs.

Equity

Key Findings	Areas for Further Research
• The gender discrepancy between e-bike users is proportionally lower than that of traditional bicycle users in the United States; however, women remain underrepresented among e-bike users. • The high upfront cost of e-bikes is a barrier to e-bike ownership and ridership. • Some shared e-bike operators provide alternative means of access for low-income or unbanked individuals or those without a smartphone, such as "text-to-unlock" features.	• Additional research could examine the factors that contribute to the gender discrepancy among e-bike riders. • Research could examine the effectiveness of policies targeted at increasing ridership among traditionally underserved populations. • Further research could examine whether stigmas or fears of harassment discourage e-bike ridership among marginalized groups.

Environment and Natural Resources

Key Findings	Areas for Further Research
Energy, Emissions, and Climate	
• E-bikes have order-of-magnitude lower lifecycle greenhouse gas and air pollutant emissions than internal combustion engine vehicles, but higher emissions than traditional bicycles. • The extent of environmental benefits of e-bikes depends on mode shift behavior (i.e., substitution of trips that would have otherwise been taken using a different mode), degree of e-bike market penetration, and attributes of electricity generation. • Research suggests that e-bikes are most commonly replacing trips taken by traditional bicycles, but are also likely leading to a reduction in vehicle miles traveled, because e-bikes enable users to bike more often, travel longer distances, and carry more cargo.	• Location-specific analysis, particularly in the U.S., can validate modeled increases in e-bike mode share and determine climate and emissions benefits. • More research on the longevity and performance of lithium-ion batteries (and novel energy storage alternatives) may clarify implications for environmental effects associated with production and end-of-life management (e.g., raw materials and appropriate disposal or recycling).

Key Findings	Areas for Further Research
Trail Surfaces	
• One study found that there was not a significant difference in soil displacement on natural surface trails between e-mountain bikes (eMTBs) and traditional mountain bikes. • Management best practices indicate that traditional mountain bike degradation can be minimized if trail users are restricted to formal trails (in contrast to visitor-created trails). • A study of traditional mountain biking effects observes that trail design and management contribute more significantly to trail surface degradation than the type or amount of use.	• Additional research could assess effects on specific types of trail surfaces by recreational activity, including a comparison between e-bikes and traditional bicycles. • There is a lack of research documenting the long-term effects, if any, of e-bikes on trail surfaces.
Wildlife and Vegetation	
• Research on traditional mountain bikes shows that their presence can disturb wildlife and effect ecosystems, similar to other forms of non-motorized recreation. • One literature review, finding no evidence that noise, speed, and trail effects were dissimilar between e-bikes and traditional bicycles, stated that the expected ecological effect of e-bikes would be similar to traditional bicycles. • There have been no fire incidents reported with e-bike devices that adopted the voluntary electrical standard (e.g., UL 2272) for micromobility devices.	• More research could determine the specific effects of e-bikes on plant life in comparison to traditional bicycles and other forms of outdoor recreation on natural surface trails. • Further research could clarify the fire risk of e-bike batteries and the possible fire damage in forested environments.

Safety

Key Findings	Areas for Further Research
• Compared to traditional bicycle riders, e-bike users tend to have a higher rate of single-bicycle crashes.[1] • E-bike crashes have been increasing in general, but this could be attributed to the increasing trend of e-bike ownership.	• Further research could compare the safety of e-bikes and traditional bicycles on natural surface trails. Most of the studies identified are generally about safety along roadways, or do not distinguish between roadways and natural surface trails. • Research could identify whether the frequency of e-bikes crashes is growing faster than e-bike ownership rates.

[1] Single-bicycle crashes are those that only involved the e-bike and the rider (for example, a collision with a fixed object, or skidding and falling).

Key Findings	Areas for Further Research
Perceptions of Safety	
• Some e-bike users feel safer on e-bikes than on traditional bicycles for reasons related to the speed and acceleration characteristics of e-bikes. • In a survey, non-e-bike riders indicated that they did not want e-bikes on trails because they were concerned that the e-bikes would travel too fast. However, the speed data showed that people using traditional bicycles traveled faster along the downhill sections than the people using e-bikes. The results of the study indicated that perceptions did not align with the observed behavior.	• Perception is measured through surveys which are inherently subjective and can be subject to bias. • More research could inform improved understanding of the discrepancy in attitudes towards e-bikes and safety outcomes among different demographic groups.
Speed	
• The average cyclist may be able to travel faster using an e-bike than a traditional bicycle; however, this does not mean that people necessarily travel at higher speeds when using e-bikes. • E-bikes generally travel at similar speeds as traditional bicycles on roadways, off-street paths, as well as natural surface trails. Depending on context, e-bikes may travel faster or slower than traditional bicycles. • Higher average speeds for e-bikes may be due to e-bikes having faster uphill speeds. Measured speeds along flat and downhill sections were relatively similar along both roadways and natural surface trails.	• Traditional bicycles offer a wide range of speed. An area for further research is to compare e-bikes to different types of traditional bicycles and cycling contexts.
Demographic Differences	
• E-bike riders tend to be older. • Men have a higher rate of crashing than women. • Women, older adults, and people who consider themselves not physically fit have a higher rate of suffering a serious injury.	• An area for further research is quantifying ridership proficiency and years of experience as it relates to safety among e-bike users. Many sources indicate the e-bikes are inviting to people with less experience, although ridership proficiency or years of experience could be documented more frequently and clearly. Cycling proficiency is typically self-reported and therefore is subject to bias.

Key Findings	Areas for Further Research
Rider Behavior	
• Compared to traditional bicyclists, e-bike riders exhibit nearly identical safety behavior for wrong-way riding, stop sign compliance, and traffic signal compliance. • Similar to traditional bicycles, speeding on e-bikes can lead to an increase in crashes, especially when weather conditions are not ideal. • Trail users stated that, with respect to passing distance and passing speed, the behavior of people using traditional mountain bikes and eMTBs was indistinguishable.	• There is a lack of research on differences, if any, between e-bike riders and traditional bicycle riders regarding the likelihood of traveling off of established natural surface trails.
Trip Purpose	
• Those who use e-bikes to commute tend to have a higher crash risk than those using e-bikes for recreation. • eMTBs (with wider tires and better suspension) have a lower crash risk than other e-bike types. •	• More research is needed comparing safety outcomes between recreational riders and commuters. Researchers suggest that there may be safety differences between recreational riders and commuters because recreational bicycle riders might have fewer distractions, fewer traffic conflicts, and plan trips to avoid traffic.
E-Bike Classification	
• Class 3 e-bike have similar crash rates as Class 1 or Class 2 e-bikes, however Class 3 may have more serious injuries.	• There is a lack of research on whether and to what extent there are differences in safety risks between e-bike classes. • Since e-bike classifications are not usually reported in crash statistics, it is difficult to draw conclusions about safety differences among e-bike classes.

User Conflict

Key Findings	Areas for Further Research
Perceptions of Conflict	
• Other trail users' perceptions of e-bikes are related to respondents' familiarity and experience with e-bikes. • Exposure to and education on e-bikes and eMTBs could lead to positive trends in perception among other trail users. • Most other trail users cannot differentiate between a traditional bicycle and an e-bike on trails.	• The overall use of e-bikes is still very low compared to use of traditional bicycles on public lands. Opportunities for conflict research specific to e-bikes are limited. • Most available research on trail user conflict is based on subjective survey methods; more observational research could develop findings about actual (not just perceived) conflict. • There is a lack of research on perceptions of noise from e-bikes.

Key Findings	Areas for Further Research
Management and Design Methods	
• Hikers and traditional mountain bikers typically have an asymmetrical relationship where hikers do not like to encounter mountain bikers, but mountain bikers are generally indifferent when they encounter hikers. • Understanding the reason or purpose people seek recreational activity is critical to understanding how to manage the trail and control trail conflicts among user groups.	• There is not research confirming whether the "asymmetrical" relationship between hikers and traditional mountain bikers is also characteristic of the relationship between hikers and eMTB riders. • There is a lack of research to inform data-driven management and design guidelines specifically tailored to e-bikes. Current research on e-bike effects does not establish a clear need for such e-bike tailored guidance.

Krista Sherwood (Conservation & Outdoor Recreation Division) and Wayne Emington (Park Facility Management Division) are the points of contact for this literature review.

2. Purpose

The National Park Service (NPS) electric bicycle (e-bike) regulation, which became effective in December 2020, defines the term "electric bicycle" and authorizes superintendents to allow e-bikes, where appropriate, on roads and trails where traditional bicycles are also allowed. As parks implement this regulation, information regarding e-bikes and their potential effects will help superintendents and park managers make informed management decisions about e-bike allowances, enforcement, and communications. This will improve transportation and recreation access and the visitor experience in National Park System.

E-bike use has grown rapidly in recent years in the United States, with imports of e-bikes doubling from approximately 270,000 in 2019 to 600,000 in 2020.[2] Advances in technology allow e-bikes to travel longer distances and be more affordable than ever before.[3]

This literature review was developed through a critical evaluation of available e-bike and related research studies to summarize key findings on the potential for beneficial and adverse effects of e-bikes, focusing on the distinct differences between an e-bike and a traditional bicycle, where such information is available. Where supported by the literature, it summarizes information related to concerns and considerations for management on various NPS landscape and trail contexts. The review distinguishes between information about subjective *perceptions* (e.g., based on surveys of e-bike riders and other trail users) of e-bikes and objective *observations* of e-bike use. Finally, the review identifies areas for further research which can help superintendents avoid inaccurate assumptions about e-bikes based on anecdotal or subjective information.

There is minimal research concerning differences in effects among e-bikes within the three-class system. Therefore, the findings and identified areas for further research in this literature review are generally applicable for class 1, 2, and 3 e-bikes, unless otherwise noted.

This literature review is an internal resource for the NPS intended to assist superintendents with management decisions related to e-bikes; it does not provide recommendations about what decisions should be made. The information in this literature review identifies both beneficial and adverse effects from e-bike use. Superintendents can apply this information,[4] along with any observed effects, to the specific site conditions of the park they manage to inform their decisions regarding e-bike use on trails and administrative roads and to support compliance with the National Environmental Policy Act (NEPA).

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[2] https://electrek.co/2020/10/28/the-us-is-doubling-e-bike-imports-this-year-to-half-a-million-and-even-that-isnt-enough/

[3] Salmeron-Manzano, E., Manzano-Agugliaori, F. (2018). The Electric Bicycle: Worldwide Research Trends. Energies. https://www.mdpi.com/1996-1073/11/7/1894

[4] Relevant information should include, at minimum, information about e-bike safety and speed per EQD Recommendations to RECs Regarding Review of Categorial Exclusion Content for e-Bike CEs That Evaluate Use on Administrative Roads and Trails, dated 3/13/20.

Where a new categorical exclusion (CE) is required, this information, and any other studies or monitoring data used to support the evaluation of effects from e-bike use, should be cited in the CE documentation and included in the project file.

How is this literature review organized?

This literature review highlights key findings from available research and is organized around common themes found across the research, then further categorized by identified concerns and considerations. The key findings highlight the potential for beneficial and adverse effects, as verified within the research. The primary common themes are briefly described as follows:

- ***Health and Wellness***: This theme considers effects of e-bikes on physical activity and the resulting effect on health and wellness.
- ***Accessibility***: This theme addresses how e-bikes affect accessibility and access when used by people with disabilities, older individuals, or people with other physical limitations.
- ***Equity***: This theme explores how e-bikes effect equitable outcomes for diverse demographic groups.
- ***Environment and Natural Resources***: This theme considers the effects of e-bikes on trail surfaces and natural resources, including erosion and wildlife considerations, as well as how e-bikes may more broadly affect climate and the environment.
- ***Safety***: This theme includes information about the safety of e-bikes, including implications related to the perception or sense of safety by the user, speed, demographic differences, rider behavior, trip purpose, and differences among e-bike classes.
- ***User Conflict***: This theme explores interactions among e-bike and other trail users, including traditional bicyclists, hikers, and equestrians.

The discussion of each theme includes a brief summary of literature sources reviewed, a synthesis of key findings related to concerns and considerations that may be relevant to parks, and areas for further research.

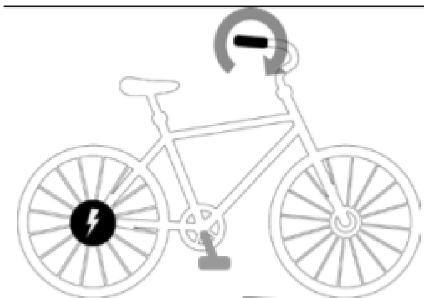
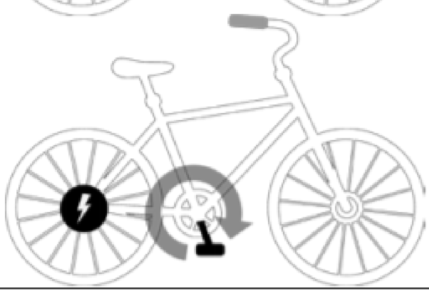
How was this literature review developed?

The NPS developed this literature review with support from the U.S. Department of Transportation John A. Volpe National Transportation Systems Center and a coordination group composed of representatives from NPS Divisions, including Conservation and Outdoor Recreation, Park Facility Management, Park Planning and Special Studies, Regulations and Special Park Uses, and Natural Resources Stewardship and Science, as well as representatives from the Department of Interior Office of the Solicitor.

This literature review includes academic journal articles as well as reports published by research organizations, governments, and non-profit organizations. The Appendix contains a list of sources consulted in the development of this literature review, drawing on previous work performed by the NPS related to the e-bike final rule and ongoing e-bike research activities conducted by the Federal Highway Administration (FHWA). This literature review summarizes a representative selection of research, chosen considering the relevance of the research to e-bikes, public lands, and affected areas of interest. Where multiple studies generated similar findings, preference for inclusion was given to more recent research. The literature review notes where findings are derived from surveys and where results are perception-based and may be subject to self-selection bias.

What are e-bikes?

E-bikes, in the context of this literature review and what would be allowed on trails and administrative roads in the National Park System, are similar to traditional bicycles but have a small electric motor and battery in order to assist the propulsion of the rider. There are two broad types of e-bikes: pedal-assisted bicycles and throttle-assisted bicycles (Figure 1). A rider must pedal to engage the electric motor of a pedal-assisted bicycle, whereas a rider uses a handlebar-mounted throttle to engage the electric motor of a throttle-assisted bicycle. In either case, riders can propel the e-bike without any electric assistance (i.e., using only human power).

	E-bike type	Alternative terms [a]
	Powered bicycle (PB, E-PB)	**Throttle-assisted bicycle**; electrically propelled bicycle (EPB); electric bike power-on-demand (POD); on-demand bikes; motorized bicycle
	Power-assisted bicycle (PAB, E-PAB)	**Pedal-assisted bicycle**; electrically assisted bicycle (EAB); pedal electric cycle (**pedelec**); electric pedal assist cycle (EPAC); human-powered hybrids

[a] Bold indicates more commonly used terms in North America.

Figure 1. Common e-bike types and terminology[5]

Which types of e-bikes are allowed, per the NPS regulations?

NPS regulations define e-bikes at 36 CFR 1.4 as:

> *a two- or three-wheeled cycle with fully operable pedals and an electric motor of not more than 750 watts that meets the requirements of one of the following three classes:*
>
> *(1) "Class 1 electric bicycle" shall mean an electric 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.*

[5] MacArthur, J., and Kobel, N. (2014) Regulations of E-Bikes in North America. Transportation Research and Education Center. https://pdxscholar.library.pdx.edu/trec_reports/126/

(2) "Class 2 electric bicycle" shall mean an electric 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.

(3) "Class 3 electric bicycle" shall mean an electric 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.

This definition is similar to the definition of "low-speed electric bicycle" in the Consumer Product Safety Act (15 U.S.C. 2085) and the definition of "electric bicycle" in the laws governing the Federal Aid Highway Program (23 U.S.C. 217(j)(2)), except that the NPS's definition:

- Does not identify a maximum e-bike weight;
- Includes e-bikes with motors *no more than* 750 watts; and
- Describes three classes (summarized in the table below) based upon the type of electric assistance and the top assisted speed.

Class	***Type of Electric Assistance***	***Top Assisted Speed***
Class 1 E-bike	Pedal	20 mph
Class 2 E-bike	Throttle	20 mph
Class 3 E-bike	Pedal	28 mph

E-bike characteristics based on classification

The three-class system, which was developed in 2015 by the Bicycle Product Suppliers Association (BPSA) and PeopleForBikes,[6] is used elsewhere in the Federal government and in a growing number of States.[7]

Another type of e-bike that is more frequently used on unpaved backcountry trails is an electric mountain bicycle (eMTB). eMTBs can be class 1, 2, or 3 e-bikes, but are typically pedal-assist. When used on NPS-managed lands, e-MTBs are subject to the same requirements that apply to other e-bikes under the NPS e-bike regulations.

It is important to note that there are other electric-assist micromobility devices on the market, such as e-scooters, that do not meet the NPS definition of an e-bike. These are not considered e-bikes in the context of this literature review.

[6] BPSA and People for Bikes would merge in 2019 with PeopleForBikes taking over management of all BPSA business-oriented projects: https://2019.peopleforbikes.org/merger/

[7] PeopleForBikes maintains information on which States have adopted the three-class system at https://www.peopleforbikes.org/topics/electric-bikes. State-specific information is available here.

3. Background Information and NPS Policy and Regulatory References

This section summarizes NPS and Department of the Interior (DOI) policies and regulations regarding e-bikes.

Alignment with the NPS Mission and Priorities

The NPS mission is to preserve unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations.

Similar to traditional bicycles, the NPS believes that, at the discretion of park superintendents, the use of e-bikes may be an appropriate activity in some park areas. E-bikes advance NPS goals for improving active transportation opportunities in national parks and their surrounding communities. E-bikes align with the health and wellness goals of the "Healthy Parks Healthy People" initiative that promotes the health of our parks and the people that visit them. E-bike also support the NPS's commitment to improve accessibility and sustainability.

DOI Secretarial Orders

The Secretary of the Interior issued Secretarial Order 3366 in April 2018 "to ensure [DOI] public lands and waters … are open and accessible for recreational pursuits." On August 29, 2019, the Secretary issued Secretarial Order 3376, which directed DOI bureaus to revise their regulations to define the term "electric bicycle" and to exempt e-bikes from the definition of motor vehicle to "increase recreational opportunities for all Americans, especially those with physical limitations, and to encourage the enjoyment of lands and waters managed by the Department of the Interior."

NPS E-Bike Regulation

NPS issued its final e-bike rule in December 2020. The rule:

- Defines e-bikes at 36 CFR 1.4.
- Excludes e-bikes from the definition of "motor vehicle."
- States that superintendents may allow e-bikes, or certain classes of e-bikes, on roads, parking areas, administrative roads, and trails that are open to traditional bicycles.
- Requires that if superintendents open locations to e-bikes, that they notify the public pursuant to 36 CFR 1.7.
- Clarifies that superintendents have the authority to limit or restrict e-bike use after taking into consideration public health and safety, natural and cultural resource protection, and other management activities and objectives.
- Applies certain regulations that govern the use of traditional bicycles to the use of e-bikes.
- Prohibits the possession of e-bikes in designated wilderness areas.
- Prohibits throttle-only use of e-bikes in non-motorized areas.

Additional public information on the NPS e-bike regulation is available at https://www.nps.gov/subjects/biking/e-bikes.htm. Information on e-bikes for NPS employees, including the official NPS e-bike symbol for use in parks, can be found on https://doimspp.sharepoint.com/sites/nps-outdoor-recreation/SitePages/Electric-Bicycles.aspx.

NPS E-Bike Memorandum to Superintendents

On June 30, 2021, NPS issued a Memorandum entitled, "*Reviewing Electric Bicycle Use on Trails and Administrative Roads under the E-Bike Regulation*." The purpose of this memorandum is to:

1) Reiterate that Policy Memorandum 19-01 (originally issued August 30, 2019) has been superseded and replaced by the final rule and has been officially rescinded and withdrawn.
2) Remind superintendents that they have the discretion to allow e-bikes or not.
3) Direct superintendents of park units that allowed e-bikes on trails or administrative roads under Policy Memorandum 19-01 to reconsider that decision under the e-bike regulation.

This literature review is produced in accordance with the June 30 memorandum.

4. Summary and Key Findings of Existing Research on E-bikes

This section summarizes available literature and articulates key findings on the potential beneficial and adverse effects of e-bikes organized according to the following common themes: health and wellness, accessibility, equity, environment and natural resources, safety, and user conflict.

Health and Wellness

E-bikes, like other forms of active transportation, can improve individual and community health. This theme of the literature review considers the effects of e-bikes on both physical and mental health and well-being.

Bourne, J., Sauchelli, S., Perry, R., Page, A., Leary, S., England, & C., Cooper, A. (2018). Health benefits of electrically-assisted cycling: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity.* https://ijbnpa.biomedcentral.com/articles/10.1186/s12966-018-0751-8

E-bikes have been highlighted as a method of active travel that could overcome some of the commonly reported barriers to cycle commuting. This literature review identified seventeen studies (11 acute experiments, 6 longitudinal interventions) involving a total of 300 participants. There was moderate evidence that e-cycling provided physical activity of at least moderate intensity, which was lower than the intensity elicited during traditional bicycling, but higher than that during walking. There was also moderate evidence that e-cycling can improve cardiorespiratory fitness in physically inactive individuals. Evidence of the effect of e-cycling on metabolic and psychological health outcomes was inconclusive. Longitudinal evidence was compromised by weak study design and quality.

Castro, A, et al. (2019). Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities. *Transportation Research Interdisciplinary Perspectives.* https://www.sciencedirect.com/science/article/pii/S259019821930017X

This study compared physical activity levels of e-bikers and traditional bicycle users (cyclists) and analyzed differences across e-bike user groups based on the transport mode substituted by e-bike. Physical activity, transport, and user related parameters were analyzed. Data from the longitudinal on-line survey of the Physical Activity through Sustainable Transport Approaches (PASTA) project were used. The survey recruited over 10,000 participants in seven European cities. Physical activity levels were measured in Metabolic Equivalent Task minutes per week (MET min/wk). Physical activity gains from active travel are similar in e-bikers and traditional cyclists. E-bikers reported significantly longer trip distances, commute distances, and total daily travel distances, however the MET min/wk was offset by the power assist feature of the e-bike. The physical activity of e-bikers who switched from traditional bicycling decreased, while those switching from private motorized vehicle and public transport increased.

Hall, C., Ho, T., Julian, C., Whight, G., Chaney, R., 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 Form Res.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6711045/

The study aimed to compare traditional mountain bike and eMTB by investigating two questions: (1) What proportion of exercise response is retained for an experienced mountain biker while using an eMTB when compared with a traditional mountain bike? and (2) What are the perceptions and beliefs of experienced mountain bikers toward eMTBs both before and after riding an eMTB? In this study, participants rode a 6-mile study loop twice, once using a traditional mountain bike, and once using an eMTB. The study loop included approximately 700 feet of elevation gain spread throughout the ride with the most intense climbing section averaging a 5% incline over a distance of 1 mile. Upon completing the study loop on their initially assigned bike, participants' heart rate and Strava data were saved. Participants also completed both a pre- and post-ride questionnaire. The average heart rate during eMTB use was 94% of the average heart rate during traditional mountain bike use. Therefore, eMTB use in this study achieved a majority of the exercise response and exceeded established biometric thresholds for cardiovascular fitness. Participants overwhelmingly perceived the potential effect of eMTB use to be positive on both pre- and post-eMTB ride questionnaires. Despite the measured benefit, participants' perceived exertion while riding the eMTB was low.

Fishman, E. & Cherry, C. (2015). E-bikes in the Mainstream: Reviewing a Decade of Research. Transport Reviews. *Transport Reviews.* https://www.researchgate.net/publication/280572410_E-bikes_in_the_Mainstream_Reviewing_a_Decade_of_Research

The focus of this study was on transport rather than recreational e-bike use. The study found that one of the primary reasons that people purchased an e-bike was to replace vehicle trips (11% in North America, 60% in Australia, 25% in Kunming, China) as well as public transportation trips in cities with high-quality transit systems. The study also noted that e-bike users achieve the necessary physical activity to help reduce the chance of sedentary lifestyle diseases. High powered e-bikes (undefined but similar to Class 3) had similar physical activity to walking uphill and standard powered e-biked (undefined but similar to Class 1) achieved higher physical activity than walking uphill. The study compared biking 5.1 km uphill versus walking 1.7 km uphill.

MacArthur, J., Dill, J., & Person, M. (2014). **Electric Bikes in North America: Results of an Online Survey.** ***Oregon Transportation Research and Education Consortium*** ***https://journals.sagepub.com/doi/pdf/10.3141/2468-14***
This study included a survey to understand whether e-bikes could reduce barriers to bicycling such as trip distance, topography, time, and rider effort. The survey included responses from 553 existing e-bike users across North America. Results suggest that e-bikes enable users to bike more often, to travel longer distances, and to carry more cargo with them. Additionally, e-bikes allow people who otherwise would not be able to bike (because of physical limitations or proximity to locations) the ability to bike with electric assist.

Leyland L., Spencer, B., Beale, N., Jones, T., & van Reekum, C. (2019). **The effect of cycling on cognitive function and well-being in older adults. PLOS ONE.** **https://doi.org/10.1371/journal.pone.0211779**
This study investigated the effect of outdoor cycling, with e-bikes and traditional bicycles, on cognitive function, mental health, and well-being in older adults. Participants were put in 3 groups, non-cycling controls, traditional bicycles, and e-bikes, and their cognitive function and well-being were measured following cycling at least three times a week for 30 minutes in duration for each cycle ride. Results found that both cycling groups improved cognitive and executive function, and an improvement in mental health, with potentially larger effect for e-bike users compared to traditional cyclists.

Health and Wellness Key Findings

The health and wellness benefits of riding a bicycle have been well-documented, including improving a person's physical and mental health and cognitive function. Existing literature generally shows that riding an e-bike has similar positive results for a rider's overall health and wellness as a traditional bicycle. Although riding an e-bike requires less physical exertion than a traditional bicycle, it still provides enough exercise to stimulate the heart, lungs, and circulatory system to provide health benefits and reduce the chance of sedentary lifestyle diseases.

Furthermore, e-bikes provide mobility to those with physical limitations that may otherwise prevent them from bicycling. This is discussed further under the Accessibility theme, but the health and wellness benefits associated with this are also well-documented particularly for those who have difficulty performing the level of exertion required to ride a traditional bicycle. E-bikes may allow persons to access areas they otherwise may be unable to reach, provide ease in use, and improve the overall experience for enjoying the activity and surrounding landscape. Additionally, research has found e-bikes have a positive effect on cognitive ability and mental health, notably among older users.

A study specific to eMTBs showed that eMTB users achieved 94% of the average heart rate of traditional mountain bike users on a 6-mile study track. Combined with the fact that eMTBs provide a lower barrier to entry, geared towards older people or people with physical limitations, eMTB use could enhance the physical activity of many people that would otherwise not consider traveling to NPS lands to enjoy a bike ride.

Health and Wellness Areas for Further Research

Most of the research on the health benefits of riding an e-bike is based on short durations of usage. Longer term observational studies may further inform understanding of the health effects of riding an e-bike, in comparison to other methods of exercise and micromobility modes. Furthermore, additional research could explore the health effects on specific demographics, in particular for older riders who tend to use e-bikes more than other age groups. Additional research could also focus on the health impacts related to mode shift due to the easier mobility of e-bikes.

Accessibility

E-bikes provide a new option for people who want to ride a bicycle but might not otherwise because of physical fitness, age, disability, recent injury, or convenience, especially at high altitude or on challenging terrain. Research on e-bikes and accessibility has primarily relied on surveys of e-bike users, including those with limited physical ability, to identify their reasons for using e-bikes, the types of trips they make using e-bikes, safety perceptions, and design considerations related to accessibility (i.e., adaptive e-bikes). Many users indicated that they use e-bikes to enable them to go farther, negotiate hills with less effort, experience overall reduced physical strain, and allow them to keep up with friends and family who cycle faster. Additional research indicated that people with physical limitations often use e-bikes for exercise and recreation, rather than commuting or other utilitarian purposes. This theme of the literature review addresses how e-bikes can give users access to cycling who would otherwise be unable to ride traditional bicycles due to physical limitations. This theme also summarizes studies on the types of trips users make using e-bikes.

Leger, S. J., Dean, J., Edge, S., and Casello, J. (2019). If I had a regular bicycle, I wouldn't be out riding anymore. *Transportation Research Part A, 123,* 240-254.
https://doi.org/10.1016/j.tra.2018.10.009

This study explores the potential for e-bikes to support independent mobility among the older population in Canada that are otherwise auto-dependent. Researchers gathered perceptual and experiential data to gauge e-bike adoption among community stakeholders and older adults in the Region of Waterloo, Ontario. Findings highlighted the importance of cycling life histories, social connection, and physical limitations to adopting cycling later in life. Contributing factors to e-bike adoption include increased convenience, reduced physical exertion, fun, and reduced reliance on a vehicle, and barriers include cycling infrastructure and road safety, regulation, and stigmatization.

Gordon, E., Shao, Z., Xing, Y., Wang, Y. (2012). Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area. *TRB 2013 Annual Meeting, 1(2),* 37-44.
http://dx.doi.org/10.1016/j.tbs.2013.10.006

Researchers interviewed 27 e-bike users in the Davis/Sacramento, California area. The study found three significant benefits of e-bikes relative to traditional bicycles: functionality (speed, acceleration, ability to carry cargo), adherence to green values, and enabling bicycle transportation to be feasible for more people and more trips. E-bikes provide an option for green transportation for people who can't participate in traditional bicycling, enabling people with certain disabilities, illness, and/or symptoms of aging to continue to bike. Interviewees included older individuals and those with physical disabilities. In a recreational context, some interviewees described using the e-bike as an “equalizer” allowing them to keep up with a spouse, friend or family member who is a faster cyclist. E-bike weight was identified as a barrier for older people.

MacArthur, J., McNeil, N., Cummings, A., & Broach, J. (2020). Adaptive Bike Share: Expanding Bike Share to People with Disabilities and Older Adults. *Transportation Research Record: Journal of the Transportation Research Board, 2674(8)*, 556-565. *https://doi.org/10.1177%2F0361198120925079*
This paper explores the market for offering e-bikes for adaptive cycling opportunities for older people or people with other physical limitations. Their research found there is an underserved market of those who feel they cannot use bike share programs due to a physical limitation. There are several challenges with implementing an effective adaptive e-bike share program (fitting into dock systems, higher maintenance costs, sufficient bikes to spread through the system to meet user needs). To address these challenges, the researchers propose a rental model for adaptive bikes to provide more personalized service for users. Additionally, the paper highlights what is unknown about users, systems, barriers, and opportunities and identifies areas for further research to create more equitable and accessible transportation options.

Gerow, Brian. (2020). E-bikes are Important Forest Accessibility Tools. *Singletracks.* *https://www.singletracks.com/mtb-columns/e-bikes-are-important-forest-accessibility-tools/*
This opinion article provides a brief anecdote on how e-bikes increase accessibility for people with physical disabilities or limitations, age, current fitness level. The article was published by Singletracks, a mountain biking media outlet geared towards educating the mountain biking community. The article focuses on the author’s experience with e-bikes making mountain biking more accessible to users who would otherwise be unable to without an e-bike. The author also noted that e-bikes bring more people to trails, which means more trail funding and other benefits to the sport. This article provides an important personal experience with e-bike use for recreation rather than transportation.

MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. *Portland State University Transportation Research and Education Center.* *https://trec.pdx.edu/research/project/1041*
Researchers sought to understand why people are motivated to purchase an e-bike and found that it is most often related to barriers that would prevent individuals from riding a traditional bicycle. These include reducing physical exertion, challenging topography, and replacing car trips. Additional analysis concluded e-bikes are making is possible for more people to ride a bicycle, and are generating more trips, longer trips, and different types of bicycle trips.

Accessibility Key Findings
Research has found that approximately one quarter of e-bike owners indicated they have a physical limitation (e.g., mobility, dexterity, or sensory impairments or health issues like respiratory, heart, or weight problems) that made riding a traditional bicycle difficult. Many indicated that they use e-bikes to enable them to go farther, negotiate hills with less effort, experience overall reduced physical strain, and allow them to keep up with friends and family who cycle faster. Some e-bike

users with disabilities have identified how e-bikes have enabled them to participate more fully in work/school life.

For people with physical limitations, e-bikes are more often used for exercise and recreation, rather than commuting or other utilitarian purposes, and users are less likely to choose replacing car trips than adults without physical limitations. Similarly, another study determined that many older e-bike users began using the technology after an injury, replacing trips they would have made by traditional bicycle.

Accessibility Areas for Further Research
Adaptive cycling is an under-researched area in general. Much of the literature on e-bikes and accessibility relies on surveys of e-bike users instead of more empirical or observational methods. There are additional knowledge gaps regarding better integration of adaptive e-bikes into bikeshare fleets such as understanding the needs of users with disabilities and how to design, finance, and operate such programs viably.

Equity

There is a growing interest in understanding how the various benefits and burdens from e-bike ridership are distributed across the population. E-bikes present an opportunity to expand access for underserved groups and the rise of shared e-bikes may lower barriers for access for lower income populations. However, their high upfront cost and limited availability in low-income neighborhoods often serve as barriers reducing access to e-bikes for traditionally underserved populations. Existing research in this area is limited but tends to focus on discrepancies in gender and lack of affordability and access.

The growth of shared e-bikes has presented opportunities and barriers for e-bike access to underserved populations, as they can experiment with e-bikes without committing to the high upfront cost, but often require users to unlock an e-bike with a smartphone or credit card and e-bike locations are often skewed towards business districts and tourist hotspots. This theme of the literature review presents studies that explore the distribution of e-bike ridership across the population, barriers to adoption, and the equity opportunities and barriers with shared e-bikes.

Alamelu, R., Anushan, C. S., & Selvabaskar, S. G. (2015). Preference of E-Bike by Women in India – A Niche Market for Auto Manufacturers. *Business: Theory & Practice, 16(1),* 25-30. *https://doi.org/10.3846/btp.2015.431*
This paper determines the factors that influence the decision to purchase an e-bike, identifies the awareness level of survey respondents towards e-bikes, and analyzes the level of satisfaction towards the use of e-bikes on roads in Madurai City in order to examine the viability of e-bikes to fill a transportation gap for women in India. The findings from the study indicate that Indian women are generally supportive of e-bikes but would like to see models with additional carrying capacity, recharging stations around the city, and government subsidies to make e-bikes more affordable.

Dill, J., Rose, G. (2012). E-Bikes and Transportation Policy: Insights from Early Adopters. *TRB, 2314(1),* 1-6. *https://doi.org/10.3141%2F2314-01*

This report presents findings from interviews with e-bike users in Portland, OR revealing potential demographic markets for e-bikes that could increase usership: women, older adults, and people with physical limitations. Interviewees noted the ability to travel longer distances, ease with hills, and arrive at destinations less sweaty or tired than a traditional bicycle. The report also revealed that the high upfront cost and additional recurring costs of an e-bike are significant barrier to greater e-bike ownership and ridership. Although potential conflict between e-bike and traditional bicycle owners is not a unique barrier for underserved populations, the threat of targeted harassment from traditional bicyclists combined with barriers of access and affordability may deter e-bike ridership among these groups.

Clelow, R. (2018). DC is growing is dockless bike and scooter program: We partnered with them to evaluate how it's expanding access in underserved communities. Populus. *https://medium.com/populus-ai/measuring-equity-dockless-27c40af259f8*

The article provides a review of dockless e-bikes and e-scooters in Washington, DC. The findings demonstrated that Black residents adopted dockless services at a significantly higher ratio to docked services when compared to white residents. These results demonstrate that dockless e-bikes and e-scooters may help to improve mobility for underserved populations; however, there is a need to ensure that unbanked individuals and those without a smartphone have access.

Stowell, H. (2020). Making Micromobility Equitable for All. Institute of Transportation Engineers. *https://www.nxtbook.com/ygsreprints/ITE/ITE_February2020/index.php?startid=46#/p/46*

This article summarizes different methods that micromobility operators and different jurisdictions use to promote equity. The article highlights the experiences of Washington, DC and Santa Monica, CA that have compelled operators to locate devices in underserved areas and offer alternative means of access for unbanked individuals and those without a smartphone.

Yanocha, D., Allan, M. (2019). The Electric Assist: Leveraging E-bikes and E-Scooters for more Livable Cities. *Institute for Transportation and Development Policy. https://www.itdp.org/wp-content/uploads/2019/12/ITDP_The-Electric-Assist_-Leveraging-E-bikes-and-E-scooters-for-More-Livable-Cities.pdf*

This paper compared the affordability and distribution of e-bike adoption in Brazil and Mexico (pre-emerging markets), the US (emerging market), China (long-term developed market), and the Netherlands (short-term developed market), and found extreme disparity in e-bike cost as percent of annual income among those markets with e-bike costs accounting for a higher percentage in less developed markets; however, the e-bike cost in each market was significantly lower than the cost of a car as a percent of annual income. Additionally, the paper noted that in theory, shared dockless e-bike and e-scooter systems are more widely available in areas of high economic hardship compared to station-based systems which would result in a more equitable distribution of e-bikes and e-scooters. In practice, however, differing use patterns of dockless e-bikes and e-scooters by socioeconomic group result in inequitable spatial access of e-bikes and e-scooters. As a result, many cities are requiring e-bike providers to deploy a certain percentage of e-bikes and e-scooters in designated underserved areas to address these equity issues. The gender discrepancy between e-bike users is proportionally lower than that of traditional bicycle users in the United States; however women remain underrepresented among e-bike users.

Uteng, T. P., Uteng, A., & Kittilsen, O. J. (2019). **Land use development potential and E-bike analysis*****. Norwegian Centre for Transport Research Institute of Transport Economics.*** ***https://www.toi.no/getfile.php?mmfileid=50260***
This white paper compared job accessibility by traditional bicycle and e-bike, and examined the relationship with land use plans of the four biggest cities in Norway. E-bikes were found to extend the accessibility for jobs, typically located in a city center, to a larger share of a surrounding area. Moreover, land use is closely tied to transportation demand and land use plans should incorporate the effects of e-bike usage. This paper could also help inform future land use planning considering multimodal transport that includes e-bikes. This paper is highly specific to Norway, so results may not hold true for other locations with different travel mode shares, social factors, and geographies. In the same way that e-bikes (relative to traditional bicycles) can improve access to jobs, they may be able to improve peoples' ability to access destinations, including sites in the National Park System.

Equity Key Findings
The high upfront cost and additional recurring costs (i.e., charging, battery replacement) of e-bikes are a significant barrier to greater e-bike ownership and ridership among lower income households.

E-bikes may help to reduce barriers to ridership for many groups including traditionally underserved populations. Older adults, women, and people who may not consider themselves physically able to ride a bicycle may look to e-bikes for commuting or personal trips. There is a lack of research examining e-bike ridership among racial groups; however, studies noted that users have at times felt apologetic or self-conscious due to being viewed as "cheating" for riding an e-bike. These sentiments are not unique to certain racial groups, but the threat of targeted harassment combined with barriers of access and affordability may deter e-bike ridership among traditionally underserved groups.

The growth of shared e-bikes has, in some ways, helped to increase access to e-bikes for traditionally underserved populations by allowing users to experiment with these modes without committing to their high upfront costs, but requires users to unlock e-bikes with a smartphone or credit card, which presents a barrier to low-income and unbanked individuals. A review of dockless e-bikes and e-scooters in Washington, DC, found that Black residents adopted dockless services at a significantly higher rate than docked services when compared to white residents. Additionally, the geographical distribution of shared e-bikes may be skewed toward central business districts and tourist hotspots, which limits access for traditionally underserved groups. Many cities have compelled bike share operators to station devices in underserved areas and offer alternative means of access for unbanked individuals or those without a smartphone.

Equity Areas for Further Research
Future research could investigate ridership by racial groups to better determine why ridership is often lower among certain underserved groups. Existing research suggests that there may be

stigmas or fears of harassment that decrease ridership among certain groups; future studies may help to identify strategies to guide policy and decision making in a manner that will support greater e-bike ridership among traditionally underserved groups. Lastly, further research could analyze the effectiveness of policies that encourage greater e-bike ridership among traditionally underserved groups.

Environment and Natural Resources

Like traditional bicycles, e-bikes can decrease traffic congestion, reduce the demand for parking spaces, and increase the number and visibility of bicyclists on the road. Researchers have analyzed both the emissions, energy, and broader environmental effects associated with e-bike use as well as longer term life cycle effects such as production, maintenance, and disposal of e-bikes. This theme of the literature review addresses how e-bikes, compared to internal combustion engine (ICE) vehicles, "consume less energy, emit less carbon dioxide (CO_2), and decrease exposure to pollution."[8]

Like other recreational uses of trails, e-bikes have the potential to affect natural resources and trail surfaces in a manner similar to traditional bicycles. Natural surface trail erosion from bike tires, noise from the mechanical operation of the bike, or other effects to flora and fauna from the presence of a bike may exist. This theme summarizes studies about the potential effects of e-bikes on energy, emissions, and climate; trail surfaces; and wildlife and vegetation. It also highlights several studies about related recreational activities and their effects on the environment and natural resources.

Energy, Emissions, and Climate

MacArthur, J., McQueen, M., & Cherry, C. (2019). The E-Bike Potential: Addressing Our Climate Crisis by Incentivizing Active Transportation. *Transportation Research and Education Center.* https://trec.pdx.edu/news/e-bike-potential-addressing-our-climate-crisis-incentivizing-active-transportation

This white paper explores the potential effects from e-bikes on person miles traveled (PMT) and greenhouse gas (GHG) emissions using a model for PMT shift and GHG reduction potential created for Portland, Oregon. The findings from the report suggest that a 15%-point increase in e-bike mode share would result in an approximately 10%-point decrease in PMT by car. Additionally, the research found that a 15%-point increase in e-bike mode share results in an 11% decrease in carbon dioxide emissions. The research shows that increasing the e-bike mode share is a beneficial way to meet carbon emission reduction goals and reduce driving; however, substantial political will is needed to promote a level of e-bike ridership necessary to realize the potential for e-bikes to reduce GHG emissions.

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[8] Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. (2015). On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D, 41, 348-366. https://pubmed.ncbi.nlm.nih.gov/32288595/

Abagnale, C., Cardone, M., Iodice, P., Strano, S., Terzo, M., & Vorraro, G. (2015). A Dynamic Model for the Performance and Environmental Analysis of an Innovative e-bike. *Energy Procedia, 81,* 618–627. https://doi.org/10.1016/j.egypro.2015.12.046
Researchers conducted tests identifying the "well-to-wheel" emissions reductions that could be achieved by replacing trips made by a moped with a four-stroke engine with an e-bike. "Well-to-wheel" analysis considers energy and emissions associated with the use phase of the lifecycle (and not production and end-of-life considerations). The study measured reductions in the amount of measured carbon dioxide, nitrous oxide, and hydrocarbons. These results suggest that increased e-bike use may provide a net reduction in well-to-wheel emissions if it substitutes for other travel modes.

Machedon-Pisu, M., & Borza, P. N. (2020). Are Personal Electric Vehicles Sustainable? A Hybrid E-Bike Case Study. *Sustainability, 12(1)*. https://doi.org/10.3390/su12010032
The results of this study found that e-bikes consume less energy and produce dramatically less pollution during their lifespans than traditional vehicles. Researchers built their own e-bike and compared e-bikes to 1) cars, trains, trams, trucks, and buses; 2) medium and heavy duty EVs; 3) motorcycles, big scooters, and mopeds; and 4) motorbikes and small scooters with respect to air pollution and energy consumption. The study accounted for emissions and energy use during production, use, disposal, and refueling/charging of each vehicle.

Woodcock, J., Abbas, A., Ullrich, A., Tainio, M., Lovelace, R., Sá, T. H., Westgate, K., & Goodman, A. (2018). Development of the Impacts of Cycling Tool (ICT): A modelling study and web tool for evaluating health and environmental impacts of cycling uptake. *PLOS Medicine, 15(7).* https://doi.org/10.1371/journal.pmed.1002622
This study modelled how CO_2 emissions would change in England if increasing proportions of the population had the same distance-based propensity to cycle as existing cyclists. If the proportion of the English population who cycled regularly increased from 4.8% to 25%, the model predicted a 2.2% reduction in car miles. If the new cyclists had e-bikes, the reduction in vehicle miles travelled would be 2.7%. These results suggest that the adoption of e-bikes can help reduce vehicle miles travelled and thus reduce overall vehicle emissions.

Li, T. Z., Qian, F., & Su, C. (2014). Energy Consumption and Emission of Pollutants from Electric Bicycles. *Applied Mechanics and Materials,* 327–333. https://doi.org/10.4028/www.scientific.net/AMM.505-506.327
This study analyzed the energy consumption and pollution emissions at different stages of the e-bike life cycle (production, use, maintenance, and recycling). Results revealed that most energy consumption by e-bikes occurs during the use stage. The emissions of pollutants by e-bikes per person per kilometer are several times lower than emissions from motorcycles and cars, equivalent to buses, and higher than traditional bicycles. These results suggest that shifts from personal vehicles can help reduce overall emissions and pollutants.

McCarren, T., & Carpenter, N. (2018). Electric bikes: Survey and energy efficiency analysis. *Efficiency Vermont.* https://www.efficiencyvermont.com/Media/Default/docs/white-papers/efficiency-vermont-electric-bike-white-paper.pdf
This survey asked 90 e-bike owners from Vermont questions about their e-bike use and general travel behaviors. Results revealed that the average respondent displaced 760 miles of driving annually with an e-bike. This suggests that increased e-bike adoption can significantly reduce overall emissions by enabling users to switch from personal vehicles.

Ji, S., Cherry, C. R., Bechle, M. J., Wu, Y., & Marshall, J. D. (2011). Electric Vehicles in China: Emissions and Health Impacts. *Environmental Science and Technology, 46(4),* 2018–2024. https://doi.org/10.1021/es202347q
Researchers compared emissions and environmental health effects of e-bikes to electric vehicles, gasoline cars, diesel cars, and diesel buses across 34 major Chinese cities. CO_2 emissions were an order of magnitude higher for all vehicles compared to e-bikes. Other emissions, such as particulate matter, nitrous oxide, and hydrocarbons were also substantially lower for e-bikes than traditional vehicles. The results emphasize the ability of e-bike adoption to dramatically reduce overall emissions and health effects from the transportation system.

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. https://doi.org/10.1016/j.trd.2015.09.007
Researchers reviewed e-bike (with a maximum assisted speed of 25km/hr), electric moped, and electric motorcycle performance on several factors including energy and emissions. The study found that e-bike adoption can reduce human exposure to polluting emissions compared to internal combustion engine vehicles. It also found that e-bikes resulted in 50-90% energy savings compared to gas-burning mopeds and motorcycles.

Trail Surfaces

International Mountain Bicycling Association. (2015). 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. https://www.americantrails.org/images/documents/A-Comparison-of-Environmental-Impacts-from-Mountain-Bicycles-Class-1-Electric-Mountain-Bicycles-and-Motorcycles.pdf
This study, completed by a mountain biking advocacy organization, is currently the only source identified which specifically measured the effect of e-bikes on natural surface trails. Soil erosion from Class 1 e-mountain bikes was not significantly different from erosion caused by traditional mountain bikes. Researchers conducted soil erosion tests on a test trail, controlling for several factors including soil type, soil moisture, level of use, trail grade, wheel size, rider weight, tire pressure, and tire make/model. Given the controlled environment of the test trail, these results may not be consistent across all trail types and conditions; further study could help generalize these findings.

Nielson, T., Palmatier, S. M., & Proffitt, A. (2019). Literature Review: Recreation Conflicts Focused on Emerging E-Bike Technology. https://assets.bouldercounty.org/wp-content/uploads/2020/01/e-bike-literature-review.pdf

The goal of this literature review was to inform policy discussions and decisions for the quickly growing e-bike market in four of Colorado's northern Front Range open space programs. Boulder County, Colorado's literature review identified no significant difference in effects to wildlife or trail surfaces between traditional bicycles and e-bikes. The review stated, "Given that e-bikes are very similar to traditional bicycles in terms of noise, trail effect, and speed, it is fair to say that their effect on wildlife habitats would be similar to other non-motorized bicycles" based on a study of recreational disturbance of deer and elk. The literature review also found that trail users were likely to have concerns about noise and trail degradation caused by e-bikes. However, since the literature review authors found few impacts from e-bikes, the review observed that "public perception surrounding e-bikes' [noise, trail surface, and speed] effect[s] may be at odds with observed effects."

Chavez, D., Winter, P., & Bass, J. (1993). Recreational Mountain Biking: A management perspective. *Journal of Park and Recreation Administration, 11(3), 8.* https://www.americantrails.org/images/documents/psw_1993_chavez001.pdf

This study analyzed responses from a telephone survey of recreation land managers across the United States regarding perceptions of mountain biking and effect on trail surfaces. While many respondents reported moderate to extensive mountain bike use in their resource areas, most did not have designated mountain bike areas. About one-third reported resource degradation attributable to mountain bike use. Few reported having management plans specifically related to mountain biking. This study did not address e-bikes specifically; however, it revealed a need for greater awareness and planning by land managers for emerging modes of recreation.

International Mountain Bicycling Association. (2016). Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results. https://www.americantrails.org/images/documents/TrailUseEMTBs.pdf

This study conducted a survey of land managers across the United States. Results revealed that very few land managers had any direct experience with e-mountain bikes (eMTB). 89% of surveyed land managers expressed some level of concern about the environmental effect of eMTBs. 91% of respondents reported that environmental effect and social effect studies of eMTBs would help inform their trail management practices. The responses to this survey reveal a widespread interest among land managers in learning more about the effects of eMTBs.

Newsome, D., & Davies, C. (2009). A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, Western Australia. *Journal of Ecotourism, 8(3),* 237–253. https://doi.org/10.1080/14724040802538308

Researchers developed a rapid assessment tool which used GPS and GIS technology to quantify the total amount of land effected by mountain bike use at a recreational park in Australia. The study did not measure specific environmental effects, but the tool effectively quantified the area effected by the creation of mountain bike-specific informal trails and trail modifications The study also did not involve e-bikes, but mapping tools like the kind developed in this study may be useful in assessing short- to long-term effects of e-bikes and e-mountain bikes outside designated natural surface or paved trails.

Wildlife and Vegetation

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(12).* https://doi.org/10.1371/journal.pone.0167259

This literature review identified 274 articles on the effects of both motorized and non-motorized non-consumptive recreation to animals. 93% of reviewed articles documented at least one effect of recreation on animals. 59% of these effects were classified as negative. The study identified that, although motorized and non-motorized activities had similar evidence for overall effects on wildlife, non-motorized had greater negative effects, counter to what may be expected. The study finds that, although motorized activities may be expected to be more harmful to animals because of vehicle speed and noise, this is not the case. The researchers acknowledge that motorized activities likely occur on larger spatial scales, and that the studies reviewed did not compare effects across spatial scales. The review did not include any studies specifically referring to e-bikes.

Thurston, E., & Reader, R. J. (2001). Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest. *Environmental Management, 27(3),* 397–409. https://doi.org/10.1007/s002670010157

This experiment compared the effects of mountain biking (though not e-bikes specifically) and hiking on understory vegetation and soil in an off-trail area of a deciduous forest. Researchers controlled for the intensity of activity. The immediate effects of both activities were severe, but quick recovery could be expected when the activities are disallowed. Results revealed that at similar intensities of activity, the short-term effects of mountain biking and hiking may not differ greatly in undisturbed (i.e., off-trail) areas of deciduous forests. It is not clear if these results hold true in other environments or with more intense activity over time.

Marion, J., & Wimpey, J. (2017). Environmental Impacts of Mountain Biking: Science Review and Best Practices. https://www.anacorteswa.gov/DocumentCenter/View/16528/EIS-mountain-bikes-and-Best-Practices

This literature review examined effects to vegetation, soil, water, and wildlife as a result of mountain bike use. Fifteen mountain bike-specific studies were found. The review found no significant difference in plant density change or soil loss between hiking and mountain biking. The review also found that effects to wildlife were similar between hikers, mountain bikers, and other non-motorized trail users. This study did not look at e-bikes, but it identified several trail management implications that could be applicable to eMTBs.

Wisdom, M., Ager, A., Preisler, H., Cimon, N., & Johnson, B. (2004). Effects of Off-road Recreation on Mule Deer and Elk. *North American Wildlife and Natural Resources Conference.* https://www.fs.fed.us/pnw/pubs/journals/pnw_2004_wisdom001.pdf

Researchers measured the effects of ATV riding, hiking, traditional mountain biking, and horseback riding on elk and deer movement in a controlled study forest in Oregon. Researchers did not specifically test e-bikes. All off-road activities resulted in substantial elk movement compared to a control period. Movement rates were much lower for deer, suggesting different behavioral responses by species to off-road non-consumptive recreation. Mountain bikes produced more disturbance than hiking and horseback riding and less disturbance than ATV riding. However, the effect of mountain biking was more similar to hiking and horseback riding, while animal movement rates for ATV riding were dramatically higher than all other activities.

Naylor, L. M., J. Wisdom, M., & G. Anthony, R. (2009). Behavioral Responses of North American Elk to Recreational Activity. *Journal of Wildlife Management 73(3)*, 328–338. https://doi.org/10.2193/2008-102
This study measured the movement of elk in response to ATV riding, hiking, traditional mountain biking, and horseback riding. The effects of ATV riding were higher than other activities. The effects of mountain biking were higher, on average, than the effects of hiking and horseback riding. The study did not specifically measure e-bikes, though it includes discussion of implications for the management of recreational activity.

Wisdom, M., Preisler, H., Naylor, L., Anthony, R., Johnson, B., & Rowland, M. (2018). Elk responses to trail-based recreation on public forests. *Forest Ecology and Management, 411,* 223–233. https://doi.org/10.1016/j.foreco.2018.01.032
Researchers measured the movement of elk in response to ATV riding, hiking, traditional mountain biking, and horseback riding. The study did not specifically measure e-bikes. ATV riding was found to have the most disturbance on wildlife, followed by mountain biking, horseback riding, and hiking. During some times of day, the disturbance caused by mountain biking was closer to the disturbance caused by ATV riding. At other times, the effects of mountain biking were closer to those observed for hiking and horseback riding. The study discusses management implications for land managers and suggests a need for more research documenting the wildlife effects of outdoor recreation.

Dawson, A. (2019). E-Bike Battery Explodes, Burning 79-Year-Old Cyclist and Causing Bushfire. Bicycling. https://www.bicycling.com/news/a25890860/electric-bike-explodes/
This anecdotal news article describes an incident of a lithium e-bike battery igniting while the cyclist was riding on a roadway and caused a fire in dry vegetation adjacent to the road. The battery had been added to a traditional bicycle through an after-market third party. These aftermarket devices, which can be used to modify traditional bikes may pose an additional fire risk.

U.S. Consumer Product Safety Commission. (2020). Safety Concerns Associated with Micromobility Products. https://cpsc.gov/s3fs-public/Report-on-Micromobility-Products_FINAL-to-Commission.pdf
A report commissioned by the Consumer Product Safety Commission warned that micromobility products, including e-bikes, may pose hazards. The report does not address wildfire risk but focuses on fire safety hazards and property damage due to battery failures and mechanical battery-mounting issues. However, the vast majority of reported safety concerns occurred before the development of voluntary electrical standards for e-bikes (e.g., UL 2272, "Electrical Systems for Personal E-Mobility Devices"). There were no concerns reported with devices that used the voluntary standard.

Energy, Emissions, and Climate Key Findings
The existing research supports the conclusion that e-bike adoption can play a role in decreasing non-renewable energy use. E-bikes produce more emissions and use more energy throughout their

lifespans than traditional bicycles. However, compared to motorized forms of outdoor recreation, such as ATVs and motorcycles, e-bikes produce fewer pollutants and greenhouse gas emissions. E-bikes also produce significantly fewer emissions and pollutants than gas-burning cars.

To the extent that e-bike trips replace motor vehicle trips, e-bikes can help support NPS active transportation and sustainability goals, while also improving air quality for greater natural resource protection and an improved visitor experience. The magnitude of the environmental benefit provided by e-bikes depends on the overall "mode shift" that occurs between motorized and non-motorized forms of transportation and recreation. Mode shift refers to substitution of one form of transportation for another. Two studies found that increased e-bike use resulted in decreased car use.

Energy, Emissions, and Climate Areas for Further Research

There is a lack of research analyzing e-bike emissions and pollution in outdoor recreational contexts. Most studies on this topic consider e-bikes in the transportation context. For instance, it is possible that emissions findings could be different for natural trail surfaces than for paved roadways.

The mode shift of e-bikes in an outdoor recreational context is also unknown. Researchers have not yet determined whether increased e-bike use displaces motorized recreation (such as ATVs) or substitutes for other non-motorized recreation (such as traditional bicycles) E-bike use may also create new recreational trips that would not have occurred otherwise.

Trail Surfaces Key Findings

The existing research on e-bikes provides an initial indication that e-bikes have natural trail surface effects not significantly different from traditional bicycles. One study found that e-bikes and traditional bicycles generally cause the same amount of degradation as hiking, and both activities cause less trail degradation than horseback riding or motorized activities.

A review of mountain biking effects on trail surfaces arrived at the following main conclusions: 1) Management best practices indicate that degradation can be minimized if trail users are restricted to formal trails (in contrast to visitor-created trails); and 2) Trail design and management contribute more significantly to trail surface degradation than the type or amount of use.

Trail Surfaces Areas for Further Research

Additional research could assess effects on specific types of trail surfaces by recreational activity, including a comparison between e-bikes and traditional bicycles. There is also a lack of research documenting the long-term effects, if any, of e-bikes on trail surfaces. Such research could aid managers with understanding appropriate management actions to mitigate adverse effects of outdoor recreation on trail surfaces.

Wildlife and Vegetation Key Findings

Research on outdoor recreation, on average, found that different types of non-motorized recreation (hiking, traditional mountain biking, and horseback riding) had similar levels of wildlife disturbance. ATV riding was found to be the most disruptive form of outdoor recreation for wildlife across all studies. Some studies found that traditional mountain biking had wildlife effects similar to ATVs depending on the time of day and the variables being measured.

There is a risk of fire from lithium batteries on e-bikes. Aftermarket additions used to retrofit traditional bikes into e-bikes may also present a fire risk. However, there have been no fire incidents reported with e-bike devices that adopted the voluntary electrical standard for micromobility devices (UL 2272).[9]

One literature review, finding no evidence that noise, speed, and trail effects were dissimilar between e-bikes and traditional bicycles, stated that the expected ecological effect of e-bikes would be similar to traditional bicycles.

Wildlife and Vegetation Areas for Further Research
There is not yet any research available which specifically measures e-bike effects to wildlife and vegetation, so the specific effects of e-bikes on the ecological system are still not well understood. There is a lack of research studying potential e-bike effects such as noise and plant trampling compared to traditional bicycling, mountain biking, or other forms of non-motorized outdoor recreation.

Safety

The NPS strives to protect public health and safety and provide for injury-free visits. In National Park System units, safety is critical to bicyclists, hikers, and other trail users. Safety considerations are particularly important on remote trails, where rescue and emergency response may be more difficult. It is acknowledged that determining the safety of e-bikes and the behavior of e-bike riders is an important factor in determining whether e-bikes should be managed differently than traditional bicycles. Initial research on the safety implications of e-bikes tended to originate from Europe or China. Despite the cultural and geographical differences of this international research, these studies can still inform a basic understanding of how riders behave while using e-bikes. E-bike ownership has steadily grown over the past decade, and with it, the availability of data, reports, and research studies related to safety. The primary method for measuring safety is through reported crash incidences and available crash data, which characterizes the frequency and severity of accidents. This theme of the literature review is organized around six sub-topics: perception of safety, speed, demographic differences, rider behavior, trip purpose, and e-bike classifications.

Perception of Safety

Johnson, M. (2015). Safety Implications of E-bikes. *Royal Automobile Club of Victoria.* https://research.monash.edu/en/publications/safety-implications-of-e-bikes

This study includes a literature review on perceptions of safety, a review of the current infrastructure design standards, and a survey of e-bike riders exploring their experiences and perceptions of safety. The survey found that hill climbing capability and spot speed are two potential e-bike performance capabilities that are different from traditional bikes in terms of how a rider interacts with on-road and off-road infrastructure. A spot speed is the speed at a specific location (e.g., at an uphill section) as opposed to average speed. There is no significant difference between e-bike and traditional bike riders in perceptions of comfort, including safety, or on a

[9] U.S. Consumer Product Safety Commission. Voluntary Standards: Batteries. https://www.cpsc.gov/Regulations-Laws--Standards/Voluntary-Standards/Topics/Batteries/

rider's perspective of cycling infrastructure. E-bike riders were found to be older riders with less riding experience, finding that "almost four in ten female e-bike riders had not been cyclists before purchasing or riding an e-bike." When compared to using a traditional bicycle, e-bike riders generally felt as safe on loose gravel surfaces, that they accelerate faster, that they could ride at higher speeds, and that it is not harder to stop.

Speed

Langford, B., Chen, J., Cherry, C., (2015). Risky riding: Naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders. *Accident Analysis & Prevention*, 82.
https://www.sciencedirect.com/science/article/pii/S0001457515001992?via%3Dihub

This is the first study to rely on naturalistic GPS data for bicycle and e-bike safety. A study was conducted using the pilot bikeshare implemented at the University of Tennessee that offered six traditional bicycles and 14 Class 1 e-bikes. Riders of e-bikes travel at higher speeds than traditional bicycles on roadways (about 2.9 kph). Riders of traditional bicycles travel at higher speeds than e-bikes on shared-use paths (about 1.6 kph). Speed on natural surface trails were not identified in the study.

Over the course of the pilot, the data showed that e-bike riders exhibit nearly identical safety behavior for wrong-way riding, stop sign compliance, and traffic signal compliance, as traditional bike riders. However, all cyclists had a poor compliance rate at stop signs (about 80% when traveling at 6 kph and about 40% when traveling at 11 kph) and at traffic signals (about 70%).

Petzoldt, T., Schleinitz, K., Jeilmann, S., Gehlert, T. (2016). Traffic conflicts and their contextual factors when riding conventional vs. electric bicycles. *Transportation Research Part F: Traffic Psychology and Behaviour.*
https://www.sciencedirect.com/science/article/abs/pii/S1369847816300924

This study examined if there are differences between traditional cyclists and e-bike riders with regard to the probability to be involved in a traffic conflict. The study investigated the circumstances under which conflicts occur to identify potential differences in risk. Researchers equipped the personal bicycles of 80 participants (31 traditional cyclists and 49 e-bike riders) with a data acquisition system that included two cameras and a speed sensor. Four weeks of "normal" cycling were recorded for each participant. The analysis showed no difference between bicycles and e-bikes with regard to their overall involvement in traffic conflicts. One notable exception were intersections, where the risk of being involved in a conflict was twice as high for e-bikes as for traditional bicycles. The speed immediately preceding a conflict was higher for riders of e-bikes compared to traditional bicycles, a pattern that was also found for mean speed.

Nielson, T., Palmatier, S., Proffitt, A., Marotti, M. (2019). Boulder County E-bike Pilot Study Results. https://assets.bouldercounty.org/wp-content/uploads/2019/09/e-bike-pilot-study.pdf

This report highlighted the results of two studies, an intercept survey and a speed observation study, conducted for the e-bike pilot program allowing Class 1 and Class 2 e-bikes on certain county open space trails in Boulder County, Colorado. The speed study included 12 identified e-bikes out of 503 total bike observations. People on traditional bikes traveled faster than e-bikes on downhill sections (15 mph vs 13.5 mph) and people on e-bikes traveled faster than traditional bikes on uphill sections (13.8 mph vs 12.9 mph).

Demographic Differences

Weber, T., Scaramuzza, G., Schmitt, K. (2014). Evaluation of e-bike accidents in Switzerland. *Accident Analysis & Prevention*, 73. https://www.sciencedirect.com/science/article/pii/S0001457514002231

The study analyzed police-recorded crashes during 2011 and 2012 involving a total of 504 e-bikers and 871 traditional bicyclists along urban and rural roadway and bicycle infrastructure (the study did not state if crashes along recreational, natural surface paths were included). Most e-bikers who sustained a crash were 40–65 years old and only a few crashes with e-bikers below 23 years of age were reported. E-bikers in the urban area sustained less single and crossing crashes and more turning and other crashes compared to e-bikers in the rural area.

Schepers, P., Fishman, E., den Hertog, P., Wolt, K., & Schwab, L. (2014). The safety of electrically assisted bicycles compared to classic bicycles. *Accident Analysis & Prevention*, 73. https://www.sciencedirect.com/science/article/pii/S0001457514002668

This case–control study compared the likelihood of crashes for which treatment at an emergency department is needed and injury consequences for e-bike and traditional bicycle crash incidents in the Netherlands among users 16 years and older. Data were gathered through a survey of victims treated at emergency departments. Additionally, a survey of cyclists without any known crash experience, drawn from a panel of the Dutch population acted as a control sample. The results suggest that, after controlling for age, gender, and amount of bicycle use, e-bike users are more likely to be involved in a crash that requires treatment at an emergency department due to a crash. When they occur, crashes with e-bikes are about equally as severe as crashes with traditional bicycles. The study did not state if crashes along recreational, natural surface paths were included.

Ma, C., Zhou, J., Yang, D., Fan, Y. (2019). Research on the Relationship between the Individual Characteristics of Electric Bike Riders and Illegal Speeding Behavior: A Questionnaire-Based Study. https://www.mdpi.com/2071-1050/12/3/799/pdf

This paper obtained 350 survey responses from e-bike riders along a roadway when the rider was asked to stop to participate in our survey. Eight individual attributes were used as potential influencing factors of rider speed choice: rider's gender, age, education level, years of experience riding an e-bike, rider's personality characteristic (melancholic, phlegmatic, sanguine, and choleric temperament), job/occupation (students, incumbents, freelancers, and retirees), corrective vision, and cycling proficiency (novice, general, more skilled, skilled). The following three rider attributes had the most significant relationship to the riding speed: education level, years of experience riding an e-bike, and riding proficiency. Riders with higher proficiency tend to ride faster. Riders with more years of experience tend to ride slower. As education level increases, riders travel at higher speeds with the exception of the highest education level (university and above) ride the slowest.

Fyhri, A., Johansson, O., Bjornskau, T. (2019). Gender Differences in Accident Risk with E-Bikes – Survey Data from Norway. *Accident Analysis & Prevention.* https://doi.org/10.1016/j.aap.2019.07.024

This study aimed to investigate the crash risk regarding e-bikes and traditional bicycles. The study included a survey in nine Norwegian urban areas in 2017 where participants were asked about behavior and crash involvement. Then, a follow-up survey in Norway's four largest cities in 2018 were given a more detailed questionnaire about their crash involvement. In this survey a crash was defined as "crashing, running of the road, or falling over, and resulting in damage either to [oneself] or to the bicycle." The survey did not include information regarding the location of the crash (along a roadway or a natural surface path). The study found an increased risk of crashes for women on e-bikes when compared with men. For men there was no risk difference found between e-bikes and traditional bicycles. Some of the elevated risk can be attributed to being unfamiliar with e-bikes, which could suggest a need for improved infrastructure or educational programs to improve safety. The study found that "e-bikes are not more likely to cause serious crashes than traditional bicycles." Additionally, e-bikes are more often involved in balance-related crashes, but that crash type is rare.

Rider Behavior

Yang, H., Liu, X., Su, F., Cherry, C., Liu, X., (2018). Predicting e-bike users' intention to run the red light: An application and extension of the theory of planned behavior. https://www.sciencedirect.com/science/article/abs/pii/S1369847817306976?via%3Dihub

This paper aims to examine the psychological motivation of e-bike users that run red lights. A survey questionnaire was designed employing the construct of theory of planned behavior (TPB). The survey was performed in Chengdu, China in November 2016. Researchers found that users older than 40 identify themselves as more cautious riders. Younger riders have higher intention to run the red light. During the review of existing literature, Yang and the team found that e-bike users were 1.834 times more likely to run the red-light than traditional bicycle users. Around 76% of e-bike users regarded running the red light as a dangerous behavior. The study noted that there are many factors contributing to the decision to run a red light, including wait time at the light. Attitude and perceived behavioral control had significant positive effects on intention.

Huertas-Leyva, P., Dozza, M., Baldanzini, N. (2018). Investigating cycling kinematics and braking maneuvers in the real world: e-bikes make cyclists move faster, brake harder, and experience new conflicts. https://www.sciencedirect.com/science/article/abs/pii/S1369847817304096?via%3Dihub

The study showed naturalistic data from cyclists switching from a traditional bicycle to an e-bike on roadways. All cyclists rode faster on e-bikes than on traditional bicycles. Abrupt braking and sharp deceleration were higher when riding an e-bike than when riding a traditional bike. All cyclists required more reactive maneuvers braking when riding e-bikes then a traditional bike. Decelerations during sharp braking were higher riding e-bikes than traditional bikes.

Trip Purpose

Hertach, P., et al. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. https://www.sciencedirect.com/science/article/pii/S000145751830174X

This 2016 study surveyed 3,658 e-cyclists in German-speaking Switzerland. The main aim of this study was to gain more knowledge on the characteristics of single-vehicle crashes with e-bikes in road traffic. In this case, a single-vehicle crash was defined as crash that only involved the e-bike and the rider (for example, a collision with a fixed object, or skidding and falling). The other category was defined as "Involvement in a collision with another road user (pedestrian/cyclist/car)". This study confirmed a few safety implications of e-bikes such as the risk for suffering a serious injury is higher for women, older adults, and those who consider themselves not physically fit. It also found that the most common crash mechanism was skidding and falling. In addition, on average, those who commute to and from work using e-bikes have a higher risk of crashing than those using e-bikes for recreation.

E-Bike Classification

Cherry, C., MacArthur, J., (2019). E-bike safety: A review of Empirical European and North American Studies. https://wsd-pfb-sparkinfluence.s3.amazonaws.com/uploads/2019/10/EbikeSafety-VFinal.pdf

This is a comprehensive white paper review of emerging research on e-bike safety in North America and Europe. This report focuses almost exclusively on objectively observed safety information and data, including records of safety proxies and crash or injury reports. The observed data is generally drawn from empirical studies or "naturalistic" rider behavior studies.

The white paper found that Class 3 e-bikes have the same crash risk as Class 1 e-bikes, but injury severity is slightly higher when they do crash. Class 1 e-bikes are marginally faster than traditional bicycles (3.0 km/hr). Their speed results in slightly higher conflict rates and safety-oriented maneuvers. Class 3 e-bikes travel substantially faster than traditional bicycles, about twice the speed on average. The review identified no definitive answer regarding whether e-bikes are more or less safe than traditional bicycling, and under which circumstances.

Perceptions of Safety Key Findings

In a North American survey, more than half of the e-bike users stated they feel safer on an e-bike than a traditional bicycle because they can keep up with vehicular traffic when bicycle facilities (e.g., protected or dedicated lanes) aren't present, have quicker acceleration through dangerous intersections, are able to accelerate away from unsafe social situations, take longer routes to avoid busy roads and intersections, and aren't as likely to lose concentration due to physical exertion.

Perceptions of Safety Areas for Further Research

More research could inform improved understanding of the discrepancy in attitudes towards e-bikes and safety outcomes among different demographic groups. Most studies that assess perceived safety aspects of e-bikes do so through surveys which are subjective and can be subject to bias. Studies that pair surveys with observational or other empirical approaches may help identify disconnects between perceived and actual safety.

Speed Key Findings

Much of the research on e-bike safety has focused on their speed compared to traditional bicycles. Class 1 and Class 2 e-bikes provide electric assistance up to 20 mph and Class 3 e-bikes provide electric assistance up to 28 mph. The average cyclist may be able to travel faster using an e-bike than a traditional bike; however, this does not mean that people necessarily travel at higher speeds when using e-bikes. Studies have evaluated the spot speed (speed at a specific location), average speed, and top speed of e-bikes. (Johnson, M.) Spot speeds, when going uphill, tend to be higher for e-bikes than for traditional bicycles. The research shows that e-bikes may have higher average speeds specifically because of the higher spot speeds during the uphill climbing sections even though the top end speeds on flat and downhill sections are similar between the e-bikes and traditional bikes.

Another study found that e-bike riders along shared use paths, on average, travel slower than traditional bicycles. (Langford, C.) Some e-bike users feel safer on e-bikes than traditional bicycles, citing speed advantages that allow them to keep up with traffic, accelerate more quickly through dangerous intersections, and away from unsafe social situations.

Speed Areas for Further Research

Traditional bicycle speeds can vary significantly from one bicycle or cycling context to another; for example, an experienced cyclist riding a road bike for a 50-mile route will travel at higher speeds than a leisurely cyclist riding a cruiser bicycle to pick up groceries on the way home from work. Further research could compare e-bike speed to that of different types of traditional bicycles in multiple cycling contexts.

Demographic Differences Key Findings

Research has shown that e-bikes attract different types of riders than traditional bicycles, specifically appealing to older riders. A study in Switzerland found that the average age of e-bike riders involved in crashes was between 40-65 years old. The same analysis found that e-bike riders were involved more in single-bicycle crashes than traditional bicycle riders. (Weber, T.) A study in the Netherlands found that older riders are more prone to single bicycle e-bike crashes because of the difficulty with balance in handling the heavier weight of the bikes during a dismount. (Schepers, P.) Another study looking at e-bike rider behavior in Switzerland found that, on average, men have a higher risk of crashing than women. However, the risk of suffering a serious injury is higher for women, older adults, and those who consider themselves not physically fit. (Hertach, P.) As with traditional bicycles, the rider’s level of experience and cycling proficiency may also affect their risk of crashing.

Demographic Differences Areas for Further Research

An area for further research is quantifying ridership proficiency and years of experience as it relates to safety among e-bike users. Many sources indicate that e-bikes are inviting to people who have less experience in bicycling. Future research could control for crashes by experience both riding an e-bike as well as riding a traditional bicycle. Cycling proficiency is typically self-reported, therefore user response bias could skew the data.

Rider Behavior Key Findings

Several studies have used GPS devices to track rider behavior. The data showed that e-bike riders exhibit nearly identical safety behavior for wrong-way riding, stop sign compliance, and traffic signal compliance, as traditional bicycle riders. All types of cyclists have a poor compliance rate at stop signs and at traffic signals. Other studies have looked into the reasons for e-bike crashes. A study in Switzerland found that the most common crash causes were slippery road surfaces and inappropriate speeds and the most common crash mechanism was skidding and falling. This indicates that the speeding behavior can lead to an increase in crashes, especially when weather conditions are not ideal. (Hertach, P.)

In another study where e-bikes were recently allowed on trails, other trail users stated that the behavior of people using traditional mountain bikes and eMTBs was indistinguishable. Both bicycle riders behaved similarly in terms of passing distance, passing speed, and general attitude of sharing the trial.

Rider Behavior Areas for Further Research

Although there is an increasing trend of e-bike crashes, this could be attributed to the increasing trend of e-bike ownership. More research, including regression analyses, could determine whether crash rates are growing faster than e-bike ownership rates, and what other factors are associated with e-bike crashes.

An area for further research is to study rider behavior of e-bike users along natural surface trails compared to the behavior of traditional cyclists (e.g., are e-bike riders more or less likely than traditional cyclists to travel off of established natural surface trails?).

Trip Purpose Key Findings

The purpose of an e-bike trip can influence safety risk. For instance, a Swiss study found that, on average, those who commute to and from work using e-bikes have a higher risk of crashing than those using e-bikes for recreation. (Hertach, P.) The study also found that riders who used eMTBs (which typically have wider tires and better suspension) had a lower crash risk than riders of other e-bikes.

A number of recent studies have tried to determine what modes are most commonly being replaced by e-bike trips and have yielded mixed results. Overall, the research suggests that e-bikes are most commonly replacing trips taken by a traditional bicycle but are also likely leading to a reduction in vehicle miles traveled by personal automobile. The people that switch from a traditional bicycle to an e-bike typically travel further distances, can carry more cargo items, and use it more frequently for commuting and daily errands.

Trip Purpose Areas for Further Research

Further research could inform better understanding of the causal factors behind the relationship between trip purpose and safety risk. Recreational riders may have fewer distractions, ride in areas with fewer traffic conflicts, and plan their trips in a way to avoid traffic conflicts. Commuters in urban areas tend to face more obstacles and traffic conflicts.

E-bike Classifications Key Findings

Several studies have tried to determine if there is a higher risk of crashing or severe injury with certain classes of e-bikes by using crash reporting such as databases maintained by hospitals. While Class 3 e-bikes were found to have similar crash rates as Class 1 and Class 2 e-bikes, Class 3 crashes resulted in more serious injury, leading to the conclusion that the users could have been traveling faster. (Cherry, C.)

E-bike Classifications Areas for Further Research

Crash reporting does not always identify what class of e-bike was involved in an incident. Most studies rely on user input which can be time consuming to collect and can result in lower response rates. E-bike classes may be difficult for users to distinguish because of their inherent similar physical features and therefore harder to report. (Cherry, C.) Since e-bike classifications are not usually reported in crash statistics, it is difficult to draw conclusions about safety differences among e-bike classes. Further research could develop more complete crash reporting data to improve understanding of potential differences in safety implications among Class 1, 2, and 3 e-bikes.

User Conflict

The Federal Highway Administration and The National Recreational Trails Advisory Committee provide a helpful description of user conflict:[10]

> *Conflict in outdoor recreation settings (such as trails) can best be defined as "goal interference attributed to another's behavior" (Jacob and Schreyer 1980, 369). As such, trail conflicts can and do occur among different user groups, among different users within the same user group, and as a result of factors not related to users' trail activities at all. In fact, no actual contact among users need occur for conflict to be felt. Conflict has been found to be related to activity style (mode of travel, level of technology, environmental dominance, etc.), focus of trip, expectations, attitudes toward and perceptions of the environment, level of tolerance for others, and different norms held by different users. Conflict is often asymmetrical (i.e., one group resents another, but the reverse is not true).*

Like any new user group, the introduction of e-bikes has the potential to create new (perceived or actual) user conflict on recreational trails. As e-bikes become more popular and trails become more crowded, conflict among trail users may become more frequent. Generally, e-bike users have similar recreational and transportation motivations as other trail users; however, if trail-user conflicts are not resolved, it can spoil trail user relationships, polarize user groups, affect visitors' ability to enjoy trails, and potentially displace certain trail users. This theme of the literature review is organized around studies of perceptions and guidelines regarding design and management approaches that can help maintain positive trail-user relationships.

[10] https://www.pedbikeinfo.org/cms/downloads/Conflicts_MultiuseTrails.pdf, page 6

Perceptions of User Conflict

Nielson*, T., Palmatier, S. M., & Proffitt, A. (2019).* Literature Review: Recreation Conflicts Focused on Emerging E-Bike Technology. https://assets.bouldercounty.org/wp-content/uploads/2020/01/e-bike-literature-review.pdf

The goal of this literature review is to inform policy discussions and decisions for the quickly growing e-bike market in four of Colorado's northern Front Range open space programs. Safety, speed, crowding, and user conflict are common concerns related to bicycles generally, and these concerns are heightened for e-bikes. Several studies show that trail users unfamiliar with e-bikes express a preference to not share the trail with them, but the majority did not notice that they were sharing the trail with e-bikes. Similarly, once trail users were exposed to e-bikes, concerns about them decrease for many.

Chaney, R., Hall, P., Crowder, A., Crookston, B., & West, J. (2019). Mountain biker attitudes and perceptions of eMTBs (electric-mountain bikes). https://www.researchgate.net/publication/333490925_Mountain_biker_attitudes_and_perceptions_of_eMTBs_electric-mountain_bikes

This qualitative study involved extracting and thematically analyzing discussion thread comments about eMTBs among nine mountain biking Facebook pages. The study found there were misconceptions about what constitutes an eMTB. Misconceptions foster fears and concerns about trail conflict, access, and the morality of individuals using eMTBs. This study included insights that will be useful in efforts to promote eMTBs for recreation, a tool to increase levels of physical activity, and in discussing potential conflicts about trail use. From among the nine mountain biking Facebook pages selected for this study, 945 comments were gathered resulting in 2,537 uniquely coded units. This study aimed to characterize attitudes of mountain bikers about eMTBs in the public forum. One of the themes, with 49% of the comments, was regarding trails, some commenters qualified their consideration for restricted eMTB trail access by describing potential on-trail conflicts. Since mountain biking often requires negotiating narrow trails, riding etiquette is important for rider safety. A minority expressed that the trails can be shared safely for all to enjoy.

Watson, A., Williams, D., & Daigle, J. (1991). Sources of conflict between hikers and mountain bike riders in the Rattlesnake NRA. https://www.researchgate.net/publication/270049782_Sources_of_conflict_between_hikers_and_mountain_bike_riders_in_the_Rattlesnake_NRA

Mountain bike riders and hikers in the Rattlesnake National Recreation Area were studied to assess the extent of conflict between the two groups and to search for underlying reasons. This study did not include information specifically about eMTBs. Visitors staying a minimum of two hours were asked to participate in the study. 211 completed questionnaires were returned. Between 30 and 37 percent of hikers indicated that they did not like meeting bicycles on trails in the Rattlesnake. Only about 20 percent of the hikers could specify bicyclist behavior that interfered with their enjoyment. Educating mountain bike riders about behavior that others consider unacceptable and educating hikers about the similarities between hikers and mountain bike riders may reduce feelings of conflict.

Nielson, T., Palmatier, S., Proffitt, A., Marotti, M. (2019). Boulder County E-bike Pilot Study Results. https://assets.bouldercounty.org/wp-content/uploads/2019/09/e-bike-pilot-study.pdf

This report highlighted the results of two studies, an intercept survey, and a speed observation study, conducted for an e-bike pilot program allowing Class 1 and Class 2 e-bikes on certain county open space trails in Boulder County, Colorado. The intercept survey included 427 responses where 35.4% use bikes (27.7% as the primary activity) and 0.9% used e-bikes. Users of the park are generally in support or neutral about allowing e-bikes on the plains (flat trails) and regional (wider with higher volumes) trails but do not support allowing e-bikes on the foothill (steeper and narrower) trails.

Jefferson County Colorado (2017). Summary of JCOS e-bike Study Findings to Date. https://www.jeffco.us/DocumentCenter/View/9674/e-Bike-Survey-Results-?bidId=; *https://prismic-io.s3.amazonaws.com/peopleforbikes/0ae45c14-69f7-458b-ae15-692be9f28b50_COSA_e-Bike-Presentation.pdf*

Jefferson County (Jeffco) Open Space conducted a pilot program study of e-bikes after the state legislature passed HB 17-1151, which allowed Class 1 and Class 2 e-bikes on bike and pedestrian paths where traditional bicycles are allowed to travel. A visitor intercept survey was conducted to measure attitudes, perceptions and acceptance with a focus on visitor engagement. Of 375 park users surveyed, 65% could not detect e-bikes being used in park, 34% would be ok with e-bikes on paved trails, 36% would be ok with e-bikes on any trails. According to a pre- and post-demo survey in Jefferson County Colorado, 65% of people felt the demo changed their perception of e-bikes with 25% approving before the pilot and 46% approving after pilot. The approval of e-bikes in the park increased from 36% (pre-ride) to 44% (post-ride) and the disapproval of e-bikes increased from 6% (pre) to 8% (post). Post-ride visitors were less inclined to approve of e-bikes on all types of trails (42% down to 37%) and there was an increase of approval for e-bikes on paved surfaced (30% up to 32%). Based on findings from a pilot program Jeffco Open Space adopted a permanent policy to allow e-bikes on Jeffco Open Space managed trails.

Chavez*, D. (1993).* Recreational Mountain Biking: A management perspective. *11(3), 8.* https://www.americantrails.org/images/documents/psw_1993_chavez001.pdf

This study analyzed responses from a telephone survey of recreation land managers across the United States regarding management perceptions of mountain biking. While many respondents reported moderate to extensive mountain bike use in their resource areas, most did not have designated mountain bike areas. Over half reported conflicts between bikers and other user groups. Few reported having management plans specifically related to mountain biking. This study did not address e-bikes specifically; however, it revealed a need for greater awareness and planning by land managers for emerging modes of recreation.

Management and Design Methods

PeopleForBikes, Bicycle Product Suppliers Association, & Bureau of Land Management (2017). eMTB Land Manager Handbook. https://www.americantrails.org/images/documents/eMTB_Book.pdf

This handbook, produced as a collaborative effort among the Bureau of Land Management and two bicycle industry/advocacy groups, provides recommendations on the planning, design, construction, maintenance, and management of sustainable Class 1 eMTB trails. The handbook describes the reasons for people to visit trails and categorizes them into five types of trail experiences: escape, solitude, challenge, plan, exercise. These five experience categories tend to be similar whether people are hiking, trail running, mountain biking, or e-mountain biking, among others. The handbook suggests that understanding the demand for these different experiences can help shape trail design and manage the trail conflicts among user groups. When it comes to choosing a traditional mountain bike versus an eMTB, challenge and exercise are the two experience types that are effected by the type of bike. The power assist provided by an eMTB can make some technical sections, specifically steep inclines, easier and more accessible and a rider seeking exercise will find most trails require less physically exertion on an eMTB and trails that would otherwise be inaccessible on a traditional bike could be accessible on an eMTB. The handbook identifies single-use, preferred-use, one-way directional trails as methods to reduce user conflict.

Bureau of Land Management & International Mountain Bicycling Association (2018). Guidelines for a Quality Trail Experience: Mountain Bike Trail Guidelines. https://www.imba.com/sites/default/files/2021-06/GQTE%20Digital%20Book%20Rev%206.11.18%20Low%20Rez.pdf

The guidelines were created to help improve the design, construction, and management of mountain bike trails all across the country. The reference does not cover e-bikes specifically but describes the relationship between bicycle users and other trail-users, several considerations are established for planning and designing trails intended to provide access for a range of activities and users. IMBA's pioneers saw that crowded trails and trail user conflict were fast becoming worldwide recreation issues. The Guidebook recommends that controlling trail access can minimize user conflicts while also accommodating user expectation for both shared use and mountain bike-only access. A trail built specifically to support mountain bike use might look quite different from one designed for shared use. Single use trails can be geared towards specific skill areas as well as single direction to limit trail user conflict.

US Federal Highway Administration and The National Recreational Trails Advisory Committee (2004). Conflicts On Multiple-Use Trails: Synthesis of the Literature and State of the Practice. https://www.pedbikeinfo.org/cms/downloads/Conflicts_MultiuseTrails.pdf

The National Recreational Trails Advisory Committee identified trail-user conflicts on multiple-use trails as a major concern that needs resolution. The source does not expressly address e-bikes. The Advisory Committee recognized that there is a significant amount of literature and expertise on this topic, but no one source that summarizes the available information. The challenges faced by multiple-use trail managers can be broadly summarized as maintaining user safety, protecting natural resources, and providing high-quality user experiences. These challenges are interrelated and cannot be effectively addressed in isolation. To address these challenges, managers can employ a wide array of physical and management options such as trail design, information and education, user involvement, and regulations and enforcement. The study identified twelve principles for minimizing conflict on multiple-use trails: (1) recognize conflict as goal interference, (2) provide adequate trail opportunities, (3) minimize number of contracts in problem area, (4) involve users as early as possible, (5) understand user needs, (6) identify the actual sources of conflict, (7) work with affected users, (8) promote trail etiquette, (9) encourage positive interaction among different users, (10) favor "light-handed management", (11) plan and act locally, (12) monitor progress.

Perceptions of Conflict Key Findings

Many studies have been conducted on the perception of e-bikes from other trail and road users. The other users felt that e-bikes travel at higher speeds due to the power assist. However, when other trail users tested an e-bike, they found that they would travel at a speed that was comfortable, and not the maximum speed of the bicycle. Many people’s perceptions changed over time once they used or saw an e-bike. Exposure to and education on e-bikes and eMTBs could lead to positive trends in the perception among other trail and roadway users.

In general people found it hard to recognize an e-bike versus a traditional bike, especially when they were on a trail. In a North American survey more than half of the e-bike users stated they feel safer on an e-bike than a traditional bike and can avoid conflicts with other users by taking an alternate and longer route and keep up with vehicular traffic when bicycle facilities (e.g., dedicated lanes) are unavailable.

E-bike users feared intimidation and harassment for using an e-bike and at times felt apologetic or self-conscious due to being viewed as “cheating” for riding an e-bike. This is especially true on trails used by people who mountain bike. One mountain biker even stated “I have a rule, I don’t yield to e-bikes,” which indicates that there are user conflicts among the mountain biking community as to whether eMTBs should be accepted.

Perceptions of Conflict Areas for Further Research

E-bikes remain an emerging trend that is growing rapidly. Even though parks have started to allow e-bikes onto trail networks, the overall use of e-bikes is still extremely low compared to traditional mountain bikes. Trail conflict among e-bike users and other trail users continues to remain low, as does related research and data collection. Many surveys regarding trail user conflict are conducted hours or days after potential encounters, making it difficult for respondents to recall the specific details. Additionally, conflict is difficult to measure experimentally, as the experience of user conflict is inherently subjective; each individual has a different opinion of what acceptable trail behavior may look and feel like.

Management and Design Methods Key Findings

Hikers and mountain bikers typically have an asymmetrical relationship where hikers do not like to encounter mountain bikers, but mountain bikers are generally indifferent when they encounter hikers. Conflicts on trails have been described as "problems of success," as an indication for the trail's popularity, but often conflicts among trail users can result in unpleasant encounters that can spoil individual experiences and polarize trail users against other user groups. As the diversity of trail uses grow, so too can the potential for conflict.

Boulder County carried out a study that observed e-bike speeds relative to traditional bicycles and conducted a user intercept survey to identify attitudes toward e-bikers on mountain trails. Non-e-bikers indicated that they did not want e-bikes on trails because they were concerned that the e-bikes would travel too fast. However, the speed data showed that people using traditional bicycles traveled faster along the downhill sections than the people using e-bikes. The results of the study indicated that perceptions did not align with the observed behavior.

According to the eMTB Handbook, understanding the reason or purpose people seek recreational activity is critical to understanding how to manage the trail. Five experience categories were identified: escape, solitude, challenge, play, and exercise. The handbook suggests that understanding the demand for these different experiences can help shape trail design and control the trail conflicts among user groups. Specifically trails that are designed for challenge and/or exercise experiences can be tailored towards traditional mountain bicycles or eMTBs to minimize conflicts among user groups. Existing user conflict management and design approaches may be applied to address e-bikes in addition to another trail uses previously contemplated.

Management and Design Methods Areas for Further Research

There is a lack of research to inform data-driven management and design guidelines specifically tailored to e-bikes. Current research on e-bike effects does not establish a clear need for such e-bike tailored guidance.

A. Appendix. Works Referenced

The accompanying Excel file contains a full list of articles compiled in the creation of the literature review.

Topic	Author	Source	Publication Year	Title
Accessibility	Gerow, B.	Singletracks	2020	E-bikes are Important Forest Accessibility Tools
Accessibility	Gordon, E., Shao, Z., Xing, Y., & Wang, Y.	TRB 2013 Annual Meeting	2012	Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area
Accessibility	Jeljis, B., Heutink, J., de Waard, D., Brookhuis, K., & Melis-Dankers, B.	Transportation Research Part F: Traffic Psychology and Behaviour	2020	How visually impaired cyclists ride regular and pedal electric bicycles
Accessibility	Leger, S., Dean, J., Edge, S., & Casello, J.	Transportation Research Part A	2019	If I had a regular bicycle, I wouldn't be out riding anymore
Accessibility	MacArthur, J., McNeil, N., Cummings, A., & Broach, J.	Transportation Research Record: Journal of the Transportation Research Board	2020	Adaptive Bike Share: Expanding Bike Share to People with Disabilities and Older Adults
Accessibility	Ruvolo, M.	UCLA Institute of Transportation Studies	2020	Access Denied? Perceptions of New Mobility Services Among Disabled People in San Francisco
Accessibility; Health and Wellness	Leyland, L., Spencer, B., Beale, N., Jones, T., & van Reekum, C.	PLoS ONE	2019	The effect of cycling on cognitive function and well-being in older adults
Accessibility; Safety; User Conflict	MacArthur, J., Harpool, M. Scheppke, D., & Cherry, C.	Portland State University Transportation Research and Education Center	2017	A North American Survey of Electric Bicycle Owners
Environment and Natural Resources	Abagnale, C., Cardone, M., Iodice, P., Strano, S., Terso, M., & Vorraro, G.	Energy Procedia	2015	A Dynamic Model for the Performance and Environmental Analysis of an Innovative e-bike
Environment and Natural Resources	Chavez, D., Winter, P., & Bass, J.	Journal of Parks and Recreation Administration	1993	Recreational Mountain Biking: A Management Perspective
Environment and Natural Resources	Cushman, H., Cooper, M., Meentemeyer, R., & Benson, S.	USFS	2008	Human activity and the spread of Phytophthora ramorum
Environment and Natural Resources	Elliott, T., McLaren, S., & Sims, R.	Sustainable Production and Consumption	2018	Potential environmental impacts of electric bicycles replacing other transport modes in Wellington, New Zealand
Environment and Natural Resources	Hall, C., Ho, T., Julian, C., Whight, G., Chaney, R., Crookston, B., & West, J.	JMIR	2019	Pedal-Assist Mountain Bikes: A Pilot Study Comparison of the Exercise Response, Perceptions, and Beliefs of Experienced Mountain Bikers
Environment and Natural Resources	Hedquist, S.L., Ellison, L.A., & Laurenzi, A.	Advances in Archaeological Practice	2014	Public Lands and Cultural Resource Protection: A Case Study of Unauthorized Damage to Archaeological Sites on the Tonto National Forest, Arizona
Environment and Natural Resources	Herrero J. & Herrero, S.	Parks Canada	2000	Management Options for the Moraine Lake Highline Trail: Grizzly Bears and Cyclists
Environment and Natural Resources	Honkonen, K.	U.S. Forest Service	2021	Hale Lake Area Management Project
Environment and Natural Resources	International Mountain Bicycling Association	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
Environment and Natural Resources	International Mountain Bicycling Association	International Mountain Bicycling Association	2016	Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results
Environment and Natural Resources	Jefferson County Colorado Open Space	Jefferson County Colorado Open Space	2017	Jefferson County Colorado E-bikes and Trails: Measuring Impact and Acceptance of Class 1 E-bikes on Trails
Environment and Natural Resources	Ji, S., Cherry, C., Bechle, M., Wu, Y., & Marshall, J.	Environmental Science and Technology	2011	Electric vehicles in China: emissions and health impacts.
Environment and Natural Resources	Kantor, S., Wisdom, M., & Johnson, B.	US Department of Agriculture	2019	Seeking ground less traveled: Elk responses to recreation
Environment and Natural Resources	Larson, C. L., Reed, S. E., Merenlender, A. M., & Crooks, K. R.	PLOS ONE	2016	Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review.
Environment and Natural Resources	Larson, C.L., Reed, S.E., Merenlender, A.M., & Crooks, K.R.	Conservation Science and Practice	2019	A meta-analysis of recreation effects on vertebrate species richness and abundance
Environment and Natural Resources	Legagneux, P. & Ducatez, S.	Biology Letters	2013	European birds adjust their flight initiation distance to road speed limits.
Environment and Natural Resources	Li, T., Qian, F., & Su, C.	Applied Mechanics and Materials	2014	Energy consumption and emission of pollutants from electric bicycles
Environment and Natural Resources	Liu, X., Ren, D., Hsu, H., Feng, X., Xu, G., Zhuang, M., Gao, H., Lu, L., Han, X., Chu., Z., Li, J., He, X., Amine, K., & Ouyang, M.	Joule	2018	Thermal Runaway of Lithium-Ion Batteries without Internal Short Circuit.
Environment and Natural Resources	Lyon, L. Jack, & Burcham, M.G	U.S. Forest Service	1998	Tracking Elk Hunters with the Global Positioning System.
Environment and Natural Resources	Lyon, L. Jack, and Burcham, M.G.	USFS	1998	Tracking Elk Hunters with the Global Positioning System
Environment and Natural Resources	MacArthur, J., McQueen, M., & Cherry, M.	Portland State University Transportation Research and Education Center	2019	The E-Bike Potential: Addressing Our Climate Crisis by Incentivizing Active Transportation
Environment and Natural Resources	Machedon-Pisu, M. & Borza, P.	Energy Procedia	2020	Are Personal Electric Vehicles Sustainable? A Hybrid E-Bike Case Study
Environment and Natural Resources	Marion, J. & Wimpey, J.	MTB Environmental Impact Study	2017	Environmental Impacts of Mountain Biking: Science Review and Best Practices
Environment and Natural Resources	McCarran, T. & Carpenter, N.	Efficiency Vermont	2018	Electric bikes: survey and energy efficiency analysis
Environment and Natural Resources	McQueen, M. & MacArthur, J.	TREC/Portland State University	2020	Can Incentivizing E-bikes Support GHG Goals? Launching the New EV Incentive Cost and Impact Tool
Environment and Natural Resources	Mellino, S., Petrillo, A., Cigolotti, V., Autorino, C., Jannelli, E., & Ulgiati, S.	International Journal of Hydrogen Energy	2017	A Life Cycle Assessment of lithium battery and hydrogen-FC powered electric bicycles: Searching for cleaner solutions to urban mobility

Environment and Natural Resources	Naylor, L.M., Wisdom, M.J., & Anthony, R.G.	Journal of Wildlife Management	2009	Behavioral Responses of North American Elk to Recreational Activity
Environment and Natural Resources	Newsome, D. & Davies, L.	Journal of Ecotourism	2009	A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, Western Australia.
Environment and Natural Resources	Nielson, T., Palmatier, S.M., Proffitt, A., & Marotti, M.	Boulder County Parks & Open Space	2019	Boulder County E-bike Pilot Study Results
Environment and Natural Resources	Phillips, G. & Alldredge, A.	Journal of Wildlife Management	2000	Reproductive success of elk following disturbance by humans during calving season
Environment and Natural Resources	Pickering, C.M., Hill, W., Newsome, D., & Leung, Y.	Journal of Environmental Management	2009	Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America.
Environment and Natural Resources	Proffitt, K.M., Gude, J.A., Hamlin, K.L., & Messer, M.A.	Journal of Wildlife Management	2013	Effects of hunter access and habitat security on elk habitat selection in landscapes with a public and private land matrix
Environment and Natural Resources	Quigley, T.M. & Bigler Cole, H.	US Forest Service	1997	The Interior Columbia Basin Ecosystem Management Project: scientific assessment
Environment and Natural Resources	Quinn, M. & Chernoff, G.	Miistakis Institute	2010	Mountain Biking: A Review of the Ecological Effects
Environment and Natural Resources	Robinson, C., Dunker, P.N., & Beazley, K.F.	Environmental Reviews	2010	Science and Policy Brief, Habitat Fragmentation from Roads: Travel Planning Methods to Safeguard Bureau of Land Management Lands
Environment and Natural Resources	Rowland, M.M., Wisdwon, M.J., Johnson, B.K., & Kie, J.G.	Journal of Wildlife Management	2000	Elk Distribution and Modeling in Relation to Roads
Environment and Natural Resources	Schmor, M.R.	University of Calgary	1999	An exploration into bear deterrents, as related to mountain biking, and the design of an ultrasonic bear warning device
Environment and Natural Resources	Stokowski, P.A. & LaPointe, C.B.	University of Vermont School of Natural Resources	2000	Environmental and Social Effects of ATVs and ORVs: An Annotated Bibliography and Research Assessment
Environment and Natural Resources	Switalski, A.	Journal of Outdoor Recreation and Tourism	2018	Off-highway vehicle recreation in drylands: A literature review and recommendations for best management practices
Environment and Natural Resources	Switalski, A.	Winter Wildlands Alliance	2014	Snowmobile Best Management Practices for Forest Service Travel Planning: A Comprehensive Literature Review and Recommendations for Management
Environment and Natural Resources	Switalski, A. & Jones, A.	Journal of Conservation Planning	2012	Off-road vehicle best management practices for forestlands: A review of scientific literature and guidance for manager
Environment and Natural Resources	Switalski, T.A. & Jones, A.	Journal of Conservation Planning	2012	Off-road vehicle best management practices for forestlands: A review of scientific literature and guidance for managers
Environment and Natural Resources	Taylor, A.R. & Knight R.L.	Ecological Applications	2003	Wildlife responses to recreation and associated visitor perception
Environment and Natural Resources	Thurston, E., & Reader, R. J.	Environmental Management	2001	Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest
Environment and Natural Resources	Trombulak, S.C. & Frissell, C.A.	Conservation Biology	2001	Review of ecological effects of roads on terrestrial and aquatic communities
Environment and Natural Resources	U.S. Forest Service	U.S. Forest Service	2011	Trail Fundamentals and Trail Management Objectives
Environment and Natural Resources	Uteng, T. P., Uteng, A., & Kittilsen, O. J.	Norwegian Centre for Transport Research	2019	Land use development potential and E-bike analysis
Environment and Natural Resources	Vandeman, M.J.	ARPN Journal of Science and Technology	2014	The Impacts of Mountain Biking on Wildlife and People A Review of the Literature
Environment and Natural Resources	Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. K.	Transportation Research: Part D	2015	On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers
Environment and Natural Resources	WildEarth Guardians	WildEarth Guardians	2020	The Environmental Consequences of Forest Roads and Achieving a Sustainable Road System
Environment and Natural Resources	Wisdom, M., Holthausen, R.S., Wales, B.C., Hargis, C.D., Saab, V.A., Lee, D.C., Hann, W.J., Rich, T.D., Rowland, M.M., Murphy, W.J., & Eames, M.R.	US Department of Agriculture	2000	Source habitats for terrestrial vertebrates of focus in the interior Columbia basin: broadscale trends and management implications, Volume 1
Environment and Natural Resources	Wisdom, M., Preisler, H.K., Naylor, L.M., Anthony, R.G., Johnson, B.K., & Rowland, M.M	Forest Ecology and Management	2018	Elk responses to trail-based recreation on public forests
Environment and Natural Resources	Wisdom, M.J., Ager, A.A., Preisler, H.K., Cimon, N.J., & Johnson, B.K.	Transactions of the 69th North American Wildlife and Natural Resources Conference	2004	Effects of off-road recreation on mule deer and elk
Environment and Natural Resources	Woodcock, J., Abbas, A., Ullrich, A., Tainio, M., Lovelace, R., Sa, T., Westgate, K., & Goodman, A.	TREC/Portland State University	2018	Development of the Impacts of Cycling Tool (ICT)
Environment and Natural Resources	Xu, Z., Liu, Z., & Sun, S.	10th Asia Pacific Transportation Development Conference	2014	Analysis of Impacts on Environment from Electric Bicycles: A Case Study of Xi'an, China
Environment and Natural Resources; Safety; User Conflict	Nielson, T., Palmatier, S. M., & Proffitt, A.	Boulder County Parks & Open Space	2019	Literature Review: Recreation Conflicts on Emerging E-bike Technology
Equity	Alamelu, R., Anushan, C. S., & Selvabaskar, S. G.	Business: Theory & Practice	2015	Preference of E-Bike by Women in India-a Niche Market for Auto Manufacturers
Equity	Clelow, R.	Populus	2018	DC is growing its dockless bike and scooter program: We partnered with them to evaluate how it's expanding access in underserved communities
Equity	Dill, J. & Rose, G.	TRB	2012	E-Bikes and Transportation Policy: Insights from Early Adopters.
Equity	Fyhri, A., Johansson, O., & Bjornskau, T.	Accident Analysis & Prevention	2019	Gender Differences in Accident Risk with E-Bikes – Survey Data from Norway.
Equity	Lee, D.	City University of New York Academic Works.	2018	Delivering Justice: Food Delivery Cyclists in New York City.
Equity	Stowell, H.	Institute of Transportation Engineers	2020	Making Micromobility Equitable for All

Equity	Yanocha, D. & Allan, M.	Institute for Transportation and Development Policy	2019	The Electric Assist: Leveraging E-bikes and E-scooters for more Livable Cities
General	Banks, N.	Forbes	2018	Looking for the Ultimate Urban Toy? Introducing SWIND EB-01
General	Bureau of Land Management	Bureau of Land Management	2014	2020 Travel and Transportation Management Vision
General	Council on Environmental Quality	Council on Environmental Quality	1979	CEQ Off-road vehicles on public land
General	Havlick, D.	Island Press	2002	No Place Distant: Roads and Motorized Recreation on America's Public Lands.
General	MacArthur, J. & Kobel, N.	National Institute for Transportation and Communities	2014	Regulations of E-Bikes in North America.
General	McQueen, M., MacArthur, J., & Cherry, C.	Transportation Research and Education Center	2019	How E-bike Incentive Programs are Used to Expand the Market
General	Mimiaga, J.	Durango Herald	2019	E-bikes tested on Phil's World ATV trails
General	National Conference of State Legislatures	National Conference of State Legislatures (NCSL)	2019	State Electric Bicycle Laws: A Legislative Primer
General	Road Bike	Road Bike	n.d.	Average Cycling Speed for New and Experienced Cyclists
General	Switalski, A.	Journal of Outdoor Recreation and Tourism	2018	Off-highway vehicle recreation in drylands: A literature review and recommendations for best management practices.
General	Transportation Research and Education Center	Transportation Research and Education Center	2017	PFB state by state summary ebike bills
General	US GAO	US GAO	2009	FEDERAL LANDS Enhanced Planning Could Assist Agencies in Managing Increased Use of Off-Highway Vehicles
Health and Wellness	Alessio, H., Reiman, T., Kemper, B., von Carlowitz, W., Bailer, J., & Timmerman, K.	Translational Journal of the American College of Sports Medicine	2021	Metabolic and Cardiovascular Responses to a Simulated Commute on an E-Bike
Health and Wellness	Bourne, J., Page, A., Leary, S., Andrews, R., England, C., & Cooper., A.	BMC Pilot and Feasibility Studies	2019	Electrically assisted cycling for individuals with type 2 diabetes mellitus: protocol for a pilot randomized controlled trial
Health and Wellness	Bourne, J., Sauchelli, S., Perry, R., Page, A., Leary, S., England, C., & Cooper, A.	International Journal of Behavioral Nutrition and Physical Activity	2018	Health benefits of electrically-assisted cycling: a systematic review
Health and Wellness	Castro, A., Gaupp-Berghausen, M., Dons, E., Standaert, A., Laeremans, M., Clark, A., Anaya-Boig, E., Cole-Hunter, T., Avila-Palencia, I., Rojas-Rueda, D., Neiuwenhuijsen, M., Gerike, R., Panis, L.I., de Nazelle, A., Brand, C., Raser, E., Kahlmeier, S., Götschi, T., & PASTA Consortium	Transportation Research Interdisciplinary Perspectives	2019	Physical activity of electronic bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities
Health and Wellness	De Geus, D. & Hendriksen, I.	Cycling Futures: From Research into Practice.	2015	Cycling for transport, physical activity and health: what about Pedelecs?
Health and Wellness	Duarte, G., Mendes, M., & Baptista, P.	INSTICC Press INSTICC INSTICC	2014	Influence of Electric Bicycle Usage on Biker Effort On-road Monitoring Application in Lisbon, Portugal
Health and Wellness	Fishman, E. & Cherry, C.	Transport Reviews	2015	E-bikes in the Mainstream: Reviewing a Decade of Research
Health and Wellness	Jones, T., Harms, L., & Heinen, E.	Journal of Transport Geography	2016	Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility
Health and Wellness	Kruijf, J., Ettema, D., & Dijst, M.	American Society of Civil Engineers Beijing Univ. Technol. Beijing Univ. Technol.	2018	A longitudinal evaluation of satisfaction with e-cycling in daily commuting in the Netherlands
Health and Wellness	Langford, B., Cherry, C., Bassett, D., Fitzhugh, E., & Dhakal, N.	Journal of Transport and Health	2017	Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles
Health and Wellness	Langford, B., Cherry, C., Bassett, D., Fitzhugh, E., & Nirbesh, D.	Journal of Transport & Health	2017	Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles
Health and Wellness	MacArthur, J., Dill, J., & Person, M.	Oregon Transportation Research and Education Consortium	2014	Electric Bikes in North America: Results of an Online Survey
Health and Wellness	Meyer, D., Steffan, M., & Senner, V.	Procedia Engineering	2014	Impact of Electrical Assistance on Physiological Parameters During Cycling
Health and Wellness	Sudfor, H., Fyhri, A.	BMC Public Health	2017	A push for public health: the effect of e-bikes on physical activity levels
Health and Wellness	Van Cauwenberg, J., de Bourdeaudhuij, I., Clarys, P., & de Geus, B.	Transportation	2018	E-bikes among older adults: benefits, disadvantages, usage and crash characteristics
Safety	Adair, P., Ayers, S., Bathalon, S., Edwards, P., Lee, D., LaRue, D., McCallion, R., Khanna, R., & Thomas, T.	US Consumer Product Safety Commussion	2020	Safety Concerns Associated with Micromobility Products
Safety	Baschera, D., Jäger, D., Preda, R., & Z'Graggen, W.	World Neurosurgery	2019	Comparison of the incidence and severity of traumatic brain injury caused by E-bike and bicycle accidents – Retrospective cohort study from a Swiss level I trauma center
Safety	Cherry, C., MacArthur, J.	People for Bikes	2019	E-Bike Safety: A Review of Empirical European and North American Studies
Safety	Clark, A.	Journal of Transport & Health	2017	New Types of Electric Pedal-Assisted Cycles (EPACs) As a Form of Active Mobility
Safety	Dawson, A.	Bicycling.com	2019	E-Bike Battery Explodes, Burning 79-Year-Old Cyclist and Causing Bushfire
Safety	DiMaggio, C., Bukur, M., Wall, S., Frangos, S., & Wen, A.	BMJ Injury Prevention	2019	Injuries associated with electric-powered bikes and scooters: analysis of US consumer product data
Safety	Dozza, M.	Proceedings, International Cycling Safety Conference	2013	e-BikeSAFE: A Naturalistic Cycling Study to Understand how Electrical Bicycles Change Cycling Behaviour and Influence Safety
Safety	Dozza, M., Piccinini, G., & Werneke, J.	Transportation Research: Part F	2016	Using naturalistic data to assess e-cyclist behavior
Safety	Eriksson, J., Forsman, Forsman, Å., Niska, A., Gustafsson, S., & Sörensen, G.	Traffic Injury Prevention	2019	An analysis of cyclists' speed at combined pedestrian and cycle path
Safety	Gogola, M.	IEEE	2018	Are the e-bikes more dangerous than traditional bicycles?
Safety	Hertach, P., Uhr, A., Niemann, S., & Cavegn, M.	Accident Analysis & Prevention	2018	Characteristics of single-vehicle crashes with e-bikes in Switzerland
Safety	Hu, F., Lv, D., Zhu, J., & Fang, J.	Traffic Injury Prevention	2014	Related Risk Factors for Injury Severity of E-bike and Bicycle Crashes in Hefei
Safety	Hu, L., Hu, X., Kuang, A., Hao, W., & Lin, M.	Applied Mechanics and Materials	2020	Casualty risk of e-bike rider struck by passenger vehicle using China in-depth accident data

Safety	Huertas-Levya, P., Dozza, M., & Baldanzini, N.	Transportation Research: Part F	2018	Investigating cycling kinematics and braking maneuvers in the real world
Safety	Langford, B.	Tennessee Research and Creative Exchange	2013	A comparative health and safety analysis of electric-assist and regular bicycles in an on-campus bicycle sharing system
Safety	Langford, B.C., Chen, J., & Cherry, C.	Accident Analysis & Prevention	2015	Risky riding
Safety	Ma, C., Zhou, J., Yang, D., & Fan, Y.	Sustainability (2071-1050)	2020	Research on the Relationship between the Individual Characteristics of Electric Bike Riders and Illegal Speeding Behavior
Safety	Ma, C., Zhou, J., Yang, D., & Fan, Y.	MDPI	2020	Research on the Relationship between the Individual Characteristics of Electric Bike Riders and Illegal Speeding Behavior: A Questionnaire-Based Study
Safety	N/A	Royal Automobile Club of Victoria	2015	Safety implications of e-bikes
Safety	People for Bikes	People for Bikes.	2018	Colorado's E-Bike Law
Safety	Petzoldt, T., Schleinitz, K., Heilmann, S., & Gehlert, T.	Transportation Research Part F	2017	Traffic conflicts and their contextual factors when riding conventional vs. electic bicycles
Safety	Pohl, J.	AZCentral.com	2018	'Personal drone' sparks 335-acre wildfire north of Flagstaff
Safety	Schepers, J. P., Fishman, E., den Hertog, P., Wolt, K. K., & Schwab, A. L	Accident Analysis & Prevention	2014	The safety of electrically assisted bicycles compared to classic bicycles
Safety	Schepers, P., Wolt, K.K., & Fishman, E.	International Transport Forum	2018	The Safety of ebikes in the Netherlands
Safety	Schleinitz, K., Petzoldt, T., Franke-Bartholdt, L, Krems, J., & Gehlert, T.	Safety Science	2017	The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles
Safety	Vlakveld, W.P., Twisk, D., Christoph, M., Boele, M., Sikkema, R., Remy, R., & Schwab, A.L.	Accident Prevention and Analysis	2015	Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: A field experiment
Safety	Weber, T., Scaramuzza, G., & Schmitt, K.-U.	Accident Analysis and Prevention	2014	Evaluation of e-bike accidents in Switzerland
Safety	Yang, H., Liu, X., Su, F., Cherry, C., Liu, Y., & Li, Yanlai	Transportation Research Part F: Traffic Psychology and Behaviour	2018	Predicting e-bike users' intention to run the red light
User Conflict	Baechle, J. & Kressler, K.	Arizona Trail Association	2020	Perceptions of Conflict Surrounding Future E-bike Use on the Arizona Trail
User Conflict	Bicycle Product Suppliers Association	Bicycle Product Suppliers Association	2017	PfB eMTB Bicycle Product Suppliers Association Intercept Study
User Conflict	Blahna, D.J., Smith, K.S., & Anderson, J.A.	Leisure Sciences	1995	Backcountry Llama Packing: Visitor Perceptions of Acceptability and Conflict
User Conflict	Bureau of Land Management & International Mountain Bicycling Association	International Mountain Bicycling Association	2018	Guidelines for a Quality Trail Experience: Mountain Bike Trail Guidelines
User Conflict	Chaney, R., Hall, P., Crowder, A., Crookston, B., & West, J.	Sport Sciences for Health	2019	Mountain biker attitudes and perceptions of eMTBs (electric-mountain bikes)
User Conflict	Chaney, R.A., Hall, P.C., Crowder, A.R., Crookston, B.T., & West, J.H.	Sport Sciences for Health	2019	Mountain Biker Attitudes and Perceptions of e-MTBs
User Conflict	Devall, B. & Harry, J.	Leisure Sciences	1981	Who Hates Whom in the Great Outdoors: The Impact of Recreational Specialization and Technologies of Play
User Conflict	Hammit, W.E., McDonald, C.D., & Hughes, J.L.	Proceedings--National Wilderness Research Conference: Current Research USDA Forest Service General Technical Repor	1986	Experience Level and Participation Motives of Winter Wilderness Users
User Conflict	Hopkin, T.E. & Moore, R.L.	USDA	1994	The Relationship of Recreation Specialization to the Setting Preferences of Mountain Bicyclists
User Conflict	Jacob, G. & Schreyer, R.	Journal of Leisure Research	1980	Conflict in Outdoor Recreation: A Theoretical Perspective.
User Conflict	Jerfferson County Colorado Open Space	Jefferson County Colorado Open Space	2017	Summary of JCOS e-bike Study Findings to Date
User Conflict	MacArthur, J., Harpool, M. Scheppke, D., & Cherry, C.	Transportation Research and Education Center	2018	North American Survey of Electric Bicycle Owners
User Conflict	Manning, R.E.	Oregon State University Pres	1999	Recreation Conflict: Goal Interference," in Studies in Outdoor Recreation: Search and Research for Satisfaction
User Conflict	Mayer, A.	International Journal of Urban Sustainable Development	2019	Motivations and barriers to electric bike use in the U.S.: views from online forum participants
User Conflict	Mcleod, K.	League of American Bicyclists	2015	Electric Bicycles: Public Perceptions & Policy. Results and Analysis of a National Survey of American Bicyclists
User Conflict	Mcleod, K.	League of American Bicyclists	2015	Electric Bicycles: Public Perceptions & Policy. Results and Analysis of a National Survey of American Bicyclists
User Conflict	Moore, R.L.	US Federal Highway Administration and the National Recreational Trails Advisory Committee	1994	Conflicts on Multi-Use Trails: Synthesis of the Literature and State of the Practice
User Conflict	PeopleForBikes, Bicycle Product Suppliers Association, & Bureau of Land Management	PeopleForBikes, Bicycle Product Suppliers Association, & Bureau of Land Management	2017	eMTB Land Manager Handbook
User Conflict	Plazier, P., Weitkamp, G., & van der Berg, A.	Journal of Transport Geography	2017	"Cycling was never so easy!". An analysis of ebike commuters' motives, travel behaviour and experience using GPS-tracking and interview
User Conflict	Watson, A., Williams, D., & Daigle, J.	Journal of Park and Recreation Administration	1991	"Sources of Conflict between Hikers and Mountain Bike Riders in the Rattlesnake NRA"