E-bike Usage on the Carriage Roads

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Abstract

In 2019 the National Park Service allowed e-bikes in all National Parks. Due to the limited nature of research on the impact of e-bikes our goal is to provide information that will help Acadia National Park make informed changes to the existing e-bike policy, focusing our research on their behavior and impacts on the Carriage Roads. Our team worked with the park to monitor the impact of e-bikes. Monitoring methods included big data, observation, interviews, and GPS tracking. From these methods we found that there were inconsistencies in the presentation of safety information to bikers as well as instances of speeding. We then developed three recommendations to the park, including improved bike education, increased use of signage, and continued monitoring of e-bikes in the park.

Executive Summary

E-bike Usage on the Carriage Roads

Patrick Bowles, Yang Lyu, Alexandra McFann, Jon Merchan, Michael Rothstein

In 2019, concern grew when e-bikes were introduced to the Carriage Roads in Acadia National Park. Since their inception in 1913, the Carriage Roads did not permit the use of motorized vehicles, but many believe e-bikes fall into a gray area. This led to a divide between those who think e-bikes belong on the Carriage Roads and those who do not. Although there is an e-bike policy specific to Acadia National Park, it is believed by many that the policy was created without taking into consideration the unique aspects of the Carriage Roads in the park. Acadia National Park seeks to update this policy to ensure that all Carriage Road users have a safe and positive visitor experience. The team's goal was to provide information that will help Acadia National Park make an informed decision regarding an e-bike policy.

To achieve this goal, the team completed three objectives;

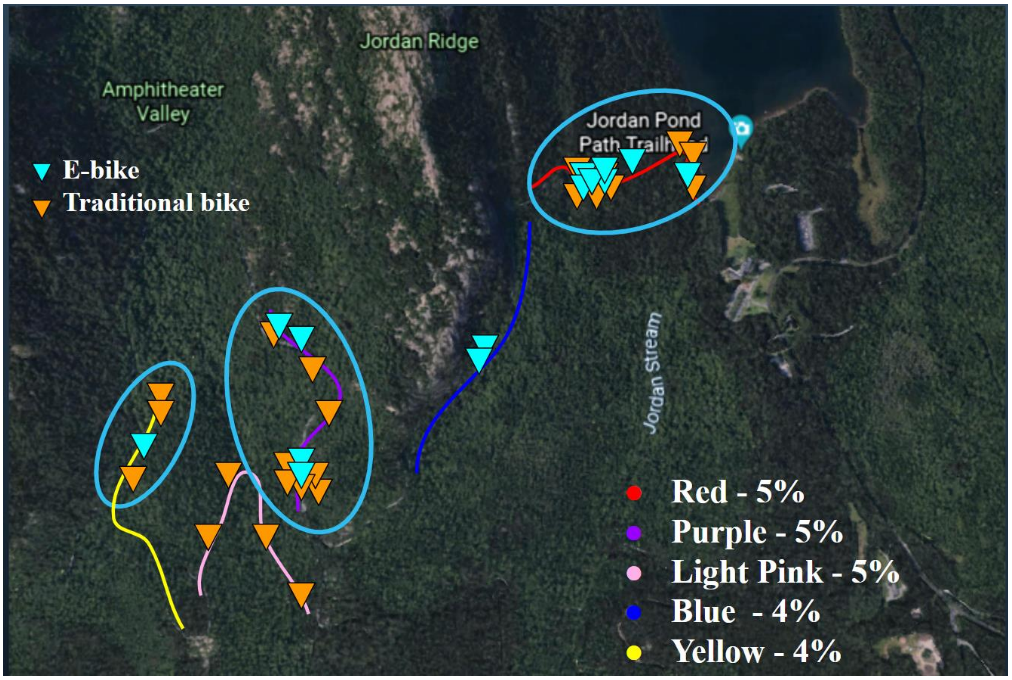
- Determine the most popular areas on the Carriage Roads.
- Understand how people use and experience the Carriage Roads.
- Learn the speeding patterns of traditional bikers and e-bikers.

The team executed multiple methods to gather the necessary information. These methods were, utilizing Streetlight (big data) and Google Earth, observation, interviews, and GPS tracking through data loggers. Drawing on the data from these methods, the team highlighted three key findings.

The first finding was determining that the Witch Hole Pond loop and the Amphitheater loop were the optimal places to hand out data loggers on the Carriage Roads, while considering several Carriage Road closures. They each had ~9% of all bike traffic, making them the third and fourth most popular Carriage Road loops, after the road closures. In addition to this, the Witch Hole Pond loop was the most popular entrance to the Carriage Roads for rented bike traffic, while the Amphitheater loop was popular with pedestrians with ~14% of them coming from the Jordan Pond House. This was discovered through the use of volume entrance analysis on the Streetlight software and a terrain examination done on Google Earth.

The second finding was that more bike education is necessary. Through administering interviews, it was discovered that bike rental shops gave inconsistent interview responses to questions regarding Carriage Road rules. Furthermore, there was non-uniform signage at carriage entrances. These results highlight that bikers are receiving varying levels of education. The lack of consistent education can be solved with an increase and standardization in biker education.

The third finding was that the majority of bikers speed on the Carriage Roads. Using the GPS data loggers, the team noted that a similar percentage of traditional bikers and e-bikers sped in different areas of the Carriage Roads. Both the Amphitheater loop and Witch Hole Pond loop had significant numbers of speeding, 88% of bikers and 39% of bikers, respectively. A map of the Amphitheater loop and the exact locations where bikers sped is shown below.



The team broke the Amphitheater loop into segments based on elevation changes to correlate speeding with the terrain. The key shows their slopes expressed as percentages. Speeding clusters were also discovered and are defined as areas in close proximity where four or more bikers sped and are represented by the circles. The speeding clusters occur in segments with a slope of 4% or greater. This condition also held true for the Witch Hole Pond loop.

These findings led the team to make three recommendations for the park;

1. **Improve bike education for Carriage Road visitors**
    - Bike rental stores should have a uniform and clear protocol for sharing bike Carriage Road rules with their customers
    - The park should offer weekly interpretive activities on bike safety and awareness on the Carriage Roads
2. **Increase the use of signage**
    - Speeding signs on areas of the Carriage Road with a slope of 4% or greater
        - Specifically address the Amphitheater loop by placing speeding signs in speeding cluster areas
    - Place uniform and straightforward signs with Carriage Road rules at the main entrances of the Carriage Roads
3. **Continue to monitor the usage of e-bikes**
    - Continued usage of data loggers
    - Study on the environmental impact of e-bikes
    - Study on e-bikes' impact on Carriage Road user conflicts

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1.0 Introduction

National Parks are unparalleled in their beauty and national heritage. For this reason, it is an American tradition to visit National Parks (US department of the interior, 2018). In fact, from 2010 to 2019, parks have seen an increase from 281 million visitors to 327 million visitors. As the number of visitors continues to increase, the NPS needs to adapt their policies and procedures to address the increased demand while still protecting the park experience. With so many visitors, every change must be carefully considered. In 2019, e-bikes were introduced to National Parks across the United States. The NPS created a blanket policy for e-bike use across all of the parks. Many people are concerned about the unintended consequences of this policy and believe more research on the impacts of e-bikes in national parks is necessary.

Acadia National Park, established in 1916, was created to protect the natural beauty of the headlands along the Atlantic shore of the United States (Foundation Document for Acadia National Park, 2016). One of Acadia's attractions are their famous Carriage Roads, created for non-motorized vehicles such as horses, bicycles, and pedestrians. Like all other national parks, Acadia recently began allowing the use of e-bikes. Since the Carriage Roads are the largest and best kept broken gravel roads in the United States (U.S. National Park Service), some believe they are in need of their own specialized e-bike policy to regulate their use.

Our goal is to provide information that will help Acadia National Park make an informed decision around any needed changes to the existing e-bike policy. Acadia National Park currently has an e-bike policy, but it was created in a short-time frame with little understanding of the impact of e-bikes on the Carriage Roads. Acadia National Park seeks to create an updated and improved policy for e-bikes to keep the users, locals, and surrounding visitors safe while on parklands.

This report outlines our work on this project. The background chapter discusses the impact of e-bikes and why an updated policy is needed at Acadia National Park. After which, the method chapter will elaborate on the team's objectives and how they will be executed using a variety of data collection techniques including the use of Streetlight software, Google Earth, GPS data loggers, observations, and interviews. Then, the team's findings chapter will present the synthesized results from each method and a related discussion with supporting research. The final chapter will state the team's recommendations for Acadia National Park.

2.0 Background

E-bikes are a massive emerging technology with 40.3 million e-bikes expected to be sold globally in 2023 (Wild & Woodard, 2019). While the majority of e-bikes are used for transportation, there has been a rise in e-bikes for recreational use, especially among older demographics as e-bikes are able to provide many of the same health benefits as traditional biking, while reducing some of the obstacles of traditional bikes such as time and convenience (Hoj, 2018). Their usage is rising in popularity in park and conservation lands, since the pedal-assist and decrease in strain associated with biking enables participants to bike farther with less strain (Cauwenberg et al., 2019). There are three different classes of e-bikes. Figure 1 details each class of e-bike, whether it has pedal-assist, a throttle, and the top speeds attainable with those features. These features reduce strain and fatigue on the rider, making it "possible for more people to ride a bicycle and generate more and longer trips" (Nielsen et al., 2019).

Figure 1
E-bike classes

	Class 1	*Class 2*	*Class 3*
Pedal-assist	Yes	Yes	Yes
Throttle	No	Yes	No
Speed (mph)	20	20	28

Note. (Juiced Bikes, 2021)

2.1 E-bike Impacts

According to the American Hiking Society (AHS), there are specific impacts that class 1 and class 2 e-bikes have on trails. These impacts can be summarized as environmental, safety, and trail user experience. E-bike policy is formed to regulate these impacts (AHS, 2017). Currently the research on the environmental impact of e-bikes on trails is inconclusive. Some studies have found that "on turns and grade changes in the trail, the eBikes[class 1 and class 2] had more of a physical impact on the soil than did muscle-powered bikes." (AHS, 2017, p. 2). Another study found that class 2 e-bikes may not be suitable for one-way mountain bike sized (singletrack) trails because they have been shown to pose greater physical damage to trails due to the throttle assist (Repanshek, 2019). However, other sources argue that "there is not much research on the impacts of e-bikes on physical trail conditions. The only study to date found that soil displacement resulting from eMTBs was not significantly different from mountain bikes, and both kinds of bikes cause significantly less damage than dirt bikes." (Nielsen et al., 2019). It is clear that the impact on the environment caused by e-bikes is an essential component of policy development that needs further research.

E-bikes also have an impact on safety. In fact, according to the League of American Bicyclists, 72% of Americans said their top concern was safety in an e-bike study (Nielsen et al., 2019). Part of this concern comes from the fact that their quiet motor and potential for high speed "surprise[s] other… users" (Haustein & Møller, 2016). Also, e-bikers' ability to travel faster, farther, and carry equipment can lead to safety problems for pedestrians who are traveling much slower than the e-bikers (Nielsen et al., 2019). However, 42% of e-bike riders in North America said their bike helped to avoid a crash (Nielsen et al., 2019). Be that as it may, when they did crash, e-bikers were more likely to be sent to an emergency department than traditional bikers (Schepers et al., 2014).

E-bikes have an impact on the trail user experience, which includes e-bikers and all other Carriage Road users. The trail user experience encompasses the behavior of e-bikers and how that affects other road users. According to a study, e-bikers tend to be unaware of the rules and have a risk-taking attitude (Wang et al., 2018). Another study found that e-bikers were prone to observe and enjoy their surroundings (Wild & Woodard, 2019). These two sources highlight factors that make e-bikes enjoyable for the rider, but concerning for other road users. This impacts the trail user experience. The attitude of e-bikers and traditional bikers are different and have an impact on road/trail users as well. In a study on the movements of e-bikers, researchers found that e-bikers and traditional bikers react and act very differently. “Cyclists brake harder on e-bikes than on traditional bicycles, even when riding at the same speed, suggesting that e-bikes induce reactive (as opposed to proactive) braking to avoid conflicts” (Huertas-Leyva et al., 2018). While this study was done in an urban environment, the same habits could cause injury to the rider or nearby pedestrians on a gravel Carriage Road. The perspective and impact on pedestrians on the Carriage Roads is also an important aspect to consider. Research has shown potential for increased conflict with walkers, hikers, and traditional bikers who encounter e-bikes (Chaney et al., 2019). Also, negative experiences have been reported from these instances such as being startled from behind or not feeling safe using the same trail with excessive speed of bikes (Stafford & Daigle, 2020). It appears that pedestrians maintain a similar relationship to e-bikes as they do conventional bikes. They frequently cite concerns about the speed, safety, and on-trail etiquette of e-bikes (Nielsen et al., 2019). These studies show that road/trail user experience is impacted by e-bikers and therefore should be considered in policy development.

2.2 Acadia National Park

Acadia National Park was established in 1916 to preserve approximately 50,000 acres along the mid-section of the Maine coast. The park includes glaciated coastal and island landscapes, an abundance of habitats, a high level of biodiversity, clean air and water, and a unique cultural heritage (Foundation Document for Acadia National Park, 2016). Rich in history, Acadia was formed from the visions and donations of citizens, including wealthy landowners from Maine. One notable individual, John D. Rockefeller Jr., played a critical role by building the famous Carriage Roads designed for horse riders and horse-drawn carriages (Hartford, 2020).

The Carriage Roads include 45 miles of rustic broken-stone road, a type of road commonly used at the turn of the 20th century. The various routes and intersections on the Carriage Roads appear in Appendix A. The Carriage Roads are a result of Rockefeller’s vision (NPS, 2020). They represent an important aspect of the park’s history, and the park spends substantial resources maintaining and protecting them. An iconic attraction of the park, the Carriage Roads are at the core of what makes Acadia unique. They provide an escape from the world as one is transported back in time described in the following passage. “I had been walking for only a few minutes but could already feel the pressure of civilization being left behind. With each turn, the Carriage Road took me father from the complex world of human discord, into one of simple, natural harmony.” (Thayer, 2002, p. 7) Many locals cherish the roads and feel as though they are an important part of the park's appeal. Given the delicate nature of the Carriage Roads, many feel it is vital that they are protected from excessive wear and tear.

According to the 2016 research study done by Jacobi, an estimated 54,631 visitors used the Carriage Roads in July of 2014, and an estimated 63,488 visitors used the roads the following month. The study found that there is a yearly increase of Carriage Road use by visitors (Jacobi, 2016). With an increase of visitors using the Carriage Roads and a rise in e-bike popularity, it is inevitable that there will be an increase of e-bike users in the park.

The NPS Policy Memorandum 19-01 describes the rules that pertain to e-bikes and traditional bikes in national parks (NPS, 2019). According to the policy, e-bikes and bicycles are allowed to be used in similar manners. The memorandum states that e-bikes are only authorized in places that allow traditional bikes and areas that allow motor vehicles. In addition to this, e-bikes must follow the same rules as traditional bikes. For example, e-bikes must follow the same right of way rules as traditional bikes and obey the same speed limit (NPS, 2019). The policy leaves room for the national park's superintendent to impose rules for e-bikes and traditional bikes while ensuring that the state law is followed. In executing this policy, National Parks are allowed to tailor the policy to reflect their own needs and unique qualities. The ability to change the policy as needed, is crucial given Acadia National Park's situation.

2.3 Bikes and Policy in Acadia National Park

Two years ago, concern grew when e-bikes were introduced to the Carriage Roads. Since their inception in 1913 the Carriage Roads have not allowed motorized vehicles, but many believe e-bikes fall into a gray area. This has led to a divide between those who think e-bikes belong on the Carriage Roads and those who do not. Although there is an e-bike policy specific to Acadia National Park, it is believed by many that the policy was created without taking into consideration the unique aspects of the Carriage Roads in the park.

To understand this concern, knowledge of the current e-bike policy is needed. The policy for traditional bikes in Acadia serves as the base for e-bike policy. Figure 2 outlines the general biking policy and safety rules for Acadia National Park. Although all Carriage Road bikers must follow the 20 MPH speed limit, it has been claimed that e-bikes can go consistently faster than traditional bicycles and pose different threats, causing them to require a separate policy (on behalf of Cohen Law Partners, 2019).

Figure 2
Bicycling rules and courtesy

Note. (NPS, 2020)

2.4 Current E-bike Policy in Acadia National Park

E-bike users must follow the same policies as traditional bike users, but have some added rules. Only class 1 bikes are allowed on the Carriage Roads while class 2 and 3 are prohibited. Also, all classes of e-bikes as well as regular bikes are allowed on roads with motorized vehicles (NPS, 2019). As mentioned before, the characteristics of all three e-bike classes are shown in Figure 1.

Friends of Acadia (FOA), is a nonprofit organization that is dedicated to assisting and preserving the park. They believe there must be further understanding of the impact of e-bikes on the park before developing and implementing policy. They said:

> It is extremely challenging to apply a national-level policy like this [memorandum 19-01] within thirty days across hundreds of unique national park units, each with its own

history and special features...FOA believes that the park would benefit from a broader community conversation and a chance to hear from the public, including Carriage Road users – walkers, equestrians, traditional bicyclists – before determining whether this directive must be implemented as is, or whether it can be waived, modified, or scaled back to best apply here at Acadia (Friends of Acadia, 2021).

Clearly, FOA believes that insufficient information has been gathered. The missing information stems from a lack of multiple perspectives and insufficient time to comment.

FOA is not the only group that wants to monitor and collect more information on the e-bike situation. Acadia National Park officials say that they "plan to monitor the use of e-bikes so they can assess any impacts on the visitor experience, park resources and facilities." (Broom, 2019).

Furthermore, Public Employees for Environmental Responsibility (PEER) are suing the Department of the Interior and challenging the legality of the NPS e-bikes approval policy. In essence, the suit would bar e-bikes from park backcountry where motorized transport is otherwise forbidden. Claiming that the NPS order was issued by an official who was illegally serving as "acting" Director and had no legal power to issue such an edict. PEER and a coalition of groups filed a suit to strike down this illegal order (PEER, 2021).

To respond to the concerns of the officials of FOA and the park, the team collected public opinion on e-bike usage in the park from a variety of stakeholders, including walkers, equestrians, bicyclists, e-bicyclists and other Carriage Road users, in addition to park and FOA leadership. It is our hope that this information will contribute to developing a comprehensive e-bike policy.

3.0 Methodology

The goal of this project was to gather and present information that will help Acadia National Park make informed changes to the existing e-bike policy. The team completed multiple objectives to collect information from stakeholders including park staff, volunteers and visitors. These objectives are outlined below.

1. Determine the most popular areas on the Carriage Roads.
2. Understand how people use and experience the Carriage Roads.
3. Learn the speeding patterns of traditional bikers and e-bikers.

3.1 Streetlight (Big Data)

The team wanted to determine where people travel on the Carriage Roads. This information is useful because it helps determine locations for data logger distribution and which areas are the most crowded. The big data program, Streetlight, was used for this purpose. Streetlight analyzes traffic data collected from smartphones across North America (StreetLight Data, 2021). We analyzed 77 segments of the Carriage Roads to determine traffic patterns using their algorithm and large dataset. These analyses identified the entrance volumes, which segments were most used by bikes, and which segments were most used by pedestrians. These two analyses were then cross-referenced to find the intersection of the Carriage Roads that were popular among bikers and pedestrians.

Additionally, to better understand the popularity of Carriage Road entrances, one more analysis was done using Streetlight. This analysis evaluated the eight rental locations on Mt. Desert Island, taking into account all 10 entrances to the carriage, focusing on the traffic entering the Carriage Roads based on the rental locations. This analysis was done to highlight the times bikers enter the Carriage Roads, their distribution between all Carriage Road entrances, and the percentage of bikers from rental stores arriving at each Carriage Road entrance.

3.2 Observation

The team also collected data on bike users and their habits. Topics such as how many bikers are following helmet rules will help the team decide if a specific issue needs to be addressed. The data was collected using a naturalistic observation technique performed at the Witch Hole Pond loop and the Amphitheater loop. The team recorded over 24 hours of observation, separated into 15-minute intervals. Naturalistic observation involves studying the spontaneous behavior of participants in natural surroundings. The naturalistic observation topics are organized into the chart in Figure 3. The chart helped present the information in a digestible manner.

Figure 3

Naturalistic Observation Data

Time	E-bikes	T-bikes	Helmets	Park Rangers	Incidents
1:15-1:30	2	5	7	-	-
1:30-1:45	-	-	-	1	-
1:45-2:00	2	13	13	-	-
2:00-2:15	9	19	26	-	-

3.3 Interviews

The team conducted 33 interviews with Carriage Road users. The team used semi-structured interviews to collect park visitors' opinions on how e-bikes impact their experiences, act on the Carriage Roads, and affect safety. Semi-structured interviews have specific guiding questions that allow the interview to flow more like a normal conversation (Berg, 2001). For an outline of the interview, reference Appendix B and Appendix C, these include interviews that are identical, but phrased depending on the respondent. The team coded the completed interviews and analyzed them using Schmidt's five stage process (Flick, 2004).

In addition to interviewing Carriage Road users, the team interviewed 4 bike rental stores to gain insights on the experience level of the typical e-bike user, and the information provided to renters before going on the carriage trails. Similarly, to the previous interview, a semi-structured format was used (Berg, 2001). The interview script can be referenced in Appendix D. Schmidt's five stage process was used to code the interviews (Flick, 2004). The team then went to the main entrances of the Carriage Roads to observe what information was provided to bike users by the park, and how it aligned with the information given by the rental stores.

3.4 GPS Data Loggers

The team also wanted to learn the speed traditional bikers and e-bikers go and how that relates to different terrains. Data loggers were used to record these patterns. Data loggers are electronic devices that automatically monitor and record environmental parameters such as speed, distance, and location. Data loggers allow these conditions to be measured, documented, and analyzed (Tinytag, 2021). The data loggers used were the Canway Canmore GPS data loggers. The loggers track speed, elevation, and location, by pinging the logger's location every time a custom condition is met. The loggers used were set to ping location every second after they were turned on, to maximize the precision of the data retrieved. A test run completed in Worcester by the team shows that the data logger is easy to use and collects the needed information. Appendix E illustrates this test.

Streetlight and Google Earth were used to determine the data logger distribution locations. The distribution locations needed to be in popular areas and include a variety of elevations and turns in order to efficiently obtain data. First, a refined version of the Streetlight analysis from section 3.1 was done, taking into account the Carriage Roads that were currently closed. Figure 4 shows a map of all of the closed Carriage Roads.

Figure 4

Map of closed Carriage Roads

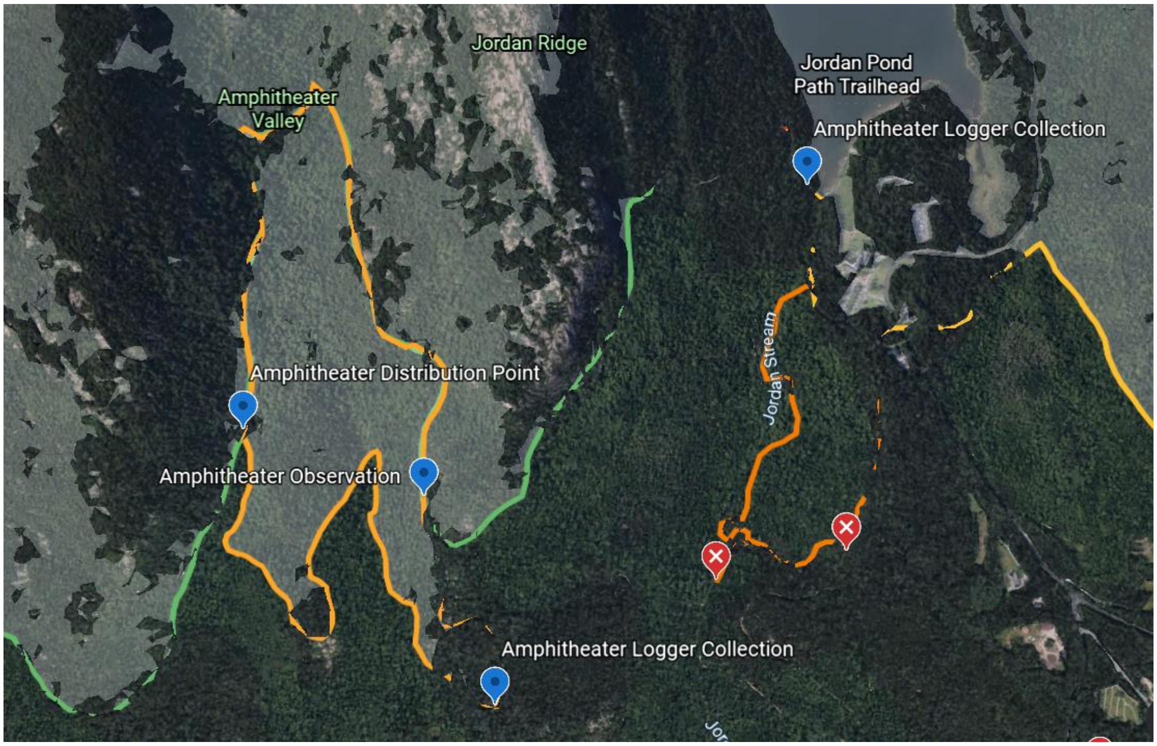
Note. (NPS, 2021)

Then, Google Earth was used to visualize the locations found on Streetlight. Google Earth is a "geobrowser that accesses satellite and aerial imagery, topography, ocean bathymetry, and other geographic data over the internet to represent the Earth as a three-dimensional globe" (What is Google Earth, 2020). The geobrowser was used to ensure the locations found on Streetlight included the desired changes in elevation and sharp turns. Google Earth was then used to determine team member placement at Carriage Road entrances and exits to prevent the loss of data loggers.

Our analysis led the team to distribute data loggers at the Witch Hole Pond loop and the Amphitheater loop. For example, at the Amphitheater loop team members were placed near the blue pins in Figure 5 in order to distribute and retrieve data loggers. The red pins in Figure 5 mark the beginning of private Carriage Roads. The data logger distribution procedure can be seen in Appendix F.

Figure 5

Amphitheater GPS data logger collection and distribution points



During the 4 weeks of data logger distribution, the team distributed 16 data loggers, capturing 111 trips spanning over 600 miles, including 46 e-bikers and 65 traditional bikers. All trips were organized into a chart with categories that include total average speed (MPH), max speed (MPH), total distance (miles), speed change (MPH), time (seconds), and deceleration (feet/second^2). Furthermore, to understand which slopes are prone to biker speeding, the team divided up the routes around the Witch Hole Pond Loop and the Amphitheater loop based on elevation. The divisions were done using Google Earth and can be seen in Figure 6 and Figure 7. The numbers in the key in Figure 6 and Figure 7 show the elevation change for each colored segment.

Figure 6

Divided Areas in Regions - Witch Hole Pond Loop

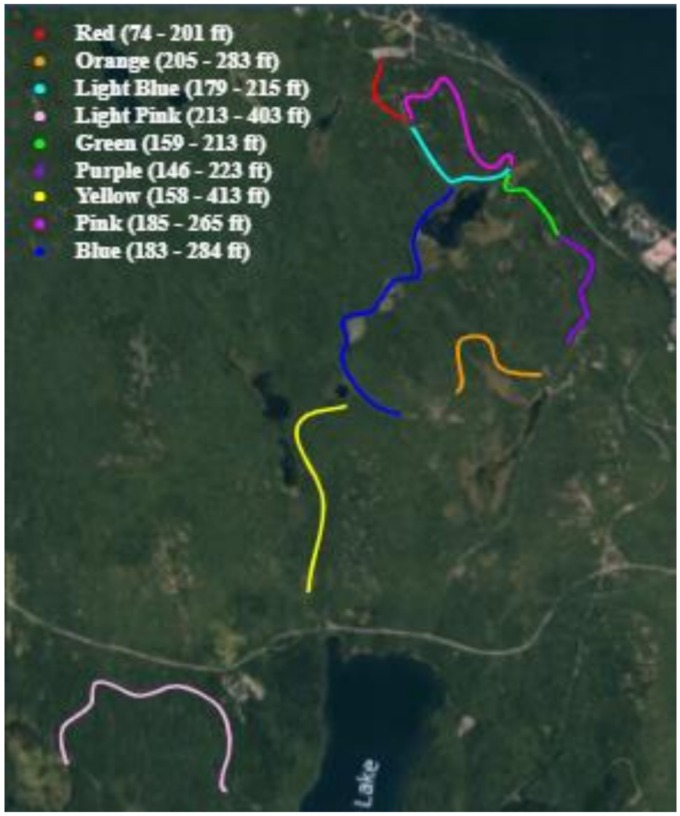
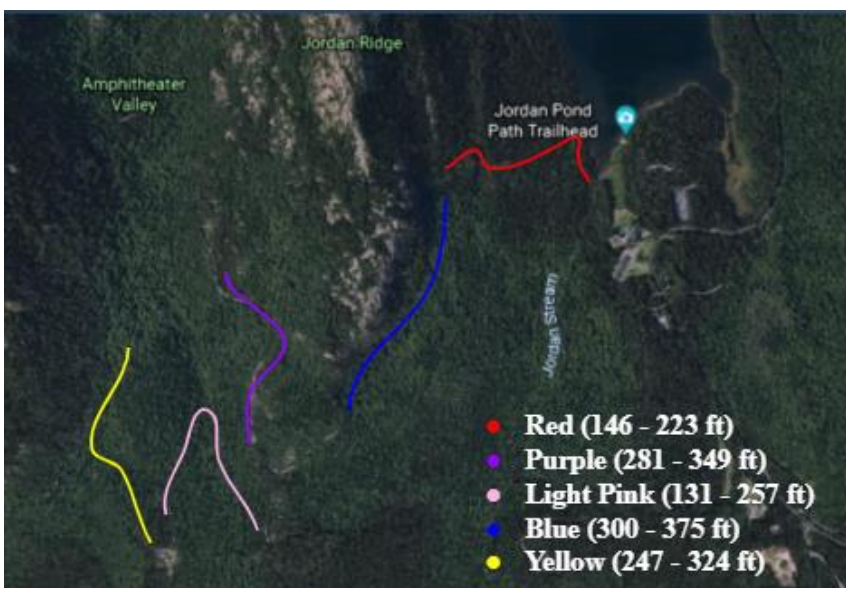


Figure 7

Divided Areas in Regions - Amphitheater Loop



4.0 Results: Findings and Discussion

This chapter discusses what we learned from our methods, such as speeding on the Carriage Roads and the education level of bikers. Drawing on the data from multiple methods, the team will highlight key findings and discussions.

Finding 1: The Witch Hole Pond loop and Amphitheater loop were the optimal places to obtain data on the Carriage Roads

The characteristics of the Carriage Road loops were analyzed and compared to find the optimal locations for data collection. The first characteristic analyzed was the distribution of bike traffic on the Carriage Roads. For the Streetlight analysis, the Carriage Roads were divided into 77 sections, the results of which are outlined in Figure 8. The most popular sections of the Carriage Roads were the Jordan Pond loop, the Eagle Lake loop, and the Around the Mountain loop, however they were all closed, or partly closed in the case of the Around the Mountain Loop, during the study period. As a result we focused on the Witch Hole Pond and Amphitheater loops which were the most popular loops accounting for the closures, with each receiving 9.35% of all bike traffic, as seen in Figure 8.

Figure 8

Streetlight Analysis of Pedestrian and Bike Traffic

Location	Distribution of Bicycle Traffic	Distribution of Pedestrian Traffic	Situation
Jordan Pond Loop	43.22	25.29	Closed
Eagle Lake Loop	`26.5	5.55	Closed
Around the Mountain Loop	21.9	19.16	Partly Closed
Witch Hole Pond Loop	9.35	3.02	Open
Amphitheater Loop	9.35	14.71	Open
Day Mountain Loop	7.12	12.79	Open
Hadlock Loop	5.61	16.05	Open

Note. The table was created using Streetlight Analyses of the Carriage Roads. It lists the percentage of all pedestrian and bike traffic on the Carriage Roads that pass through each loop, also noting whether they were open at the time of data collection.

To get a better understanding of the impact of e-bikers on the experience of other trail users, it was important for both observation and interviews that a good mix of bikers and pedestrians would be present using the trails. The team found that identifying the locations popular among pedestrian and rented bike traffic would help ensure a high probability of e-bikes and pedestrians being present during the study period, enabling the team to monitor any interactions taking place. The Jordan Pond entrance, which leads to the Amphitheater loop, had only 4.56% of rental traffic, but was much more popular among pedestrians, with 14.71% of all pedestrian traffic, from Figure 8. Making it a good location for biker-pedestrian interactions.

The third characteristic analyzed was the distribution of bicycle traffic entering the Carriage Roads based on all the rental locations on Mt. Desert Island. This allowed for the placement of our team to encompass locations popular among rented bike traffic. The result of the analysis is outlined in Figure 9. From Figure 9, the most popular entrance is the Hulls Cove entrance for rented bikes with 25.77% of rented bicycle traffic. The duck brook bridge, Hulls Cove entrance, and Witch Hole second entrance are all part of the Witch Hole pond loop.

Figure 9

Bike Rental Traffic Matrix Into the Carriage Roads

Origins	Duck Brook Bridge Entrance	Eagle Lake Turnoff Entrance	Hulls Cove Entrance	Jordan Pond House Entrance	Witch Hole Second Entrance	Total
Acadia Bike Rentals	3.03	3.03	0	0	3.03	9.09
Acadia Outfitters	4.55	4.55	1.52	0	4.55	15.17
Bar Harbor Bicycle Shop	6.06	4.55	1.52	1.52	4.55	18.2
Island E Bike Rental Drop Off	6.06	7.58	21.21	1.52	7.58	43.95
Pedego Electric Bikes Bar Harbor	3.03	4.55	1.52	1.52	3.03	13.65
Total	22.73	24.26	25.77	4.56	22.74	100.06

Note. Figure 9 shows the percentage of bike traffic originating by rental location to each entrance on the trails. Origins and destinations with no bike traffic were removed from the table. The left column is the origins, and the top row is the destinations. The right column shows the sum of traffic distribution by origin, while the bottom row shows the sum of traffic distribution by destination.

Another factor in choosing the primary data collection was the characteristics of the Carriage Road and terrain in the loops. Using Google Earth, the Witch Hole Pond loop was determined to be a good mix of steep inclines and flat stretches of road. Figure 10 shows a map of the Witch Hole Pond loop. The map is divided into colored segments based on changes in elevation. The key on the map shows the slope percentage corresponding to each of the segments. The Witch Hole Pond loop has a variety of slopes ranging from 2%-9%, with 9% being the largest slope among our data collection areas. The Amphitheater loop also proved to be a good data collection location based on its consistently high slope terrain. Figure 11 breaks the Amphitheater loop up by changes in elevation and shows the slope percentage in the key. The Amphitheater loop's slope percentage had a smaller range of values than the Witch Hole Pond loop, but always stayed at 4% or above.

Figure 10
Witch Hole Pond divided by slope

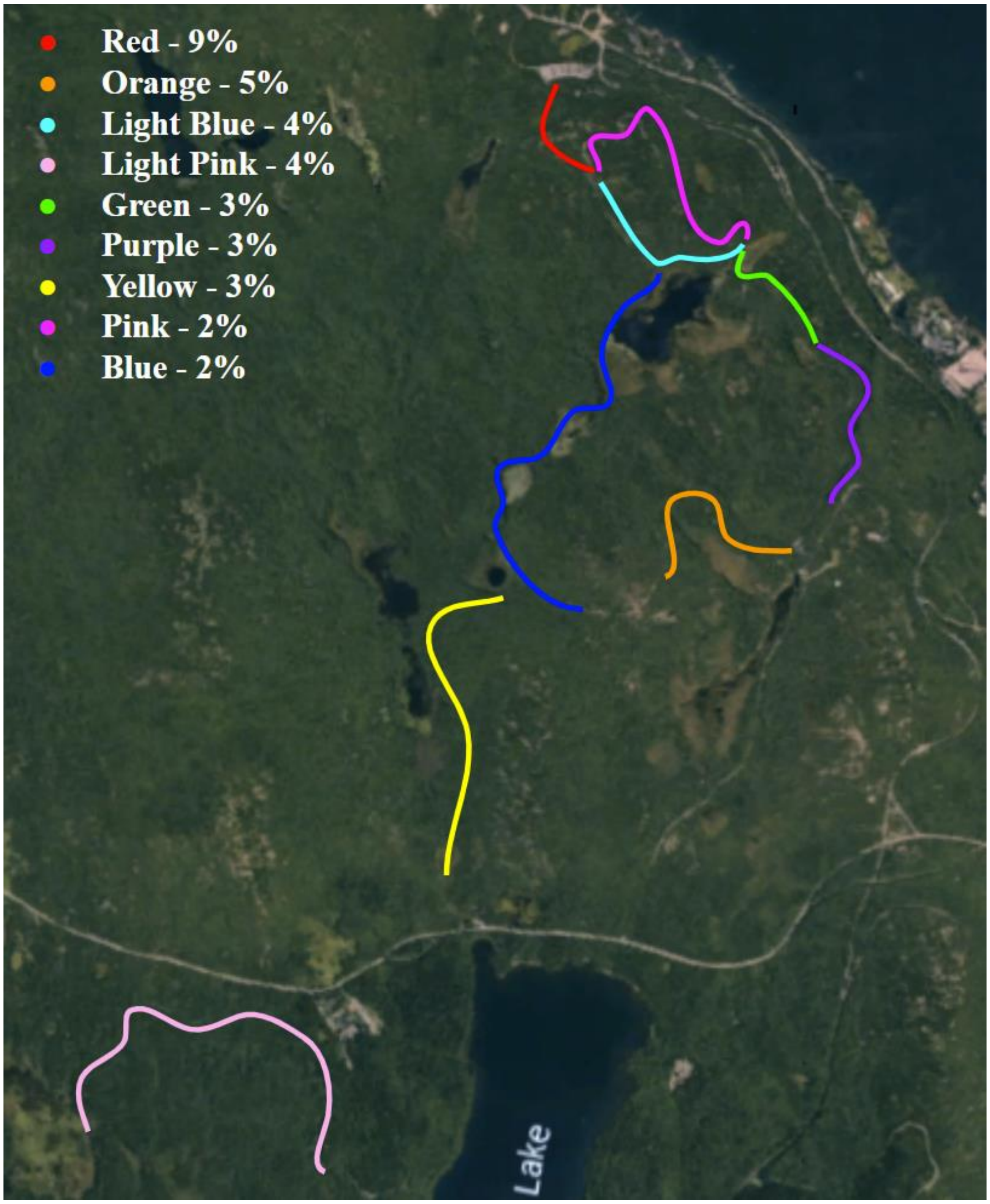
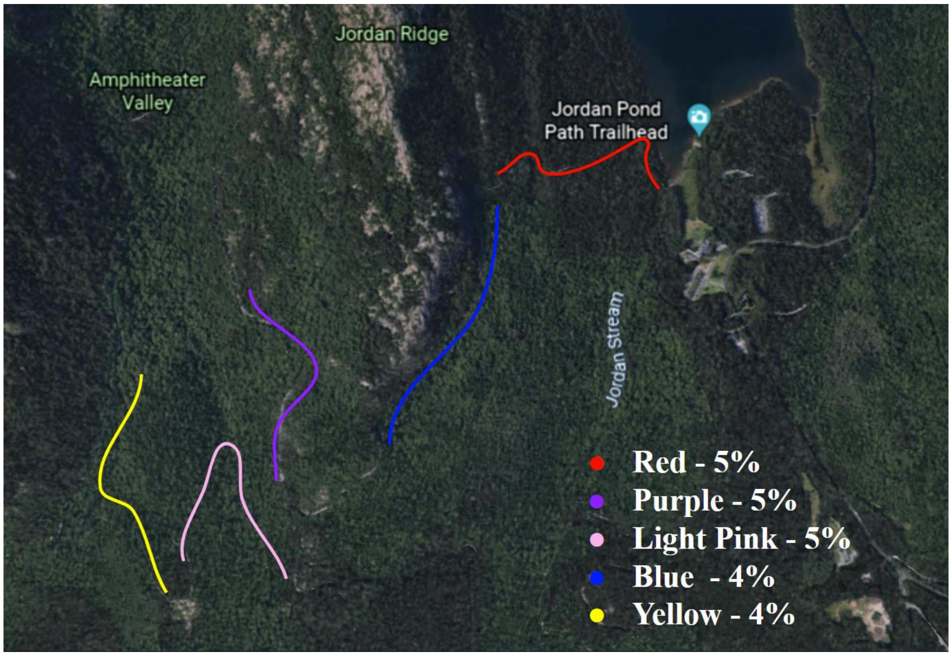


Figure 11
Amphitheater loop divided by slope



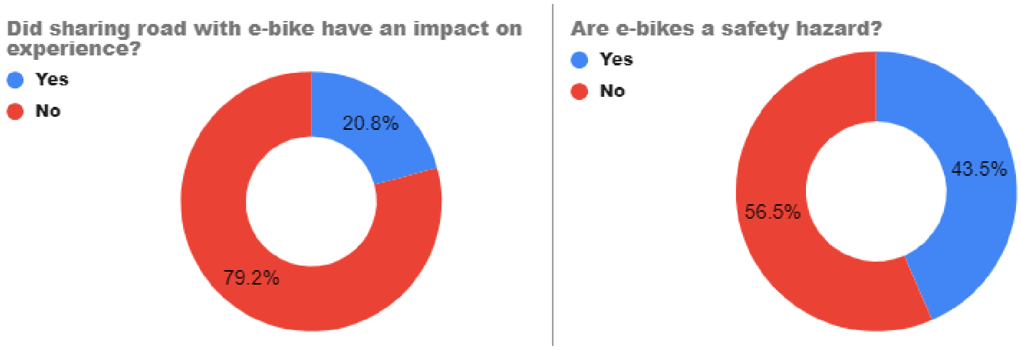
Drawing from all these factors, the optimal locations for data collection were found. First, Witch Hole Pond loop, for its range of terrain, popularity with rented bikes and large percentage of total bike traffic. The second location, the Amphitheater loop, was picked for its popularity among bikers and pedestrians as well as its consistently large slopes.

Finding 2: Bike education is necessary

The team determined that bike education is necessary. This finding is supported by four key results. The first reason bike education is needed is because there is a bias from visitors on the Carriage Roads towards e-bikers. The interviews given to visitors suggested this bias. When the respondents were asked if sharing the road with e-bikers impacted their experience, the majority of them said that e-bikers had no impact. However, when the respondents were asked if e-bikers were a safety hazard, slightly less than half of them said yes, as shown on Figure 12.

Figure 12

Experience and safety hazard of e-bikes



This implies that some of the respondents believe e-bikers have a negative impact on safety, even though their experience was not impacted. This shows that a significant amount of Carriage Road users have a bias against e-bikers, that is not supported by their experience. Education is needed to remove this bias against e-bikes, which may help future research on this topic, helping to reduce the amount of negative feedback based on incorrect assumptions.

The second result showing that bike education is needed is because bike rental shops do not have a standardized process for e-bike education. This was determined through interviews administered by the team. From Streetlight, the team determined that Acadia Outfitters, Acadia Bike Rentals, Pedego Electric Bikes Bar Harbor, and Bar Harbor Bicycle Shop were the most popular shops that had bikers traveling from their store to the Carriage Roads. The relevant interview question responses are shown in Figure 13, and the rest are shown in Appendix G.

Figure 13

Bike Shop Interview Matrix

	Acadia Outfitters	Acadia Bike Rentals	Pedego	Bar Harbor Bicycle Shop
Bike safety rules?	Yes	Yes	Yes	No
Sign stating they understand rules/courtesies?	Yes	No	No	No
Opportunity for renters to practice?	No	Yes	Yes	Yes
Percentage of renters that regularly ride bikes/e-bikes?	99%	95 - 100%	75%	50%

The above matrix highlights inconsistencies across the bike stores in their presentation of safety and courtesies to their customers. When asked if they went over bike safety rules and courtesies with customers, only 3 out of 4 responded yes. Then when asked if they had their customers sign a document stating that they understood the rules and courtesies, only 1 out of the four rental shops said that they did. When asked if their renters were provided an opportunity to practice on the bikes before leaving, only 3 out of the 4 locations did so. And finally, the stores, when asked what percentage of the customers they believed were experienced bikers, gave varying answers ranging from 50% to 100%.

Not only do the bike rental stores provide inconsistent information, but so does the signage outside of the 10 main Carriage Road entrances. The team observed four different types of signs that displayed differing Carriage Road rules and courtesies. These signs can be seen in Appendix H. Figure 14 shows which locations had which signs. None of the main Carriage Road entrances had all four signs and the majority of the entrances had less than 3 signs posted. 20% of the entrances were also missing a speed sign that displays the Carriage Road speed limit of 20 MPH. The lack of a speeding sign can allow for bike users to unknowingly speed. This provides further evidence that bikers do not receive consistent information on the rules and courtesies of the Carriage Roads.

Figure 14

Carriage Road Entrance Signage

	Construction Sign	Wooden "Share the Road" Sign	Speed Sign	Rules of the Road Sign
Hulls Cove Visitor Center	Yes	Yes	Yes	No
Duck Brook Bridge	Yes	No	Yes	No
Jordan Pond	Yes	No	No	No
Gate House	No	No	Yes	Yes
Gate House (Across Street)	No	No	Yes	Yes
Eagle Lake Parking Lot	Yes	Yes	Yes	No
Eagle Lake Parking Lot (Across Street)	Yes	No	No	No
Parkman Mountain Parking Lot	Yes	Yes	Yes	No
Brown Mountain Parking Lot	Yes	Yes	Yes	No
Bubble Pond Entrance	No	Yes	Yes	No

All of these results show that bike education is necessary. The Carriage Road user interviews showed a perceived bias against e-bikers. Next, the inconsistent bike shop interview responses and the non-uniform signage highlighted that not all Carriage Road users were informed. These issues can be fixed with bike education.

Finding 3: The majority of bikers speed

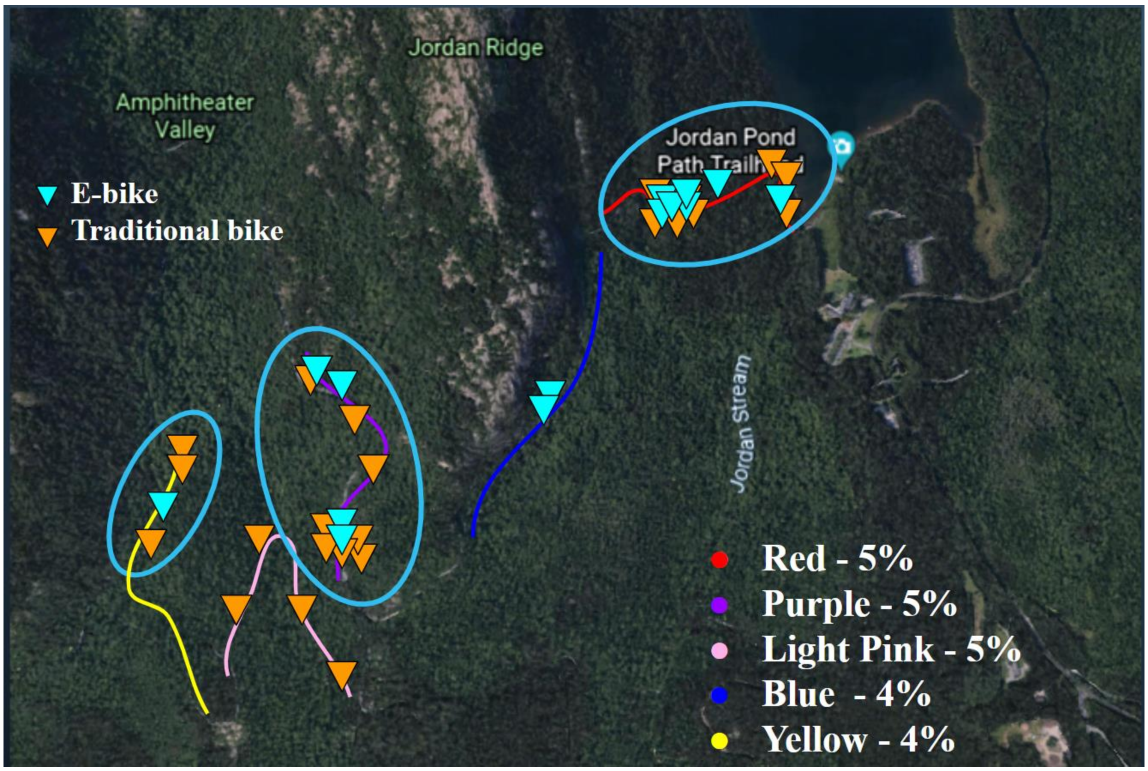
The information collected from the data loggers showed that the majority of bikers speed on the Carriage Roads. In total 59.59% of bikers speed. When broken down in terms of the type of bike, 58.53% of e-bikers speed and 60.34% of traditional bikers speed. This shows that most traditional bikers and e-bikers exceed the 20 MPH speed limit. These numbers can also be analyzed by location.

At the Amphitheater loop, 86.66% of e-bikers and 88.88% of traditional bikers speed. We then broke the Amphitheater loop up into segments based on elevation changes to correlate speeding with terrain. Figure 15 shows these segments, their slopes expressed as percentages, where e-bikers and traditional bikers sped, and speeding clusters. The speeding clusters were defined as areas in close proximity where 4 or more bikers sped and are represented by the circles. This was done to stress the significance of a few of the most prominent speeding locations. Notably, each of these speeding clusters occur in segments with a slope of 4% or greater.

Taking a closer look, 50% of bikers in the red region sped, 9.1% of bikers in the blue region sped, 23.5% of bikers in the light pink region sped, and 46.7% of bikers in the yellow region sped. An interesting aspect to consider is the red segment on the top right of Figure 15 because 50% of bikers in that region sped, it is a speeding cluster, and according to Streetlight, it has a high volume of pedestrians. These characteristics are problematic when put together and create a higher risk for accidents.

Figure 15

Marked Speeding on Amphitheater Loop



A similar analysis was done on the Witch Hole Pond loop. At the Witch Hole Pond loop a similar amount of e-bikers and traditional bikers speed. In fact, 37% of traditional bikers sped and 42% of e-bikers sped.

The Witch Hole Pond loop was also broken up into several segments. The segments were divided based on elevation changes. Figure 16 shows these segments, their slopes expressed as percentages, where e-bikers and traditional bikers sped, and speeding clusters. Using the same speeding cluster definition as the Amphitheater loop, 2 more speeding clusters were circled. Each of these speeding clusters also happened in segments with a slope of 4% or greater. The percentage of bikers who sped in each segment can be seen in Figure 17.

Figure 16

Marked Speeding on Witch Hole Pond Loop

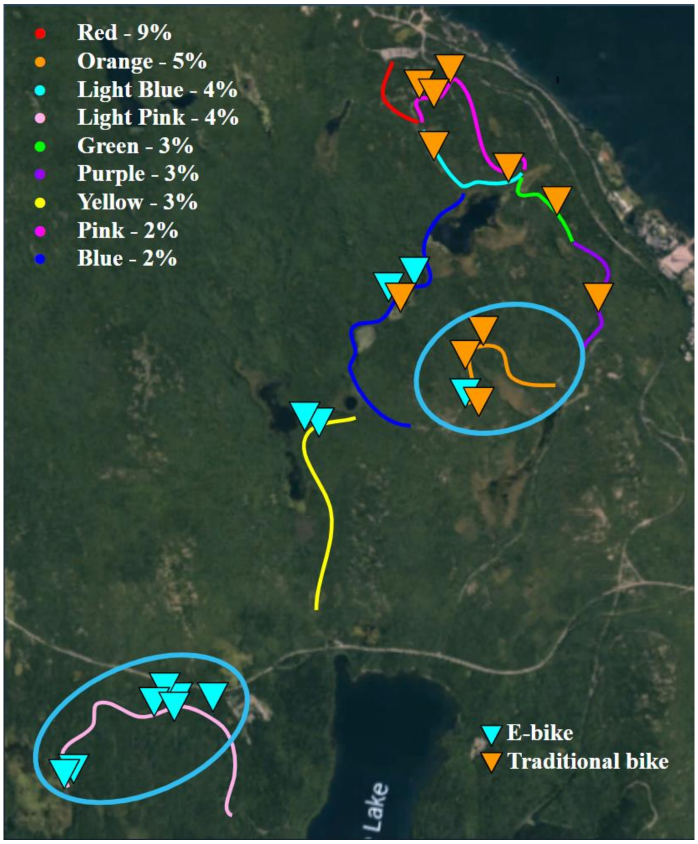


Figure 17

Percentage of Bikes that Sped by Colored Segment

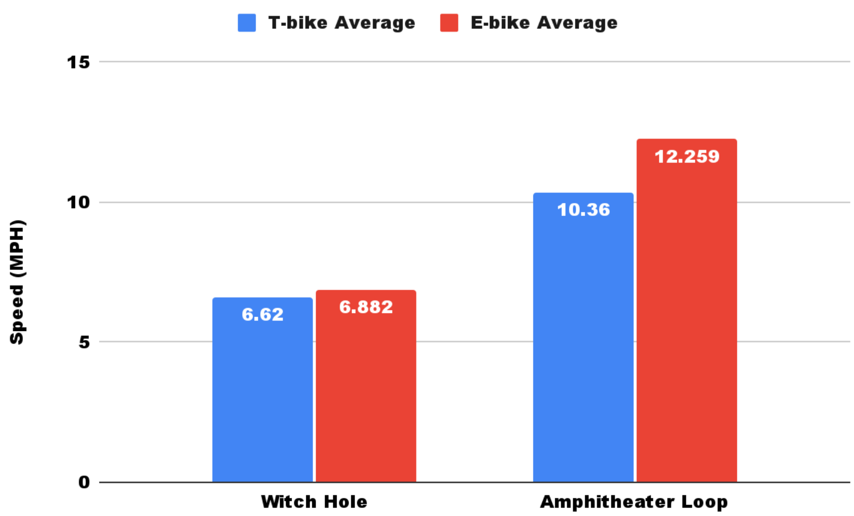
Color Segment	Speed Percentage
Red	0%
Orange	12.8%
Light Blue	4.3%
Light Pink	53.3%
Green	3%
Purple	4.8%
Yellow	6.25%
Pink	26.1%
Blue	7.1%

As seen in Figure 16 and Figure 17, no speeding occurred in the red segment at the beginning of the Witch Hole Pond loop. This segment was the only segment with no bike speeding and had the largest slope out of all the locations we monitored. It had signs that display danger, steep grade, sharp curve warnings, and a speed limit sign at the entrance. This demonstrates a correlation between the use of caution signs and speeding.

It is important to note that although a similar amount of traditional bikers and e-bikers sped, they did not exhibit the exact same speed behaviors. Figure 18 shows that e-bikers have a slightly higher average speed than traditional bikers. This is due to the fact that e-bikes can travel uphill with more ease.

Figure 18

Average Bike Speed



These results show that the majority of bikers on the Carriage Roads are speeding. Through the use of the GPS data loggers, the team noted that a similar percentage of traditional bikers and e-bikers sped in different areas of the Carriage Roads. Bikers speeding is an important finding, and should be addressed.

Discussion

Education is a crucial part of safety. A study done by Acadia National Park highlights recommendations that relate to education (Jacobi, 2016). The four recommendations were, seasonal park staff should be trained about courtesy guidelines and communicate them to visitors at every opportunity, local bike shops should be urged to continue their courtesy guidelines education for bike rental customers, courtesy guidelines should be posted prominently in the park visitor center and other contact areas, and to implement the presence of interpretation and visitor protection staff on the Carriage Roads at the highest level possible (Jacobi, 2016). These recommendations from the 2016 study all suggest that biker education is necessary. In addition, a study done in Jiangsu showed that 50% of traffic accidents involving e-bikes were caused by traffic rule violation behavior (Tang et al., 2020). This illustrates that knowing the traffic rules can help prevent e-bike accidents, and indicates that a lack of bike education on the Carriage Roads can lead to more accidents.

Bike speeding is a hazard and poses a high risk for accidents and injuries. The Baltic Journal of Road and Bridge Engineering conducted a case study on University students in

Montreal about risk taking by young bicyclists. The research done by this study shows that 45% of bicycle related injuries were for excessive speeding, over maneuvering, and violating traffic signals (Amin, 2017). In Norway, Fyhri et al. (2012) estimated a strong correlation between accidents and speed cycling. Additionally, several studies in the United States revealed that high speed was the main reason for over occurrence of bicycle-related accidents (Amin, 2017).

Signage is an effective way to ensure road rules and courtesies are being followed. There are two examples proving that signs are effective in Acadia National Park. The first example, as mentioned earlier in the Findings section, is that no bikers sped on the entrance area to the Witch Hole Pond loop that displays danger, steep grade, sharp curve warnings, and a speed limit sign. The second example is in a past research project in Acadia, students attempted to reduce man-made noises at Thunder Hole. A single sign telling people to reduce their noise pollution was able to reduce total decibel levels by 26.4%, showing that Acadia National Park visitors effectively responded to signs (Weissman et al., 2017). According to a study done in the Journal of the Transportation Research Board on the evaluation of dynamic speed display signs, it was found that average speeds were reduced by 9 MPH in a school speed zone where speed signs were being tested (Ullman & Rose, 2005). The study concludes that speed display signs can be effective at reducing speeds in permanent applications if appropriate site conditions apply.

E-bikes are here to stay. The team's observation showed that the percentage of bikers that were e-bikers increased by over 500% from 2020 to 2021. This year, 16.7% of bikers on the Carriage Roads were e-bikers as opposed to the 3% last year (Wang et al., 2020). In addition to this, according to the Journal of Transport & Health, 40.3 million e-bikes are expected to be sold globally in 2023. With this rise in popularity, it is important for the park to understand where e-biking fits within current mobility patterns (Bourne et al., 2020). Furthermore, the past year's e-bikes research team from WPI stated that Acadia National Park should continue to monitor e-biking activity because they will continue to be present (Wang et al., 2020).

5.0 Recommendations

Drawing on the findings from the team's research as well as the current body of research done on the topic, the team came up with three main recommendations for Acadia National Park. These recommendations address the issue of a lack of education, speeding, and the future of e-bikes in the park.

1. **Improve bike education for Carriage Road visitors**
    - Bike rental stores should have a uniform and clear protocol for sharing bike Carriage Road rules with their customers
    - The park should offer weekly interpretive activities on bike safety and awareness on the Carriage Roads
2. **Increase the use of signage**
    - Speeding signs on areas of the Carriage Road with a slope of 4% or greater
        - Specifically address the Amphitheater loop by placing speeding signs in speeding cluster areas, as shown in Figure 15
    - Place uniform and straightforward signs with Carriage Road rules at the main entrances of the Carriage Roads
3. **Continue to monitor the usage of e-bikes**
    - Continued usage of data loggers
    - Study on the environmental impact of e-bikes
    - Study on e-bikes' impact on Carriage Road user conflicts

Conclusion

Our team arrived in Acadia National Park with the goal of gathering information that would be helpful for the park to make any needed changes to their current e-bike policy. To complete this goal, we performed observation, administered interviews, and distributed GPS data loggers. Our methods led us to discover the optimal locations on the Carriage Roads for data collection, the fact that bike education is necessary, and that the majority of bikers speed. Using these critical insights, we developed three recommendations for the park. They can be summarized as improving bike education for Carriage Road visitors, increasing the use of signage, and the continued monitoring of e-bike usage on the Carriage Roads. Interestingly, these recommendations align with Jacobi's recommendations done in 2016 (Jacobi 2016). Even with the introduction of e-bikes in the park in 2019, Jacobi's recommendations are still relevant because we've found that there is little difference between the behavior of traditional bikers and e-bikers.

As mentioned earlier, the percentage of bikers that were e-bikers increased significantly from 2020 to 2021 in Acadia National Park (Wang et al., 2020). Thus, it's clear that e-bikes are here to stay, and have the potential to change the landscape of the Carriage Roads. Although this project was specific to Acadia, the information collected and methods used remain relevant to all parks and conservation lands.

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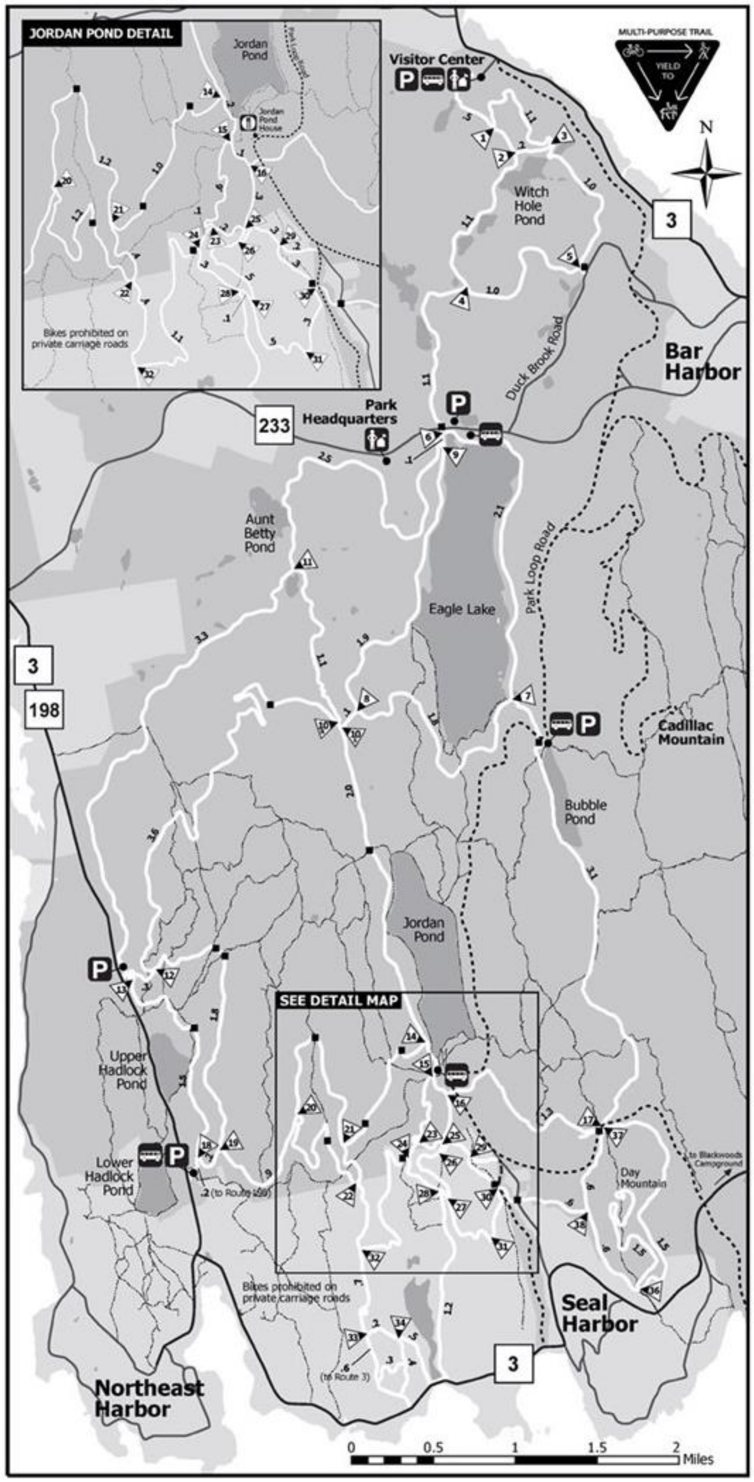
Appendix A: Carriage Roads Map (NPS, 2020)

Below is an official Carriage Road map from Acadia National Park. The carriage routes are highlighted in white, and the intersections of the roads are marked with the numbered triangles.



Appendix B: Interview script outline for e-bike users

Hello, we are a team of students from Worcester Polytechnic Institute in Massachusetts. We are conducting interviews to determine the impact of e-bikes on safety and experience. Our goal is to collect information to provide to Acadia National Park to help them improve the e-bike policy. Can you help us? This interview is confidential. You can skip any question at any time, also you can opt-out at any time. Our team email is gr-e-bikes@wpi.edu, and our project advisor's email is cbkurlanska@wpi.edu if you need to contact us.

E-bike User - Interview Questions
1. Do you own or did you rent this e-bike? How long do you have it for?
2. How did you get your e-bike here?
3. Where have you been on your e-bike?
4. Did being on an e-bike have an impact on your experience in the park? How did it change your experience?
5. Currently the park only allows class 1 e-bikes on the Carriage Roads. They are expected to follow the same rules as regular cyclists. Based on your experience in the park, do you think that there should be separate or different regulations for e-bike users? Yes/No Why?
6. Have you ever seen or experienced an accident on the Carriage Roads caused by an e-bike? Yes/No
(If yes) Can you elaborate on what happened?
7. Based on your park experience, do you think e-bikes are a safety hazard? Yes/No Why? And how do you think it could be reduced?
8. What do you think the park should do about e-bike usage on the Carriage Roads?

Appendix C: Interview script outline for all other park visitors

Hello, we are a team of students from Worcester Polytechnic Institute in Massachusetts. We are conducting interviews to determine the impact of e-bikes on safety and experience. Our goal is to collect information to provide to Acadia National Park to help them improve the e-bike policy. Can you help us? This interview is confidential. You can skip any question at any time, also you can opt-out at any time. Our team email is gr-e-bikes@wpi.edu, and our project advisor's email is cbkurlanska@wpi.edu if you need to contact us.

All Other Park Visitors - Interview Questions
1. Have you encountered/noticed any e-bikes in the park?
2. Where did you see e-bikes in the park?
3. Did being around or sharing the road/path/Carriage Road with an e-bike have an impact on your experience in the park? Did it make an impression on you?
4. Currently the park only allows class 1 e-bikes on the Carriage Roads. They are expected to follow the same rules as regular cyclists. Based on your experience in the park, do you think that there should be separate or different regulations for e-bike users? Yes/No Why?
5. Have you ever seen or experienced an accident on the Carriage Roads caused by an e-bike? Yes/No
(If yes) Can you elaborate on what happened?
6. Based on your park experience, do you think e-bikes are a safety hazard? Yes/No Why? And how do you think it could be reduced?
7. What do you think the park should do about e-bike usage on the Carriage Roads?

Appendix D: Bike rental shop interview outline of script

Hello, we are a team of students from Worcester Polytechnic Institute in Massachusetts. We are conducting interviews to determine the impact of e-bikes on safety and experience. Our goal is to collect information to provide to Acadia National Park to help them improve the e-bike policy. Can you help us? This interview is confidential. You can skip any question at any time, also you can opt-out at any time. Our team email is gr-e-bikes@wpi.edu, and our project advisor's email is cbkurlanska@wpi.edu if you need to contact us.

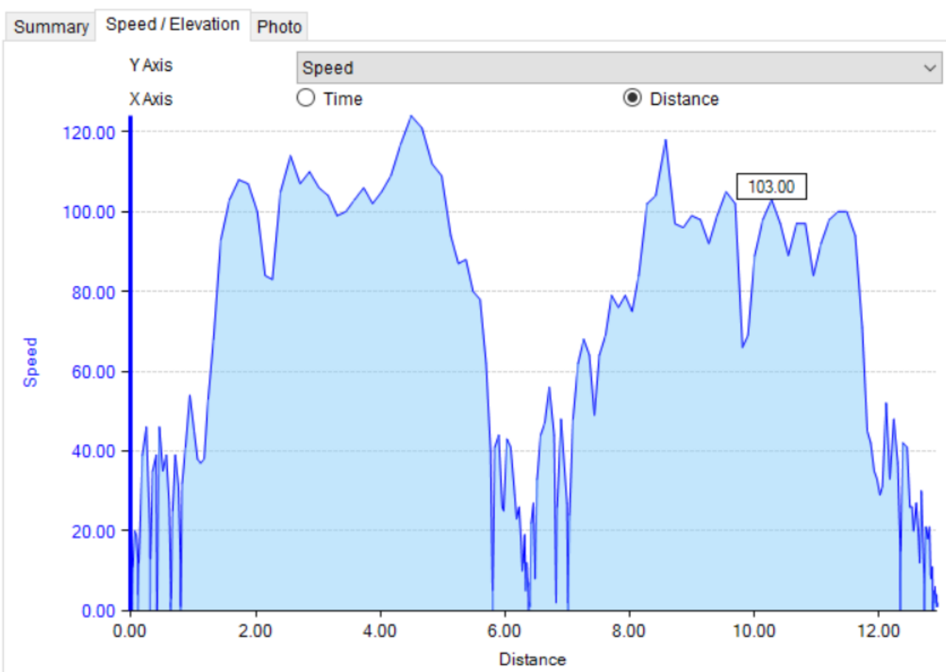
All Other Park Visitors - Interview Questions
1.Can you explain the process of renting out an e-bike?
2. Do you go over bike safety rules or the Carriage Road rules?
3. Do they sign anything that they understand the rules and courtesy rules of Acadia National Park?
4. Do you provide helmets or ask that they wear helmets while using the bikes?
5. Do you know on average how many e-bikes are rented per day?
6. What's the most popular type of e-bike that people rent?
7. Do you inform them that only Class 1 e-bikes are allowed on the Carriage Roads?
8. Do you give recommendations on where to go in the park? - If so, what do you say?
9. Do you deliver or drop off e-bikes to renters?
10. Where's the most popular destination e-bikers go from your store?
11. Do you provide an opportunity or require renters to practice before leaving the shop?
12. What percentage of your renters do you believe regularly ride bicycles or e-bikes?

Appendix E: Canmore Data Logger

The Canmore GT-730FL-S GPS Data Logger can track speed, distance, location, and elevation. The data logger tracking information is downloaded onto the CanWay software. It generates tables and graphs (see below) that depicts the data collected. The user manual and the data sheet for the data logger can be found in the following links.

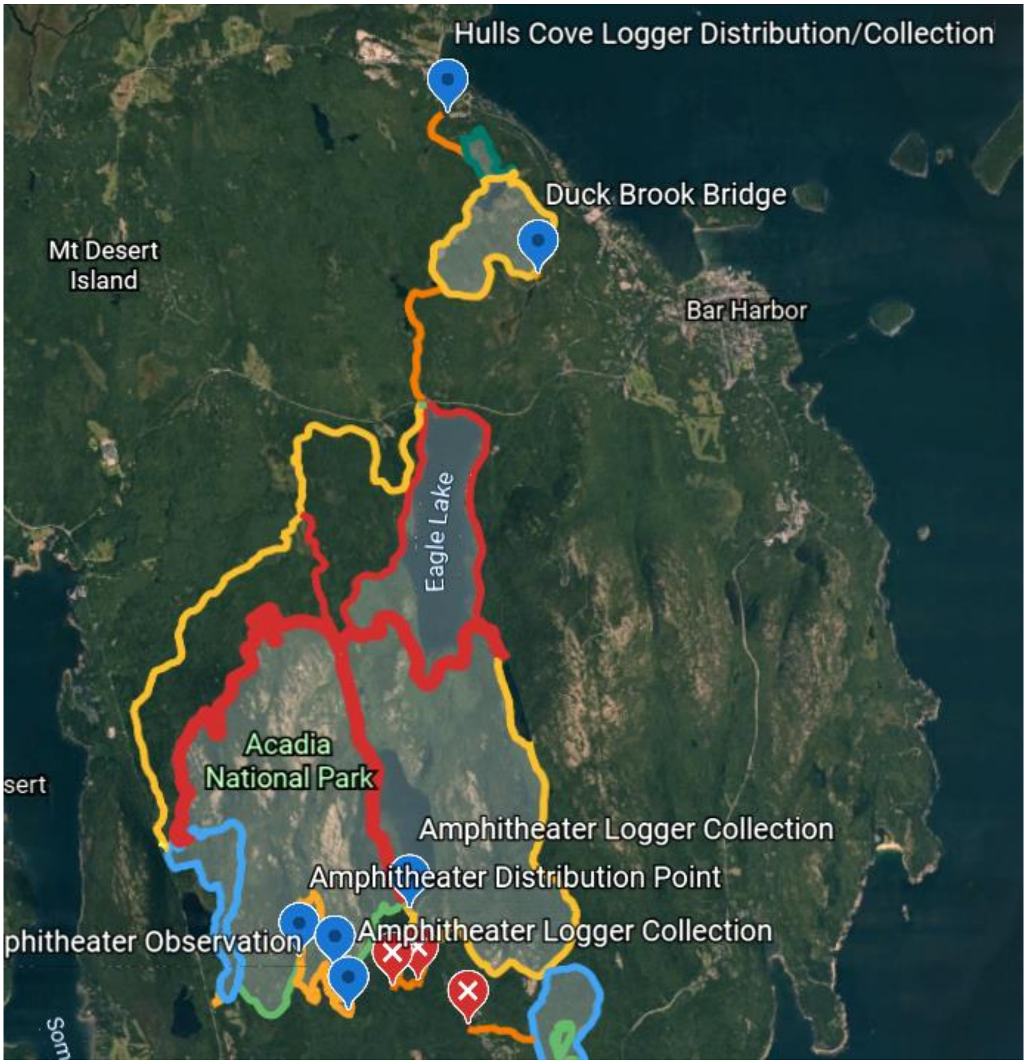
Canmore GT-730FL-S: User Manual
https://cdn.shopify.com/s/files/1/2104/5147/files/GT-730FL-S_user_manual.pdf?v=1599939668
Canmore GT-730FL-S: Data Sheet
https://cdn.shopify.com/s/files/1/2104/5147/files/GT-730FL-S_DataSheet_v7.pdf?v=1599939675

This data logger has been field-tested in Worcester, and can collect information on parameters such as speed, distance, and altitude. This information is shown below. Shown in the graph is speed, in kilometers per hour, to distance, in kilometers. The data was logged during a car drive team member Alexandra took, from Grove Street, down I-290, to North Lake Avenue, Worcester, and back.



Appendix F: Data logger distribution script outline, locations, and procedure

Hello, I am a student from Worcester Polytechnic Institute in Massachusetts. I am working on a project to improve Acadia's e-bike policy. I was wondering if you could take this data logger that records anonymous information such as speed. Just keep biking along your normal path and you will see my team member wearing a similar red shirt with a clipboard. You can drop off the data logger to them and continue on with your day. Thank you for your help with our project and have a nice day.



Note. The above figure shows all the Acadia operated carriage trails, with each road loop set as a different color to distinguish them easily. The red trails are the currently closed sections of roads from construction and weather damage. The blue pins show the distribution and collection sites for the Amphitheater loop and the Witch Hole Pond loops.

Appendix G: Bike Rental Shop Interview Responses

This is the complete interview response matrix from the bike rental shop interviews.

	Acadia Outfitters	Acadia Bike Rentals	Pedego	Bar Harbor Bicycle Shop
1. Can you explain the process of renting an e-bike?	Renters can call, rent online (only can rent for a day)	Rent to 18+ w/ drivers license	Put renters in system	Put renters in system (only 16+)
2. Do you go over bike safety rules/Carriage Road rules?	Yes (on Carriage Roads map they provide)	Yes (no handout)	Yes (no handout)	No
3. Do they sign anything that states they understand the rules and courtesies of ANP?	Yes	No	No	No
4. Do you provide helmets or ask that they wear helmets while using the bikes?	Yes we provide	Yes	Yes	Yes
5. Do you know on average how many e-bikes are rented per day?	5 (all they have)	5	15	25
6. What's the most popular type of e-bike rented out?	I-zips, rolleys	All of them	Step-through	Turbo como 3.0
7. Do you inform them that only class 1 e-bikes are allowed on the Carriage Roads?	Yes	Yes	Only have class 1	Yes, only have class 1
8. Do you give recommendations on where to go in the park? (If so, where in park?)	Give them map of Carriage Roads & how to get there	Give them map of Carriage Roads	Jordan Pond House, Witch Hole Pond, Paradise Hill	Show closed roads, directions to duck brook & upper hadlock
9. Do you deliver/drop off e-bikes to renters?	No	No	No	No
10. Where's the most popular destination e-bikers go from your store?	Carriage Roads	Carriage Roads	Carriage Roads	Duck Brook
11. Do you provide an opportunity or require renters to practice before leaving the shop?	No	Yes, 5 minute trial	Yes	Yes, provides tutorial
12. What percentage of your renters do you believe regularly ride bikes/e-bikes?	99% are experienced riders	95 - 100%	75%	50% regular cyclists, 50% casual riders

Appendix H: Carriage Road entrance signage

The team observed the signage at the main Carriage Road entrances. There were four different types of signs, as shown below.

Construction Sign

Wooden "Share the Road" Sign

Speed Sign

"Rules of the Road" Sign