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Shifting Paradigms in Recreation Management: Applying Social-Ecological System Frameworks to Parks and Protected Areas

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SHIFTING PARADIGMS IN RECREATION MANAGEMENT: APPLYING SOCIAL-ECOLOGICAL SYSTEM FRAMEWORKS TO PARKS AND PROTECTED AREAS

by

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ABSTRACT

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by

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Utah State University, 2024

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Park and protected area (PPA) recreation management is often characterized by social, ecological, and managerial dimensions that have increasingly been conceptualized as social-ecological systems (SESs) to understand the complex interrelationships between these dimensions. The contemporary trends of increased visitation on public lands in the United States, including US National Parks, have accentuated the complex interactions between the amount of recreation use and the capacity of the setting, the quality of the visitor experience, as well as ecological resource conditions. These challenges of managing recreation use and understanding these interactions will be further compounded by climate change and its effects on ecosystem composition and dynamics. The first chapter will provide the context for this dissertation that illustrates these challenges to PPA management in the context of global conservation and habitat conservation efforts. Examining the complex interactions between social, ecological, and managerial dimensions in park and protected area recreation management through the lens of social-ecological systems is part of an evolving adaptive management paradigm for PPAs and natural resources.

The second chapter is centered on the managed-access Timed-Entry Reservation System (TEPS) reservation system in Rocky Mountain National Park (RMNP), where managers utilized the park's transportation system to target desired conditions and consequently moderate the flow of people and vehicles entering the park. This study examines visitor perceptions and evaluations of managed-access reservation systems at the PPA scale which may contribute to a more systematic and sustainable alternative to the conventional demand-driven approach. The TEPS reservation system is a novel implementation of the use of rationing and allocation techniques through a reservation system for an entire park. The results suggest that the conditions visitors experience are highly influential in shaping attitudes and perceptions about TEPS. In addition, the manuscript highlights the importance of justice, equity, and public-lands access considerations of managed-access reservation systems.

The third and fourth chapters shift the focus to a management experiment that evaluates the effect of a direct trail management strategies in PPAs in Orange County, CA, which introduced direction and use-type trail designations. The third chapter evaluates the efficacy of these approaches, which have not been systematically studied in the literature on recreation management, to address concerns regarding visitor experience, safety, and conflict. The fourth chapter evaluates the effects of these trail management strategies on trail biophysical conditions with a UAV (drone) prior to and after the management actions were implemented. Together, these third and fourth chapters illustrate the complex and coupled interactions between the social and ecological dimensions of PPA management and provide a novel contribution to the literature by jointly examining them as part of the experimental design.

The fifth and concluding chapter provides reflection upon the preceding chapters and their contributions to PPA recreation management.

(207 pages)

PUBLIC ABSTRACT

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Park and protected area (PPA) recreation management is often characterized by social, ecological, and managerial dimensions. These dimensions have increasingly been conceptualized as social-ecological systems (SESs) to understand the complex interrelationships between them. Contemporary trends of increased visitation on public lands in the United States, including US National Parks, have accentuated the complex interactions between the amount of recreation use, the capacity of the setting, the quality of the visitor experience, and ecological resource conditions. These challenges of managing recreation use and understanding these interactions will be further compounded by climate change and its effects on ecosystem composition and dynamics. The first chapter will provide the context for this dissertation that illustrates these challenges to PPA management in the context of global conservation and habitat conservation efforts. Examining the complex interactions between social, ecological, and managerial dimensions in park and protected area recreation management through the lens of social-ecological systems is part of an evolving adaptive management paradigm for PPAs and natural resources.

The second chapter is centered on the managed-access Timed-Entry Reservation System (TEPS) reservation system in Rocky Mountain National Park (RMNP), where managers utilized the park's transportation system to target desired conditions and consequently moderate the flow of people and vehicles entering the park. We developed an email-based

survey instrument to understand visitors' evaluations of their experience under the TEPS system and elicited their attitudes toward use-limiting strategies such as TEPS. We found that 78% of the respondents reflected favorably on the managed-access park experience, although these attitudes are often value-laden and involve expectations about the conditions they experience.

The third and fourth chapters shift the focus to a management experiment the evaluates the effect of a direct trail management action in PPAs in Orange County, CA, which introduced direction and use-type trail designations. The third chapter evaluates the efficacy of these approaches, which have not been systematically studied in the literature on recreation management, to address concerns regarding visitor experience, safety, and conflict. The fourth chapter will evaluate the effects of these trail management strategies on trail resource conditions by monitoring biophysical indicators of recreation disturbance with a UAV (drone) prior to and after the management actions were implemented. Together, these third and fourth chapters will illustrate these complex and coupled interactions between the social and ecological dimensions of PPA management and provide a novel contribution to the literature by jointly examining them as part of the experimental design.

The fifth and concluding chapter provides reflection upon the preceding chapters and their contributions to PPA recreation management.

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Lastly, I want to thank my parents for instilling a curiosity about the natural world, and an appreciation for nature and all of the individual growth and lessons it can offer.

Noah Creany

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"Recreation ecology may then be regarded as the science of a destructive process, but if people's reverence for life is increased by visiting the natural environment, then it is possible that the overall effect will be beneficial for the survival of the world's biota."

— Michael J. Liddle (1997, p.550)

CHAPTER I

INTRODUCTION

1.1 Introduction

Parks and protected areas (PPA) in the United States are managaged or adminstered by Federal, State, County, and local land jurisdictions with varied priorities and mission statements that form a mosaic of protected area conservation. However, despite the differences in the political influences, historical and organizational contexts that shaped these institutions, they share a common directive to conserve habitat and biodiversity while also providing opportunities for recreation and the associated individual, societal (Rice et al., 2020; Thomsen et al., 2018), and cultural (Corvalán et al., 2005) benefits of PPAs.

Among federal land management agencies, the dual mandate mission is reflected in the founding legislative mandates of agencies (i.e., U.S. Forest Service (USFS) Multiple Use-Sustained Yield Act,1960) to provide opportunities for recreation on public land while also conserving and protecting resource conditions for future generations (i.e., NPS Organic Act, 1916). Keiter (2013) argues these directives amount to "a nearly impossible mission. . . [t]o safeguard these special places. . . in an ever more complex world while also making them available for an ever more demanding general public"(p.9). The complexity and significance associated with effectuating these mission statements in the modern era is compounded by a confluence of social-ecological interactions that will require integrated social-ecological approaches to protected area management. Principal among these challenges are the effects of climate change that are buffered and, in part, mitigated by PPAs. Nevertheless, PPAs also play an important role in supporting global conservation initiatives (Dinerstein et al., 2019) by protecting critical habitat and biodiversity, while also fostering a conservation and stewardship ethic among visitors.

1.2 Protected Areas & Climate Change

In its 2023 Sixth Assessment Report, the International Panel on Climate Change (IPCC), and an overwhelming consensus of scientists, concluded that human-induced climate change has unequivocally resulted in 1.1 °C of warming between 2011-2020 from the 1850-1900 baseline and has resulted in “widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere” (p. 46). According to Díaz et al. (2019), current estimates of biodiversity loss and rate of species extinction as a result of human induced climate change are “tens to hundreds of times over background rates” (p. 3), and are approaching levels associated with global extinction events (Isbell et al., 2023; Rockström et al., 2009). In response to and recognition of the important role PPAs play in maintaining biodiversity and ecosystems, the United Nations Framework Convention on Climate Change (UNFCCC) in the Paris Climate Agreement and the Global Deal for Nature (GDN) proposed ambitious targets for the conservation of global terrestrial and marine habitats that may still be insufficient to stabilize biodiversity and prevent the most catastrophic effects of climate change (Dinerstein et al., 2019). Further compounding this dual crisis of climate change and loss of biodiversity, in a global analysis of PPA conservation Saura et al. (2018) found that only 15% of terrestrial PPAs are sufficiently connected to facilitate ecosystem resilience through large-scale ecological processes such as gene flow, migration, and range shifts.

The idiosyncratic effects of climate change present serious challenges that have the potential to fundamentally alter the structure and function of ecosystems globally (Pecl et al., 2017). Forecasts of ecosystem pathways under future climate scenarios have illustrated serious concerns about species redistribution and ecosystem resilience (Carroll et al., 2015; Hoffmann et al., 2019). In a study focused on North American protected areas, Batllori et al. (2017) found that approximately 80% will experience moderate to high rates of climate change that will alter the abundance and distribution of species. Furthermore, recent research, which found that more than 1000 metric tons of microplastics are deposited in US protected areas annually (Brahney et al., 2020) whose long-term ecological implications are poorly understood. This provides further evidence of the pervasive human influence on the planet. Collectively, these studies highlight several critical challenges to the North American PPA framework, from landscape fragmentation and scarcity of connectivity corridors (Barnett & Belote, 2021; Brennan et al., 2022; Harwood et al., 2022) (Figure 1.1) to a relatively inflexible legal framework to adapt PPA conservation goals to protect critical habitat (McDonald & Styles, 2014).

1.3 Challenges for Protected Area Conservation & Recreation Management

Recreation ecology over the course of nearly a century (e.g., Bates, 1935; Meinecke, 1928) as an applied subdiscipline of disturbance ecology has systematically evaluated the effect of recreation disturbance on wildand ecosystems. An implicit and widely shared belief supported by the recreation ecology literature (Hammitt et al., 2015; Liddle, 1997) is that recreation use is an appropriate and compatible use of PPA settings, but rests on the expectation that recreation use is *managed*.

The anticipated trends of climate change and its effects on ecosystems and biodiversity has directed greater focus on the varied mosaic of land use in areas that ajoin and surround PPAs (DeFries et al., 2010). Protected Area Centered Ecosystems (PACEs) (Hansen et al., 2011) attempt to delineate the spatial scale of PPA ecosystems, illustrating the patchwork of land use and the variegated matrix of protected area designations that surround PPAs. Nevertheless, this suggests the need for collaborative approaches to cross-boundary recreation management to maintain ecological conditions in both PPAs and across PACEs (Aslan et al., 2022; Tarver, 2023). Harmonizing recreation management approaches across PACEs face significant challenges to bridge philosophical and managerial discord in protected areas that surround or buffer the PPA core of PACEs (Figure 1.2). These protected areas, particularly in the Western United States (Figure 1.2b), are administered by the USFS and the Bureau of Land Management (BLM). The USFS and BLM, which collectively manage nearly 72% of U.S. public land, and are managed for multiple-uses include resource extraction, and motorized recreation (i.e. off-highway vehicles (OHVs)) that introduce broad spatial patterns of disturbance (Battisti et al., 2016) and fragmentation[1] (Loucks et al., 2003) to ecosystems[2](Ouren et al., 2007; Switalski, 2018).

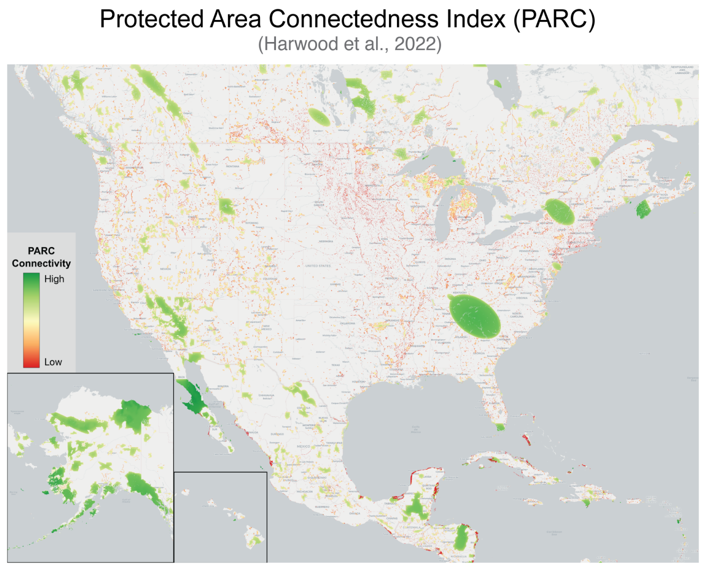
Furthermore, motorized and non-motorized recreation use results in biotic and abiotic disturbances to air, water, soils, vegetation, and wildlife that can alter the structure and function of ecosystems (Hammitt et al., 2015; Liddle, 1997). A rich line of inquiry in recreation ecology has specifically investigated the effects of motorized (Dorrance et al., 1975; Gump & Thornton, 2023; Olson et al., 2017) and non-motorized recreation (Lewis et al., 2021; Patten & Burger, 2018), as well as the mere presence of humans in natural areas (Nickel et al., 2020) on wildlife. This line of research in recreation ecology, when combined with non-stationary climate and ecosystems, will become an important area of focus for recreation-climate interactions (Monz et al., 2021) given the anticipated concern regarding intensified conflict between recreation and biodiversity conservation, particularly in novel and isolated habitats (Pecl et al., 2017). A limited but growing number of studies support this concern, illustrating the readily apparent effects of climate change between winter recreation and highly sensitive species, including birds (Brambilla et al., 2016), lynx (Olson et al., 2018), wolverines (Heinemeyer et al., 2019), and bighorn sheep in Grand Teton National Park (Courtemanch, 2014).

1.4 Shifting Paradigms of Protected Area Recreation Management

Kuhn (2009), in his seminal essay on the nature of scientific progress, suggests that in the course of *normal science* encountering new anomalies, initial investigation often yields results that are neither consistent nor simple . . . and amount to little more than “mere

[1]Although broadly considered a threat to biodiversity, the effects of fragmentation on ecosystems is vigorously debated (e.g., Fahrig, 2017; Fahrig et al., 2019; Fletcher et al., 2018)

[2]*Disturbance to wildlife:* (Blickley et al., 2012; Bury & Luckenbach, 2002; J. S. Cole et al., 2019; D’Eon & Serrouya, 2005; Tull & Brussard, 2007; Wilson et al., 2009; Wisdom et al., 2018); *Vegetation:* (Chisholm & McCune, 2024; Farmer, 1993; Gelbard & Belnap, 2003; Taylor et al., 2012), *Soil and Air Quality:* (Belnap, 2002; Goossens & Buck, 2009)



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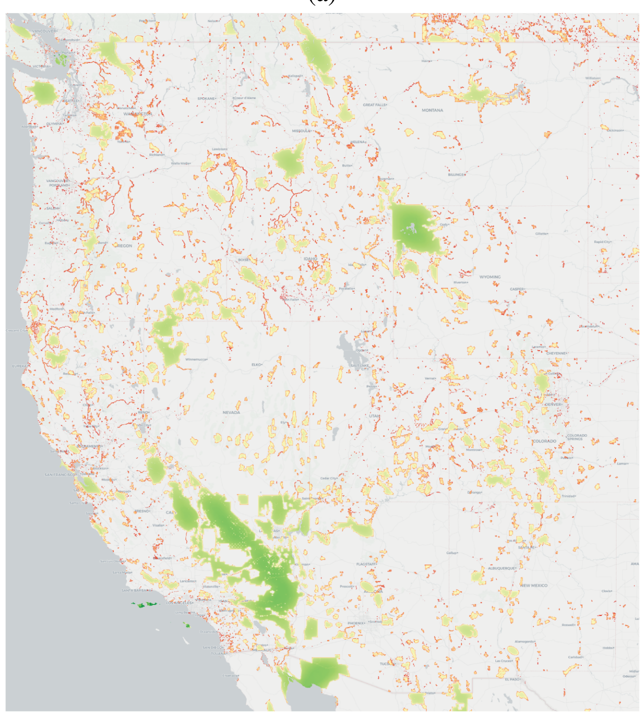
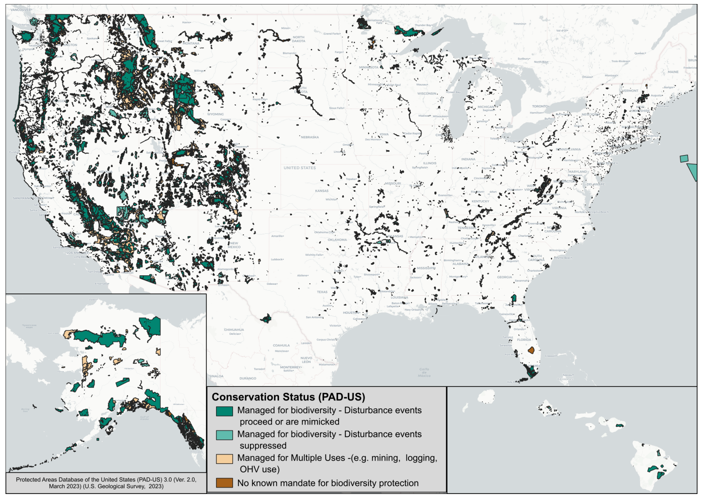
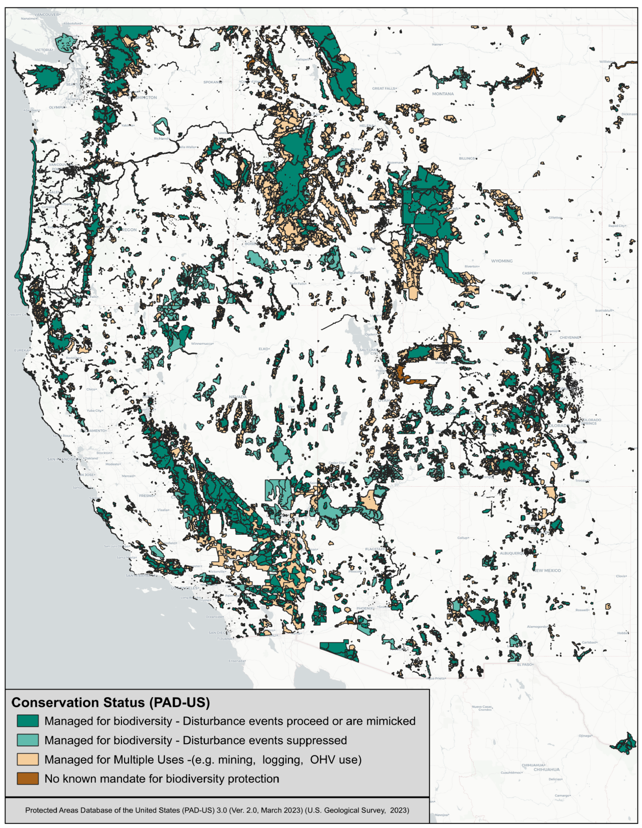


(b)

Figure 1.1: North America (a) and Western US (b) Protected Area Connectedness Index (PARC) Harwood et al., 2022 illustrating the degree to which terrestrial protected areas are ecologically representative and are well connected to other PAs and surrounding intact natural ecosystems.



(a)



(b)

Figure 1.2: North America (a) and Western US (b) Protected Area Biodiversity Conservation Status according to the Protected Area Database (PAD-US) (U.S. Geological Survey, 2023).

facts, unrelateable to the continuing progress of [the subsequent paradigm]" (p.35). Kuhn offers an example of the circumstances under which new theories emerge that seems to capture the evolving nature of the interdisciplinary study of human-environment interactions, where "the nature [of the phenomenon] is indicated by existing paradigms, but whose details can be understood only through further theory articulation" (p.97). The basic ideas behind Social-Ecological Systems (SES) (Berkes et al., 2002; Ostrom, 2007), also referred to as coupled and complex adaptive systems (Gunderson, 2000; Hartvigsen et al., 1998; Levin, 1999), is that social and ecological systems interact in ways that shape collective outcomes. Additionally, the notion that humans are part of natural systems, has been articulated in both social (e.g., Alihan (1938)) and ecological (e.g., Adams (1935)) science for quite some time. In the intervening years, the development and maturation of SES as an interdisciplinary approach to human-environment interactions has contributed to major shifts in perception, or paradigms, in the social and natural sciences (McDonnell et al., 1997).

Nevertheless, SES has been criticized for its lack of an overarching theoretical framework and skepticism regarding its deficiency to translate into practice and inform management (Sakai & Umetsu, 2014). These criticisms seem conceivable, given the broad range of SES subframeworks (e.g., descriptive Berkes et al. (2002), diagnostic Ostrom (2007), and integrative Collins et al. (2011)), and the range of contexts and approaches where it has been applied (Partelow, 2018). As a framework that draws upon theories from many disciplines rather than a single unified theory, SES often does not fit neatly into *normal science* and its applications in research are often characterized as action-oriented or problem-oriented frameworks or tools (Sakai & Umetsu, 2014). Nevertheless, SES are a useful lens or mental model for studying complex issues that have stymied reductionist approaches and provide the ability to hone understanding of component parts by seeing the interconnections and relationships of the system that affect behaviors and future outcomes, identify the leverage points that shape system dynamics, and stimulate the growth of adaptive capacity to learn from and respond to changes in a way that maintains critical functions of the system (Meadows & Wright, 2011).

In their succinct synthesis of SES Sakai and Umetsu (2014) propose several criteria for the theory-oriented study of SES, which include analysis and conclusions that are supported by rigorous empirical support (*á la* Popper) that can be connected or explained by existing theory. McDonnell et al. (1997) reflect many of the same ideas priorities and highlight approaches to satisfy such criteria complementary to the tradition of falsification in ecology including meta-analyses and multi-causal analysis and synthesis, but also propose the scientific approach of confirmation (*á la* Hempel) may prove beneficial because of its ”robust approach for developing models and theories of complex, multi-causal systems” (p.315). Nevertheless, these differing traditions and approaches within science can be complementary, where their interplay can contribute to a more comprehensive and robust understanding of phenomena.

A vast resource that may serve these combined bottom-up and top-down approaches to science is the availability of visitor-generated (Norman & Pickering, 2017; Procko et al., 2024; Rice et al., 2019), big data (e.g., Creany et al., 2021; Monz et al., 2019; Wilkins et al., 2021; Wood et al., 2013), and “big qualitative data” (Derrien et al., 2024) that have advanced our understanding of spatio-temporal patterns of use and human-environment relationships to inform effective management. These novel sources of data combined with the accessibility of contemporary machine learning, often characterized as inductive approaches, show significant promise in advance our understanding of SES by elucidating non-linear cause-and-effect interactions, patterns, and relationships (Dagan & Wilkins, 2023). Finally, as Gelman and Shalizi (2013) suggests, Bayesian analytical approaches are particularly well suited for the social sciences and the development, testing, and refinement of models because of their capacity to incorporate inductive approaches by comparing competing models and their comparability with the hypothetico-deductive approach by evaluating models against empirical evidence, thereby highlighting modifications and enhancements to the model.

1.5 Integrated Social-Ecological Protected Area Recreation Management

Recent trends toward changing (Lucas & Stankey, 1989) and increasing demand for wildland recreation (Balmford et al., 2009, 2015) have resulted in new and unique pressures on PPA managers to balance recreation use with habitat and resource conservation goals. Drawing upon a tradition in recreation management of defining protected areas as social, managerial and ecological systems (Machlis et al., 1981; Manning, 2022), recreation research employed concepts and ideas from SES to reframe mental models of the interaction between human and natural systems in PPA settings (Cumming & Allen, 2017; D'Antonio et al., 2013; Ferguson et al., 2022; Miller et al., 2022)). According to these approaches, increased demand and recreation use have been viewed positively as an endorsement of the value and importance of protected areas and a measure of their missions, in stark contrast to traditional management practice that regarded increased visitation as a problem or threat (Blahna et al., 2020). According to Blahna et al. (2020), this evolution of thought and approach to recreation management that broadens conceptual boundaries and definitions amounts to a paradigm shift. However, considerable challenges remain to operationalize these approaches, which aim to balance providing opportunities for recreation use and sustaining resource conditions along with the broader goals of system resilience.

Navigating what appears to be a narrow pathway for PPAs to sustain ecosystems and biodiversity while also providing high-quality opportunities for recreation that stimulate human growth, enjoyment, awe, and stewardship of those places will require integrated interdisciplinary approaches to recreation management. Recreation ecology can play an important role in helping inform sustainable management approaches and recent reflections on its maturation and progression (D. N. Cole, 2021; Garthe, 2019; Sumanapala & Wolf, 2019) have highlighted gaps and opportunities for future research. Among some of the most pressing areas of research, identified by Liddle (1997) nearly 30 years ago, is a synthesis of disturbances and changes in vegetation, soil and wildlife that result from a single recreation "impact", but also linking these effects to the social and managerial dimensions of PPA management. Such systematic approaches to understanding the relationships and linkages between those dimensions of PPAs and the subcomponents of each system can elucidate the effectiveness of recreation management approaches, as well as unintended feedbacks or side effects.

Nevertheless, while significant challenges remain to better bridge and integrate the social and ecological domains and deliver on the promise of what SES offers to complex problems in recreation management, contemporary analysis methods and techniques provide the opportunity to empirically test and refine the proposed integrated models of visitor use management (Perry et al., 2020) (Figure 1.3 A) and recreation-wildlife interactions (Miller et al., 2022) (Figure 1.3 B), which are based on a rich corpus of literature (Hammitt et al., 2015; Manning, 2022) (Figure 1.3 C).

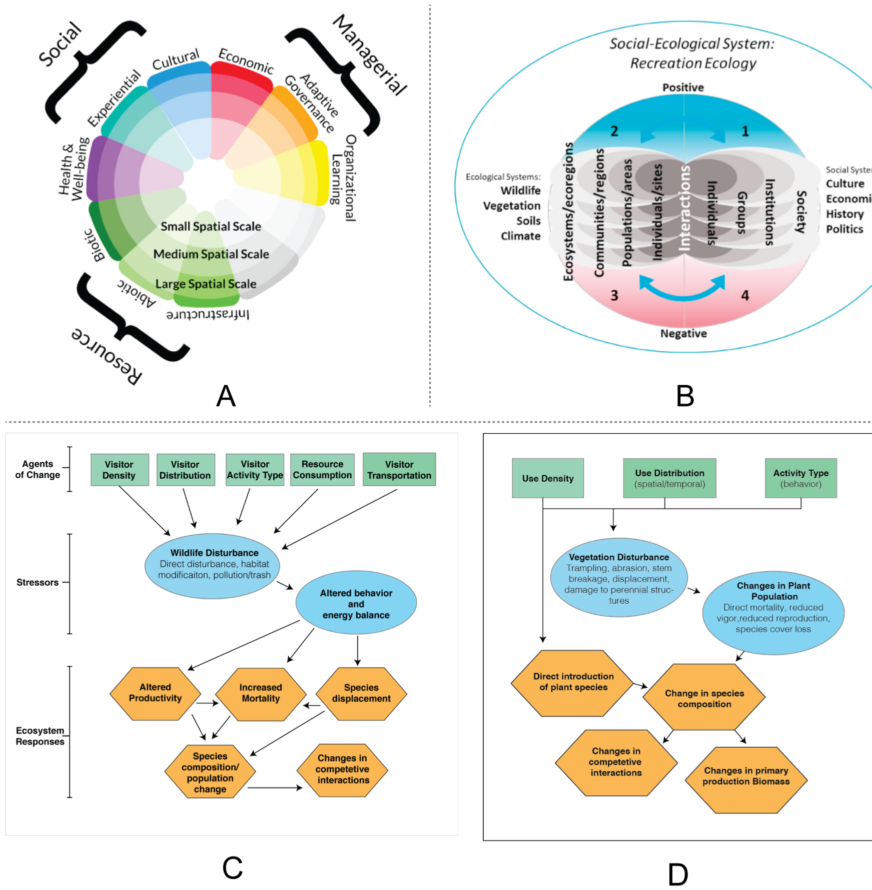


Figure 1.3: Recreation management conceptual models and organizing frameworks that incorporate the multi-scalar interactions and feedbacks of social ecological systems from Perry et al. (2020) (A), Miller et al. (2022) (B), and (C,D) *adapted from* Hammitt et al. (2015)

1.6 Research Objectives and Dissertation Overview

This dissertation has three main objectives, which correspond to the manuscripts and chapters that follow. These objectives are: (1), to demonstrate the applicability and utility of a diagnostic social-ecological systems framework (Ostrom, 2007) to a contemporary context of managed-access strategies to address challenges and trade-offs associated with high levels of recreation use; (2) evaluate the efficacy of direct and intensive management strategies to address social concerns related to perceptions of safety and visitor conflict; and (3) assess the effects of those strategies on ecological resource conditions that will collectively contribute to an integrated social-ecological approach to PPA management.

A fifth and final chapter will provide a broad overview and synthesis of the findings and their limitations, as well as a reflection on the contributions of the preceding chapters to PPA recreation management and directions for future research.

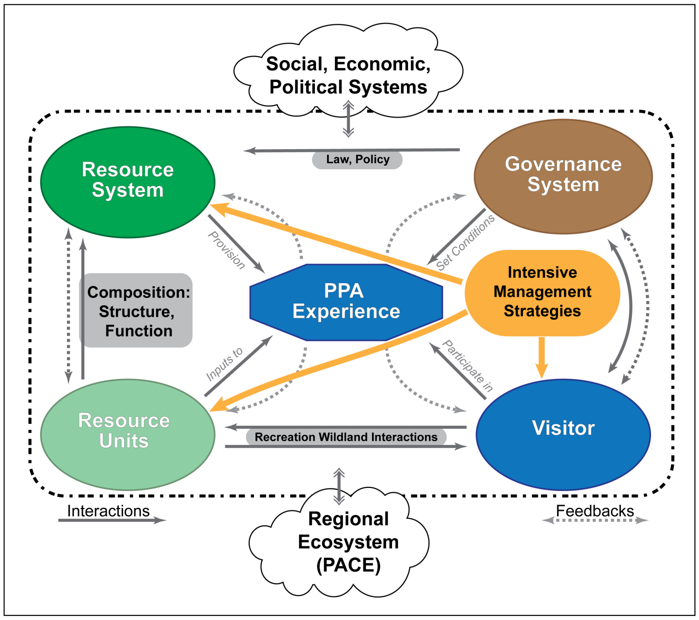


Figure 1.4: Conceptual model of PPAs as a social-ecological system that illustrate feedbacks and interactions. The focus of this dissertation will be to evaluate how management actions and interventions affect social and ecological dimensions of PPAs, illustrated by the orange bubble and pathways. *Model adapted from* (McGinnis & Ostrom, 2014), *licensed under* CC BY 4.0

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CHAPTER II

UNDERSTANDING VISITOR ATTITUDES TOWARDS THE TIMED-ENTRY RESERVATION SYSTEM IN ROCKY MOUNTAIN NATIONAL PARK: CONTEMPORARY MANAGED ACCESS AS A SOCIAL-ECOLOGICAL SYSTEM

2.1 Introduction

Contemporary discourse in recreation management literature often cites the increased demand for outdoor recreation (e.g., Balmford et al., 2015; Cordell, 2012) to provide context for the challenges managers of parks and protected areas (PPAs) face. This often serves to underscore the implications of increased visitor use on the social dimensions (i.e., visitor experience), disturbance to the ecological dimension (i.e., resource conditions), and increased burden on the managerial dimension (i.e., operations) of the setting. Because the social, ecological, and managerial dimensions of PPA management are so coupled and interdependent, the social-ecological systems (SES) theoretical framework (Blahna et al., 2020; Morse, 2020; Ostrom, 2009) has demonstrated utility for conceptualizing the complex and hierarchical nature of the relationships and interactions between the social and ecological systems and governance structures responsible for PPA management (Ferguson et al., 2022; Miller et al., 2022). In this study, we conceptualize PPA management through an SES framework that helps illustrate the dynamics and relationships between increased demand for recreation and the impacts and disturbance to the social and ecological conditions that visitors experience.

2.1.1 Crowds in the Commons

Over the past decade, several studies have highlighted and quantified trends of intensifying visitor use at many of the most visited national parks in the United States (Clark et al., 2019; Tenkanen et al., 2017; Wood et al., 2013). Visitation among the national parks in the inter-mountain region in 2019 was on average 129% greater than visitation in 2012, and more specifically 126% greater during the same time period in Rocky Mountain National Park (RMNP) adding an additional 1.44 million visitors (N.P.S., 2023a). However, these trends of increasing visitor use are not an entirely new phenomenon in recreation management, but rather an episodic and persistent challenge that requires managers to effectively balance visitor use with PPA capacities. Capacities in a recreation management context are defined as the ”maximum amount of recreation use and resulting impacts that can be accommodated in a park or outdoor recreation area” or the ”type and amount of visitor use beyond which desired environmental and experiential conditions are adversely affected” (Whittaker et al., 2011, p. 15). Inherent in these definitions of capacity are the relationships between the visitor experience, social conditions, and the desired ecological conditions which are the focus and context of the experience. While intensifying trends in visitor use to PPAs suggest an endorsement of the value of PPA settings, the individual and public benefits of wildland recreation, and the ecosystem services these settings provide for society, they can also contribute to perceptions of crowding and lead to visitor coping behaviors to contend with a diminished quality of the visitor experience (Manning, 2022). This response is particularly pronounced among visitors with highly developed ecological knowledge and preferences (D’Antonio et al., 2012). Using Ostrom’s (2009) SES framework, visitor coping or displacement behaviors can be regarded as a form of self-organizing or collective action behavior by resource users precipitated by resource scarcity to contend with the trade-offs in ecological conditions and the visitor experience. Ostrom (2009) notes that while self-organizing behavior is one approach to averting the ”tragedy of the commons” (Hardin, 1968), the efficacy and sustainability of these self-organizing behaviors are dependent on a range of resource system attributes and factors, such as the number of users of the system. Ostrom (2009) goes on to suggest that ”long-term sustainability [of the SES] depends on rules matching the attributes of the resource system, resource units, and users” (p. 421) indicating that in some circumstances governance system rules for resource use may be necessary to avoid over-harvest when collective action is insufficient.

2.1.2 Rationing and Allocation in Wildland Recreation

Wildland Recreation research began to explore the relationship between visitor use and the effects of the social and ecological resource conditions in the 1970s when visitation to national parks (Lucas & Stankey, 1989) and wilderness areas (Fazio & Gilbert, 1974; Stankey, 1973; Stankey & Baden, 1977) was rapidly increasing. The principal concern with the intensifying use was that managers might increase development to these areas to accommodate the increased visitation which could fundamentally alter and or compromise the primitive character of wilderness (Hall, 2001). Research during this era began to explore the utility of use limits and rationing and allocation techniques and to understand how these approaches contribute to the ability of managers to balance recreation use with capacities. Rationing and allocation techniques are characterized as direct management strategies that place emphasis on regulating visitor behavior and limiting individual choice (Manning, 2022). Research evaluating the application of these techniques in wilderness contexts has suggested that direct management strategies should be secondary to indirect approaches because of the concern of imposing upon and burdening the visitor and thus adversely constraining opportunities for unconfined recreation. However, in PPA settings managed for more diverse opportunities, research suggests that direct management strategies including limits on use are perceived to be acceptable to many visitors (Martin et al., 2009), and can expand visitor freedom by reducing conflict (Dustin & McAvoy, 1984) and enhance aspects of the visitor experience (Frost & McCool, 1988). For example, in Glacier National Park, Frost and McCool (1988) found that regulations are most effective and viewed as acceptable by visitors when the rationale behind regulations is clearly articulated, additionally, visitors with more knowledge and experience with the setting are more likely to perceive the regulations as enhancing their experience.

The recreation ecology literature is perhaps the most critical and circumspect of the use of rationing and allocation techniques to manage resource and ecological conditions because of the non-linear, asymptotic relationship between recreation use and resource disturbance (Cole et al., 1997). This curvilinear relationship characterizes the initial use resulting in the greatest proportional disturbance while the rate of disturbance decreases with subsequent use (Cole, 1992), which suggests use-limitations provide little benefit to resource conditions unless the amount of use is dramatically reduced. Further, acknowledging the unpredictable nature of visitor behavior in response to management actions, rationing techniques implemented in one area can contribute to displacement behaviors with visitors traveling to new, low-capacity settings which can result in greater resource disturbance than if they recreated in their preferred setting (McCool, 2001). Despite the lack of theoretical grounding for use-limits and rationing techniques to address resource conditions, visitors to PPAs often support these strategies if they believe they are necessary to sustain resource conditions but tend to be less supportive of their use to address aspects of the social and visitor experience (Cole & Hall, 2008).

Rationing and allocation techniques represent a range of strategies used to apportion visitor use in balance with site capacities and management goals and to provide those opportunities in a fair and just manner (Stankey & Baden, 1977). One of the techniques used to allocate recreation use is a reservation system which is among the most commonly employed techniques in public land management in the United States because of its appeal to a widely held perception of fairness in American culture for ”first come first serve”. Stankey and Baden (1977) expressed concerns about direct management approaches and rationing and allocation techniques and developed a matrix of criteria to evaluate the advantages, disadvantages, and efficacy to avoid sub-optimal outcomes. Stankey and Baden goes on to advise that these techniques should be focused on ”reducing the physical and social impacts associated with use, rather than simply cutting back on use itself” (p. 15). Because of the implication that rationing techniques may ultimately limit public access to public lands, where rationing and allocation techniques have been implemented procedural justice considerations like visitor perceptions of equity, equality, and fairness have been considered an important metric of their performance (Shelby et al., 1989b). Several studies have approached this distributive justice aspect of rationing and allocation techniques and broadly report that while reservation systems most adversely affect trip spontaneity and visitors who are unable to plan ahead or those who have jobs with irregular schedules that preclude long-term planning, they are generally highly acceptable to visitors (Shelby et al., 1989a; Stankey, 1973). Shelby et al. (1989a) evaluated visitor perceptions of the barriers, currencies, and costs associated with various rationing and allocation techniques and reported similar conclusions about long-term planning but noted that visitors ”perceive their chances of success through a filter of adaptability. If a permit system appears to block access to those who do not control enough currency, they may find a way to gain more of that currency” (p. 143). Further, Shelby et al. (1989a) suggests that visitor perceptions of success and predicting which groups may be affected by these techniques are quite complex which may explain studies finding that even visitors unsuccessful at obtaining reservations or permits still view them as acceptable (Bultena et al., 1981; Cole et al., 1997). Consequently, reservation systems have a long history of use and offer PPA managers a tool to plan and allocate high-value recreation opportunities and experiences such as rafting the Colorado River of the Grand Canyon (Whittaker & Shelby, 2008) and hiking Half Dome at Yosemite (Pettebone et al., 2013).

In 1973 Rocky Mountain National Park (RMNP) was among the first national parks to implement a rationing and allocation permit system in response to high demand for backcountry camping use. RMNP began requiring visitors in the park’s backcountry to obtain a permit and camp in designated sites in what was described at the time by Fazio and Gilbert (1974) as ”the most restrictive permit system ever devised for the control of wilderness use” (p. 753), but what is now a commonplace practice for backcountry visitor management in the National Parks. Fazio and Gilbert (1974) concluded that concerns the permit system would spark public backlash were unsubstantiated and their findings corroborated Hendee and Lucas (1973) which suggested that these techniques were less controversial among visitors than initially expected. Fazio and Gilbert (1974) found that 86% of visitors who obtained a permit and 80% of visitors unsuccessful at obtaining a permit were still supportive of the permit system. More recently, RMNP visitor management has shifted its focus to the high-use, front-country Bear Lake Road Corridor where the park shuttle bus system improved transportation system conditions in the park but delivered more visitors to trailheads than the capacity those settings were able to accommodate (Lawson et al., 2011).

2.1.3 Rocky Mountain National Park TEPS

In 2016 in response to several years of substantial increases in visitation RMNP began implementing a temporary vehicle closure of Bear Lake Road during times of high use during the peak visitation months which redirected visitors to other areas of the park (Wesstrom et al., 2021). This management action achieved the goal of relieving some visitation pressure on this high-use area of the park but ultimately did not address the underlying imbalance of the recreation demand and supply of facilities and infrastructure to support that demand while maintaining high-quality visitor experience conditions the park manages for. In 2020, in response to the COVID-19 pandemic and concern for visitor and staff safety RMNP introduced the Timed-Entry Permit System (TEPS), a managed-access reservation system, which required visitors to place a reservation through Recreation.gov (www.recreation.gov) and allocated a fixed number of reservations per hour to moderate the flow of vehicles entering the park. Although reservation systems are commonplace across public lands in the United States they are often used to allocate high-value experiences and high-visitor-use sites, however, managed access systems like TEPS in RMNP are among the first to be implemented at a whole PPA scale.

While there is a substantial corpus of recreation literature examining the effectiveness of rationing and allocation techniques as well as offering considerations for aspects of their efficacy, efficiency, and visitor burden, the context of many of the studies is designated *wilderness*[1] which is managed for different values, recreation opportunities, and visitor experiences than the front country settings in a national park. Further, park visitors, society, and culture at large have certainly evolved since early studies approached use-limiting strategies with deference for value-laden constructs like fairness, equity, and freedom which may hold different meanings or importance to park visitors today. Now, 50 years after Stankey (1973) explored how reservation systems affect visitors it is necessary to revisit some of these assumptions about how these systems operate to understand visitors' acceptability and perceptions of rationing and allocation techniques like managed-access reservation systems and to better understand the barriers these systems may present for visitors in the contemporary manifestation of the national park experience. Because of the novel implementation of this reservation system rationing and allocating access to an entire park, the RMNP TEPS system offers an opportunity to study a contemporary managed-access reservation system in consideration of the existing literature, its effect on the aspects of the visitor experience, and to understand what aspects of the visitor and their park experience shape or influence attitudes and evaluations of managed-access systems.

2.2 Methods

2.2.1 Study Area

Established as one of the earliest national parks in the USA in 1915, RMNP is situated among the southern Rocky Mountain Range along the continental divide approximately 50 miles northwest of Denver, Colorado (Musselman, 1971). The history of the area before the

[1] Among federal public lands in the United States, Wilderness is a Congressional designation overlayed on existing PPAs that prescribes a biospheric land-management philosophy but permits traditional or primitive non-mechanized recreation use. Along the International Union for Conservation of Nature (IUCN) framework, wilderness areas in the United States fall under management category ib, while the Rocky Mountain National Park is designated as category ii, and a UNESCO-MAB Biosphere Reserve.

park extends back nearly 11,000 years and is located within the ancestral and traditional homeland of the Ute, Arapaho, and Cheyenne whose legacy is recognized in place names of mountains and topographic features throughout the park. RMNP protects more than 100,000 ha and receives approximately 4.5 million visitors (N.P.S., 2023c) who come to experience the park's scenic alpine lakes, tundra, and vistas as well as the unique flora and fauna such as Lodgepole Pine (*Pinus contorta*), Colorado Columbine (*Aguilegia coerulea*), Rocky Mountain elk (*Cervus canadensis nelsoni*), Pika (*Ochotona princeps*), White-tailed Ptarmigan (*Lagopus leucura*), and Cutthroat trout (*Oncorhynchus clarkii stomias*). The majority of visitor use within the park is temporally concentrated in the summer months between May and September and spatially concentrated in two main areas; Trail Ridge Road which climbs and crosses the continental divide at approximately 3,650 m, and the Bear Lake Road Corridor which is a highly developed area of the park that offers easy access to trailheads leading to alpine lakes and striking mountain vistas.

RMNP first operationalized TEPS in the spring of 2020 in response to the COVID-19 pandemic out of concern for visitor and staff safety for the duration of the peak summer months of intensive visitation and continued this managed access reservation system through the same periods in 2021 and 2022. The TEPS system includes other broad visitor management goals to improve and maintain opportunities for high-quality visitor experiences and visitor safety, reduce crowding and congestion in high-use areas, manage the flow of vehicles and visitors in balance with infrastructure and capacities to maintain ecological resource conditions concordant with the National Park Service's (NPS) dual mandate. The Timed-Entry Reservation System, as opposed to Ticketed-Entry Reservation Systems used in some other US National Parks, rations the total number of visitors entering the park during the peak use hours of the day (i.e., between 9am and 3pm) and allocates a fixed number of reservations per daily time window to moderate the flows of vehicles entering the park throughout the day. In 2021, visitors were offered two TEPS reservation options, one to access the Bear Lake Road Corridor (from 5 am and 6 pm), and a second to access the remainder of the park (from 9 am to 3 pm). Before or after those peak use hours, no reservation was required to enter the park or the Bear Lake Road corridor.

2.2.2 Survey Development

We developed and operationalized a survey instrument (see Appendix A) in collaboration with RMNP management staff (OMB Control #: 1024-0224 / IRB Approval #: 12225). The survey items reflected descriptive and evaluative aspects of the visitor experience, which based on their experience, the RMNP staff indicated were the most managerially relevant and contributed to understanding the effects of the TEPS system on aspects of the visitor experience (Figure A.1, Appendix A).

First, in order to explain and better characterize the visitor, the survey sought to understand visitors' motivations for their park visit and understand their relationship with the dimensions of place at RMNP. The motivations of the visitors were assessed using a modified Recreation Experience Preference (REP) (Driver, 1976) scale with multi-item indicators measuring seven latent constructs such as socialization, relaxation, nature immersion, and risk/adventure. Similarly, to understand visitors' relationship with dimensions of place, we included a multi-item indicator scale to measure the dimensions of place attachment, place dependence, and social bonding (Kyle et al., 2005; Williams & Roggenbuck, 1989; Williams & Vaske, 2003). Finally, to describe and characterize the visitor and their visit, respondents were asked questions about their visit to RMNP (i.e., length of visit, experience-use history at RMNP) and general socio-demographic questions (i.e., country/ZIP code, age, gender, group size and race/ethnicity).

Next, we identified three areas of focus to elicit evaluations of the TEPS system with respect to its effect on the general visitor experience, trip planning, and transportation conditions, as well as their attitudes toward rationing and allocation techniques. Indicators commonly used by the NPS (N.P.S., 2023b) to measure the quality of the visitor experience were included in the survey instrument to understand the effect of the TEPS system on respondents' evaluations of perceptions of crowding and conflict with other visitors, the adequacy of infrastructure and signage, the absence of litter / human waste and the ability to experience natural sounds. Because use-limiting strategies when framed to address and protect resource conditions are generally highly acceptable to visitors despite weak theoretical and empirical support to achieve those goals unless the use is dramatically reduced, we determined that perceptions of resource conditions to the visitor experience were important to measure in relation to evaluations of the TEPS system. To understand the importance of resource conditions to visitors' experiences, we developed a suite of common resource disturbances like the trampling of vegetation and feeding/approaching wildlife and asked the visitor how important the management of these disturbances was to their experience. In order to understand how visitors navigated some of the potential barriers to the TEPS system we measured visitors' evaluations of the experience of obtaining a reservation through the on-line reservation process (Recreation.gov), the availability of a reservation for their desired date/time, the quality of the information about the TEPS system on the park website, as well the quality of interactions with staff to provide assistance and offer alternative activities.

The TEPS system enables managers to ration the rate of private automobiles, and ultimately the number of visitors, entering the park during peak use periods to target the desired social and ecological conditions for visitor experience and resource protection. In order to understand the effect of the rationing of vehicle entry into the park and the transportation system in the park we included survey questions to measure visitor's expectations for the traffic conditions as well as the conditions they experienced, and how important transportation conditions were in shaping their visitor experience in the park.

The third area of focus for the survey sought to understand visitors' direct evaluations of the TEPS system, as well as to better understand respondents' preferences and level of acceptability of intensive visitor management practices under contemporary pressures and challenges. We developed a list of scenarios that juxtaposed a range of potential implications of high levels of visitor use with park resources and visitor experience conditions. Finally, a common practice with natural resource decision-making processes is to consider a range of alternative approaches that would address the management challenge at hand. The management staff at RMNP offered a variety of indirect and direct management strategies as alternatives to the TEPS system that we asked respondents to rank in order of their preference, offering managers a sense of the most broadly acceptable approaches.

2.2.3 Sampling Methods

RMNP staff queried records of visitor reservations through Recreation.gov and provided a list of TEPS reservations placed by RMNP visitors and the corresponding contact information. In total, the records contained approximately 610,000 email addresses and included metadata about the visit, including the date of the park visit and the date the reservation was placed, whether the reservation was canceled or confirmed, and the type of reservation (i.e., Bear Lake Road, or the rest of the Park). Because a census sampling strategy would produce a prodigious amount of data and in consideration of minimizing the burden on the visitor, we employed a stratified random sampling approach using the metadata variables listed above after filtering the list for unique email addresses. The email-based survey method, compared to traditional visitor intercept sampling methods, afforded the means to efficiently gather a robust sample of visitor attitudes towards TEPS with minimal sampling error. As such, during the calculations of the appropriate sample size, we selected tighter parameters for the confidence intervals (99%) and margin of error (3%) than would typically be selected for visitor intercept type sampling (e.g., 95%C.I., 5% m.o.e.) to produce a sample that is accurate and generalizable to the population of RMNP visitors.

The stratified sample targeted RMNP visitors who placed reservations between May and October during the summer of 2021 when the TEPS system was in effect. The sampling strategy was operationalized with two sub-samples among visitors who placed a reservation for park visits between the months of May through August and reservations during the months of September and October which correspond to peak and off-peak visitor use seasons. Finally, informed by expected response rates to other email-based survey instruments from Dillman et al. (2009) we assumed a 5% response rate for our May through August sub-sample, but following distribution and observing a higher than expected response rate, the expected response rate was increased to 10% for the September through October sample. The surveys were distributed through Qualtrics (Qualtrics, 2023) first to RMNP visitors from May through August in mid-October 2021 and then to visitors from September and October in mid-November to provide a similar separation between the park visit and the survey experience to minimize the effect of this time difference on survey responses. Following recommendations from Dillman et al. (2009), emails were distributed on Monday morning so that they would appear at the top of email inboxes, and a reminder email was sent to those who had not opened or completed the survey the following Monday. The metadata variables used to develop the stratified sample were embedded in the respondent's survey response so they could later be used to evaluate the generalizability of the sample and to be used as variables in the analysis. Following the data collection period, we replaced any personally identifiable information in the dataset with unique hexadecimal codes to protect the anonymity of the respondents in accordance with the Institutional Review Board (IRB) and Office of Management and Budget (OMB) data storage guidelines.

2.2.4 Statistical and Analysis Methods

Statistical analyses were conducted in Python using Pandas (McKinney, 2013), Scikit Learn (Pedregosa et al., 2012), SciPy (Virtanen et al., 2020), Statsmodels (Seabold & Perktold, 2010), MLxtend (Raschka, 2018), and visualizations were created using Seaborn (Waskom, 2021). The responses collected through Qualtrics were downloaded and pre-processed to prepare responses to open-ended questions for analysis. The metadata variables included in the survey responses were summarized and used to create new variables related to the respondent and their visit, such as the difference in time (i.e., days) between when a respondent placed an order for a reservation through Recreation.gov and the date of their park visit. We used a ranked-choice instant runoff voting method with PyRankVote (Tingvold, 2019) to identify which alternative management strategies to TEPS would be acceptable to the majority of visitors, even if it was not their first choice. The instant choice runoff method takes the votes for the strategy with the least votes in each round and reallocates that vote to a respondent's next choice of the remaining alternatives until one strategy captures the majority (>50%) of votes.

The REP and Place Attachment scales were evaluated for scale reliability, consistency, and sampling adequacy before conducting a principle components exploratory factor analysis to reduce the dimensions of the REP and Place Attachment scales. The factor analysis of the REP scale was performed using a minimum residual method and varimax rotation, and the number of latent factors was determined by interpretation of a scree-plot and eigenvalue scores. We performed a principal components dimension reduction on the place attachment scale to force the multi-item indicators of the dimensions of place attachment (i.e., place identity, place dependence, social bonding) into a single component solution for each dimension. We developed a multiple linear regression model to understand what aspects of the visitor characteristics, experience, and attitudes influence perceptions of the TEPS system on the visitor experience. The model used visitors' evaluations along a five-point Likert scale of whether the TEPS system improved or detracted from their experience as the response variable and included 65 predictor variables from the dataset that were considered potentially relevant to attitudes towards managed-access including the characteristics of the visitor and the visit characteristics (i.e., number of visits to RMNP, the month of visit, duration of visit, etc.), as well as their evaluations of the visitor experience and conditions they experienced. To perform variable selection preserving as much information in the dataset as possible by keeping partially completed responses with missing values, we used a multivariate imputation by chain equation (MICE) technique, which creates a series of regression models to predict missing values based upon responses to other variables (Azur et al., 2011). Next, we used a sequential stepwise feature selection technique (Raschka, 2018) with all possible permutations of the predictors to identify the most parsimonious yet interpretable model that explained the greatest proportion of variance (r^2). After the final model and corresponding predictors were identified, the regression was performed on the original, nonimputed data, omitting the partial responses with missing values.

2.3 Results

2.3.1 Sample Descriptive Statistics

The response rate to the survey for the May-August subsample was 18. 9% and the September-October subsample 15. 9%, resulting in a collective response rate of 17.5%. Approximately 99% of the respondents who opened the link in the study invitation email agreed to participate in the study, which yielded a total of 9,684 responses. We received 37 replies to the survey invitation email that provided feedback with critiques about the length of the survey instrument (n=12), regarding concerns about TEPS restricting access (n=10), dissatisfaction with how RMNP operationalized the TEPS system (n=8), and comments sharing local perspectives (n=3) and other general comments about the park (n=5).

We performed a Chi-square goodness-of-fit test on the survey strata variables to determine if the sample follows the same distributions as the population from the email list used to invite participants (Franke et al., 2012). Goodness-of-fit tests returned statistically significant p-values for the number of reservations a respondent placed (χ^2(4,N = 9,9162)=372.27, p<.001, φ=.076), the month of the park visit (χ^2(5,N=9,162)=67.68, p<.001, φ=.032), and whether the date of the reservation was a weekday or weekend (χ^2(1,N=9,162)=20.47, p<.001, φ=.018). The type of reservation a visitor placed (i.e., Bear Lake Road, or Park Only) was the only non-significant result, (χ^2(1,N=9,162)= 0.61, p=.434, φ=.003). Given the large sample size and its effect on the interpretation of p-values (Lin et al., 2013), we also examined the Phi(φ) effect sizes and found all significant results had Phi values below the thresholds for small effect sizes, suggesting that the observed proportions differ only marginally from the expected proportions. Furthermore, we plotted the data and found that the patterns of the sample followed the distributions of the population very closely and were determined to be representative of the population of visitors to RMNP in the summer of 2021 who obtained permits through Recreation.gov. We summarized the demographic profile of the survey respondents (Table 2.1) and determined the average age of respondents was 54.1 years old, the median age 58 years, with 51.7% of the respondents identifying themselves as female, and 89.6% reported white as their race/ethnicity.

Table 2.1: Descriptive statistics of survey respondent socio-demographic and visit characteristics (n=9,684).

Variable	Category	Percent of Sample
	18-24	2.3%
	25-34	10.1%
	35-44	13.3%
Age	45-54	13.2%
	55-64	20.4%
	65-74	19.5%
	75-100	3.4%
	Female	51.7%
	Male	45.5%
Gender	Prefer not to say	2.2%
	Prefer to self-describe	0.4%
	Non-binary/ third gender	0.2%
	White	89.6%
	Other	3.3%
	American Indian or Alaska Native	2.8%
	East Asian/Asian American	2.1%
Race/Ethnicity	South Asian/Indian American	1.4%
	Middle Eastern/Arab American	0.4%
	Black/African American	0.3%
	Native Hawaiian/Pacific Islander	0.1%
	1	27.5%
Reservation Count	2-10	66.7%
(number of reservations	11-20	4.6%
placed per email)	21-50	1.2%
	51-95	0.04%
	1	3.7%
	2-3	9.1%
	4-8	15.1%
Previous RMNP Visits	9-15	15.2%
	16-20	8.1%
	21-70	25.0%
	71+	22.4%

The majority of respondents (61.1%) obtained a reservation for Bear Lake Road and the remaining 38. 9% of the visitors obtained a reservation for the park only. Approximately a quarter of respondents placed only one reservation through Recreation.gov for a RMNP visit, but most of the respondents (66. 7%) placed between 2 and 10 reservations throughout the summer. The survey respondents were from 17 countries including the United States, and all 50 US states and the District of Columbia were represented in the sample. The top five U.S. states of the respondents to the survey were Colorado (24.9%), Texas (7.61%), Illinois (3.95%), Missouri (3.48%), and California (3.2%) (Figure 2.1).

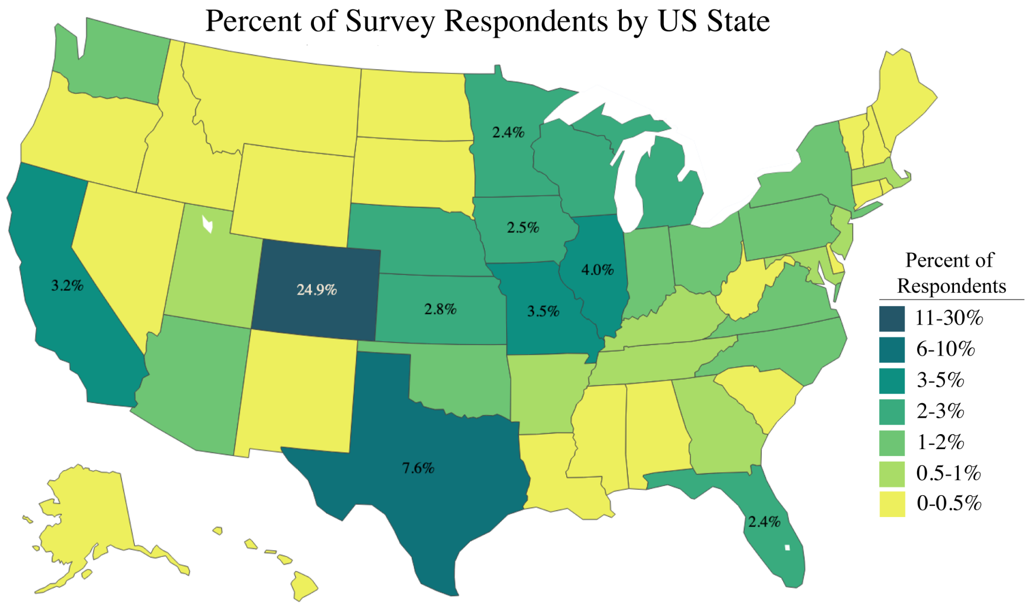

Figure 2.1: Percent of survey sample responses from U.S. States The states with the ten highest frequencies within the sample are annotated with the percentage of the total sample from the state (n=8,007).

After obtaining a TEPS reservation through Recreation.gov, 98.15% of the respondents visited RMNP in 2021 and 32.2% of respondents indicated it was their first visit to RMNP. The remaining 67.8% of respondents were asked to report the frequency of previous visits to RMNP, and more than 50% of those respondents indicated they visited RMNP 21 or more times prior to their visit during the summer of 2021 (Table 2.1). When asked about the duration of their visit, 37. 6% of the respondents reported staying most of the day, 28.8% multiple days, 25.8% a few hours, and 7.8% a full day in the park.

The number of days between when a respondent obtained a TEPS reservation and their park visit was on average 27 days (SD=20), while the median difference was 32 days.

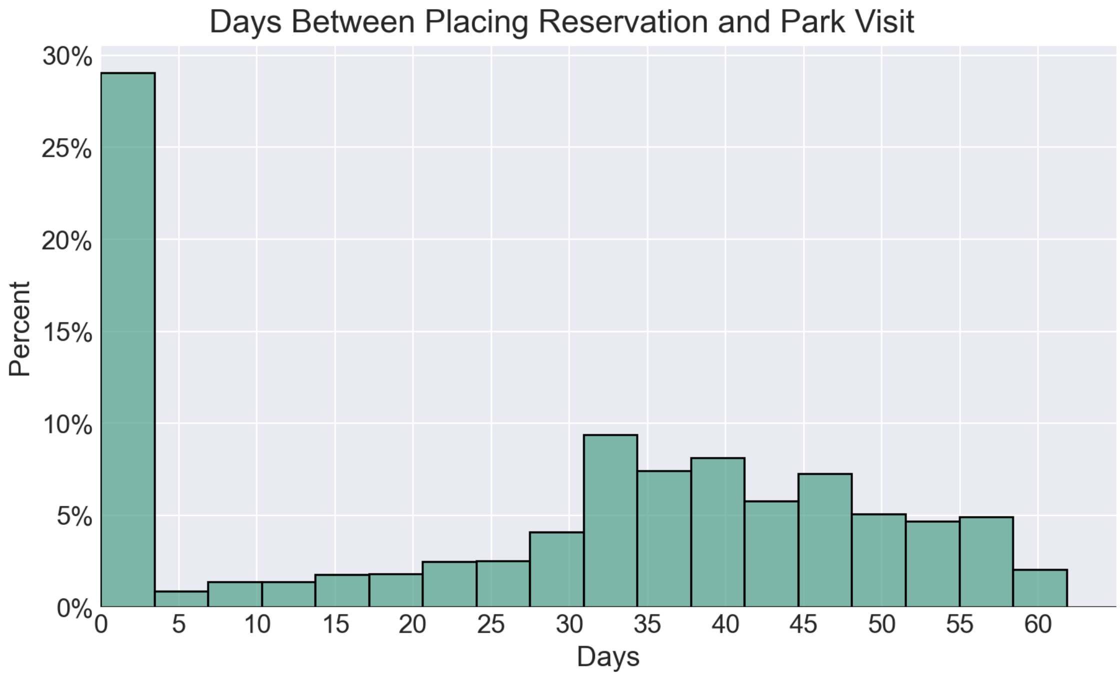

Figure 2.2: Distribution of the difference in days between when respondents placed an order for a TEPS reservation, and the date of their park visit (n=9,163).

However, this distribution was highly positively skewed, with the mode a difference of 1 day (Figure 2.2). Approximately 26.3% of survey respondents placed a reservation the day prior to their visit, 99% of whom listed the United States as their primary country of residence, and 2.2% obtained a permit on the day of their visit. We evaluated the correlation between the difference in reservation order and park visit and responses to a variable that measured whether the TEPS system improved or detracted from their experience and found a very weak yet significant relationship, $r_s(8625) = .059$, $p < .001$. Among the respondents, 60.7% obtained a reservation for the high-use Bear Lake Road Corridor and 70.4% of the respondents indicated that they visited the Bear Lake Corridor during their visit presumably before or after the reservation period had ended.

2.3.2 Visitor Experience

Respondents were asked to evaluate a suite of indicators designed to measure the quality of their experience, and included items that may enhance or detract from the experience. Responses to these indicators suggest generally positive evaluations of the visitor experience under TEPS, with means between 3 and 4 for items evaluating the adequacy of site facilities and infrastructure and opportunities to experience solitude, and lower means for statements about undesirable impacts and behaviors of other visitors and negatively phrased statements about trail and resource conditions (Table A.1).

In addition, respondents were asked to indicate how important management of disturbances of the resources, such as trampled vegetation, erosion, water quality, and improper disposal of human waste was to their experience. The mean of responses across the disturbances was 4.2 measured along a five-point Likert scale, which indicates a high degree of importance to the visitor experience (Table A.2). To test the assumption that visitors are supportive of rationing and allocation practices when they perceive them to protect resource conditions, we constructed a simple linear model using these resource disturbance variables as predictors and an evaluation of the TEPS system as the response variable. Although this model returned a statistically significant result, the relationship between these resource importance variables and attitudes towards the TEPS system was very weak ($R^2 = .033, F(7, 7814) = 39.37, p \leq .001$).

2.3.3 Planning and Traffic

The respondents were then asked to consider the extent to which a variety of transportation-related conditions affected their park experience, including congestion on roads, scenic overlooks, and entrance stations, as well as the availability of parking and the park shuttle bus. The mean of the responses to these conditions ranged from 1.45 to 2.61 on the five-point Likert scale, falling between ”not at all” (1) and ”moderately” (3) (Table A.3). The conditions the respondents reported that had the greatest impact on their experience included the inability to obtain a permit for the desired entrance time ($\bar{X}$=2.61, SD=1.55), traffic congestion at entrance stations ($\bar{X}$=2.50, SD=1.22), and parking congestion/shortages ($\bar{X}$=2.39, SD=1.23). Additionally, respondents were asked how the conditions they experienced compared to their expectations, as well as the effect of those conditions on their experience. The responses to these questions were jointly visualized to illustrate the relationships between the responses to traffic expectations and the impact on the visitor experience (Figure 2.3). Approximately 20.6% of respondents indicated that the traffic they experienced was somewhat or far more than what they expected, while only 10.1% of respondents indicated the conditions they experienced had very much or extremely detracted from their experience.

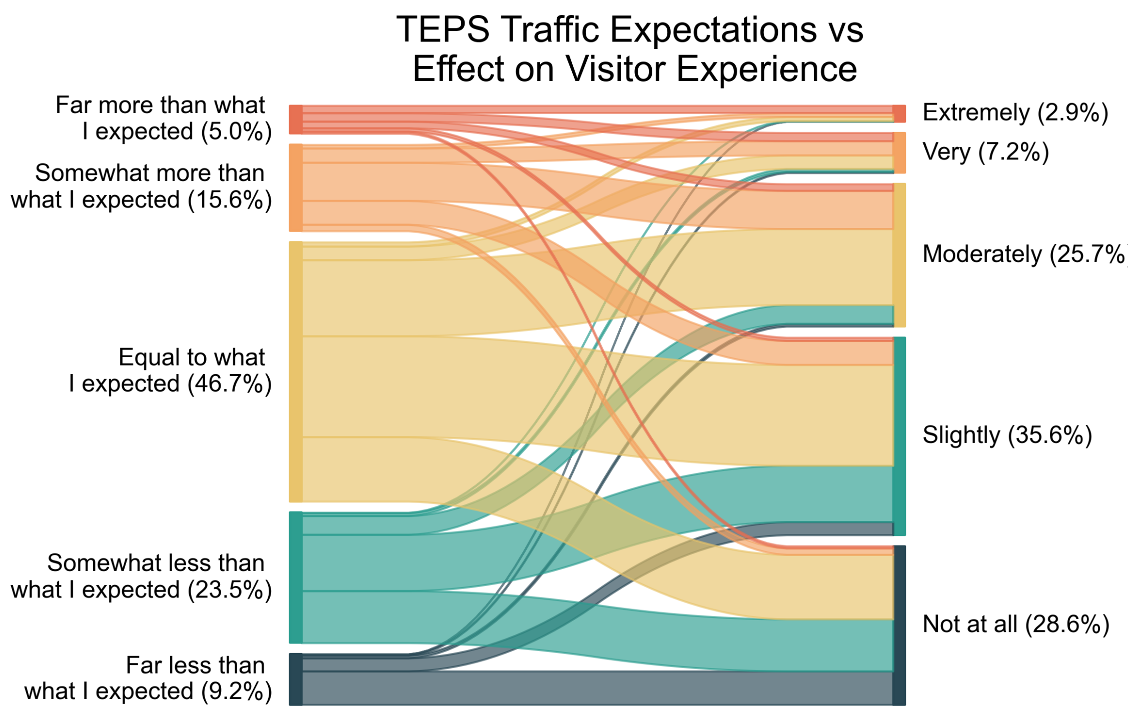

Figure 2.3: Flow diagram of the relationship between survey respondents' traffic expectations (Left) and the effect of the conditions they experienced on their park experience (Right) (n=8,771).

2.3.4 Attitudes Towards TEPS, Use Limits, and Management Alternatives

Respondents were asked a series of questions to understand the effects of the TEPS system on their park experience, specifically whether on the whole the TEPS system improved or detracted from their experience. We subsetted the responses of respondents who had visited RMNP prior to 2021 and could compare these visits with their experience in the TEPS park. Among these return visitor respondents, approximately 76% indicated that their park experience under the TEPS system was about the same, somewhat better or much better, and nearly half reported that their experience was somewhat better (24.1%), or much better (21.0%) (Figure 2.4).

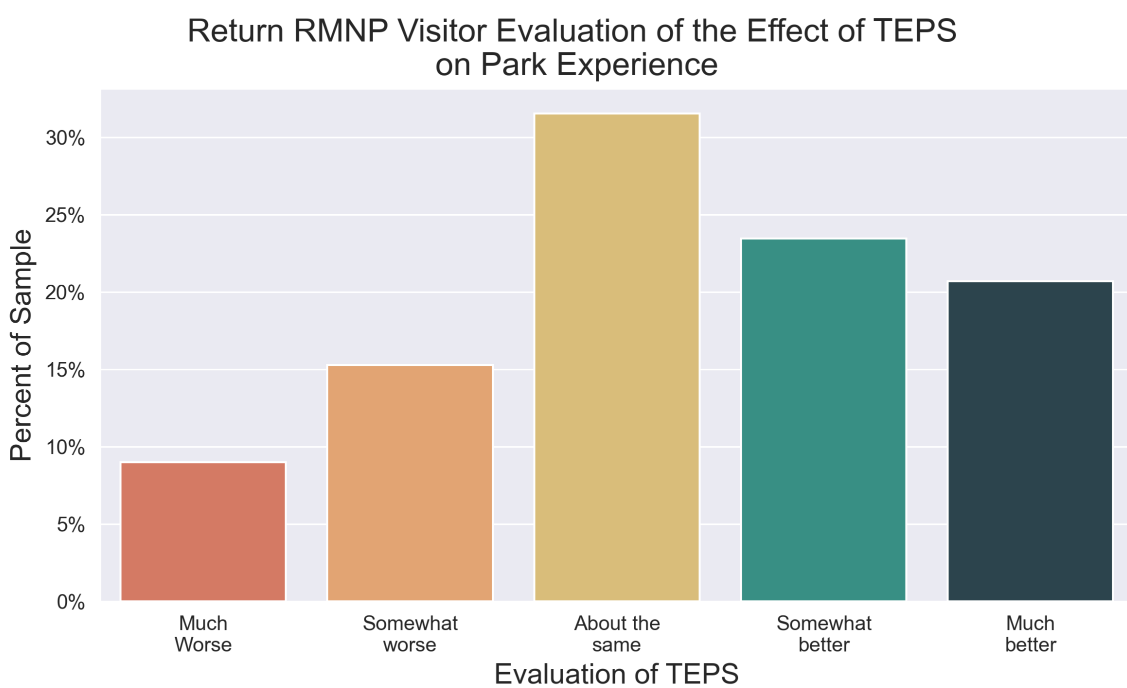

Figure 2.4: Distribution of return RMNP visitors' evaluations of whether the TEPS system improved or detracted from their experience on the whole (n=5,508).

We sought to better understand visitor attitudes towards managed-access strategies, and the conditions or circumstances that the respondents believed justified and acceptable to implement such management actions (Table 2.2). Broadly, respondents were generally supportive of managed-access strategies to address the effects of crowding on emergency response ($\bar{X}$ = 4.05, SD=1.05) and park upkeep and maintenance ($\bar{X}$ = 3.67, SD = 1.09), and for the protection of park resources for future generations' enjoyment ($\bar{X}$ = 4.01, SD=1.08).

However, respondents' level of agreement with some scenarios was more variable, such as mitigating the effects of crowding on park facilities ($\bar{X}$ = 3.51, SD =1.19), preserving opportunities for solitude ($\bar{X}$ = 3.38, SD=1.18), as well as to manage the availability of parking ($\bar{X}$ = 3.38, SD=1.24). Overall, we found that the respondents reported favorable attitudes towards managed-access strategies and largely rejected the notion that managed-access strategies were unacceptable ($\bar{X}$ = 2.07, SD =1.18) for RMNP.

Table 2.2: Descriptive Statistics for responses to the level of agreement with managed-access strategies to address a range of management scenarios, and resource and visitor experience conditions. The Likert response scale measuring agreement ranged from (1) Strongly disagree to (3) Neither agree nor disagree to (5) Strongly agree.

Statement	Mean	SD
If emergency response is delayed by crowding and congestion	4.05	1.05
If visitor-caused resource impacts impair future generations' enjoyment	4.01	1.08
If crowding and congestion impairs Park upkeep maintenance	3.67	1.09
If facilities (i.e., restrooms,VCs) are overwhelmed	3.51	1.19
If opportunities for solitude are lost	3.38	1.18
If trailheads are so busy no parking is available	3.38	1.24
There should never be managed-access, even if use is high	2.07	1.18

We prompted respondents to rank in the order of their preference potential alternatives to TEPS that park management might consider to address visitor experience and resource management challenges. The ranking of preferences for these alternatives was evaluated in the form of votes in a ranked-choice instant runoff until one alternative captured the majority of support. In the first round, limiting the number of automobiles captured 35.5% of votes, followed by a Bear Lake Road/Longs Peak Permit (14.2%), a temporal zoning strategy (13.5%), extending the park shuttle system (12.8%). After five rounds, limiting the number of automobiles captured the majority of support (¿50%) among visitors with 54.0%, followed by Extending the Visitor Shuttle (23.4%), and a Bear Lake Road and Long's Peak Permit (22.6%) (Figure 2.5).

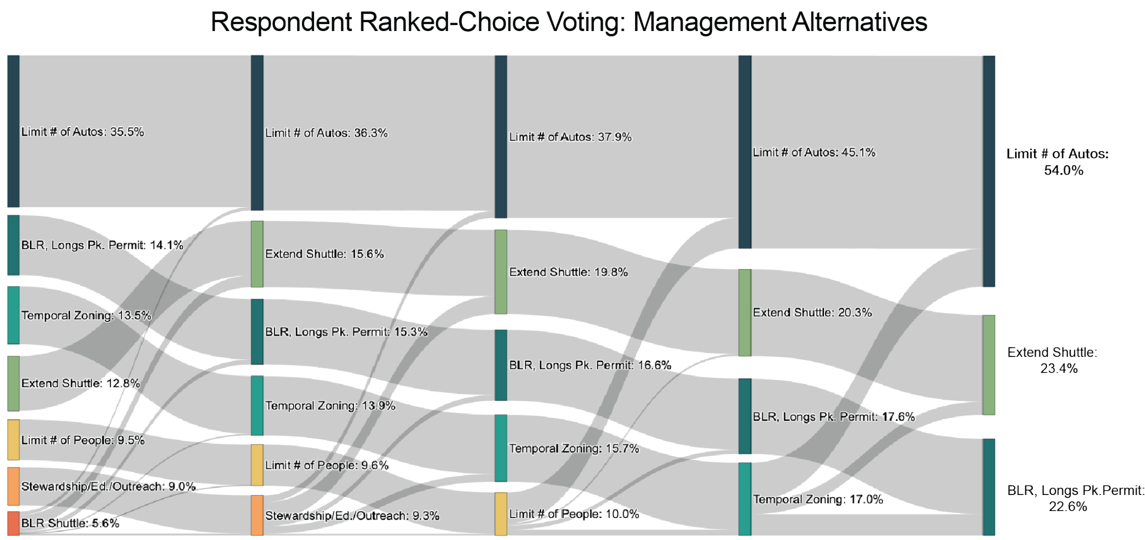

Figure 2.5: Flows of ranked-choice votes for management alternatives to TEPS. Limiting the number of automobiles remains consistently the most favorable choice throughout the rounds, but extending the shuttle, while initially less favorable becomes more acceptable to respondents throughout the rounds (n=7,308).

Finally, we developed a multiple linear regression model (Table 2.3) to understand what aspects of the visitor and the visitors' experience influence perceptions of whether the TEPS system improved or detracted from their RMNP experience. The final regression model included 13 predictors and explained 43.1% of the variance in the responses (Adj. $R^2 = .431, F(13, 3671) = 215.8$, p<.001). We found no statistically significant relationships between the TEPS evaluations and dimensions of Place Attachment or the latent REP factors. Instead, the five most important predictors in the model were whether a respondent believed managed-access strategies should never be imposed (β= -.229, p <.001), if their desired entrance time was unavailable (β=-.180, p <.001), the ease of obtaining a permit (β=.173, p <.001), if they believed managed-access was justified to provide trailhead parking (β=.136, p <.001), and finally their expectations for the amount of traffic in the park (β= -.111, p <.001).

Table 2.3: Summary of linear regression model predicting response variable measuring whether the TEPS system improved or detracted from the visitor experience.

Predictors	B	SE	95% CI		β	t	p
			LL	UL			
Intercept	2.296	.18	1.95	2.64	-	13.056	<.001
Managed Access: Never justified	-.230	.02	-.26	-.20	-.229	-13.631	<.001
Desired reservation time unavailable	-.138	.01	-.16	-.11	-.180	-11.326	<.001
Ease of obtaining a reservation	.163	.02	.13	.20	.173	9.616	<.001
Managed Access: Trailhead and parking	.130	.02	.10	.16	.136	8.349	<.001
Expectations for park traffic	-.137	.02	-.18	-.09	-.111	-5.885	<.001
Quality of TEPS info	.108	.02	.07	.14	.095	5.912	<.001
Expectation of the number of other visitors	-.094	.02	-.14	-.05	-.073	-3.891	<.001
Number of reservations placed	.123	.03	.07	.18	.060	4.609	<.001
Visited Bear Lake	.136	.03	.07	.20	.052	3.961	<.001
Managed Access: Opportunities for solitude	.047	.02	.02	.08	.047	3.105	.026
Previous park visitation	.036	.01	.02	.06	.044	3.296	.001
Staff helpfulness	.063	.02	.02	.11	.038	2.682	.007
Expectations for finding parking	.034	.01	.01	.06	.033	2.515	.012

Note: $Adj.R^2$=.431,F(13,3671)=215.8, p<.001

2.4 Discussion

2.4.1 Reflections on the Evolution of Rationing and Allocation

The literature focused on rationing and allocation techniques extends back nearly fifty years when researchers and PPA managers began to contend with the implications of intensifying visitor use on resource conditions and the social conditions of the visitor experience. This literature acknowledges the limitations and challenges of these strategies that can be philosophically controversial, and in some cases antithetical to the concept of PPAs on public lands (Behan, 1974; Hendee & Lucas, 1973, 1974), and theoretically antithetical to sustaining resource conditions despite the support of the public they garner when framed to do so (Cole et al., 1997; Cole & Hall, 2008; Hall, 2001). Much of this literature has been focused on applications of these techniques in backcountry and wilderness settings which are managed with different philosophies that prescribe specific wilderness experience opportunities and values for resource management and conservation objectives. Additionally, the early rationing and allocation discourse was often framed through and influenced by Hardin's (1968) *Tragedy of the Commons* (e.g., Dustin & McAvoy, 1980). Through the work of Ostrom (2007, 2009), Ratzlaff (1969), and Berkes et al. (2002) our understanding of natural resource systems shifted when framed as social-ecological systems that link the actors, relationships, interactions, and feedbacks which shape the system's outcomes. This study offers several insights into the contemporary use of a managed-access reservation system at the PPA scale and structures the results through a social-ecological systems framework to assess the diverse implications of the TEPS system at RMNP.

2.4.2 Rationing and Allocation Practices Beyond Wilderness

While visitor attitudes towards rationing and allocation practices are generally favorable (Bultena et al., 1981; Watson, 1993), some studies have found more mixed support (Cole & Hall, 2012) attributed to the rationing technique employed and the behaviors or use being rationed which contribute to the notion that managers might face opposition by these techniques (Hall, 2001). The respondents in this study broadly indicated support for use-limiting strategies to protect park resources, minimize impacts on managerial operations, and protect the quality of the visitor experience and largely reported positive evaluations of the TEPS system on their experience. This suggests some support for the argument by Dustin and McAvoy (1984) as well as Frost and McCool (1988) that some regulations and intensive management strategies in PPA settings may enhance aspects of the experience among visitors. Further, the difference in contexts between wilderness and the high-use, developed, front-country settings of the national parks might also contribute to the high level of support for TEPS we observed and may be a function of the difference in visitors' attitudes and expectations for the recreation experience and the acceptability of direct management strategies. In the context of a social-ecological system, Ostrom (2009) suggests the relationship between the number of users and the size of the resource system are important attributes to understand when self-organization and collective action may be sufficient to avoid undesirable system outcomes and where governance system rules might be warranted when collective action is insufficient. Further, where visitors are unable to self-organize or effectively cope with high levels of visitor use, governance systems can play a critical role in coordinating this use in a manner that is more sustainable and produces desirable outcomes with respect to the quality of the visitor experience and resource conditions.

2.4.3 Management Actions Underpinned by Resource Protection

We conceptualized the visitor experience as a function of the social, managerial, and ecological conditions and elicited respondents' evaluation of their RMNP experience along these dimensions under the TEPS managed-access system. The mean responses of the social and ecological indicators of the visitor experience were generally positive assessments of their experience under TEPS with some exceptions of persistent visitor management challenges such as visitor-wildlife interactions. Further, respondents indicated that the quality and management of resource conditions were highly important to their experience in the park. Interestingly, we found weak relationships between respondents' perceptions of the importance of management of recreation-related resource disturbances and their evaluations of the TEPS system but found the strongest support for use-limiting strategies was to protect resource conditions, similar to other studies in the literature conducted in wilderness settings (Cole & Hall, 2008). So while respondents acknowledged the importance of management of resource conditions to their experience and PPA settings, the relationships between the management of those disturbances and the TEPS system were more opaque to respondents. This aligns with several studies that have found that PPA visitors are capable of articulating the effect(s) of resource disturbances on their experience (Farrell et al., 2001; Lynn & Brown, 2003; Manning et al., 2004; Monz, 2009), but their ability to identify and link those disturbances to ecosystem stressors and responses and management of the setting (Monz et al., 2010) can differ substantially from the perspectives of management and recreation ecologists (Van Riper et al., 2010). Furthermore, visitors effectively place a high degree of trust and responsibility in PPA managers to protect and conserve ecological resources, even when this may involve more direct and intensive visitor use management of these areas.

2.4.4 Using Transportation Systems to Target Desired Conditions

Visitor transportation in RMNP, and by extension many aspects of the visitor experience, is centered around personal vehicles to experience and access various areas of the park. Fundamentally, TEPS targets the desired conditions for the visitor experience and resource protection by rationing the rate of visitors entering the park in private automobiles. This provides management the opportunity to utilize the system of park transportation, as Lawson et al. (2017) concisely stated, ”to deliver ”the “right” number of visitors in the “right” places at the “right” times” p.106, which has historically presented a challenge at RMNP, particularly in the Bear Lake Road corridor (Wesstrom et al., 2021). Visitors’ responses to the evaluations of traffic conditions under TEPS generally indicated low impacts on their experience in terms of parking shortages, traffic congestion, and shuttle bus wait times and access, and visitors’ expectations for traffic conditions were generally aligned with the traffic conditions they experienced. These positive evaluations of traffic conditions suggest the TEPS system is effective towards realizing the desired social conditions and may ameliorate some concerns about potential unintended feedbacks of the system displacing visitors to other areas of the park and surrounding PPAs (McCool, 2001; Wesstrom et al., 2021). While the personal vehicle is the mode of transportation used by the majority of visitors when prompted to rank preferences for alternative management strategies to TEPS nearly 70% of respondents supported limiting the number of automobiles in the park or expanding the park shuttle bus service. This finding is perhaps the most interesting result of this study, which potentially signals a shift in contemporary visitor expectations for the national park experience that is more receptive toward intensive management of automobiles and alternative transportation modes. In concluding remarks, Lawson et al. (2017) suggest that a more systematic and sustainable alternative to the conventional demand-driven approach can use transportation as a tool to manage visitor use according to the desired visitor experience and resource conditions, like managed-access under TEPS, that integrates the dynamics and relationships between the social and ecological systems of PPA management.

2.4.5 TEPS Drivers, Dynamics and Considerations

We explored some of the potential barriers of the TEPS system which we suspected might differ from early studies conducted before the advent of the internet and the ubiquity of internet-connected devices. Stankey (1973) and Shelby et al. (1989a) both expressed concerns that visitors unable to plan ahead for their visit would be adversely affected by advanced reservation systems. While most visitors placed reservations to RMNP a month or more ahead of their visit when they became available on Recreation.gov, nearly 30% of respondents placed a reservation the day prior or the day of their park visit. This distribution is very similar to the National Park campsite reservations in Walls et al. (2018) which were made available 180 days prior instead of 60 days but were also booked through Recreation.gov. We found no statistically significant relationships between when a reservation was placed and evaluations of the TEPS system. Rather, what we find is that attitudes about TEPS and managed access systems are more nuanced and value-laden.

The results of the multiple linear regression model suggest that what influences visitor attitudes most about the TEPS system are philosophies and values about public lands and the right for the public to enjoy them. Visitors who believed rationing and allocation techniques were never appropriate had the most critical attitudes toward the TEPS system. How reservations are allocated and distributed by these systems is also important to visitors. Visitors who reported ease of obtaining a reservation had positive attitudes about the TEPS system, however, if visitors were unable to obtain a reservation for their desired entrance time their attitudes were more critical of the TEPS system. This underscores the importance of ”allocation” in rationing and allocation techniques and how reservations are distributed. By setting a proportion of the reservations available a month or more in advance of a park visit and setting aside a proportion of reservations that become available the day prior and the day of a park visit these systems could accommodate visitors with varying preferences for planning, flexibility, and spontaneity. Next, visitor attitudes about the TEPS system involve certain expectations about the conditions they experience during their visit. When the amount of other vehicles and traffic in the park a visitor experienced exceeded their expectations, attitudes towards the TEPS system were more critical. Similarly, visitors who believed rationing and allocation techniques were appropriate to ensure the availability of trailhead parking had positive attitudes towards the TEPS system. Taken together, these results suggest that how these managed-access systems are operationalized and the social, managerial, and ecological conditions visitors experience are influential in shaping visitor perceptions and attitudes.

The focus of this study was to elicit visitor feedback about the TEPS system and offer insights into the contemporary use of managed access reservation systems but also acknowledge the limitations in the generalizability of the sample and results that apply only to visitors who visited Recreation.gov for a TEPS reservation. Notably, this omits feedback from visitors who were unable, or unwilling to obtain a reservation through Recreation.gov and chose not to visit the park because of the TEPS system. Although there is evidence in the literature that suggests the general population of visitors may differ from those who obtain permits or reservations, given the high proportion of returned visitors there may be similarities in attitudes towards and experience with the setting, as well as perceptions of the TEPS system (Watson, 1993). Nevertheless, we recognize the importance of understanding the procedural justice implications of these managed-access systems which warrant further study.

2.5 Conclusion

After recognizing a pattern of increasing intensity of visitor use during the peak summer months, RMNP initiated an adaptive management process to help maintain and achieve desired resource and visitor experience conditions. To better understand the nature and relationships between park transportation systems and infrastructure, resource conditions, and the visitor experience RMNP initiated a program of research into park transportation systems (Lawson et al., 2011; Lawson et al., 2017; Taff et al., 2013) and its effects on ecological conditions and the visitor experience (Monz et al., 2016). In 2016 RMNP employed a strategy of temporary vehicle closures of Bear Lake Road for portions of the day during the high-use summer months (Wesstrom et al., 2021) when congestion and conditions warranted. An important attribute of adaptive management strategies involves organizational learning that incorporates new information to monitor and evaluate the effectiveness and effects of management strategies and consider when to explore alternatives. TEPS might be viewed as an evolution of this process in response to these management challenges, and this study provides empirical data for the acceptability of managed-access strategies among visitors and the effects on their experience. Subsequent stages of the adaptive management process require continued monitoring and evaluation of the relevant indicators of the TEPS system in order to adjust (i.e., expand or reduce) its use according to various temporal scales (i.e., seasonal and daily) and visitation trends.

Although the focus of this study was the visitor survey, important questions remain about the effects of the TEPS system on the ecological dimensions of PPA social-ecological system. As Shelby et al. (1989a) suggests when visitors lack an allocation ”currency” they find ways to compensate or ”game” the system, and in the case of the TEPS there was some evidence of visitors entering the park prior to or after the hours of the day which required a reservation (Creany & Monz, 2022). This visitor coping behavior may represent an important change in the temporal and spatial behavior of visitor use and further study may be warranted to better understand the effects on flora (Willard et al., 2007) and fauna (Gutzwiller et al., 2017; Lewis et al., 2021; Taylor & Knight, 2003; Wisdom et al., 2018) together with more broad scale stressors of climate change on PPAs (Fisichelli et al., 2015; Monz et al., 2021) and anthropogenic disturbances (e.g., nutrient cycles (Baron et al., 2021) and plastics (Brahney et al., 2020; Forster et al., 2023)).

This research offers some insights into perceptions and evaluations of a managed-access reservation system and presents signals in contemporary PPA contexts that both complement and differ from the conclusions in the literature published more than fifty years ago which may require revisiting. For example, we found weak relationships between enduring recreation research concepts such as place attachment and motivations and assessments of TEPS and instead found that visitors' expectations for the park experience and values involving protected area use and access moderate or influence perceptions of the TEPS system. Given the apparent disconnect among respondents between TEPS and resource management, this suggests that outreach and interpretation programs should, as McCool (2001) advises, clearly communicate the relationships between the management action, resource conditions, and the PPA experience to visitors to illustrate their rationale and benefits for the PPA social-ecological system.

In the modern era with the near ubiquity of smartphones and the internet, obtaining a reservation likely presents less of a barrier to visitor spontaneity (Stankey & Baden, 1977) given the similarities with Walls et al. (2018) in the distributions and surge in reservations placed a day prior to the visit. Future studies might offer some insights into variations in allocation strategies, for example, how many days in advance and the proportion of reservations made available along with other techniques to reduce barriers among underserved populations such as older visitors and those with little or no access to the internet.

We would also like to underscore the importance of the justice, equity, diversity, inclusion, and access considerations of these managed-access systems which require further study to understand their effects not only among overnight campers (Rice, 2022) but also on the broader population of National Park visitors. Nevertheless, there may be a plausible argument that these managed-access systems may offer some benefits to considerations of equity and inclusion by providing the uninitiated visitor, who lacks previous experience and thus what types of conditions they might expect in these settings, an opportunity to enter and experience the park with the desired conditions managers have established for the setting. Further, there are some empirical data that suggest managed-access systems can increase access, such that because of the TEPS system coordinating visitor behavior and daily temporal patterns of visitation the total visitation was consistent with and at times exceeded visitation levels in prior years without the TEPS system (Creany & Monz, 2022; N.P.S., 2023a).

Alternatively, prior to the managed-access reservation systems, the high levels of visitor use often led to the closure of large areas (i.e., Bear Lake Road) or entrances and the entire PPA (i.e., Arches National Park, Utah). This calls into question what visitor "freedom" means in these circumstances and the need to consider and evaluate the normative assumptions regarding the national park visitor experience and values that shape PPA management. Ultimately, all management actions and decisions involve a degree of trade-offs where some goals, ideals, and values are constrained by others. Where value-laden concepts like freedom and access are invoked, PPA managers, visitors and the public should engage and deliberate on the qualitative meanings and importance of these concepts in the contemporary era of PPAs that considers these trade-offs amongst the broader dynamics of the PPA social-ecological system.

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CHAPTER III

WALK THIS WAY: INTENSIVE VISITOR-USE MANAGEMENT STRATEGIES FOR HIGH-USE URBAN-PROXIMATE PARK AND PROTECTED AREAS

3.1 Introduction

Management of wildland recreation faces diverse and evolving challenges to provide high quality recreation opportunities while also protecting ecological resources and character of the setting. Recent reports suggest outdoor recreation continues to grow in popularity, with over 150 million people in the US participating annually, resulting in over 10.2 billion recreational outings (Cordell, 2012; Outdoor Foundation, 2019). Participation rates in all forms of outdoor recreation have grown by an average of 1.4% annually since 2016. Much of this activity occurs in urban-proximate wildland settings (D'Antonio & Monz, 2016; Kyle & Graefe, 2007) with recent data suggesting that 63% of participants primarily recreate within 10 miles of their homes (Outdoor Foundation, 2019). Parks and open-spaces in close proximity to urban populations are often highly desirable for urban residents seeking opportunities to experience nature for exercise and renewal. Consequently, the demand for access and participation in a range of recreation activities is often extremely high in urban-proximate locations. For example, a recent study of visitor use trends at 11 park locations in Orange County found a 64% increase in recreation visits from 2014 to 2018, with total visitation increasing from 3.4M to 5.5M during this period (Monz et al., 2019).

Urban-proximate Parks and Protected Areas (PPAs) face unique a challenges in recreation management to provide opportunities for a broad diversity of visitors and activity-types on multiple-use trails in systems with high levels of visitor use. Multiple-use trails are common across many PPAs and public lands, which allow for various use-types, or activity-types, to coincide on a shared trail resource. However, under this multiple-use trail model conflicts between visitors often emerge, whether actual or perceived. It is the responsibility of land managers to mitigate these conflicts through efficient system management (Shilling et al., 2012). The factors that contribute to conflict between visitors have been well researched (Jacob & Schreyer, 1980; J. J. Vaske et al., 1995) in recreation literature and are believed to be exacerbated in systems with high encounter rates with diverse and varied activity-types (Chavez, 2001).

3.1.1 Visitor Experience Aspects of Trail Systems

Trails are a focal point of the visitor experience in PPAs, and as a result the social/experiential conditions and biophysical trail condition and quality can have a significant effect on visitors' overall experience. Although the relationships between the amount of visitor use and the experience or perception of conflict are complex, visitors generally seek out conditions that allow them to realize their activity goals and setting preferences (Manning, 2022). Therefore, understanding effects of visitor use management strategies on real or perceived conflict are an important component of successful trail management.

Conflict has been examined extensively among a broad range of recreation activity-types and contexts. Many of these studies have examined conflict among activity-types on trail systems (Jacob & Schreyer, 1980; Ramthun, 1995) to support and inform management strategies aimed at minimizing conflict. The source of conflict between activity-types has been attributed to many different factors, from resource specificity (the significance attributed to using a resource for a specific activity), mode of experiencing nature, lifestyle preferences (Manning, 2022; Ramthun, 1995), skill level or experience (J. Vaske et al., 2004), as well as social and PPA values (Blahna et al., 1995; Carothers et al., 2001; J. J. Vaske et al., 1995). A classic example of conflict which appears often in recreation research occurs between motorized and non-motorized activity-types (Albritton et al., 2009; Shilling et al., 2012; J. J. Vaske et al., 2007), which shares some similarities with pedestrian and cyclist conflicts when one group of visitors are perceived as disrupting traditional uses and behavioral norms (Mann & Absher, 2008; Watson et al., 1991). Additionally, conflict can emerge when new activity-types or technologies are introduced in recreational settings with established uses already in place, and consequently are perceived as disruptive.

3.1.2 Multiple Use Trails, Visitor Safety, and Intensive Management

Various safety concerns, both perceived and actual, have been identified in the context of visitors with varying styles and behaviors on multiple-use trail systems. For example, mountain bikers travel at much greater speeds than pedestrians and can surprise hikers on blind corners. Studies suggest that pedestrians often emphasize this as a safety issue, but there is some indication that the perception of safety hazards may exceed the reality (Cessford, 2003). The typical progression of management response to these concerns regarding visitor safety and conflict first rely on more indirect management strategies which employ educational approaches (i.e., yield "triangle" signs) to educate visitors on appropriate trail behavior and etiquette and encourage visitors to be courteous and "share the trail". However, Cessford (2003) suggests that if these strategies are determined to be ineffective at addressing these concerns, managers can employ direct, or intensive management strategies such as developing spatial or temporal zoning strategies (Manning, 2022) to separate activity types or coordinate visitor behavior by designating a direction of trail use .

In PPA settings with high levels of visitor use and mixed-use (i.e., multiple activity-type) trails, zoning strategies that spatially or temporally disperse select activity types are relatively commonplace. Activity-type designations, also referred to as spatial zoning or separation techniques, have a long tradition as a management tool in multi-use recreation settings like the U.S. Forest Service (USFS) (Clark & Stankey, 1979) where managers plan landscapes to spatially separate incompatible uses. These strategies are often justified on the basis that they reduce conflicts between visitors. However, we have been unable to find any studies have critically evaluated the effectiveness of these strategies. On the one hand, these strategies appear to make intuitive sense; by segregating trail users in space or time, or coordinating their behavior to travel in the same direction, it would seem to follow that this would contribute to fewer conflicts between visitors. However, in the absence of empirical evidence, if this line of reasoning is incorrect, it would unnecessarily burden visitors and limit their access and choice. Therefore, it is important to empirically evaluate the effectiveness of these strategies to justify their use and ensure that they aren't contributing to unintended consequences.

3.2 Research Objectives

A contemporary framework for addressing and developing a response to a recreation management concern uses an adaptive approach, which by design is iterative and responsive to new information that can inform subsequent planning (IVUMC, 2019). The Trail Use Designation Pilot Program (TPP), designed by OC Parks, is an example of this adaptive management approach to recreation that developed strategies to address conflict between visitors and increase perceptions of safety for trail users. The key indicators used to evaluate the effectiveness of the TPP strategies for this study were focused towards whether the effect on visitor reported conflict and perceptions of safety, and whether they resulted in changes in patterns of visitor use and behavior.

The methods and results that follow will address the following research questions that are centered on evaluating the effects of TPP management on addressing the management concerns regarding visitor safety and conflict and their effects on visitor behavior. Broadly, the TPP employed two direct trail management strategies, one designating the direction of trail use (i.e., uphill vs. downhill) and a second designated the permitted activity-types (i.e., hikers, cyclists, etc.). A conceptual model of the study design

3.1 provides a high-level overview of the two main focus areas of the analysis, sources and relations of data sources, and analysis procedures and statistical tests.

Research Questions

RQ1) Do intensive trail management strategies that designate direction of use and activity-type restrictions reduce visitor reported conflict?

RQ2) What is the effect of these strategies on visitor perceptions of safety, conflict, and the recreation experience?

RQ3) What is the effect of these strategies on trail behavior patterns of visitor use?

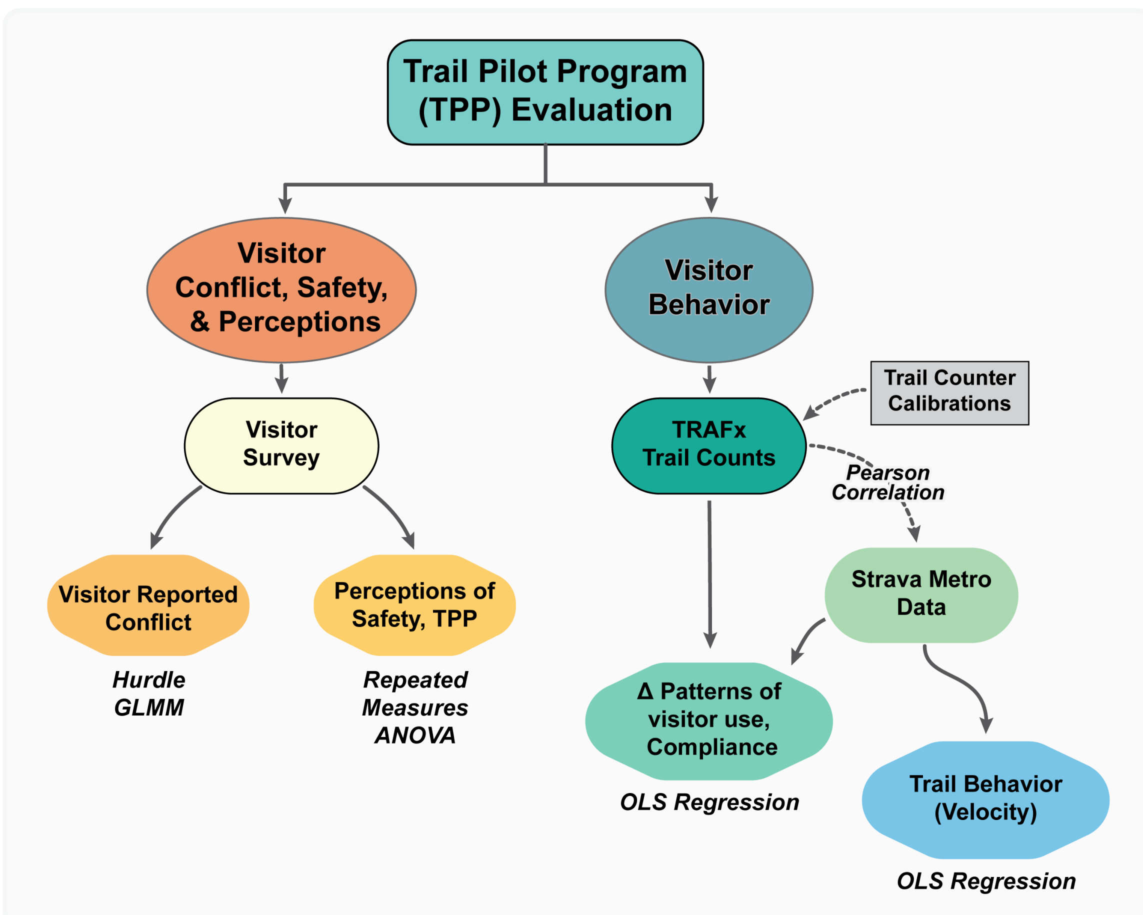

Figure 3.1: Summary of the foci of TPP dimensions, sources of data, analysis steps and methods.

3.3 Methods

3.3.1 Study Sites and Experimental Design

The study areas in this research are three parks managed by Orange County Parks (OC Parks): Aliso and Wood Canyons Wilderness Park (ALWO), Laguna Coast Wilderness (LACO), and Santiago Oaks Regional Park (SAOA) (Figure 3.2). Both ALWO and LACO are large PPAs adjacent to the Pacific coastline, while SAOA is situated in the interior part of Orange County close to the Santa Ana Mountains. The term “wilderness” in the names of these PPAs in this urban-proximate context indicates a managerial mandate for habitat conservation under the Natural Community Conservation Planning Act (Cal. FGC §2800, 1991). This legislation was enacted in response to mounting land-use and development pressures and development to protect critical habitat for thirty-nine plant and animal species listed under the California and federal Endangered Species Act (1973). However, these PPAs also provide the 3.2 million residents of Orange County, CA. (U.S. Census Bureau, 2024) access and opportunities for outdoor recreation. The PPAs in this study received approximately 760 thousand visits in 2017-2018 (Monz et al., 2019). Accordingly, OC Parks managers are face challenges to protect and conserve critical habitat while also to provide a high-quality recreation experience in settings with very high levels of visitor use. Adding to the challenge of providing a high-quality recreation experience with high levels of visitor use, OC Parks sought to formulate a management response to visitors’ concerns regarding the safety of the multi-use trails within these parks and visitor conflict between different uses or activity-types (i.e., hiking, biking, equestrian, etc.).

To address concerns regarding trail safety and conflict, OC Parks managers modified the management of TPP trails designating permitted activity-types (e.g., hike only, bike only) and directions of trail of use (e.g., uphill only, downhill only) within the three park study areas summarized in Table 3.1. OC Parks purposively selected the trail management strategies for each trail, however as evidenced in Table 3.1, this resulted in a complex

Orange County, CA PPA Study Areas

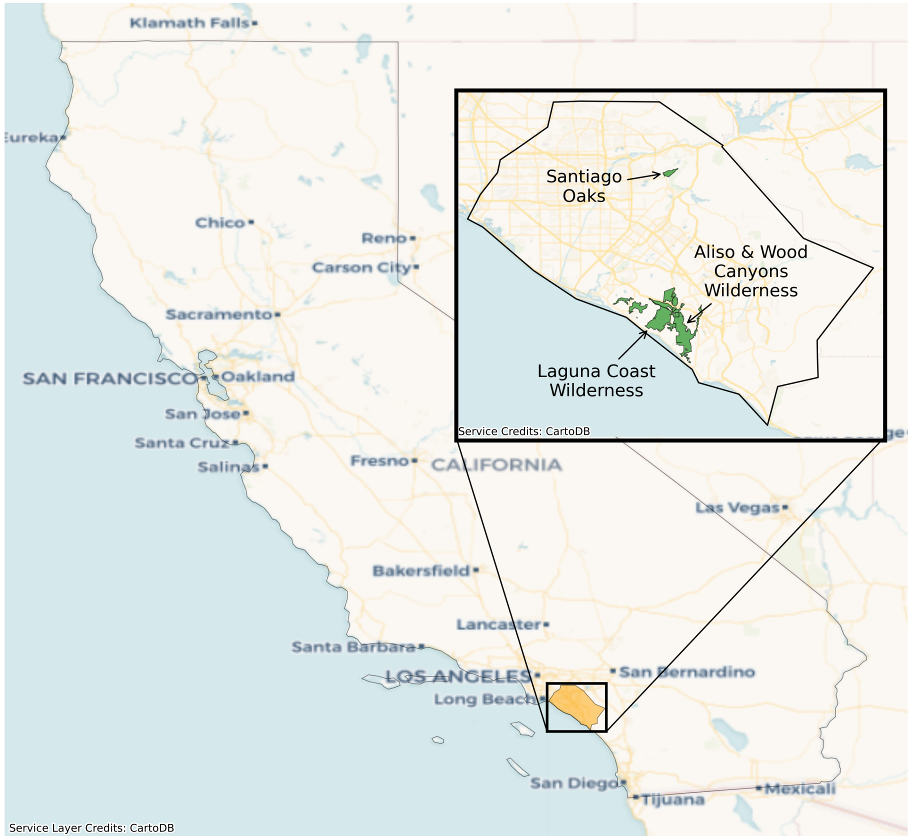

Figure 3.2: Location of PPA study areas within Orange County, CA.

structure for the TPP activity-type and direction designations and required a flexible experimental design to handle this imbalance. Ultimately, a Before-After-Control-Impact Paired Series (BACIPS) study design was selected, which is common in ecological study designs to evaluate the effects of experimental conditions (Underwood, 1993) such as restoration techniques (e.g., Conner et al., 2016) and can accommodate sub-optimal designs that lack randomization or where logistical constraints lead to an unbalanced design. A suite of analysis techniques and approaches have been developed for BACIPS studies that can account for confounding factors, including time (i.e. pre/post) and pseudo-replication (Stewart-Oaten et al., 1986), as well as background effects and variability, which in the context of an evaluative visitor survey might include the type of trail and patterns of use or the visitor’s activity type.

Table 3.1: Summary matrix of TPP activity-type and direction of use designations on TPP Trails. Filled circles (●) indicate TPP trail management designations relevant to that activity type, while empty circles (○) indicate activity types that were not permitted.

		TPP Management						
		Activity Designation			Direction Designation			
Trail Name	Study Category	*Hikers*	*Cyclists*	*Equestrians*	*Hikers*	*Cyclists*	*Equestrians*	Interpretation
Cactus Canyon	Treatment	●	●	●	●	●	●	Multi-use, downhill only
Cholla	Treatment	●	●	●	●	●	●	Cyclists uphill only
Chutes Ridgeline	Treatment	○	●	○	-	●	-	Cyclists downhill only
Grasshopper	Control	-	-	-	-	-	-	
Laguna Ridge	Treatment	○	●	○	-	●	-	Cyclists downhill only
Lizard	Control	-	-	-	-	-	-	
Lynx	Treatment	-	●	-	-	●	-	Cyclists downhill only
Old Emerald	Treatment	●	●	●	-	●	-	Cyclists downhill only
Peralta Hills	Treatment	●	○	●	-	-	-	Hike/Eq. only, bidirectional
Pony Trail	Treatment	●	○	●	-	-	-	Hike/Eq. only, bidirectional
Sage Ridge	Control	-	-	-	-	-	-	
Rock-It	Control	-	-	-	-	-	-	
Yucca Ridge	Treatment	●	●	●	●	●	●	Multi-use, downhill only

3.3.2 Visitor Evaluative Survey

We developed a survey instrument to elicit OC Park visitors' evaluations of the effectiveness of TPP trail management strategies, their effect on perceptions of safety, and the experience of conflict while using the trails. A conceptual diagram illustrating the full scope of experiential dimensions and components measured in the survey (Figure B.1), as well as the full survey instrument can be found in Appendix B (p. 161). We operationalized this survey using a systematic random visitor intercept technique stratified across days of the week and hours of day. In order to collect trail users' evaluations of their experience, we determined that in situ (i.e. at the trailhead) sampling would be advantageous to ensure that they had actually used a TPP or control trail and that the conditions they experience on the trail were salient at the time of the survey. Researchers were stationed at each of the TPP and control trails at either the start or end of the trail, and invited the next trail user to participate in the survey at six randomly selected minutes-on-the-hour throughout the day from approximately park open until close. Sampling occurred during the month of May 2021, prior to the implementation of the TPP, and following its implementation in late July through early August 2021. Visitors who agreed to participate in the survey were provided an iPad to self-administer the survey that was designed on Qualtrics (Qualtrics, 2023) software.

3.3.3 Visitor Use Monitoring

A component of evaluating the effect of the TPP on visitor use and behavior involved monitoring the amount of use and activity-types on trails to establish an understanding of the existing patterns of use. We measured the amount of visitor use on treatment and control trail segments using infra-red trail counters that provided total visitor use counts and temporal patterns of visitor use for the duration of the study period. TRAFx automated trail counters were installed along each of the TPP treatment and control trails at key locations. To correct for the measurement error of the TRAFx counters and produce accurate estimates of visitor use (Pettebone et al., 2010), researchers and OC Parks volunteers calibrated the trail counters with direct observations (i.e. counts of trail users). In addition to counting the number of trail users, the field protocols for TRAFx counter calibration also included a classification of trail users' activity type and direction of trail use.

Additionally, we sought to evaluate the efficacy of visitor-generated data (Fisher et al., 2018) from Strava Metro, an analytics platform that aggregates Strava user data, to measure visitor trail use and monitor behavior. A growing number of studies have used Strava data and demonstrated its utility as a tool for managers to identify the use of social trails (Rice et al., 2019) and estimate factors that contribute to park visitation (Norman & Pickering, 2019). However, because no studies have critically evaluated Strava Metro data, we sought to first understand the strength of the relationship between these data and the well-developed methods for use estimation from the TRAFx data. By comparing these two data sources we could gain an understanding of how generalizeable the Strava Metro data were to the "population" of trail users in these PPAs.

We evaluated Strava Metro data with calibrated trail counter data by performing a series of correlation tests comparing estimates of pedestrian, cyclist, and total counts as well as uphill and downhill directional counts.After establishing the reliability and generalizability of Strava Metro data, we could then evaluate this novel data source as a tool for monitoring and measuring the response to the TPP trail management strategies on visitor behavior, primarily direction of use and mountain bike trail velocities.

3.3.4 Data Analysis

After the completion of the survey data collection, the survey responses were downloaded from Qualtrics servers and prepared for analysis. Data preparation was carried out using statistical packages in Python, including SciPy (Virtanen et al., 2020), Pandas (Team, 2023), Pingouin (Vallat, 2018) and visualizations with Seaborn (Waskom, 2021). The responses collected in the *pre* and *post* sampling periods were cleaned for missing and erroneous data and merged into a single dataset. The analysis of the survey data in this manuscript is centered on two dimensions of the study, first to evaluate the effect of the TPP trail management strategies on visitor reported conflict, and second to evaluate visitor perceptions of the efficacy of the TPP trail management to address the concerns surrounding visitor safety, conflict, and the quality of the visitor experience.

Visitor Reported Conflict

The survey data were prepared for modeling the visitor-reported conflict by specifying the order of factor levels for variables (e.g. pre, post) and calculating a composite dependent variable, weighted conflict, which aggregated responses to two sets of survey scales. The survey design first asked respondents if they had experienced conflict with another activity type on the trail being sampled, if they did not experience any conflict, they proceeded onto the next set of questions. However, if a respondent indicated they had experienced conflict with another activity-type or trail user, a follow-up question asked them to report the frequency or likelihood of experiencing conflict with that activity-type along a five-point likert scale (extremely unlikely, . . . , extremely likely). The weighted conflict variable was calculated by taking the sum of the reported likelihood of conflict with each activity-type the respondent reported. For example, if a respondent indicated that they did not experience conflict, the weighted conflict value would be 0, but if respondents indicated that they experienced conflict with more than one group, for example, mountain bikes = *somewhat unlikely* (2) + runners = *extremely likely* (5) the weighted conflict value would be 7.

To model visitor-reported conflict, we used a generalized linear mixed-effects model in R (R Core Team, 2023) fitted with the package glmmTMB (Brooks et al., 2017). The model fit and residuals were evaluated with several continuous and discrete distributions and found that the models were either overdispersed or had weak explanatory power. After reevaluating the peculiar distribution of the weighted conflict variable that had a higher than expected amount of zeros for most models, we chose to model the data with a hurdle, or zero-adapted model, that would partition the zeros from nonzero values (Feng, 2021). This hurdle model also provided the benefit of modeling both whether a responded experienced conflict (i.e., the zeros), as well as the likelihood of that conflict (i.e., the non-zero values) in a single model. The hurdle, or zero-adapted model, assumes that the difference between zeros and non-zeros is a product of a single process; thus, all zeros in the data were true or structural, as opposed to a zero-inflated model that models two distinct processes that produce zeros or non-zeros and where zeros represent a combination of structural and sampling zeros (Hu et al., 2011; Zuur et al., 2009). In the context of this study, we assumed the former, which treated the zeros as structural because the survey respondents either reported experiencing conflict or not (Brooks et al., 2017).

The hurdle model used a truncated negative binomial distribution with a log link to model the non-zero weighted conflict observations, and a logistic distribution to model the observations of zeros to non-zero observations. Potential candidate models that were fit with truncated Poisson and generalized Poisson distributions were also evaluated; however, the negative binomial distribution was better suited to accommodate the persistent overdispersion present in the count data. The selection of the final model was carried out iteratively by adjusting fixed and random effects and identifying suitable models that maintained the variables of interest for the analysis and minimized the Akaike Information Criterion (AIC), which offers some advantages over likelihood ratio tests and helps identify models with the highest predictive power (Bolker et al., 2009).

Following the canonical design of BACI models (Pardini et al., 2018; Scotti et al., 2022, e.g.,), we included an interaction term between the treatment/control variable and the pre/post variable as well as interactions between variables that indicated treatments of activity type or direction of use designations. Because trails are sampled, before and after the TPP was implemented, the trail variable was treated as a repeated measure with its own random effect, as well as a nested random effect among trails within the pre/post variable to account for clustered and correlated observations, which can increase the likelihood of type I errors. Furthermore, the type of activity of the respondent was treated as a random effect because comparisons between groups were not of primary interest for this analysis but could still account for variation in the experience of conflict within and between activity-types.

The final model (eq 3.1) parameter estimates were calculated using restricted estimation maximum likelihood (REML) and was diagnosed and evaluated with the DHARMa package (Hartig, 2022) which provides a visual and statistical model diagnosis for dispersion, outliers, and residuals following best practices for the fitting of glmm models(Bolker et al., 2009). The package emmeans (Lenth, 2024) provided post hoc estimated marginal mean comparisons, plots were produced with the package sjstats (Lüdecke, 2023) , and model fit statistics including the Nakagawa R^2 (Nakagawa & Schielzeth, 2013) were calculated with the package performance Lüdecke et al., 2021. The model was specified with sum to zero contrasts for all fixed effects and polynomial contrasts for trails and activity type. With this contrast scheme, the model returned the main effects of the treatments that simplify the interpretations of the model coefficients and interactions (Davis, 2021).

$$weightedconflict = TC \cdot PP + A \cdot PP + D \cdot PP + AT + (1|AT) + (1|T) + (1|Tr{:}PP) \quad (3.1)$$

Eq. 3.1: Formula for negative binomial generalized linear mixed model where *TC* is the treatment-control, *PP* is pre-post, *A* is activity-type designation, *D* is direction designation, *AT* is activity type, and *T* is trail.

Visitor Perceptions of TPP Management

In addition to understanding whether TPP management strategies were effective in reducing the presence and likelihood of visitor reported conflict, we sought to understand visitor perceptions of their efficacy and the effect on their recreation experience. Analysis of this dimension of the study was focused on survey responses to a scale of statements that asked visitors whether the activity-type or direction designations were effective in reducing conflict and increased safety measured with a likert scale of agreement (i.e. strongly disagree,. . . , strongly agree). We analyzed these responses using a repeated measures ANOVA test to determine if these perceptions differed before and after the implementation of the TPP management strategies. Post-hoc comparisons were evaluated with a marginal pairwise test and p-value adjustments for multiple comparisons with a Bonferonni correction.

Visitor Use and Behavior

Trail counter calibration observation records were collated and compared with the respective TRAFx data records to produce a correction coefficient and estimate measurement error. Additionally, calibrated counts were further post-processed for anomalous or erroneous measurements using SciPy's (Virtanen et al., 2020) univariate derivative interpolation by grouping observations by the day of the week and hour of the day and smoothing observations with z scores beyond an absolute value of 3. Because the TRAFx trail counters only measures the amount of use, we used the calibration records to produce estimates of the proportion of pedestrians and cyclists and their direction of trail use (i.e., uphill, downhill). These estimates provided an understanding of the effect of the TPP on the patterns of use and activity-types on treatment and control trails, as well as a sense of the compliance with the TPP trail management regulations.

To assess the effect of TPP management on trail behavior, we acquired Strava Metro data for OC Parks trails between May and September 2021. This dataset contained aggregated and de-identified daily summaries of Strava app users' bicycle and pedestrian trail use, including direction of travel on the trail and aggregate trail velocities. We compared the Strava Metro mountain bike data using an OLS linear model before and after the TPP management went into effect to determine if there were any significant differences in trail velocity.

3.4 Results

The response rate to the survey was high with an overall acceptance rate of 86.3% (pre - 87.4%, post - 85.1%) and consistent with previous visitor intercept surveys conducted in Orange County PPAs (Sisneros-Kidd et al., 2019). In total, we collected 1,140 survey responses from park visitors that, after data preparation and processing, resulted in 975 complete surveys and 162 non-response surveys. The sample was slightly unbalanced with 627 (62.6%) surveys from the May "pre" sample and 374 (37.4%) from the July-August "post" sample. We attribute this to lower levels of visitor use in the warmer months of July and August, which according to TRAFx data were between 30-40% lower than levels of visitation in May. Additionally, the composition of the sample among activity-types was inconsistent between the two samples (χ^2(5,1139)=14.97 p<.05), however the within sample proportions of the most common activity-types, hikers and mountain bikers, were roughly similar between the two samples. Nevertheless, these data provided a sufficient sample size for the glmm and we accounted for the between-sample variation with the random effects in the model.

3.4.1 Visitor Reported Conflict

Approximately 62% of survey respondents did not report experiencing conflict with other visitors, while the remaining 38% reported experiencing conflict with one or other activity-types. The negative binomial hurdle model provided two frames of reference, the presence or absence of conflict (i.e., zero-inflation model) and the likelihood of conflict (i.e., conditional model), to evaluate the effects of trail regulations on visitor reported conflict (Figure 3.3). The variance among random effects in both models was very small among activity types, and almost non-existent among trails within the nested trail and pre/post variable. The model did not indicate any convergence issues, and although the variances were small they contributed to the models' explanatory power.

Broadly, the model explained a marginal amount of variation in visitor reported conflict with a Nakagawa R^2=.136 for the conditional model and R^2=.157 for the zero-inflated model (Table 3.2). However, the conditional model returned a significant positive marginal effect of the pre/post variable and a significant interaction effect of treatment/control and pre/post. There was significantly more reported conflict in the post-sample than in the pre-sample, and curiously in the pre-sample the likelihood of conflict on the treatment trails was less than on the control trails. However, in the post-sample the likelihood of conflict was significantly higher on treatment trails compared to control trails. Finally, there were no significant effects of the activity designation or direction designations but their effects diverged in opposite directions, positive and negative respectively.

The zero-inflated model had no significant results, despite the presumption that modelling the presence or absence of conflict, rather than the likelihood, might be less complex. The positive contrasts in the zero-inflated model indicate a higher chance of the absence of conflict, while negative contrasts indicate a greater chance of the presence of conflict. While the direction designation variable fell short of significance at $\alpha < .05$, the estimate was positive along with the activity type designation.

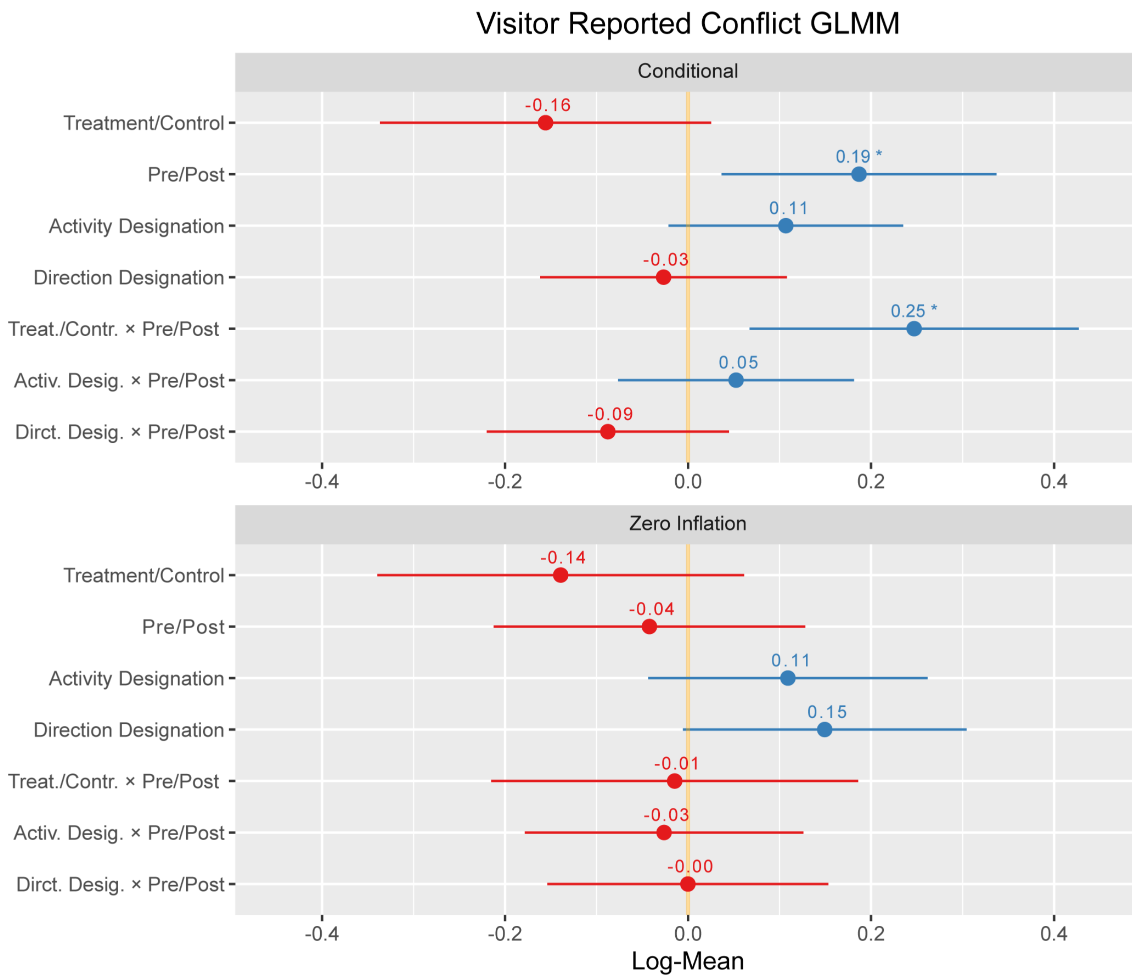

Figure 3.3: Forest plot of conditional and zero-inflated model parameter estimates. Positive parameter estimates for activity-type and direction designations in the zero-inflated model indicate a higher likelihood for the absence of (*less*) visitor reported conflict (zeros), while the positive treatment/control and activity-type interaction term parameter estimates in the conditional model indicate a higher likelihood of (*greater*) visitor reported conflict.

Figure 3.4 provides a visualization of the estimated marginal mean effects plots for each of the interaction terms where the trends towards lower levels of conflict, though not statistically significant, are apparent on the activity-type and direction designation treatments. Respondents most likely to report conflict during their experience in both the Pre & Post-TPP surveys are males who visited the study area trails on a regular basis with intermediate to advanced self-reported levels of specialization.

Table 3.2: Negative-binomial hurdle model of visitor-reported conflict model with a positive and statistically significant interaction effect of the treatment/control variable indicating that odds of visitor reported conflict on treatment trails were 28% higher than control trails.

Conditional Model					
Predictors	Log-Mean	SE	CI		p
			LL	UL	
(Intercept)	0.86	0.16	0.55	1.17	<.001
Treatment/Control	-0.16	0.09	-0.34	0.03	.092
Pre/Post	0.19	0.08	0.04	0.34	<.05
Activity Designation	0.11	0.07	-0.02	0.24	.103
Direction Designation	-0.03	0.07	-0.16	0.11	.697
Treatment/Control × Pre/Post	0.25	0.09	0.07	0.43	<.01
Activity Designation × Pre/Post	0.05	0.07	-0.08	0.18	.425
Direction Designation × Pre/Post	-0.09	0.07	-0.22	0.04	.194
Random Effects					
Parameter	Variance	Std. Dev			
Activity Type	0.047	0.216			
Trail	$6.69{\times}10^{-10}$	$2.59{\times}10^{-5}$			
Trail:Pre/Post	$3.69{\times}10^{-9}$	$6.08{\times}10^{-5}$			
Zero-Inflated Model					
Predictors	Log-Odds	SE	CI		p
			LL	UL	
(Intercept)	0.42	0.11	0.20	0.64	<.01
Treatment/Control	-0.14	0.10	-0.34	0.06	.173
Pre/Post	-0.04	0.09	-0.21	0.13	.627
Activity Designation	0.11	0.08	-0.04	0.26	.161
Direction Designation	0.15	0.08	-0.01	0.30	.059
Treatment/Control × Pre/Post	-0.01	0.10	-0.22	0.19	.886
Activity Designation × Pre/Post	-0.03	0.08	-0.18	0.13	.735
Direction Designation × Pre/Post	0.00	0.08	-0.15	0.15	.998
Random Effects					
Parameter	Variance	Std.Dev			
Activity Type	0.012	0.111			
Trail	$6.15{\times}10^{-9}$	$7.84{\times}10^{-5}$			
Trail:Pre/Post	$1.27{\times}10^{-10}$	$1.13{\times}10^{-5}$			
Model Performance					
Count Model: Conditional/Marginal R^2		.136/.079	Sigma (σ)	0.72	
Zero-Inflated Model: R^2/ Adj. R2		.163/.157	ICC	.061	

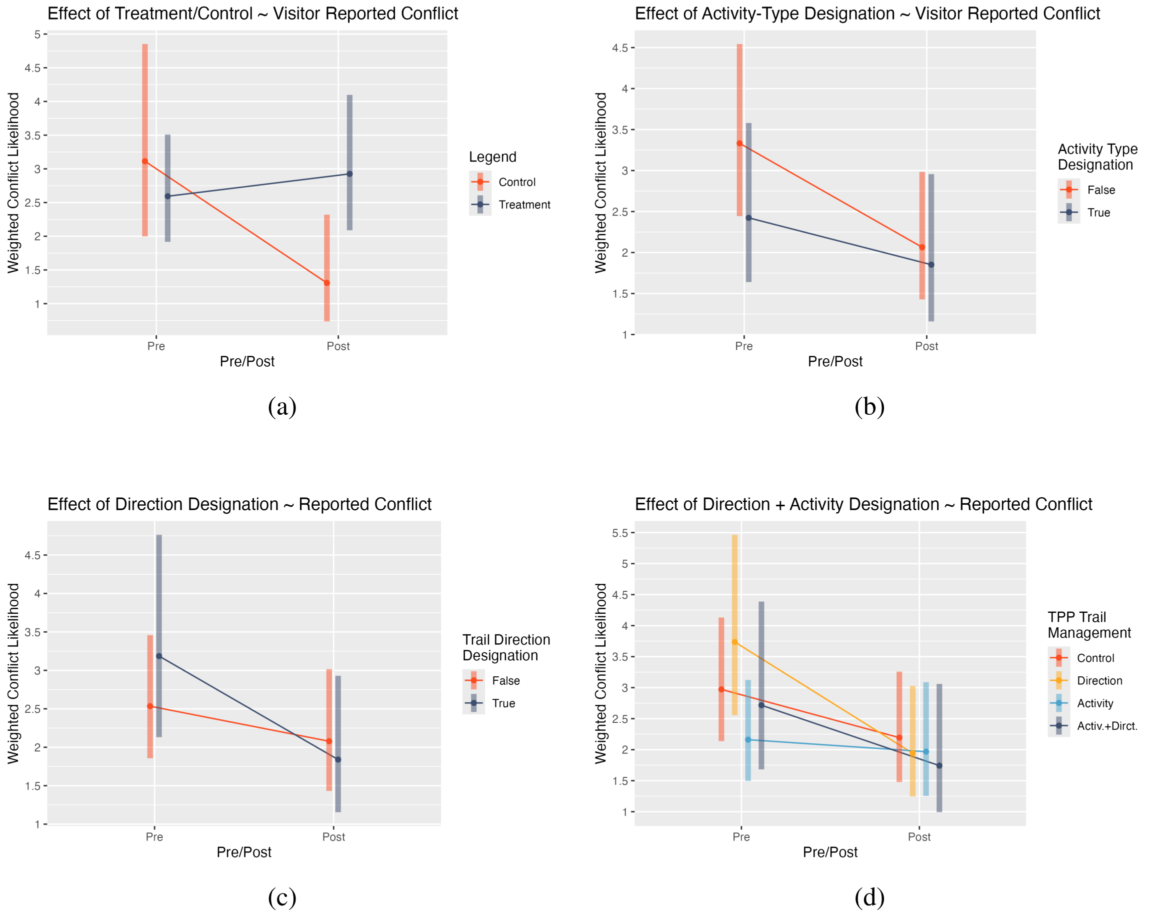

Figure 3.4: Conditional model estimated marginal mean effects plots of (a) treatment-control, (b) activity-type designation, (c) direction designation, and (d) combined activity-type and direction designation on the likelihood of visitor reported conflict. The treatment/control variable distinguishes TPP (treatment) from non-TPP trails (control), while the activity-type and direction-designation variables are the specific TPP trail management strategies.

3.4.2 Safety & Effectiveness

Safety, like conflict, is a complex construct shaped by visitor perceptions and experience and is difficult to measure in recreation contexts. To elicit responses from visitors regarding perceptions of safety in relation to TPP trail management strategies (i.e., activity type restrictions and direction of trail use), we designed statements to evaluate each strategy and its effect on visitor safety (Table 3.3). Visitors reported moderate levels of agreement in the pre-sample, and there was a statistically significant difference in the post-sample responses $F(1,11)=28.681$, $p < .001$. Next, a marginal one-tailed pairwise post-hoc test indicated that there were statistically significant increases in agreement to the majority of the statements regarding TPP management strategies from the pre-sample to the post-sample (Table 3.3. Although the means of all statements were higher in the post-sample, the statements regarding trail direction of use strategies contributing to safer conditions and fewer conflicts had significantly higher levels of agreement along with the statements that measured the effect of the TPP trail management on the quality of the visitor experience.

Table 3.3: Visitor evaluations of TPP management strategies effects on safety, reduction in conflict, and visitor experience. Responses are on 5-point Likert scale measuring agreement (1=Strongly Disagree, 3=Indifferent/Neutral, 5= Strongly Agree).

Statement	Mean		T	df	p-corr	Hedges g
	Pre	Post				
Restricting activity types on some trails creates safer conditions	3.64	4.03	2.24	22	.107	.883
Restricting activity types on some trails reduces conflict	3.52	3.95	1.47	22	.468	.579
Designating the direction of trail use creates safer conditions	3.81	4.18	4.54	22	<.001	1.79
Designating the direction of trail use reduces conflict	3.64	4.02	4.36	22	<.001	1.718
TPP trail regulations increased the quality of my experience	3.58	3.81	3.03	22	<.05	1.195
TPP trail regulations increased the quality of all visitors' experience	3.72	4.03	3.28	22	<.05	1.294

Visitors in the post-sample reported a statistically significant increase in agreement that the trail management strategies changes to activity restrictions and direction designations increased safety, reduced conflict, and increased the quality of the visitor's experience. Finally, visitors were asked to evaluate the TPP subjectively and objectively, whether the TPP "increased the quality of (their) experience" and "create(s) a better experience for all visitors". The level of agreement on the effect of the TPP on all visitors' experience was higher than the effect on the individual's experience of the TPP in both the pre and post-samples.

3.4.3 Visitor Behavior

Patterns of Visitor Use

TRAFx infrared trail counters continuously measured visitor use on TPP and control trails throughout the summer of 2021. Daily and weekly temporal patterns of visitor use were generally consistent across the summer. Between May and the end of September there were 111 trail counter calibration observations which provided robust estimation of correction coefficients to apply to the TRAFx data. After analyzing the calibration record activity-type and direction of use proportions, it was evident that there were some shifts in trail use among activity-types and direction of use from the pre to post TPP monitoring periods but were mostly in line with new trail management regulations (Figure 3.5). Trails in Laguna Coast Wilderness did not have any calibrations performed in pre-TPP period, so we were unable to determine any changes in trail use on those trails. Nevertheless, the position of each point in Figure 3.5 represents the median proportion, to limit the influence of outliers, of the trail activity-type and direction of use patterns. The arrows illustrate the changes in activity-type and direction proportions from the pre to post-TPP time periods, where for example the Grasshopper (control) trail shifted towards more downhill and pedestrian use, whil the Lynx (treatment) trail shifted to nearly 100% cyclists travelling downhill. Other trails such as Cholla and Rock-It showed very subtle shifts in direction of use and activity-type.

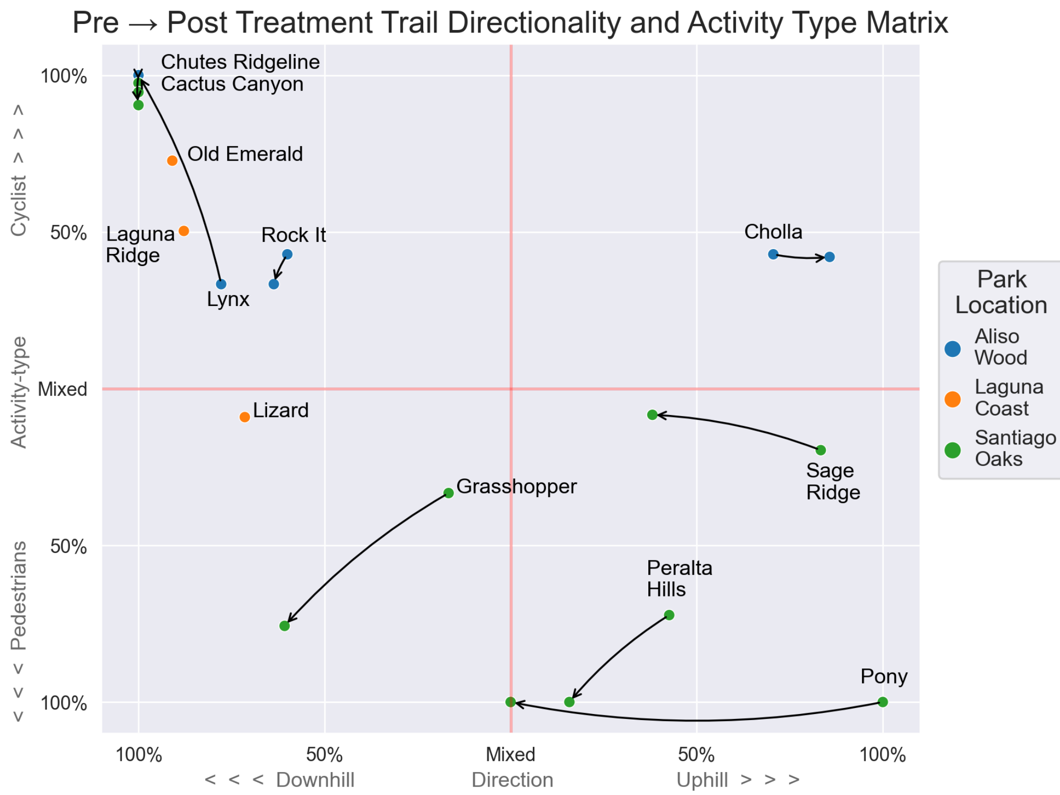

Figure 3.5: Trail activity-type and direction of use matrix illustrating the changes in the proportions of pedestrian vs mountain bike (y-axis) and downhill vs uphill trail direction of use (x-axis) in response to TPP trail management. Arrows indicate change from the pre-TPP patterns of use to the post-TPP patterns of use for trails in Aliso Wood and Santiago Oaks. For example, the TPP trail management on the Lynx trail shifted the proportion of activity-type to 100% mountain bikes and the direction of use to 100% downhill.

Trail Behavior

We compared the visitor-generated trail use data obtained from Strava Metro with calibrated TRAFx trail use estimates to evaluate the strength and relationship of these datasets in estimating pedestrian, cyclist, and total use as well as the proportions of uphill and downhill counts (Figure 3.6). The Pearson correlation coefficients were highest for cyclists and nearly all trails had statistically significant results. Generally, trails with higher total count and down count correlations were popular mountain bike trails, while trails with weaker correlations, e.g., Pony Trail, were predominately used by pedestrians which were underrepresented in the Strava Metro data relative to cyclists. Broadly, these data aligned with the TRAFx calibrations, where trails in the upper-left quadrant of Figure 3.5 had the highest correlations with the Strava Metro data.

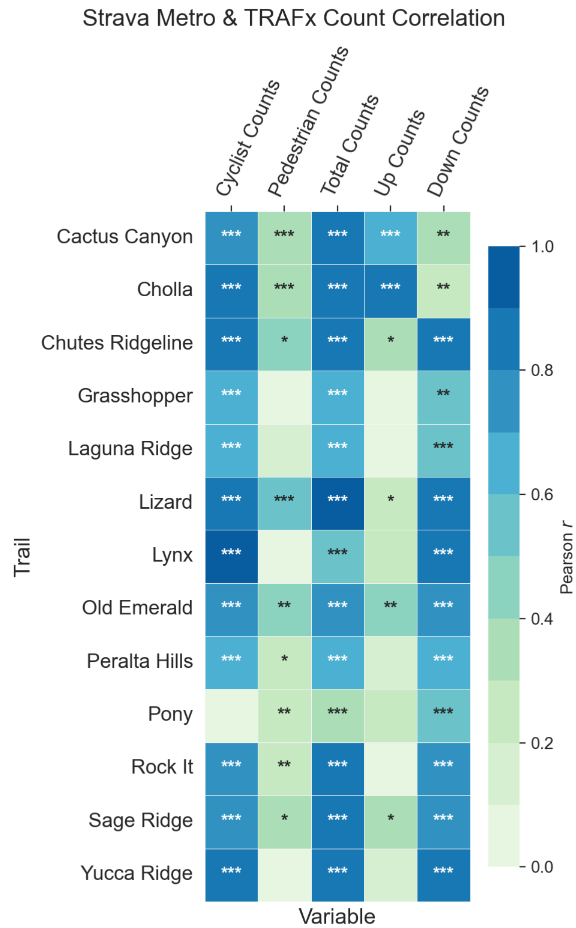

Figure 3.6: Pearson's *r* correlation matrix of TRAFx trail counts with Strava Metro Data. The rows represent the comparisons for each trail and the columns represent the comparison between TRAFx data and Strava Metro data. P values for statistical significance of the correlations is represented with asterisks where * <.05, ** <.01, and *** <.001.

Next, we used an OLS regression model to compare uphill and downhill mountain bike velocities on each trail between the pre and post time periods to determine if TPP trail management resulted in significant changes in cyclist trail behavior (Table B.1). We found that there were no significant differences between uphill velocities on any of the trails, but observed significant increases in trail velocities on the Yucca p<.001, Cholla p<.01, Grasshopper p <.05, and Chutes Ridgeline p<.05 trails (Figure 3.7). Table B.1, included in Appendix B (p. 184), provides a summary of the OLS regressions on mountain bike velocities for each trail . Additional figures illustrating the distribution of uphill and downhill velocities before and after the TPP trail management are included in Appendix B (Figures B.2 - B.13, p. 185).

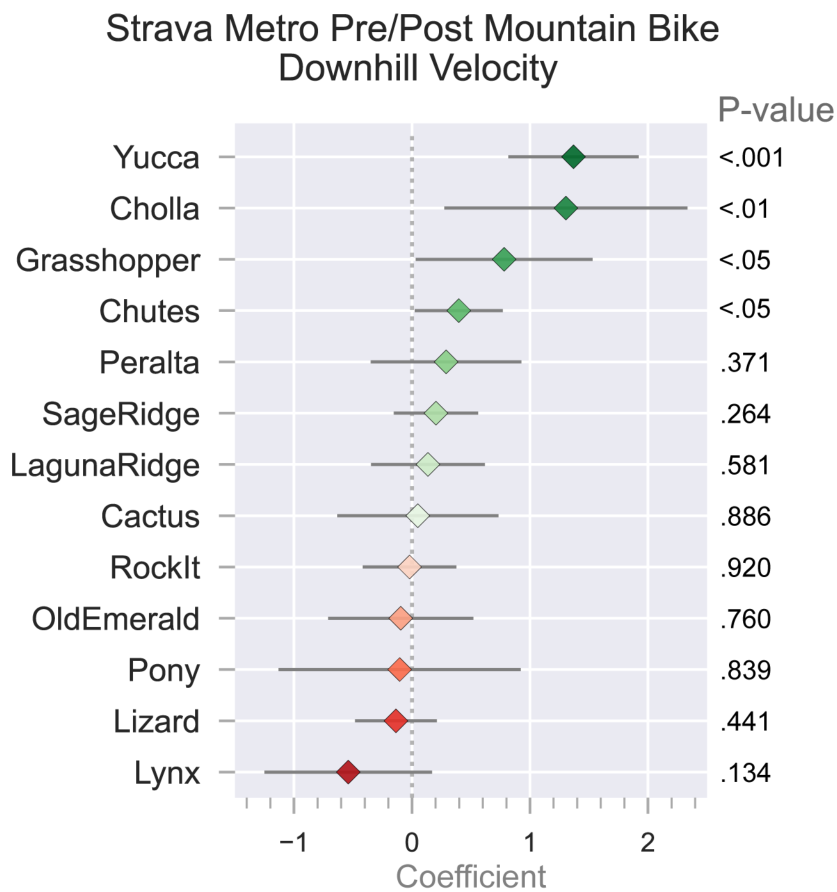

Figure 3.7: OLS model coefficients summarizing the pre to post magnitude and statistical significance of changes in downhill mountain bike trail velocity. Statistically significant increases in trail velocities were observed on four trails: Yucca, Cholla, Grasshopper, and Chutes.

3.5 Discussion

3.5.1 Visitor Reported Conflict

These results suggest that intensive trail management strategies like the TPP activity-type and direction of use designations produced marginal reductions in visitor reported conflict, but relative to the control trails, those treatments were not statistically significant. Additionally, while there was a significant interaction effect for the treatment trails in the post time period, the interpretation of this contrast is somewhat opaque because the treatment/control variable primarily distinguished trails whose management had changed under the TPP from those whose management was unchanged and not any particular strategy. The estimated marginal means for this contrast (Figure 3.4a) were averaged across the activity-type and direction designations which doesn't characterize the effect of the TPP very well for any particular trail. Overall, the analysis was encumbered by the complexity of the various permutations of the activity-type or direction designation strategies where we could only explore a few combinations of the partial factorial design.

These findings do not provide sufficient evidence to establish causation between TPP management and a reduction in visitor reported conflict. However, it is important to point out that the between both the pre and post-samples, the majority of visitors reported they did not experience conflict (66%) while only a minority of visitors (33%) reported conflict in the survey. Further, among the respondents who did experience conflict, the majority indicated the conflict was generally minor or infrequent which made the changes and comparisons quite subtle. Nevertheless, the finding that male, highly specialized survey respondents were most likely to report experiencing conflict is reflected in recreation management literature on conflict. Previous research on this topic found that visitors with high levels of specialization have more developed and specific preferences for the social, ecological, and managerial characteristics of the setting (Manning, 2022).

The hurdle glmm model explained only 14%-16% of the total variation in visitor reported conflict, which suggests that there are some significant confounding factors that influence conflict that we did not measure. Further, despite the sophisticated and robust attempts to account for possible variation between trails, treatments, and points in time, it remains unclear why visitor reported conflict on control trails dropped so precipitously, despite no changes in trail management. This finding likely warrants further inquiry to better understand, but we speculate that there may be edge and/or or spillover effects from the TPP trail management on the surrounding trails within a park system. Additionally, because these PPAs were relatively small visitors may have used both control and treatment trails, and thus were not completely independent subjects when they responded to the survey. Trails form a network with emergent patterns of visitor use and behavior, therefore, manipulations to the permitted activity-types and directions trail of use may introduce new and unexpected dynamics on other trails within the system.

3.5.2 Visitor Perceptions of TPP Trail Management Strategies

Broadly, survey respondents indicated high levels of agreement and support for the TPP trail management strategies. The results indicate that, overall, visitors believe that the trail management strategies enhanced the quality of their experience. The survey scale included a statement concerning the effect of the TPP strategies to prompt respondents to consider the perspectives of managers which likely differ from their own as a function of how any given trail, activity-type, or pattern of use was affected by TPP management. When prompted to reflect objectively on the effect on all visitors, reported even higher levels of agreement that the TPP management increased the quality of the experience for all visitors. Nevertheless, although managers typically prefer more indirect management strategies out of deference to minimizing the burden on visitors (Manning, 2022), the application of direct management strategies when warranted by the context and setting can be viewed favorably among visitors and contribute to a higher quality visitor experience (Creany et al., 2024; Frost & McCool, 1988).

Additionally, respondents largely regarded the direction designations as effective, and to a lesser extent the activity-type designations, in mitigating conflicts and create safer conditions. Further, there were significantly higher levels of agreement in the post-sample the direction of use designations were effective at these addressing these goals of the TPP. While there is no literature to compare these findings to, it may lend credence to and be explained by the apparent ubiquity of these trail management strategies in multi-use settings with high-levels of visitor use. Nevertheless, while visitors indicated a high degree of agreement and support for TPP trail management strategies to address management concerns of conflict, these perceptions of reduction in conflict were not corroborated by the model evaluating the effects of these strategies on visitor reported conflict. This disconnect between experience and perception (i.e. cognitive dissonance (Festinger, 2001)) has been pointed out in other recreation use studies which have found inconsistencies between stated and actual evaluations of conditions (e.g., satisfaction and levels of visitor use) (Manning & Valliere, 2001).

3.5.3 Effects of TPP Trail Management on Visitor Behavior

This study used several sources of data to monitor and understand the effect of the TPP trail management on visitor use, which provide a broader understanding of the response to management actions and the subsequent changes in behavior. First, the shifts in the composition of trail activity-types and direction of use generally aligned with the changes in trail management. For example, the proportion of mountain bikes on the Lynx trail shifted to nearly 100% and alternatively the proportion of pedestrian trail users on the Peralta Hills trail shifted to nearly 100%. These observations suggest visitors were generally compliant with the changes in trail management. However, it's unclear why we observed large shifts in patterns of use on control trails such as Grasshopper which did not have any changes in trail management. Similar to our finding of reduced conflict on control trails, this may further support the explanation that changes in trail management on select trails can produce new patterns of behavior across a trail network. Nevertheless, the observations of trail use patterns likely fall short meeting criteria for a systematic random sample, and instead were conducted somewhat opportunistically based upon the availability of OC Parks volunteers. Notwithstanding these limitations, which may have resulted in spatial and temporal biases, we can't reliably infer much about the shifts in patterns of use from the calibration observations.

The Strava Metro data correlations aligned closely with our a-priori impressions of the trails and their activity-types and direction of trail use from the visitor intercept survey. Additionally, the Strava Metro data appears to be highly consistent among trails frequented by mountain bike users (e.g., Chutes Ridgeline, Lizard, Lynx, Old Emerald, Rock It, Yucca Ridge) which resulted in strong correlations with cyclist counts, total counts, and the prevailing direction of use. Taken together, the strong and statistically significant positive correlations, face and construct validity, and reliability of the Strava Metro data suggest that this visitor generated data can provide managers a useful tool to measure and monitor mountain bike use.

We observed a statistically significant increase in mountain bike trail velocities, indicating a behavioral response to TPP trail management. Interestingly, we did observe a significant increase in downhill trail velocities on the Cholla trail that were non-compliant with the TPP up-hill only travel for cyclists. Although there were far fewer cyclists travelling downhill on the Cholla trail after the TPP regulations went into effect, the de-identified and anonymized Strava Metro data obscures details about the time of day when these trips were recorded. One would hope that these record breaking descents by Strava users occurred during a low-use time of day or day of the week. Nevertheless, the fact that we found any significant differences was somewhat unexpected because of how the Strava Metro data aggregated visitor recorded trips and averaged their velocities across a trail segment. Accordingly, this Strava Metro data didn't represent the behavior of any individual but rather dozens of trips that were averaged together. To a certain extent, this averaging across individuals diminishes the resolution of the data, but also provides some additional assurance that the significant differences in trail velocity are less susceptible to Type I errors. Alternatively, as this reasoning cuts both ways, some of the non-significant differences may be more susceptible to Type II errors.

These findings offer several important considerations for managers. First, TPP trail management strategies like designating the direction of use can result in significant changes in visitor behavior where mountain bikes on cyclist-only and downhill trails (e.g. Chutes Ridgeline), assured by the understanding that they won't encounter hikers or uphill travelers, descend at higher velocities. Next, we found a consistent pattern of mountain bike velocities on trails with downhill direction of use designations, this management approach does not appear to be appropriate for multiple-use trails and could potentially generate additional conflict and safety concerns. Taken together, these findings suggest that prior to adopting either strategy of activity-type or direction designations, management should carefully consider the existing patterns of use and potential changes in trail use that might emerge on other trails within a network.

3.6 Conclusion

Adaptive management involves land managers developing, implementing, and evaluating the effectiveness of management actions to meet goals and objectives by monitoring key performance indicators (IVUMC, 2019). Accordingly, this involves identifying meaningful, managerially relevant, quantifiable, and sensitive indicators to track and monitor their steps to address the issue. The TPP is an example of this adaptive management approach that developed trail management strategies to address concerns regarding visitor safety and conflict. This research supported this adaptive management process by evaluating the effects and efficacy of those strategies, demonstrated several novel techniques to monitor visitor use patterns and behavior, but also illustrates the complexity of visitor perceptions of conflict and safety.

While we found that the most of visitors reflected favorably on the TPP as an effort to address key dimensions of their recreation experience, we did not find any substantial relationships with TPP strategies to support that belief. However, although the TPP treatments in this study had no statistically significant effects, the positive evaluations toward the TPP among visitors suggests they value the managerial willingness to initiate action. This highlights an important consideration for managers, that the public views the actions of management based on their perceived intentions, and perhaps to a certain extent absent any guarantee on the outcomes.

Managerial concerns regarding visitor conflict appear to be quite commonplace, however in this study we found the prevalence of conflict among visitors was far lower than managers may have believed from the outset of the research. Further, visitor reported conflict may be a poor indicator to evaluate management concerns regarding conflict. This does not suggest that the experience of visitor conflict is unimportant, but rather it is likely not a very sensitive measure or metric for evaluating conflict especially when the majority of visitors, and even those who experience conflict, reporting having a high-quality experience.

The strongest and most consistent signals from this research were from the behavioral response to the trail management strategies where we found that trails with downhill direction designations lead to increase mountain bike velocities. Nevertheless, while these strategies might be appealing to coordinate visitor behavior and perhaps reduce conflict within an activity-type (i.e., mountain bikes), we urge caution when considering these strategies. It seems reasonable to suggest that if managers designate a downhill direction of trail use for mountain bikes, they may be poorly suited as mixed-use trails and should likely be accompanied with activity type restrictions for trail safety and to mitigate conflicts between activity types. Furthermore, managers should also carefully consider the potential effects that any new trail management approach may introduce on other trails within a trail system. We observed shifts in the composition of trail use activity-type, direction of use, and significant changes in trail velocities, which collectively represent shifts in patterns of behavior and visitor use which are closely linked and associated with the patterns of ecological impacts and disturbance.

Finally, it seems reasonable to view these direct, or intensive management strategies as a zero-sum-gain, where on one hand conflicts between trail users are somewhat ameliorated but on the other hand visitors have fewer options and a more structured and regulated experience. These strategies appear to be perceived as effective and acceptable among visitors and may offer PPA managers the ability to score some political capital to demonstrate addressing visitor use concerns. Perhaps this is a foreseeable consequence of the increased demand for recreation and the accompanying high levels of visitor use, however the available recreation opportunities in PPA settings have not expanded at the same rate. There are only so many trails to separate activity-types between, and as new activity-types continue to emerge (e.g., hoverboards?), these direct trail management strategies can only go so far. Nevertheless, ensuring that PPAs provide the greatest benefit to the most people may require these trail management approaches to coordinate visitor behavior, but would be complemented by a doubling down on indirect techniques like education and messaging to encourage visitors to treat each other with amiability, cooperation, understanding, and to “share the trail”. Urban-proximate PPAs provide recreation opportunities in wildland settings proximate to large and diverse populations, and therefore have an enormous potential to provide a basis for and appreciation of value of these settings to protect critical habitat and support biodiversity conservation. These goals for visitor experience and habitat conservation can only be realized through the co-operation between visitors and with the agencies that manage these PPAs.

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CHAPTER IV

THE “30-METER VIEW” THE INTERACTIONS BETWEEN RECREATIONAL TRAIL MANAGEMENT AND DISTURBANCE

4.1 Introduction

Recreation ecology is the study of the direct and indirect ecological disturbances to the structure and function of biotic and abiotic systems in wildland settings as a result of recreation use (Cole, 2021). This sub-field of disturbance ecology has systematically cataloged a wide range of factors related to recreation use (Hammitt et al., 2015; Liddle, 1997) and their mechanistic or biological effects on ecological resources such as soils, vegetation, and wildlife. The relationship between the amount of recreation use and the concomitant disturbance is characterized by an asymptotic, or curve-linear relationship, where the initial use results in greater proportional disturbance than subsequent use. In order to mitigate resource disturbance, recreation use is often deliberately concentrated on trails, which minimizes the relative magnitude and spatial extent of recreation disturbance. As a result, a considerable amount of recreation ecology research has examined factors that affect trail conditions and quality (Leung & Marion, 1996), in an effort to encourage and constrain recreation use to sustainably designed and planned trails.

4.1.1 Influential Factors of Trail Condition

Trail systems are a fundamental recreational component of any Park and Protected Area (PPA) setting that provide access and opportunities for visitors to connect with and experience nature. The design, maintenance, and management of trail infrastructure is the prevailing factor in the overall sustainability of a trail system. Many of the disturbances to ecological resources that occur on or around trails, such as soil compaction, deposition, erosion, and vegetation trampling can be mitigated through proper planning, design, location, and construction (Leung & Marion, 2000; Marion & Wimpey, 2017). Nevertheless, the type of activity or mode of travel is also a contributing factor to trail conditions, and studies have found that the magnitude of the disturbance varies depending on the mode (Liddle, 1997; Olive & Marion, 2009), but also depends on the biome, climate and soil substrate types (White et al., 2006). For example, studies have generally found that equestrian use on trails contributes to significantly more soil sediment transport and erosion than pedestrian or cycling use (Svajda et al., 2016), and llamas (Deluca et al., 1998). With respect to mountain bike use, research suggests that soil erosion rates are similar to hiking, however, in areas with steep slopes and loose soil substrates cycling behaviors such as tire skidding can contribute to trail-widening behaviors (Evju et al., 2021; Hammitt et al., 2015; Martin et al., 2018; Newsome & Davies, 2009; Pickering & Growcock, 2009). The mechanical forces of spinning tires dislodge soil leading to increased soil transport, erosion, and vegetation damage, as well as a wider and more deeply incised trails which can contribute to downstream effects on water quality. Consequently, managers concerned with sustainable use of trail systems may direct recreation use to certain trail segments where specific modes of travel can be best accommodated safely, sustainably, and in a manner that limits the potential for conflict among visitors.

While the effects of various activity-types on trail resource conditions are fairly well understood, several studies (Leung & Marion, 1996; Marion & Leung, 2001; Marion & Wimpey, 2017) have noted that the relationship between managerial factors, particularly trail management actions, and trail conditions are relatively understudied. Wimpey and Marion (2010) evaluated the influence of managerial factors related to trail design such as grade, alignment, and rugosity on trail width, and found these to have an outsize influence relative to topographical and use-related factors. However, we have been unable to find any studies that have evaluated the effects of trail management strategies on trail conditions. An example of these managerial actions are intensive, or direct trail management strategies such as designating the direction of travel or limiting access to certain activity types. Although these techniques are commonly employed in multi-use recreation settings to mitigate conflict between trail users and increase perceptions of safety, the effect of these strategies on trail resource conditions is not well understood. Further, because behavior is considered an intermediate factor that contributes to trail disturbance (Leung & Marion, 1999a), it is important to understand the effects of trail management strategies on visitor behavior and the associated trail disturbance.

Because of the inter-play between the visitor experience and trail resource conditions (Dorwart et al., 2009; Farrell & Marion, 2001), managers must balance the disturbance that results from recreation use on ecological trail conditions, thus forming a social-ecological system with inter-relationships and feedbacks between the social (managerial and recreation use related factors) and ecological (trail resource conditions) dimensions of the setting. As a result, developing an understanding the dynamics as a result of global-scale interactions like climate change on PPA resource conditions as well as small scale interactions like recreation disturbance can inform more sustainable, adaptive management strategies.

4.1.2 Measurement of Trail Resource Conditions

Monitoring trail resource conditions has traditionally employed intensive point sampling approaches that require rigorous study design (e.g., Marion & Leung, 2001; Monz, 2002; Pickering & Growcock, 2009; Tomczyk & Ewertowski, 2013) and sampling approaches (Leung & Marion, 1999b; Pettebone et al., 2009), or rapid assessments of trail networks that can provide general assessments of trail conditions to prescribe trail maintenance (e.g., Eagleston & Marion, 2020; Marion et al., 2011; Spernbauer et al., 2023). Studies employing these methods have contributed to a robust understanding of the influence of ecological characteristics such as soil substrates, vegetation cover types, and trail design, as well as topographic characteristics such as slope, alignment with the prevailing landform, and azimuth. In addition, these studies have identified and systematically evaluated key indicators of trail resource conditions (Farrell & Marion, 2001; Marion et al., 2006), including trail width, depth, or incision from the surface prior to trail construction, and cross-sectional area (CSA) (Cole, 1983). Trail incision and CSA are similar, in that they are metrics of soil loss, however, CSA offers the ability to calculate the total volume of soil loss from the pre-trail surface and consequently some argue that it provides a more reliable methodological approach (Hammitt & Cole, 1998; Olive & Marion, 2009). However, these intensive point sampling approaches, most notably CSA, are cost and time intensive and require highly skilled and trained technicians, which place significant constraints on data collection.

In recent years, several studies have tested and demonstrated a variety of remote sensing techniques, including LiDAR (Arredondo et al., 2021; Eagleston & Marion, 2020), structure-from-motion photogrammetry (Arredondo, 2023), and unmanned aerial vehicles (UAVs) or drones (Ancin-Murguzur et al., 2019; Tomczyk & Ewertowski, 2023) to monitor and measure trail or campsite conditions in geospatial environments. These new approaches are not without limitations, but present several advantages for measurement and monitoring resource conditions with a high level of accuracy and precision. Additionally, due to the rapid rate of data collection, UAVs can provide data at relevant spatial and temporal scales (Anderson & Gaston, 2013), and help differentiate between the naturally occurring dynamics of ecological disturbance and those created by recreational use.

A considerable benefit provided by the use of UAVs for trail condition monitoring is the replicability and repeatability of measurements that can be achieved with the programming of flight parameters using automatic flight planning apps. Although UAVs are a relatively new technology, studies have demonstrated their efficacy and validity in measuring physical conditions such as trail width and incision (Ancin-Murguzur et al., 2019; Tomczyk et al., 2023), as well as for identifying and monitoring informal or non-designated trails (Grubesic & Nelson, 2020). Additionally, a recent UAV-based study employing an experimental design concluded that bicycle impacts develop more rapidly than those from hiking (Martin et al., 2018), which is consistent with the findings of previous studies (Evju et al., 2021; Pickering & Growcock, 2009) and lends credibility to the reliability of UAVs as a research and monitoring tool.

4.1.3 Research Objectives

This study employed a UAV trail monitoring strategy to evaluate the effect of trail management actions on trail conditions as part of the Orange County Parks (OC Parks) Trail Use Designation Pilot Project (TPP) in three PPA locations (Figure 3.2). In this study we evaluate the effects of two trail management strategies; activity-type and direction of use designations, on three common indicators of trail disturbance; width, incision, and cross-sectional area. Figure 3.1 provides a synthesis of the inter-relationships between factors that affect trail disturbance, and illustrates the direct relationship between managerial actions and trail disturbance that is being tested in this study. Specifically, this study addresses a gap in the literature, exploring the effects of social/managerial factors on trail disturbance.

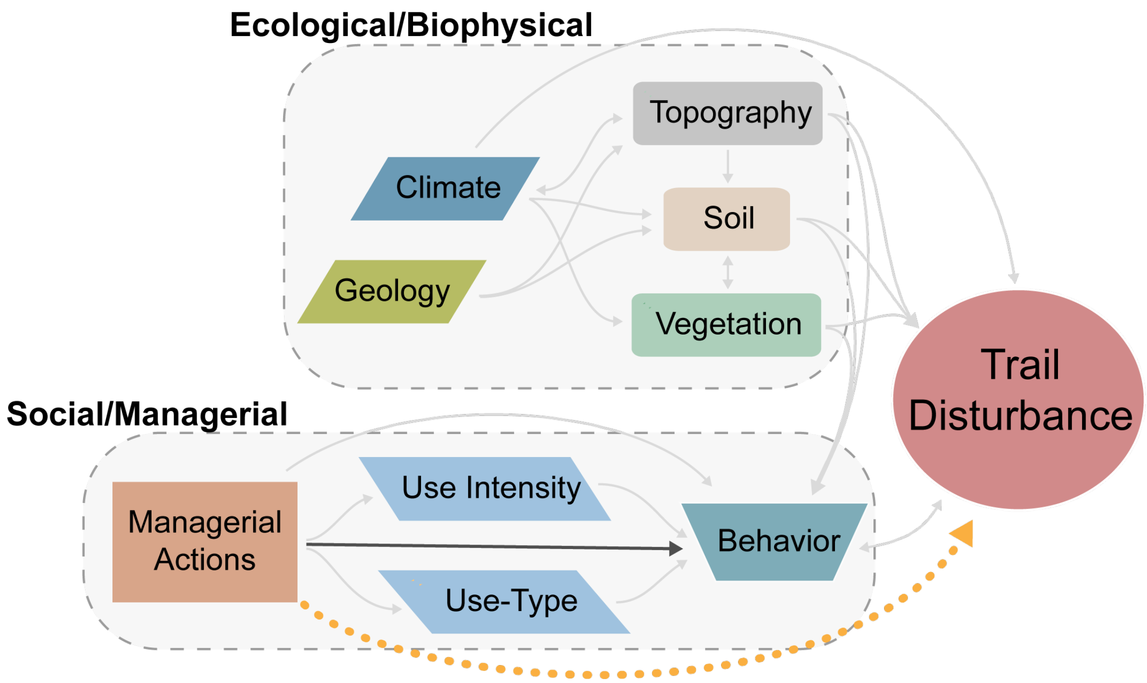

Figure 4.1: Conceptual diagram, adapted from Leung and Marion (1996), of the environmental and social/use-related factors that affect trail disturbance. The black, solid line indicates the relationship found between trail management and visitor behavior in Chapter 3. The orange, dotted line indicates the relationship between managerial factors and trail disturbance to be tested in this study.

Research Questions:

RQ1) Do managerial factors that affect patterns of use, such as activity-type restrictions, have a significant effect on trail conditions?

RQ2) Do managerial factors that affect behavior, such as direction of use-designations, have a significant effect on trail conditions?

4.2 Methods

4.2.1 Study Design

Similar to the TPP visitor-intercept study in Chapter 3, the UAV trail condition assessments followed a Before-After-Control Paired Series (BACIPS) experimental design. The BACIPS design (Osenberg et al., 1994; Stewart-Oaten et al., 1986) is commonly used in ecology as it provides a pairing of control and impact (treatment) sites, or replicates to capture within site variation, that are monitored across a series of observations (time) in a simultaneous or paired manner that minimize variation in conditions that may be due to timing (Osenberg et al., 2006). The prototypical analysis strategy for BACIPS designs interprets the interaction effect between the control/treatment and before/after variables, which if significant, is indicative of an "effect" being tested. This design also helps isolate the effect of the treatments from the differential natural disturbance affecting all trails, as well as the underlying disparities between treatment and control trails (Popescu et al., 2012). Osenberg et al. (2006) caution that sampling carried out too close in time can lead to autocorrelation and confound results. Accordingly, we monitored trail conditions on treatment and control trails prior to the start of the TPP in May 2021 to establish "baseline" conditions, and post-TPP repeat measurements were conducted in May 2022.

The trails included in the TPP were spread across three PPAs; with two treatment trails in Aliso-Wood Canyon Wilderness Park (ALWO) and Laguna Coast Wilderness (LACO) and five treatment trails in Santiago Oaks (SAOK). We selected one control trail in ALWO and LACO and two control trails in SAOK to provide a more balanced sample between the control and treatments. We conducted pre-TPP flights on all 13 trails in the study; nine treatment trails and four control trails (see Table 3.1). However, we were unable to sample all of the trials in the post-TPP flights due to some logistical and methodological constraints. For example, trail maintenance was performed on one of the control trails, Lizard (LACO, prior to the post-TPP flight. A second control trail in SAOK (Sage Ridge) was a wide (2-3m) trail that park staff would drive trucks and all-terrain vehicles on for patrol and response to visitor medical emergencies. Because the differences in conditions we may have observed for both trails could not be attributed to natural variation or factors related to visitor use, they were prevented from repeating measurements. Additionally, we determined that the Pony trail in Santiago Oaks was a short, infrequently used, spur trail bisected by an intermittent stream and was ill-suited for repeat measurements of trail condition. Finally, after all of the pre-TPP flights were concluded, we found that the image processing for the Laguna Ridge trail failed due to the UAV GPS sensor inaccuracies. Furthermore, the analysis was then limited to a total of nine trails, seven treatment and two control trails, which provided a sub-optimal ratio but the two remaining control trails were reasonably analogous to many of the treatment trails where mountain bike use was common or the majority activity-type.

4.2.2 Data Collection

Although UAV data collection is rapid in the field, a considerable amount of planning and preparation is required beforehand. Before flights were carried out, we obtained geospatial data from an OC Parks GIS database for each trail in the study. We added points along each trail line at 3 meter intervals, which corresponded to a photo capture point for the drone, and added the elevation at each point to ensure a consistent perspective and flight altitude above ground level (AGL) as the drone ascended and descended the hilly terrain. The flight waypoints were then exported to DJI-Go/GSPro (DJI, 2023), an automatic flight programming app, to ensure that the UAV's location and altitude would be accurate, precise, and consistent between repeat measurement.

Following the best available practices for the use of UAVs in a PPA setting, we conducted the flights at 30 meters (AGL) to mitigate disturbance to raptors and other sensitive avian taxa (Brisson-Curadeau et al., 2017; Vas et al., 2015) and provided a sufficient ground sample distance of 1.6cm/pixel spatial resolution for the analysis. Flights were designed as linear patterns following the trail corridor to provide a predictable direction of movement and efficient data collection. When available, OC Parks biologists accompanied the flights to observe and monitor bird behavior and response.

Prior to the flights we placed 5 ground control points (GCP) (5 gallon bucket lids) adjacent to the trail and after the flight was completed collected X,Y, and Z coordinates for each GCP using a Trimble Geo7x GNSS device with an external pole-mounted antenna. We applied a differential spatial correction to the GCP coordinates using Trimble GPS Pathfinder Office, which increased the accuracy of the GCP positions to within 0-15cm of the absolute position. We planned flights between the hours of 12pm and 2pm when the sun elevation angle was highest in the sky and minimized shadows in the imagery. We employed two measures to obtain accurate and high quality imagery, first applying a color correction by capturing images of a photo-gray card prior to take off, and second applying radiometric corrections to the imagery from the UAV's integrated spectral sensor which measured solar irradiation. Flights were conducted using a DJI Phantom P4 multispectral UAV, which captured five bands of imagery (blue, green, red, red edge, and near-infrared) at each point along the trail.

4.2.3 Data Processing

Following the completion of the flights and data collection, the workflow to process the raw imagery into data for analysis involved two stages: image photogrammetry processing and image classification, and four intermediate steps (Figure 4.2).

Image Photogrammetry Processing

The corrected GCP positions were exported to Pix4D Mapper ("Pix4D Mapper", 2023) photogrammetry software to provide spatial reference points and fix the position of the GCPs in the raw imagery to high-accuracy locations. The imagery was then stitched together using a Structure-from-Motion (Sfm) approach (Wang & Watanabe, 2022; Westoby et al., 2012) to construct 3-dimensional digital surface models (DSM) and generate orthomosaics for each trail (Figure 4.2-2). We selected photogrammetry processing options in Pix4d that maximized the relative accuracy of the result such that the size and area of objects within the dataset were precise and consistent; however, this approach results in trade-offs of absolute accuracy with geographically correct positions. Nevertheless, flight planning and design provided sufficient forward overlap between images to provide approximately 4-5 thousand points/m^2 for the generation of point clouds and the construction of DSMs.

Image Classification

The next step in the analysis was to isolate the trail tread from the rest of the imagery to enable systematic measurement of the indicators of interest in this study. Traditional monitoring approaches employ well-developed protocols and training to ensure a high degree of reliability and consistency of measurement between technicians in determining the boundary or edge of the trail. However, with UAV imagery determining the boundary of the trail and tread is more challenging and requires image classification and segmentation techniques in order to objectively delineate the trail from the surrounding landscape when the trail dimension measurements are indicators of interest. Our initial methods for pixel-based image classification used unsupervised clustering techniques common in remote sensing (Aber et al., 2010) such as distanced based iso-clustering and k-means as well as less conventional techniques like density based DBSCAN clustering and nearest-neighbor spectral clustering (Pedregosa et al., 2012). However, we found these techniques were effective in some locations where the land cover adjacent to the trail was dense coastal sage-scrub or chaparral but were ineffective where the contrasts were more subtle. Next, we attempted a more sophisticated object-based image segmentation and classification following recommendations from Tomczyk et al. (2017) for spectral and spatial parameters of the segmentation, however we still found these approaches produced inconsistent results across the heterogeneous land cover types between the three PPAs.

To overcome these challenges with traditional land cover classification approaches we first generated a spectral indices using Spyndex (Montero et al., 2023) in order to accentuate the contrasts between landcover-types and the exposed soils on trails as well as to increase the dimensionality of the data. Using combinations of the five-band UAV imagery, we used Xarray (Hoyer et al., 2024) to calculate six indices that would distinguish vegetation (Normalized Difference Vegetation Index (NDVI), Blue-Normalized Difference Vegetation Index (BNDVI), Modified Soil Adjusted Vegetation Index (MSAVI), Transformed Vegetation Index(TVI)), post-fire areas (Burn Area Index (BAI)), shadows (Shadow Index (SI)), as well as a euclidean distance raster originating from the trail center-line (Figure 4.2-3a). We generated training points that were randomly distributed over the trail area with an approximate density of one point for every 2m^2. Each of these training points were then manually labeled 0 (off trail) or 1 (on trail), and paired with the corresponding value from each of the 12 raster bands. We shifted our classification approach to use gradient-boosted (GB) decision-tree models (Samat et al., 2021) using CatBoost (Prokhorenkova et al., 2017) for each trail that was trained via grid-search hyper-parameter tuning specified for binary classification (Figure 4.2-3b). By fitting a model for each trail, the GB decision-tree models were highly effective at identifying patterns in that corresponded to the trail tread and provided a better delineation of the trail tread in post-fire areas with sparse vegetation and high soil exposure adjacent to the trail (Figure 4.2-3c).

Trail Measurement Sampling

With the trail tread accurately delineated in the imagery, the final step in the data processing was to calculate sample measurements of trail disturbance indicators in a GIS environment for the analysis (Figure 4.2-4). The sampling strategy closely followed traditional in-field approaches outlined by Leung and Marion (1999b) and Pettebone et al. (2009) where we selected a continuous random number between 1 and 10 to use as the starting distance from the trail line for the location of the first transect measurement. We then generated transects that spanned the width of the trail, perpendicular to the trail center-line, at one meter intervals for the remaining distance of the trail. Because of the considerable size of the datasets and repeat measurements, we performed the trail measurement sampling programmatically with the geo-spatial Python package GeoPandas (Jordahl et al., 2020). Trail width was calculated by measuring the length of the transect line that was trimmed, or clipped, to the edges of the trail tread. The trail incision and width measurement followed in-field measurement protocols, where a “taut-line” spanning the distance of the trail tread provided a reference for the pre-trail construction surface. The taut-line was interpolated from the elevation of the trail tread edges, and the difference between the tread surface and the taut-line provided measurement of trail incision at 1cm intervals (see Figure 4.2- (4)-Incision). The cross-sectional area measurement used the same interpolated taught-line to approximate the area between the line and the trail tread profile using the trapezoidal rule with NumPy (Harris et al., 2020). Trail slope alignment (TSA) was calculated following Spernbauer et al. (2023) by taking the difference between the line bearing and the land-form slope azimuth, and subtracted 90° from TSA values over 90 to maintain a range of 0°-90°. Next, we selected a random subset of 20% of the transects for each trail and visually inspected each transect against the orthomosaic to ensure measurements weren’t affected by localized distortions or gaps in the DSM. Finally, we evaluated the overall distributions for each of the three dependent variables and calculated z-scores by grouping observations among each trail and the year of the observation (pre/post). We calculated the total number of observations with z-scores greater than an absolute value of 2 to identify outliers in the data and found approximate 3-4% of observations in each variable fell into this range. To ensure we weren’t removing valid trail measurements, we also evaluated the dependent variables using an isolation-forest anomaly detection technique (Liu et al., 2008) and specified the expected proportion of anomalies, or contamination, in the data corresponded to the same 3-4% of observations identified as outliers from the z-scores. Observations that were identified as outliers from both approaches were then removed from each variable, which yielded a final dataset containing 2,955 trail condition measurements.

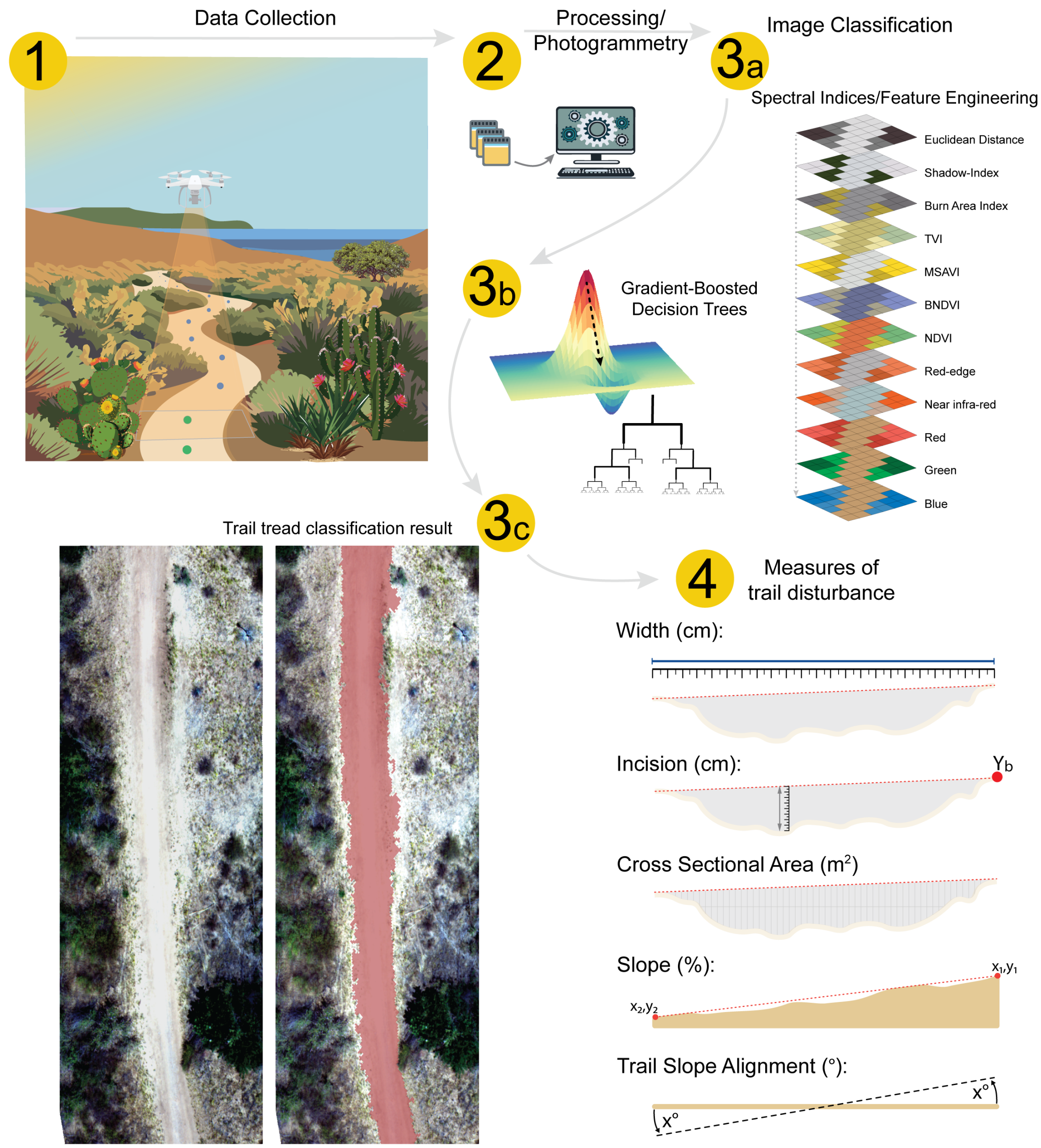

Figure 4.2: Illustration of the UAV data collection and processing workflow: (1) Flights conducted over trails, (2) Drone imagery photogrammetry and processing, (3a) Image classification and feature engineering, (3b) Gradient-boosted decision tree training and tuning, (3c) Trail tread classification inspection, and (4) Calculating trail disturbance metrics including width, incision, cross-sectional area (CSA), slope, and trail slope alignment (TSA).

4.2.4 Data Analysis

The analysis approaches of many trail disturbance and BACI studies have traditionally relied on general linear models, such as analysis of variance (e.g. Marion & Wimpey, 2017; Olive & Marion, 2009; Stewart-Oaten et al., 1992) and to a lesser-extent auto-regressive (ARIMA) models (e.g. Carpenter et al., 1989). However, advances in computational capacity and statistical software have lowered barriers for the use of robust analysis methods that, to some extent, can help overcome some of the methodological concerns regarding pseudo-replication with BACI study designs by treating the control/impact sites as random effects in a generalized linear mixed model (GLMM). Similar to the visitor survey analysis in Chapter 3, three GLMM models in R (R Core Team, 2023) for each of the three dependent variables in the analysis (width, incision, and CSA), fitted using the glmmTMB package (Brooks et al., 2017). We used the same formula specification for each of the models, that tested the pre/post interaction effect for treatment and control trails in the TPP study as well as the effect of activity-type and direction designation treatments. The model included two random effects terms which were specified for random intercepts for each trail and a random intercept for each combination of trail in the pre/post to account for the differing treatments across trails. We evaluated model fits and residuals for several continuous distributions and determined that a gamma distribution with a log link provided the best model fit for all models.

Model parameters were estimated using restricted estimation maximum likelihood (REML) and residual patterns were visually inspected, diagnosed, and evaluated with the DHARMa package (Hartig, 2022). Additionally, because of the spatial nature of the data, we used the DHARMa package global Moran's I test for distance-based auto-correlation to evaluate the presence of spatial patterns in the model residuals. Plots of parameter estimates were produced with the package sjstats (Lüdecke, 2023) package and goodness-of-fit statistics were calculated with the package performance Lüdecke et al., 2021.

4.3 Results

Among the 2,955 trail condition measurements in the dataset, approximately 70%

were from the 9 treatment trails, and the remaining 30% from the two control trails in the analysis. We found that the incision and CSA variables had a relatively high positive correlation, with a Pearson's correlation coefficient of $r(2954)=.724$, $p<.001$. The residuals of all of the models did not exhibit any significant indications of spatial auto-correlation; width (Moran's I=-0.318, p=.375), incision (Moran's I =-0.274, p=.484), CSA (Moran's I =-0.173, p = .825). The model for trail width provided the best overall goodness of fit with a Nakagawa marginal R^2 of .438, followed by the CSA model (R^2=.128), and the trail incision model (R^2=.064) which had marginal explanatory power.

Regarding the effect of trail activity-type designations on trail conditions (RQ1), there were no significant main-effects or interaction effects in any of the indicator models. Similarly, with respect to the effect of trail direction of use designations, there were no significant main-effects or interaction effects in any of models. However, in all models, trail slope and TSA were significant predictors consistently demonstrating a similar sized effect in the same direction across all three models

Figure 4.3 provides a visual summary of all model results which shows that slope and trail slope alignment (TSA) were the only significant predictors of the trail disturbance response variables. Slope had a positive relationship with all three response variables, where increasing trail slope was associated with an 8% increase in trail width, 12% increase in incision, and 18% increase in CSA. Conversely, TSA had a negative relationship with the trail disturbance indicators, where trails with higher trail slope alignment (i.e., trails oriented closer to values of 90°or more perpendicular to landform fall-line) were 6% narrower in width, 9% less deeply incised, and had 10% lower volumes of soil-loss (CSA).

The confidence intervals around the model predictors for the trail activity-type and direction-of-use managerial factors were very wide with coefficients for the main effects and interaction terms about or very near to zero effect on the response. Although these metrics of trail disturbance measure different trail characteristics, there was some general consensus among the models in the direction of the relationships. For example, the activity-type

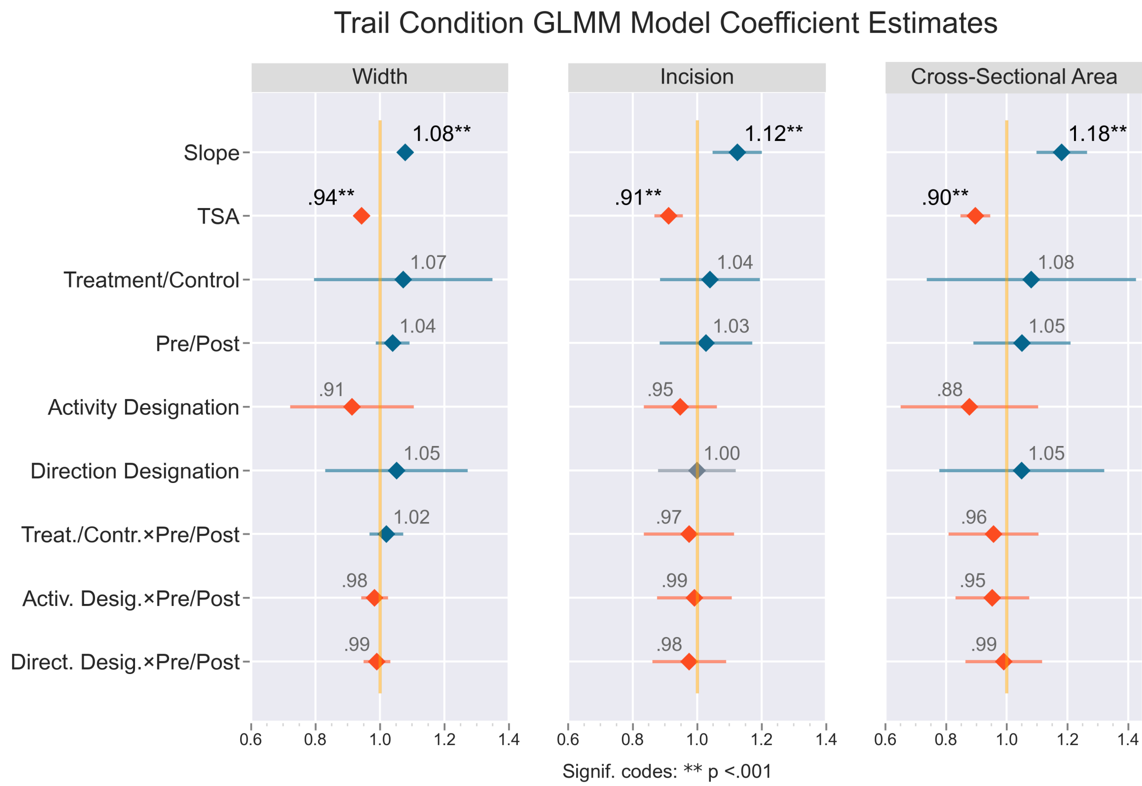

Figure 4.3: Summary forest plot of the parameter estimates for the Width, Incision, and cross-sectional area (CSA) trail condition models. Coefficients are standardized, transformed parameter estimates indicating the direction and magnitude of the relationship with the response variable. In all three models, slope and trail-slope alignment (TSA) are significant predictors of trail width, incision, and CSA, where increasing slope contributes to wider, more incised, and larger volumes of of soil-loss. Conversely, trails with greater TSA (i.e., trails more perpendicular to landform fall-line) are less wide, deeply incised, and have lower volumes of soil-loss.

designation coefficients trend negatively with the response variables, while the direction designation coefficients trend positively with width and CSA but no effect on incision.

Table 4.1: Model parameter estimates for the Width, Incision, and CSA GLMM Models.

	Width			Incision			CSA		
Predictors	Std. β	CI LL – UL	p	Std. β	CI LL – UL	p	Std. β	CI LL – UL	p
(Intercept)	2.37	[1.83 - 3.05]	<.001	13.33	[11.55 - 15.38]	<.001	.18	[1.83 - 3.05]	<.001
Slope	1.08	[1.06 - 1.10]	<.001	1.12	[1.05 - 1.20]	<.001	1.18	[1.06 - 1.10]	<.001
TSA	.94	[.93 - .96]	<.001	.91	[.87 - .96]	<.001	.90	[.93 - .96]	<.001
Treatment/Control	1.07	[.83 - 1.38]	.594	1.04	[.90 - 1.21]	.607	1.08	[.83 - 1.38]	.629
Pre/Post	1.04	[.99 - 1.09]	.131	1.03	[.89 - 1.18]	.707	1.05	[.99 - 1.09]	.531
Activity Designation	.91	[.74 - 1.12]	.390	.95	[.84 - 1.07]	.376	.88	[.74 - 1.12]	.313
Direction Designation	1.05	[.85 - 1.29]	.639	1.00	[.89 - 1.13]	.986	1.05	[.85 - 1.29]	.715
Treat/Cntrl. × Pre/Post	1.02	[.97 - 1.07]	.452	.97	[.84 - 1.12]	.724	.96	[.97 - 1.07]	.572
Activ. Desig. × Pre/Post	.98	[.94 - 1.03]	.425	.99	[.88 - 1.11]	.882	.95	[.94 - 1.03]	.449
Dirct. Desig. × Pre/Post	.99	[.95 - 1.03]	.648	.98	[.87 - 1.10]	.674	.99	[.95 - 1.03]	.872
Random Effects									
	Variance (Std. Dev)			Variance (Std. Dev)			Variance (Std. Dev)		
Trail	.072 (.269)			.001 (.031)			.086 (.293)		
Trail:PrePost	.004 (.062)			.030 (.174)			.034 (.183)		
Model Performance									
ICC	0.39			0.03			0.09		
Sigma(σ)	0.12			0.92			1.25		
Conditional/Marginal R^2	.081/.438			.032/.064			.045/.128		

4.4 Discussion

The models in this analysis explained moderate (R^2=.438) to marginal (R^2=.064) variation in the trail condition response variables which suggests that there are substantial deficiencies in the predictors of the models, and would benefit from the inclusion of other biophysical and ecological variables such as soils/substrate types and topographical position and orientation of the transects (Hammitt et al., 2015; Leung & Marion, 1996). However (Olive & Marion, 2009) found that even fully saturated models including those environmental, geographic, and use-related predictors explained only 32% of the variation in CSA.

The consensus among the models for the slope and TSA results align neatly with previous studies (Olive & Marion, 2009; Spernbauer et al., 2023; Tomczyk et al., 2017; Wimpey & Marion, 2010) that found that trails with higher TSA values tend to be narrower and less prone to soil loss and higher slopes tend to result in greater incision and soil loss.Although there were clear signals that the TPP trail management strategies contributed to shifts in trail patterns of use and behavior in Chapter 3, we did not find any significant relationships between these strategies and the three metrics of trail disturbance that we measured in this analysis. As a result, we cannot reject the null hypotheses that there is no effect of management actions that alter or affect patterns of use and behaviors on trail conditions. Nevertheless, according to recreation ecology use-impact theory, since the trails in this study were well established the effect of these factors on the trail conditions was likely very subtle, and difficult to detect within the temporal scale of the study. Because the design of this study was focused towards larger scale, between-trail patterns and interactions and did not include or evaluate other potentially important intermediate factors like amount of use, use-type, or trail user behavior on trail conditions. Furthermore, this study corroborates existing recreation ecology trail literature (Marion & Wimpey, 2017) that argues that trail design and maintenance are the most influential factors on trail conditions, while use-related or trail management related factors are less influential.

This study provides a case-study for the adaptation of traditional trail condition assessment techniques to emerging, contemporary methods carried out in GIS environments. Tomczyk et al. (2023) and Arredondo (2023) report that while there are subtle variations in measurements between traditional and GIS-based methods, there is a high degree of consensus in the conclusions and relationships. Although there were no direct comparisons with in-field measurements performed in this study, we would not anticipate that there would be any significant differences in the outcomes or conclusions from the analysis.

We demonstrated a new technique for calculating CSA using the trapezoidal rule integration technique. This technique calculates the total “area under curve” across the transect that could be used to quantify the volume of displaced soil for the extent of the trail. Because of the significant practical challenges associated with in-field CSA measurements (Marion et al., 2013; Monz et al., 2010), the use of CSA as a measure of trail disturbance has been sporadic. However, (Cole, 1983) made a strong argument for the use of CSA over incision measurements to measure soil loss and erosion because it can provide a more reliable and methodologically valid volumetric measure of the irreversible post-construction trail disturbance and the associated “downstream” effects. For example, Olive and Marion (2009) offered conservative estimates that the total soil volume displaced from trails in Big South Fork National River Recreation Area would fill between 1100-4500 single-axle dump trucks which represent an ecologically significant disturbance to watershed quality. This provides further support and validation for the use of UAVs in trail-condition monitoring programs and research which can provide a high-quality “base-line” condition assessment for repeat monitoring.

Finally, we tested and illustrated a gradient-boosted regression tree classification approach which was highly effective at distinguishing the trail tread from the surrounding vegetation. This technique required labeled training data from the points we randomly generated across trail areas, but then required very minimal post-classification adjustments and manipulations aside from the infrequent occurrence of “holes” in the the middle of the tread where there were small vegetation patches. Although the models were trained and tuned for each trail, a considerable advantage of the CatBoost implementation of gradient-boosting is its ability to handle categorical predictors which could conceivably allow a single model to be trained on an entire dataset with trail specific labelling which could considerably shorten the training time for multi-site or repeat site image classification models.

4.4.1 Limitations and Recommendations

There were several factors to this study which contributed to limitations in the approach and analysis. The first is that the test of the effects were based upon two sets of measurements (pre and post), separated by only one year. We suspect that this was a sufficient interval for repeat monitoring (Osenberg et al., 2006). We believe a multi-year or long-term monitoring approach would be necessary to stabilize the natural variation in conditions as a result of seasonal weather patterns and climate to be able to detect any meaningful or measurable effects of these treatments. Additionally, aside from the complexity of the various management treatments to trails, the two remaining control trails from two PPAs (ALWO and SAOK) in the analysis may not have been representative or analogous to the treatment trails in terms of design or activity-type and use-patterns. From an ecological and biophysical perspective, while these PPAs were only separated by 26km/17mi they spanned a steep climatic gradient from maritime coastal sage-scrub and live-oak woodland landscapes to interior chaparral arid-landscapes with very different soil substrate types, plant communities, and precipitation patterns. Moreover, this study would have benefited from additional monitoring, a more constrained experimental design, and additional controls across a range of confounding factors.

Despite these limitations, some of the methods and analysis approaches in this study likely contributed to these challenges. For example, CSA have generally been conducted with repeated measures (Hammitt et al., 2015) at precise locations. Cole (1991) found that there were no significant changes in CSA in the Selway-Bitterroot Wilderness after 11 years of monitoring but noted that a purposive random sample produced significant deviations. Several studies have evaluated the effects of the distance between samples on measurement and identified ideal sampling rates that provide a balance of accuracy to the "true" conditions and the time constraints associated with those in-field measurements (Leung & Marion, 1999b). The random sampling technique we used in this study was selected to help mitigate the potential effects of spatial autocorrelation, but may have had the unintended effect of obscuring variation we may have observed and resulted in very small parameter estimates. Furthermore, although the time constraints associated with the collection and calculation of trail condition metrics are negligible in GIS environments, the methodological and considerations regarding measurement validity and sampling and bias remain and should follow and reflect the same protocols and methods used with in-field studies. In Table 4.2 we offer recommendations that add to Tomczyk et al. (2023) for best-practices in UAV trail monitoring, as well as some lessons learned in this study.

Table 4.2: Summary of challenges we experienced in this study and potential solutions and best-practices for UAV trail monitoring

Challenge	Description	Recommendation
Positional error in imagery/ photogrammetry results	Issues with gps sensor error led to unusable imagery because software was unable to compute key-point matching from the initial camera positions	- Start flights at the "top" or at higher elevations to avoid GNSS dilution of precision from topography in valley or canyon areas - Allow the UAV to be powered on and actively connected to GNSS satellites for 2-5 minutes before flight -Increase the number of ground control points. Consider a rate of approximately one GCP per every 100m.
Steep, hilly terrain/ linear flight path	The linear flight path along the trail provided a sufficient density of points to construct a point cloud on the trail tread, but quickly deteriorated to a flat plane beyond the edges of the trail	- Decrease the interval between photo capture points - Collect a combination of nadir and oblique images to provide better image overlap between successive capture points
Artifacts or irregularities in Digital Terrain/Surface Models	The initial image processing parameters produced results where the trail tread contained irregular "sand dune"-like patterns	- Increase the smoothing parameters for the Digital Surface model. This will minimize the effects from extreme and anomalous points and produce a more reliable representation of the trail tread
Long trail segments	Some trails in this study were up to 1.9 km/1.2mi long which presented challenges with flight time and batteries	- Purposively constrain the area of monitoring/analysis to areas of concern or with a high potential for biophysical change (e.g. steep slopes, trails aligned to landform fall-line)

4.5 Conclusion

When taken together, the results of this study (ecological dimension) and those from

Chapter 3 (social dimension) highlight some of the challenges of PPA management where settings have both habitat conservation and recreation opportunity/visitor experience goals. Although the results in social dimension study were somewhat conflicting, there were observable and measureable effects in visitors' attitudes and behavior in response to management action changes in a matter of two to three months. However, the ecological and biophysical response was more difficult to disentangle due to a range of factors, and would likely require more long-term study to fully understand. This illustrates the uncertainty and complexity associated with making informed decisions about management actions and their effects of social ecological systems in PPAs. The loosely-coupled and non-linear temporal feedbacks of the interactions between these systems are difficult to fully understand within timelines dictated by demands for management actions and short-term research studies.

Although we did not find any significant relationships between the trail management actions and the three measures of trail disturbance, managerial factors like trail grade, design, and alignment, have a substantial influence on trail conditions. Nevertheless, the shifts in activity-type patterns of use and visitor behavior are important and significant factors that can affect trail conditions. This illustrates the social-ecological interactions and relationships between behavior, the quality of the visitor experience (i.e. conflict, safety) and ecological resource conditions (i.e. trail width, incision) mediated and influenced by a range of factors including management. This underscores the importance of considering these interactions between management, recreation use, and ecological resource conditions for the long-term sustainability of PPAs.

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CHAPTER V

CONCLUSIONS

5.1 Summary of Findings

The preceding chapters provide a modest contribution to the evolving paradigms and philosophies of recreation and Park and Protected Area conservation and management. In the introductory chapter, I outlined the important role PPAs play in global habitat and biodiversity conservation and protection, and highlighted the critical challenges and risks posed by climate change. An objective of this dissertation was to emphasize the potential for recreation management to support those broader PPA conservation goals, provided that visitor use is balanced with long-term ecological resilience. This can be achieved when management decision making is informed by a systematic approach and understanding of the social-ecological dynamics and inter-relationships at play, as well as a shared sense of stewardship among all who value these precious spaces

In Chapter II, I examined the Timed-Entry Permit System (TEPS) in Rocky Mountain National Park through the lens of a social-ecological system. This offers an alternative perspective to the traditional demand driven approaches and makes an argument that increased visitation to Parks and Protected Areas can be managed sustainably through more structured governance of the resource. The determination of the level of “acceptable” visitor use has largely been approached from the perspective of the visitor, which is important from the standpoint of the outcome of the experience and mission of the National Park Service. However, this visitor-centric frame of reference has perhaps been self-sacrificing for the NPS and diminished the consideration of the effects on managerial operations and to some extent, protection of park resources. This survey-based study was specifically focused on evaluations of the quality of the TEPS visitor experience, which revealed that visitors have an understanding and appreciation of the trade-offs associated with PPA management. Nearly 80% of the respondents in the survey indicated they were supportive of strategies that manage visitor-use and access to protect park resources for future generations.

In Chapter III, I studied the effects of direct trail management strategies on visitor-reported conflict and behavior. I showed in this study that the TPP strategies did not appear to have any significant effects on reducing reported conflict, but did result in significant shifts in patterns of visitor behavior. Conflict was far less severe and frequent than managers may have expected from the outset. Although managers often feel compelled to capitulate to concerns expressed about conflict and take action, conflict cannot be entirely eliminated by management. Rather, the focus should be redirected, as it is incumbent on visitors to adhere to management guidelines and to share and steward the resource, even if that involves coping with sub-optimal conditions. Nevertheless, this study also demonstrated the interplay between the trail management designations and visitor behavior, which should be carefully considered before those strategies are employed in multi-use trail settings.

Finally, in Chapter IV we evaluated the effects of those trail management strategies (from Chapter III) on biophysical conditions. While the study did not find any significant changes as a result of the TPP, it does offer a few lessons and considerations for future research. Foremost among these are the challenges associated with a social-ecological experimental design, where we observed differential temporal scale feedbacks and mismatches in the social and ecological response to trail management actions. Next, emerging tools and technology can provide novel insights and understanding, and help overcome some of challenges associated with traditional approaches. However, the underlying empirical methodologies remain and can be difficult and challenging to adapt with new approaches.

A considerable challenge throughout the design, analysis, and writing of this dissertation was to effectively frame the social-ecological system of PPAs at an appropriate scale. While Chapters III and IV were part of the same study, they narrowly focused on the social and ecological dimensions, respectively, and offer a limited perspective of the system-level interactions and dynamics. Nevertheless, a through-line in the preceding chapters applies a focus to an intensive recreation-use management action and evaluates its' effects on social or ecological dimensions of the setting. While it's difficult to speculate on the nature of system-level interactions, Chapters III & IV offer some insights to comment on these dynamics. Although managers might be justifiably concerned about the social and ecological impacts associated these high-profile management actions, what this research suggests is that the "everyday-business" of visitor use management and trail infrastructure design and planning have a more outsize impact on social and ecological interactions. This offers a few important takeaways, that (1) intensive visitor-use management actions targeting more sustainable PPA management can be viewed as acceptable or favorably by the visiting public and can generate political capital on behalf of the managing agency, but that (2) the social-ecological interactions can be difficult to isolate, respond at different spatial and temporal scales, and subtle to detect.

5.2 Concluding Remarks

In his introduction to *Wilderness In the American Mind*, Roderick Nash articulates the philosophical transformation that took place following the colonial settlement of the American West that gave rise to the idea of protected areas:

> Some even began to reason that since the wilderness had been conquered, now it was time to conquer the self-destructive tendencies of civilization.

However, implicit in this genesis story of PPAs were assumptions which would later have to be reconciled, namely that PPAs were a model of "fortress conservation" that protected ecosystems from human use. Analogous to the contemporary recognition of the folly of wildfire suppression, which undermined the vital role of fire disturbance in ecosystems, numerous researchers have devoted careers to unraveling many of the flawed assumptions with the fortress conservation model by decoupling the flawed assumption of a linear relationship between use and disturbance. Demonstrating the curve-linear progression of recreation disturbance showed that targeted strategies to minimize the initial impacts could allow for sustainable recreational use and the associated benefits and affordances that allow visitors to connect with and become stewards of PPAs.

The current era of PPAs could be characterized by a broad, outward focus that encompasses large-scale and trans-boundary dynamics that shape outcomes. This research demonstrated some of the challenges of understanding these social-ecological dynamics at small scales. These challenges are compounded at larger spatial scales and with more complex ecosystem functions and processes. Moving forward, there are substantial opportunities to apply these social-ecological approaches to bridge our understanding of recreation to broader landscape-scales.

APPENDICES

APPENDIX A

Rocky Mountain Timed-Entry Permit System (TEPS)

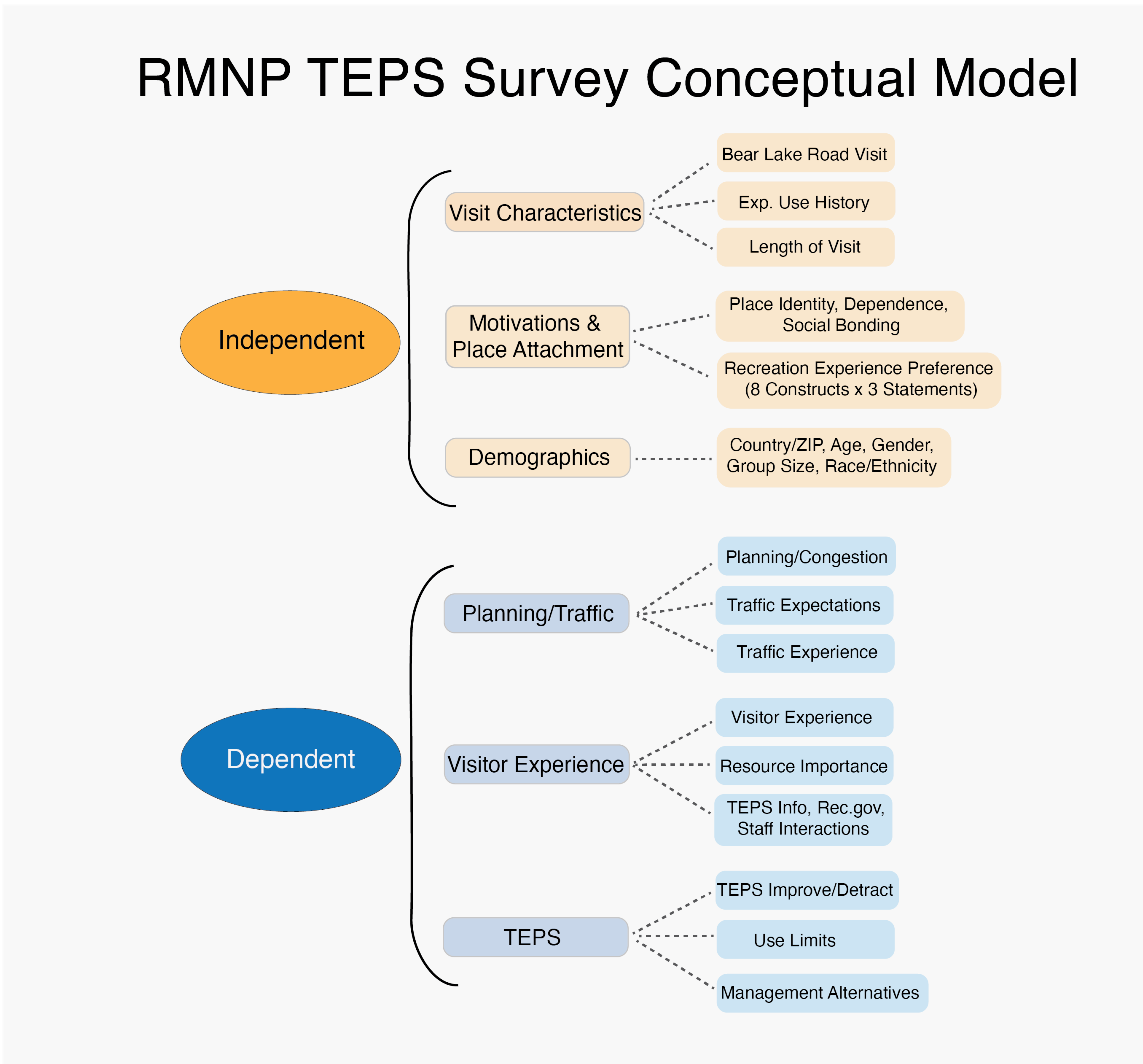

Figure A.1: TEPS visitor questionnaire conceptual model illustrating key areas of focus for visitor evaluations of their park experience.

Rocky Mountain National Park Timed-Entry Permit System (TEPS) Survey

Start of Block: Informed Consent

Q1.2 [Informed Consent] **Participation in this Study:**
Purpose:
The goal of this survey is to better understand how park visitors' experiences are influenced or changed under the Timed Entry Permit System. This management change was initiated to reduce impacts and exposure from the COVID-19 pandemic in order to keep the park open and operating while providing the safest visitor experience possible.
Procedures:
Your participation will involve completion of an anonymous (#of Qs) question survey reflecting on your visit to Rocky Mountain National Park during the summer or fall of 2021 which should take between 10-15 minutes.
Risks: By continuing on to the survey, you agree to participate in this minimal risk research study. That means that the risk of participating are no more likely or serious than those you encounter in everyday activities. There are no foreseeable risks or discomforts associated with this research aside from the time needed to answer the questions about your visit. In order to minimize those risks and discomforts, you may choose not to answer any question at any time during the survey.
Confidentiality: The data for this study are being collected anonymously. Your identity is not known to anyone involved in this study and will not be revealed in any publications, presentations, or reports resulting from this study.

Would you like to participate in this survey?

○ Yes (1)

○ No (2)

End of Block: Informed Consent

Start of Block: Visit Characteristics

Q2.1 [Visited Park] **Please respond to the following questions about your visit to Rocky Mountain National Park (RMNP).**

	Yes (1)	No (2)
After making a reservation to visit Rocky Mountain National Park through Recreation.gov, did you visit the Park?	○	○

Q2.2 [Visit Characteristics] **Please respond to the following questions about your visit to Rocky Mountain National Park**

	Yes (1)	No (2)
Was this visit your first time to Rocky Mountain National Park? *If you selected 'No', approximately how times have you visited Rocky Mountain National Park in your <u>lifetime</u>?* ____#________	○	○
Did you obtain a reservation through Recreation.gov to visit Bear Lake?	○	○
Did you visit Bear Lake during your visit?	○	○

Q2.3 [Visit Duration] **Approximately how long did you spend in the Park during your visit?**
If you made multiple reservations, please indicate the average total time spent during your visits.

- ○ A few hours (1)
- ○ Most of the day (2)
- ○ The full day (3)
- ○ Multiple days (4)

End of Block: Visit Characteristics

Start of Block: PlaceAttachment_Motivations

Q3.1 [Place Attachment] **Please indicate your level of agreement or disagreement with each of the following statements.**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree or disagree (3)	Somewhat agree (4)	Strongly agree (5)
Rocky Mountain National Park means a lot to me. (Place Identity 1)	○	○	○	○	○
I am very attached to Rocky Mountain National Park. (Place Identity 2)	○	○	○	○	○
Few people know Rocky Mountain National Park like I do. (Place Identity 3)	○	○	○	○	○
I wouldn't substitute any other place for the access to Wilderness in Rocky Mountain National Park. (Place Dependence 1)	○	○	○	○	○
I get more satisfaction out of visiting Rocky Mountain National Park than other public open spaces or land. (Place Dependence 2)	○	○	○	○	○
I enjoy scenic views in Rocky Mountain National Park more than in any other park. (Place Dependence 3)	○	○	○	○	○
Viewsheds of tundra landscapes in Rocky Mountain National Park are more important than scenic views in any other place. (Place Dependence 4)	○	○	○	○	○
Rocky Mountain National Park is a very special place for my family. (Social Bonding 1)	○	○	○	○	○
Many important family memories are associated with Rocky Mountain National Park. (Social Bonding 2)	○	○	○	○	○
Rocky Mountain National Park contributes to the character of my community. (Social Bonding 3)	○	○	○	○	○

Q3.2 [Motivations/REP Scale] **The following is a list of experiences you may have or would like to have during your visit to Rocky Mountain National Park. Please rate how important of each of items below is to your experience.**

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
To view scenic beauty (Enjoy Nature/Scenery)	○	○	○	○	○
To be close to nature (Enjoy Nature/Scenery)	○	○	○	○	○
To have my mind move at a slower pace (Relax)	○	○	○	○	○
To physically relax (Relax)	○	○	○	○	○
To experience tranquility (Escape/Physical Pressures)	○	○	○	○	○
To feel independent from the rest of society (Escape/Physical Pressures)	○	○	○	○	○
To be away from crowds of people (Escape/Physical Pressures)	○	○	○	○	○
To take risks (Adventure/Risk Taking)	○	○	○	○	○
To have thrills (Adventure/Risk Taking)	○	○	○	○	○
To experience a sense of exploration (Adventure/Risk Taking)	○	○	○	○	○
To share photos on social media (Sharing)	○	○	○	○	○
To tell others about my trip (Sharing)	○	○	○	○	○
To have others know that I have been here (Sharing)	○	○	○	○	○
To be with people who share similar values (Socialization)	○	○	○	○	○

To be with others who enjoy the same things I do (Socialization)	◯	◯	◯	◯	◯
To get away from the noise back home (Quiet/Natural Sounds)	◯	◯	◯	◯	◯
To enjoy the sounds of nature (Quiet/Natural Sounds)	◯	◯	◯	◯	◯
To experience natural quiet (Quiet/Natural Sounds)	◯	◯	◯	◯	◯
To gain a sense of self-confidence (Achievement/Stimulation)	◯	◯	◯	◯	◯
To learn what I'm capable of (Achievement/Stimulation)	◯	◯	◯	◯	◯
To show others my abilities (Achievement/Stimulation)	◯	◯	◯	◯	◯

End of Block: PlaceAttachment_Motivations

Start of Block: Planning/Traffic

Q4.1 **[Park Planning] When you planned this trip to Rocky Mountain National Park, did you anticipate that it may be too congested or crowded to find a parking spot?**

◯ Definitely not

◯ Probably not

◯ Might or might not

◯ Probably yes

◯ Definitely yes

Q4.2 [Traffic Expectations] **Overall, how did the conditions you experienced compare to what you expected?**

	Far less than what I expected	Somewhat less than what I expected	Equal to what I expected	Somewhat more than what I expected	Far more than what I expected
Traffic in Rocky Mountain National Park	○	○	○	○	○
Display This Question: If Bear Lake Visitor Traffic in the Bear Lake Road Corridor of Rocky Mountain National Park	○	○	○	○	○
Number of people in Rocky Mountain National Park	○	○	○	○	○
Display This Question: If Bear Lake Visitor Number of people in the Bear Lake Road Corridor	○	○	○	○	○

Q4.3 [Traffic Experience] **To what extent did the following factors impact your experience in Rocky Mountain National Park?**

	None at all (1)	A little (2)	A moderate amount (3)	A lot (4)	A great deal (5)
Traffic congestion on the roads	○	○	○	○	○
Traffic congestion at entrance stations	○	○	○	○	○
Traffic congestion at roadside pullouts	○	○	○	○	○
Parking congestion/shortages	○	○	○	○	○
Crowding at scenic overlooks	○	○	○	○	○
Lack of Park shuttle bus service/options	○	○	○	○	○
Park shuttle bus wait times	○	○	○	○	○
Display This Choice: If Bear Lake Visitor Parking congestion/shortages on Bear Lake Road	○	○	○	○	○
Display This Choice: If Bear Lake Visitor Traffic congestion on Bear Lake Road	○	○	○	○	○
Display This Choice: If Bear Lake Visitor Bear Lake Road Restrictions	○	○	○	○	○
Could not obtain a permit for my desired entrance time	○	○	○	○	○

End of Block: Planning/Traffic

Start of Block: Visitor Experience

Q5.1 [Experience Evaluations] **Please indicate how much you agree or disagree with the following statements regarding your concerns while using the trails at Rocky Mountain National Park.**
At places I visited in Rocky Mountain National Park I experienced...

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Crowding from too many other hikers	○	○	○	○	○
Adequate information and signs at the trailhead	○	○	○	○	○
Adequate signs marking the trail routes	○	○	○	○	○
Sufficient parking access at the trailhead	○	○	○	○	○
High noise level from other hikers	○	○	○	○	○
Unfavorable actions or behaviors of other hikers	○	○	○	○	○
Poor quality of trail surfaces	○	○	○	○	○
Too much human waste on or near trails	○	○	○	○	○
Too much litter on the trails	○	○	○	○	○
Too many non-sanctioned or unmarked trails	○	○	○	○	○
Not enough trails that go to places I want to go	○	○	○	○	○
Opportunities to experience solitude	○	○	○	○	○

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Adequate conditions of infrastructure such as vault toilets and backcountry privies	○	○	○	○	○
Visitors too close to wildlife	○	○	○	○	○
Adequate air quality near the roadways	○	○	○	○	○

Q5.2 [Resource Importance] **On your visit(s) to Rocky Mountain National Park, how important is <u>management</u> of the following resource disturbances to you?**

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)	Don't Know/Not Sure (6)
Trampling vegetation and fragile plants	○	○	○	○	○	○
Eroding soils	○	○	○	○	○	○
Polluting of streams or lakes	○	○	○	○	○	○
Feeding, approaching, or otherwise disturbing wildlife	○	○	○	○	○	○
Making noise that mask the sounds of nature	○	○	○	○	○	○
Air pollution from roadways	○	○	○	○	○	○
Improper disposal of human waste	○	○	○	○	○	○

Q5.3 [Staff Evaluation] **Please rate the quality of your interaction with staff(in-person, over the phone, or online) at Rocky Mountain National Park.**

	Very Poor (1)	Poor (2)	Average (3)	Good (4)	Excellent (5)
Helpfulness & Courteousness of Park Staff	○	○	○	○	○
Ease of obtaining a permit	○	○	○	○	○
Availability of permits for desired dates/times	○	○	○	○	○
Park staff assistance in finding alternative activities in Rocky Mtn National Park	○	○	○	○	○
Quality of information provided about the TEPS system on RMNP website	○	○	○	○	○
Navigation of the Recreation.gov website	○	○	○	○	○

End of Block: Visitor Experience

Start of Block: TEPS

Q6.1 [TEPS Evaluation] **After entering the Park did the Timed-Entry Permit System improve or detract your experience on the whole?**

○ Much worse (1)

○ Somewhat worse (2)

○ About the same (3)

○ Somewhat better (4)

○ Much better (5)

Q6.2 [Use Limits] **Please indicate the extent to which you agree or disagree with each of the following statements concerning management of visitation in Rocky Mountain National Park.**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
If trailhead and parking lots are so busy that parking at your desired locations is unavailable, use limits should be imposed	○	○	○	○	○
If visitor-caused resource impacts are so high that it impairs future generations opportunities to enjoy Rocky Mtn National Park, use limits should be imposed	○	○	○	○	○
Use limits should never be imposed, even if use is high	○	○	○	○	○
If solitude is lost, use limits should be imposed	○	○	○	○	○
If facilities such as restrooms or visitor centers are overwhelmed, use limits should be imposed	○	○	○	○	○
If congestion and crowding cause delays in the ability to respond to an emergency situation, use limits should be imposed	○	○	○	○	○
If congestion and crowding delay impede or impair the maintenance of park facilities (i.e. servicing restrooms), use limits should be imposed.	○	○	○	○	○

Q6.3 [Management Alternatives] **Several approaches for reducing congestion, crowding, and resource degradation are being considered at Rocky Mountain National Park. Please rank the following approaches based on your preferences.**

(Drag and drop the approaches according to your preference)

______ Limit the number of vehicles entering the park daily (1)
______ Limit the number of people entering the park daily (2)
______ Distribute visitation throughout the day (3)
______ Require permit access for specific areas of the park (e.g. Bear Lake Road Corridor, Longs Peak) (4)
______ Extend Park shuttle bus services to other areas in the park (5)
______ Shuttle service access only to the Bear Lake Road Corridor during peak visitation (6)
______ Increase stewardship educational programs and outreach (7)

End of Block: TEPS

Start of Block: Demographic

Q7.1 [Country] **In which country do you currently reside?**

▼ United States of America (1) ... Zimbabwe (1357)

Display This Question:

If Country = United States of America

Q7.2[ZIP Code] **What is the zip code of your primary residence?**

____

Q7.3 [Age] **What year were you born?**

____

Q7.4 [Gender] **What is your gender?** *(Please select one)*

- ○ Male (1)
- ○ Female (2)
- ○ Non-binary / third gender (3)
- ○ Prefer not to say (4)
- ○ Prefer to self-describe (5) ____

Q7.5 [Group Size] **How many people were in your personal group, including yourself? (# of people)**
If you made multiple reservations, please indicate your average group size across visits.

____

Q7.6 [Race/Ethnicity] **Which of the following options best describes your race/ethnicity? Answer only for yourself.**
(Please select one or more)

- ▢ American Indian or Alaska Native (1)
- ▢ White (2)
- ▢ Black/African American (3)
- ▢ Native Hawaiian/Pacific Islander (4)
- ▢ East Asian/Asian American (5)
- ▢ South Asian/Indian American (6)
- ▢ Middle Eastern/Arab American (7)
- ▢ Other (8)

End of Block: Demographics

Table A.1: Summary and descriptive statistics of responses to indicators of the quality of the visitor experience under TEPS.

Visitor Experience Indicator	Agreement: Strongly Disagree (1)	Somewhat Disagree (2)	Neither Agree nor Disagree (3)	Somewhat Agree (4)	Strongly Agree (5)	Mean $\bar{x}$	Standard Deviation σ
Adequate signs marking trail routes	2.0%	5.4%	13.6%	37.5%	41.5%	4.11	0.96
Adequate information and signs at the trailhead	2.3%	5.1%	14.0%	37.4%	41.1%	4.10	0.98
Adequate air quality near the roadways	3.1%	6.4%	27.2%	36.9%	26.4%	3.77	1.01
Opportunities to experience solitude	6.3%	14.7%	19.6%	37.8%	21.5%	3.54	1.16
Adequate cond. of infrastructure (i.e toilets & privies)	4.5%	11.4%	30.5%	37.5%	16.0%	3.49	1.03
Visitors too close to wildlife	11.1%	17.9%	29.1%	27.0%	14.9%	3.17	1.21
Sufficient parking access at trailhead	9.5%	28.0%	23.4%	30.2%	8.9%	3.01	1.15
Crowding from too many other hikers	18.2%	22.5%	27.9%	26.3%	5.1%	2.77	1.17
High noise level from other hikers	19.3%	29.1%	31.6%	16.9%	3.1%	2.55	1.08
Unfavorable actions or behaviors of other hikers	32.1%	26.4%	24.4%	13.1%	4.0%	2.31	1.16
Too many non-sanctioned or unmarked trails	37.0%	27.0%	29.5%	5.5%	1.0%	2.07	0.99
Not enough trails that go to places I want to go	41.7%	25.8%	25.6%	6.0%	0.9%	1.99	1.00
Too much litter on the trails	44.6%	28.0%	18.5%	7.6%	1.4%	1.93	1.03
Too much human waste on or near trails	47.5%	25.1%	20.1%	6.0%	1.3%	1.89	1.01
Poor quality of trail surfaces	40.9%	34.1%	21.4%	3.2%	0.4%	1.88	0.88

n=8,218

Table A.2: Summary and descriptive statistics of responses to how important the management of resource disturbance is to visitors and their experience.

Resource	Importance to Visitor: Don't Know Unsure (-)	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)	Mean $\bar{x}$	Standard Deviation σ
Water quality of streams and lakes	1.0%	0.5%	1.5%	4.5%	28.3%	64.2%	4.56	0.70
Feeding/disturbing wildlife	1.0%	0.9%	2.3%	8.9%	29.2%	57.6%	4.42	0.82
Improper disposal of human waste	2.8%	1.4%	3.7%	9.2%	27.4%	55.6%	4.36	0.90
Trampled Vegetation	1.3%	1.3%	4.6%	13.9%	35.9%	43.1%	4.16	0.92
Erosion of Soils	2.1%	1.4%	4.9%	15.4%	38.3%	37.8%	4.08	0.93
Noise that masks sounds of nature	2.3%	3%	5.9%	17.3%	30.9%	40.9%	4.02	1.05
Air quality	1.9%	3.4%	10.0%	22.8%	31.4%	30.5%	3.77	1.10

n=8,218

Table A.3: Summary and descriptive statistics of responses to visitors' traffic experience under TEPS.

Traffic Experience Statement	Impact on Experience: Not at all	Slightly	Moderately	Very much	Extremely	Mean $\bar{x}$	Standard Deviation σ
Could not obtain a permit for desired entrance time	37.60%	15.40%	15.10%	12.40%	19.50%	2.61	1.55
Traffic congestion at entrance stations	24.60%	29.60%	25.10%	12.60%	8.10%	2.50	1.22
Parking congestion/ shortages	24.70%	31.90%	24.80%	12.20%	6.50%	2.44	1.17
Parking congestion/ shortages on Bear Lake Road	28.60%	30.90%	21.10%	11.30%	8.10%	2.39	1.23
Bear Lake Road Restrictions	37.70%	23.80%	18.30%	10.90%	9.20%	2.30	1.32
Crowding at scenic overlooks	26.90%	35.40%	24.30%	9.80%	3.70%	2.28	1.07
Traffic congestion on the roads	28.60%	35.60%	25.70%	7.20%	2.90%	2.20	1.03
Traffic congestion at roadside pullouts	31.90%	34.80%	23.20%	7.40%	2.60%	2.14	1.03
Traffic congestion on Bear Lake Road	35.70%	32.20%	19.20%	7.90%	5.00%	2.14	1.14
Lack of Park shuttle bus service/options	72.80%	12.50%	8.80%	3.90%	2.00%	1.50	0.95
Park shuttle bus wait times	72.80%	15.40%	7.70%	2.70%	1.40%	1.45	0.85

n=8,783

Table A.4: Summary of variable, type, measure, and levels in multiple linear regression model.

Variable Name	Data Type	Measure	Levels
Managed Access: Never Justified	Likert (ordinal)	Agreement	1)Strongly disagree 2)Somewhat disagree 3)Neither agree nor disagree 4)Somewhat agree 5)Strongly agree
Ease of obtaining a reservation	Likert (ordinal)	Quality	1)Very Poor 2)Poor 3)Average 4)Good 5)Excellent
Visited Bear Lake	Nominal (dichotomous)	Yes/No	0-No 1)Yes
Number of reservations placed	Ordinal	# of Reservations	1) 1 2) 2:10 3) 11:20 4) 21:50 5: 51)95
Expectations for park traffic	Likert (ordinal)	Expectations	1)Far less than what I expected 2)Somewhat less than what I expected 3)Equal to what I expected 4)Somewhat more than what I expected 5)Far more than what I expected
Desired reservation time unavailable	Likert (ordinal)	Impact on experience	1)Not at all 2)Slight 3)Moderate 4)Very 5)Extreme
Managed Access: Trailhead & parking	Likert (ordinal)	Agreement	1)Strongly disagree 2)Somewhat disagree 3)Neither agree nor disagree 4)Somewhat agree 5)Strongly agree
Quality of TEPS info	Likert (ordinal)	Quality	1)Very Poor 2)Poor 3)Average 4)Good 5)Excellent
Expectation of the number of other visitors	Likert (ordinal)	Expectations	1)Far less than what I expected 2)Somewhat less than what I expected 3)Equal to what I expected 4)Somewhat more than what I expected 5)Far more than what I expected
Staff helpfulness	Likert (ordinal)	Quality	1)Very Poor 2)Poor 3)Average 4)Good 5)Excellent
Previous park visitation	Likert (ordinal)	# of previous visits	1) 0-3 2) 3-10 3) 11-20 4) 21-60 5) 61-∞
Managed Access: Facilities & maintenance	Likert (ordinal)	Agreement	1)Strongly disagree 2)Somewhat disagree 3)Neither agree nor disagree 4)Somewhat agree 5)Strongly agree
Managed Access: Opportunities for solitude	Likert (ordinal)	Agreement	1)Strongly disagree 2)Somewhat disagree 3)Neither agree nor disagree 4)Somewhat agree 5)Strongly agree
Expectations for finding parking	Likert (ordinal)	Anticipation of difficulty	1) Definitely not 2) Probably not 3) Might or might not 4) Probably yes 5) Definitely yes

APPENDIX B

Trail Pilot Program Survey and Visitor Behavior

OC Parks Trail Management & Regulations: Visitor Evaluative Survey

Start of Block: Survey Intro

Q1.1 **Purpose:**
OC Parks is piloting changes to the management and regulations of trail use in Aliso-Wood Canyon Wilderness Park, Laguna Coast Wilderness, and Santiago Oaks Regional Park and is gathering feedback from the public about these changes and their effect on visitors' recreation experiences.

Participation in this Study: By continuing on to the survey, you agree to participate in this study. You indicate that you understand the risks and benefits of participation, and that you know what you will be asked to do. You also agree that you have asked any questions you might have, and are clear on how to stop your participation in the study if you choose to do so. Please be sure to retain a copy of this form for your records.

Would you like to participate in this survey?

○ Yes

○ No

End of Block: Survey Intro

Start of Block: Non-Response + Visitor Characteristics

Display This Question:

If Q1.1 = No

Q2.1 What is your primary constraint or reason for not participating in this study?

- ◯ Language Barrier
- ◯ Not enough time
- ◯ Not interested
- ◯ Safety Concerns due to COVID-19
- ◯ Other: (Please explain) ____

Q2.2 What park are you visiting today?

- ◯ Aliso-Wood Canyon Wilderness Park
- ◯ Laguna Coast Wilderness Park
- ◯ Santiago Oaks Regional Park

Q2.3 What is the primary activity you planned to participate in on your visit to the park today?

- ◯ Walking/Hiking
- ◯ Running
- ◯ Biking
- ◯ Dog Walking
- ◯ Horseback Riding

Display This Question:

If Q2.3 = Biking

Q2.4 What type of bike are you riding?

- ◯ Mountain Bike (Cross-country or Enduro)
- ◯ E-Bike
- ◯ Gravel Bike
- ◯ Hybrid Bike
- ◯ Road Bike
- ◯ Other ____

End of Block: Non-Response + Visitor Characteristics

Start of Block: Pre-Evaluations

Q3.1 On average, how many days per year do you participate in ${Q2.3/ChoiceGroup/SelectedChoices}?

- ◯ 0-10 days
- ◯ 11-25 days
- ◯ 26-50 days
- ◯ 51 or more days

Q3.2 Please rate your current experience level in ${Q2.3/ChoiceGroup/SelectedChoices}.

- ◯ Beginner
- ◯ Novice
- ◯ Intermediate
- ◯ Advanced
- ◯ Expert

Q3.3 Have you experienced some form of conflict with any of the following user groups? (Select all that apply)

- ▢ Walkers/Hikers
- ▢ Runners
- ▢ Bikers
- ▢ Dog Walkers
- ▢ Horseback Riders
- ▢ Others ____

Carry Forward Selected Choices from "Q3.3"

Q3.4 On average, what is the likelihood or chance you to experience some form of conflict with the groups you selected?

	Extremely unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Extremely likely
Walkers/Hikers	○	○	○	○	○
Runners	○	○	○	○	○
Bikers	○	○	○	○	○
Dog Walkers	○	○	○	○	○
Horseback Riders	○	○	○	○	○
Others	○	○	○	○	○

Display This Question:

If Q3.3 = Bikers

Q3.5 You indicated you have experienced conflict with **Bikers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Speeding
- ☐ Failure to comply with regulations
- ☐ Crowding

Display This Question:

If Q3.3 = Walkers/Hikers

Q3.6 You indicated you have experienced conflict with **Hikers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Failure to comply with regulations
- ☐ Crowding

Display This Question:

If Q3.3 = Runners

Q3.7 You indicated you have experienced conflict with **Runners.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Failure to comply with regulations
- ☐ Crowding

Display This Question:

If Q3.3 = Dog Walkers

Q3.8 You indicated you have experienced conflict with **Dog Walkers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Crowding
- ☐ Dogs off-leash, not under control
- ☐ Feces

Display This Question:

If Q3.3 = Horseback Riders

Q3.9 You indicated you have experienced conflict with **Horseback Riders.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Crowding
- ☐ Feces

Q3.10 **We would like to know <u>how effective</u> you think the current signage communicates the following park regulations and expectations for visitor behavior:**

	Not effective at all	Slightly effective	Moderately effective	Very effective	Extremely effective
Trail speed limit of 10 mph	○	○	○	○	○
Multi-use trail etiquette and behavior	○	○	○	○	○
Trail closures for the preservation and protection of natural or cultural resources	○	○	○	○	○
OC Parks regulations about e-bikes (electric bicycles)	○	○	○	○	○
Drawing connections between recreation management and habitat conservation goals in parks	○	○	○	○	○

Q3.11 Please indicate your level of agreement or disagreement with the following statements about trail management:

	Strongly disagree	Somewhat disagree	Indifferent / Neutral	Somewhat agree	Strongly agree	Don't Know/ Unsure
Restricting activity types on some trails would create safer conditions for everyone.	○	○	○	○	○	○
Restricting activity types on some trails would reduces conflict.	○	○	○	○	○	○
Designating trail direction would create safer conditions for everyone.	○	○	○	○	○	○
Designating the direction of trial use would reduce conflict.	○	○	○	○	○	○
Overall, new trail regulations would increase the quality of my experience.	○	○	○	○	○	○
Overall, OC Parks employing new trail regulations would create a better experience for all visitors.	○	○	○	○	○	○

Q3.12 In your opinion, is enough management presence (i.e., rangers, staff) on trails to educate visitors and enforce trail regulations?

- ◯ Far too little
- ◯ Slightly too little
- ◯ The right amount
- ◯ Slightly too much
- ◯ Far too much

Q3.13 Do you agree or disagree that the current trail regulations contribute to OC Park's habitat conservation goals for ${Q2.2/ChoiceGroup/SelectedChoices}?

- ◯ Strongly disagree
- ◯ Somewhat disagree
- ◯ Indifferent/ Neutral
- ◯ Somewhat agree
- ◯ Strongly agree
- ◯ Don't Know/Unsure

Q3.14 What is your age?

- ◯ 18-19
- ◯ 20-34
- ◯ 35-54
- ◯ 55-64
- ◯ 65+

Q3.15 Which gender do you most identify with?

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Genderqueer and or gender non-conforming
- ◯ Prefer not to answer
- ◯ Identity not listed above

Q3.16 On average, how many days per year do you participate in ${Q2.3/ChoiceGroup/SelectedChoices}?

- ◯ 0-10 days
- ◯ 11-25 days
- ◯ 26-50 days
- ◯ 51 or more days

End of Block: Pre-Evaluations

Start of Block: Post-Evaluations

Q4.1 Please rate your current experience level in ${Q2.3/ChoiceGroup/SelectedChoices}.

- ○ Beginner
- ○ Novice
- ○ Intermediate
- ○ Advanced
- ○ Expert

Q4.2 Have you experienced some form of conflict with any of the following user groups? (Select all that apply)

- ▢ Walkers/Hikers
- ▢ Runners
- ▢ Bikers
- ▢ Dog Walkers
- ▢ Horseback Riders
- ▢ Others ____

Page Break

Carry Forward Selected Choices from "Q4.2"

Q4.3 On average, what is the likelihood or chance you to experience some form of conflict with the groups you selected?

	Extremely unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Extremely likely
Walkers/Hikers	○	○	○	○	○
Runners	○	○	○	○	○
Bikers	○	○	○	○	○
Dog Walkers	○	○	○	○	○
Horseback Riders	○	○	○	○	○
Others	○	○	○	○	○

Display This Question:

If Q4.2 = Bikers

Q4.4 You indicated you have experienced conflict with **Bikers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ▢ Failure to yield/follow trail right of way
- ▢ Lack of communication
- ▢ Discourteous behavior
- ▢ Speeding
- ▢ Failure to comply with regulations
- ▢ Crowding

Display This Question:

If Q4.2 = Walkers/Hikers

Q4.5 You indicated you have experienced conflict with **Hikers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ▢ Failure to yield/follow trail right of way
- ▢ Lack of communication
- ▢ Discourteous behavior
- ▢ Failure to comply with regulations
- ▢ Crowding

Display This Question:

If Q4.2 = Runners

Q4.6 You indicated you have experienced conflict with **Runners.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ☐ Failure to yield/follow trail right of way
- ☐ Lack of communication
- ☐ Discourteous behavior
- ☐ Failure to comply with regulations
- ☐ Crowding

Display This Question:

If Q4.2 = Dog Walkers

Q4.7 You indicated you have experienced conflict with **Dog Walkers.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ▢ Failure to yield/follow trail right of way
- ▢ Lack of communication
- ▢ Discourteous behavior
- ▢ Crowding
- ▢ Dogs off-leash, not under control
- ▢ Feces

Display This Question:

If Q4.2 = Horseback Riders

Q4.8 You indicated you have experienced conflict with **Horseback Riders.** Please identify the specific behaviors you believe are the source of the conflict (select all that apply):

- ▢ Failure to yield/follow trail right of way
- ▢ Lack of communication
- ▢ Discourteous behavior
- ▢ Crowding
- ▢ Feces

Page Break

Q4.9 Regarding the signage about the new trail regulations, please rate your level of agreement with the following statements:

	Strongly disagree	Somewhat disagree	Indifferent / Neutral	Somewhat agree	Strongly agree	Don't Know/Unsure
There is enough signage about new trail regulations	○	○	○	○	○	○
The signage is positioned in the right locations	○	○	○	○	○	○
The signage is clear and effective at communicating the new regulations	○	○	○	○	○	○
The signage communicates OC Park's expectations for visitor behavior	○	○	○	○	○	○

Q4.10 Please indicate your level of agreement or disagreement with the following statements about the new trail management and regulations:

	Strongly disagree	Somewhat disagree	Indifferent / Neutral	Somewhat agree	Strongly agree	Don't Know/Unsure
Restricting activity types on some trails creates safer conditions for everyone.	○	○	○	○	○	○
Restricting activity types on some trails reduces conflict.	○	○	○	○	○	○
Designating trail direction creates safer conditions for everyone.	○	○	○	○	○	○
Designating the direction of trial use reduces conflict.	○	○	○	○	○	○
Overall, the new trial regulations increases the quality of my experience.	○	○	○	○	○	○
Overall, the new trail regulations are fair and create a better experience for everyone.	○	○	○	○	○	○

Q4.11 In your opinion, is enough management presence on trails to educate visitors and enforce the new trail regulations?

- Far too little
- Slightly too little
- The right amount
- Slightly too much
- Far too much

Q4.12 Do you agree or disagree that the new trail regulations contribute to OC Park's habitat conservation goals for ${Q2.2/ChoiceGroup/SelectedChoices}?

- Strongly disagree
- Somewhat disagree
- Indifferent/ Neutral
- Somewhat agree
- Strongly agree
- Don't Know/Unsure

Q4.13 What is your age?

○ 18-19

○ 20-34

○ 35-54

○ 55-64

○ 65+

Q4.14 Which gender do you most identify with?

○ Male

○ Female

○ Non-binary

○ Genderqueer and or gender non-conforming

○ Prefer not to answer

○ Identity not listed above

End of Block: Post-Evaluations

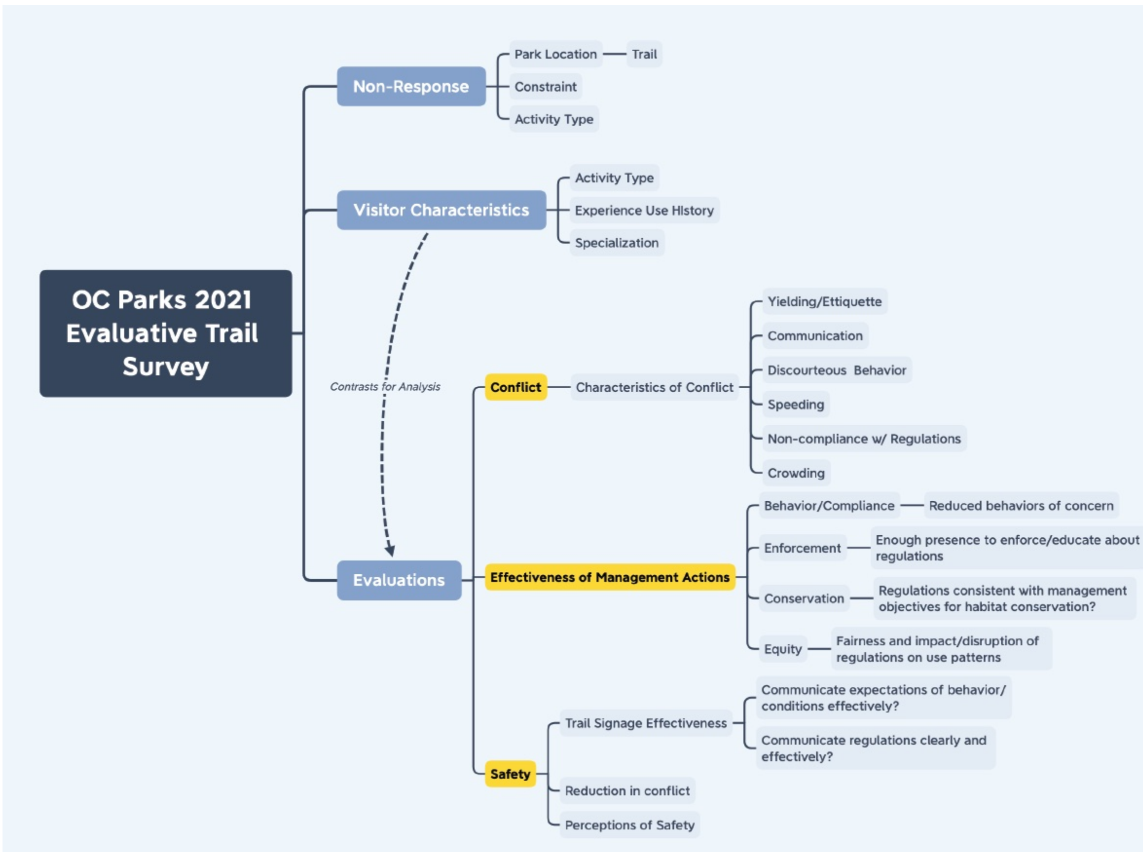

Figure B.1: Survey instrument conceptual diagram of variables measured

Table B.1: OLS regression comparisons between mountain bike trail velocities prior to and during the implementation of the TPP management strategies.

Trail	Direction	Coef	df	T	LL	UL	p
Cactus	Uphill	-0.04	151	-0.63	-0.16	0.08	.529
	Downhill	0.05	127	0.14	-0.63	0.73	.886
Cholla	Uphill	-0.06	147	-1.37	-0.14	0.03	.173
	Downhill	1.30	33	2.58	0.27	2.33	<.05
Chutes	Uphill	0.35	10	0.96	-0.46	1.15	.359
	Downhill	0.40	146	2.10	0.02	0.77	<.05
Grasshopper	Uphill	-0.19	7	-0.50	-1.08	0.70	.630
	Downhill	0.78	146	2.06	0.03	1.53	<.05
LagunaRidge	Uphill	-0.02	2	-0.03	-2.86	2.81	.976
	Downhill	0.14	185	0.55	-0.35	0.62	.581
Lizard	Uphill	0.34	31	0.92	-0.41	1.08	.364
	Downhill	-0.14	256	-0.77	-0.48	0.21	.441
Lynx	Downhill	-0.54	63	-1.52	-1.25	0.17	.134
OldEmerald	Uphill	0.04	48	0.29	-0.24	0.33	.776
	Downhill	-0.10	134	-0.31	-0.71	0.52	.760
Peralta	Downhill	0.29	98	0.90	-0.35	0.93	.371
Pony	Uphill	0.23	33	0.50	-0.72	1.18	.621
	Downhill	-0.10	61	-0.20	-1.13	0.92	.839
RockIt	Uphill	-0.12	56	-0.69	-0.47	0.23	.492
	Downhill	-0.02	146	-0.10	-0.42	0.38	.920
SageRidge	Uphill	-0.13	206	-0.47	-0.67	0.41	.639
	Downhill	0.20	290	1.12	-0.15	0.56	.264
Yucca	Uphill	0.78	2	0.97	-2.69	4.25	.434
	Downhill	1.37	144	4.90	0.82	1.92	<.001

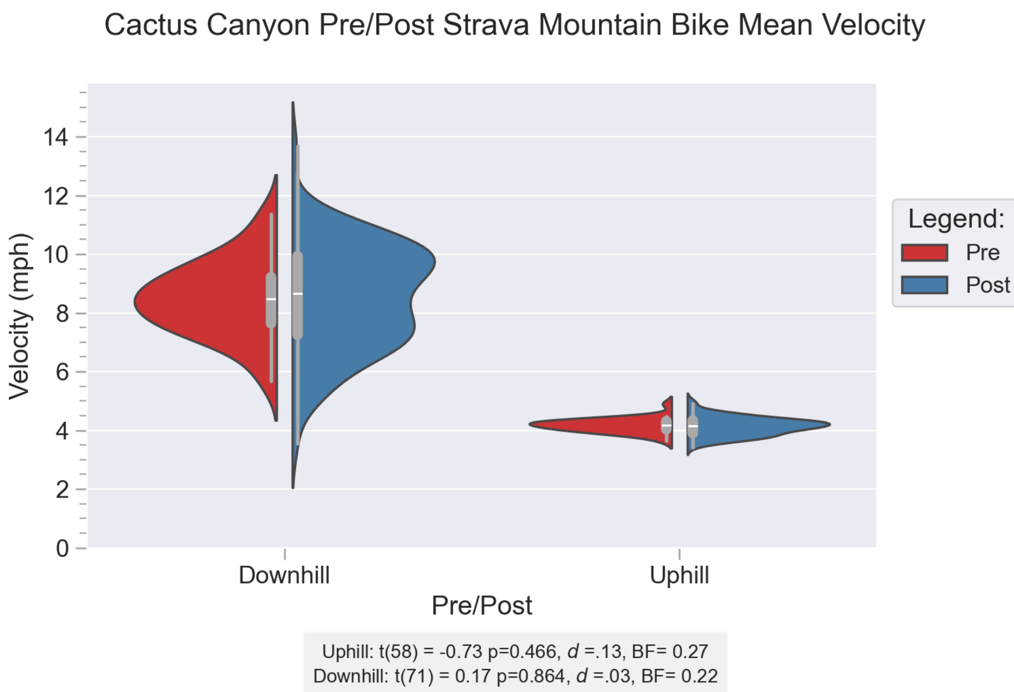

Figure B.2: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Cactus Canyon Trail

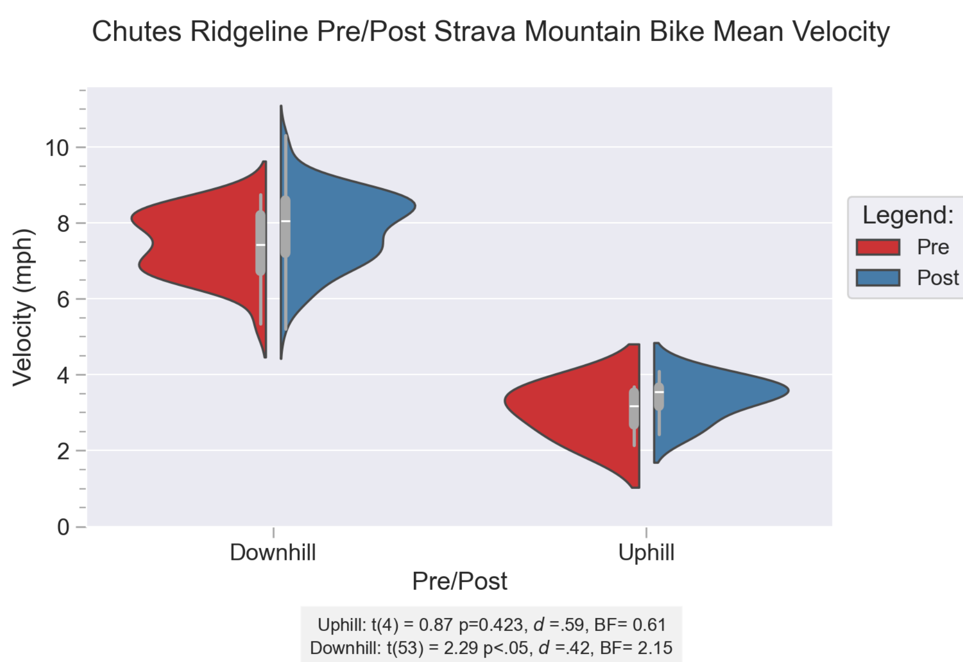

Figure B.3: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Chutes Ridgeline Trail

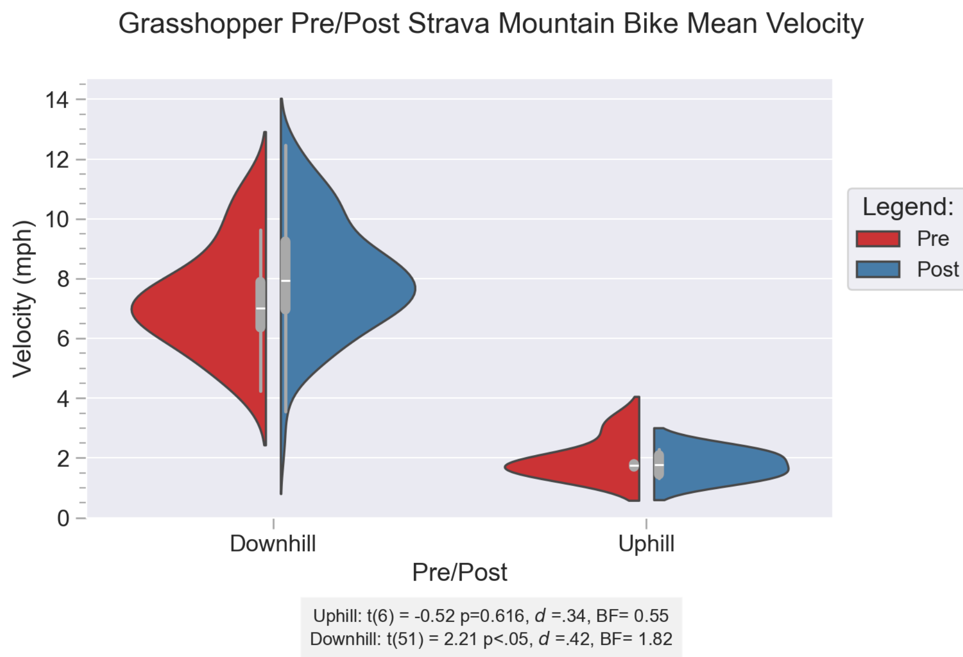

Figure B.4: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Grasshopper Trail

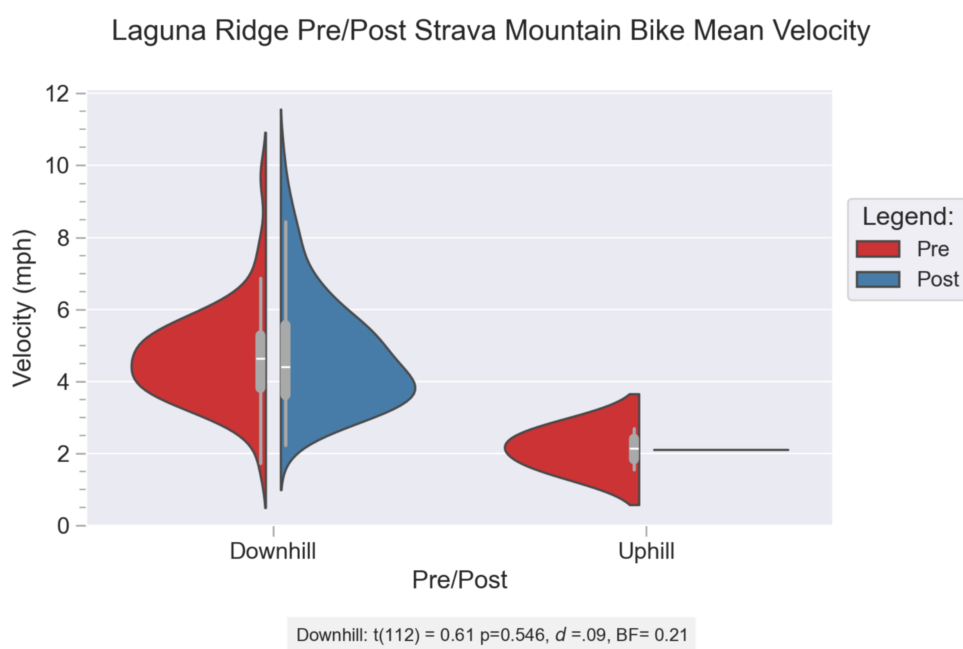

Figure B.5: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Laguna Ridge Trail

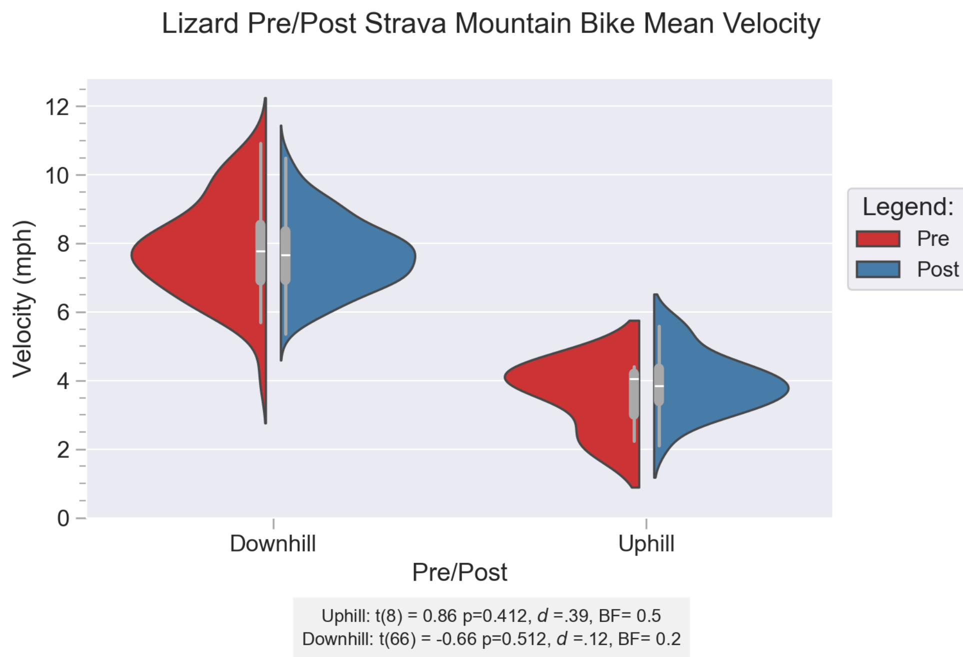

Figure B.6: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Lizard Trail

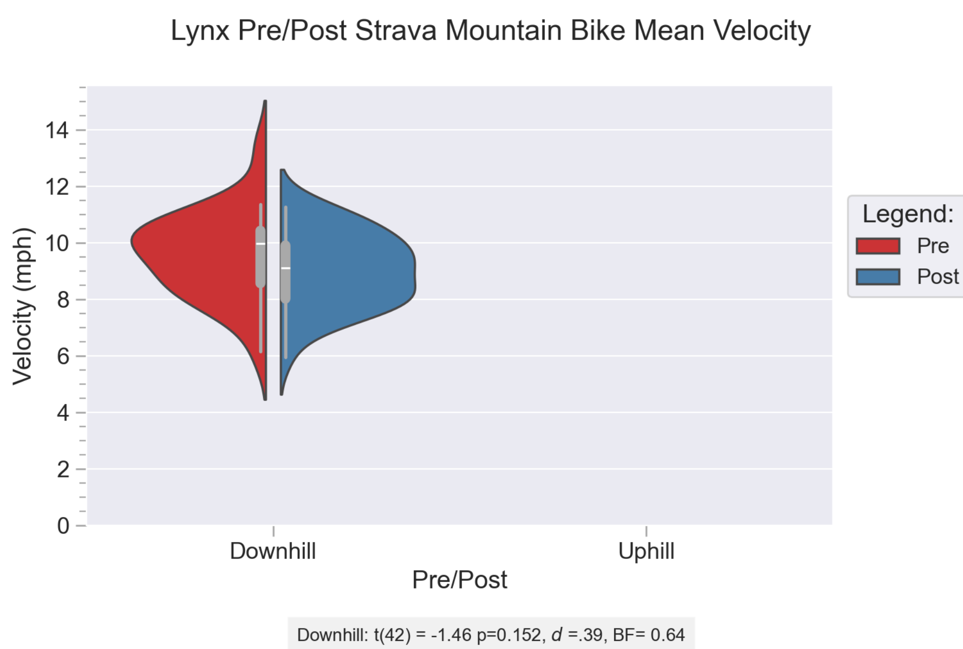

Figure B.7: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Lynx Trail

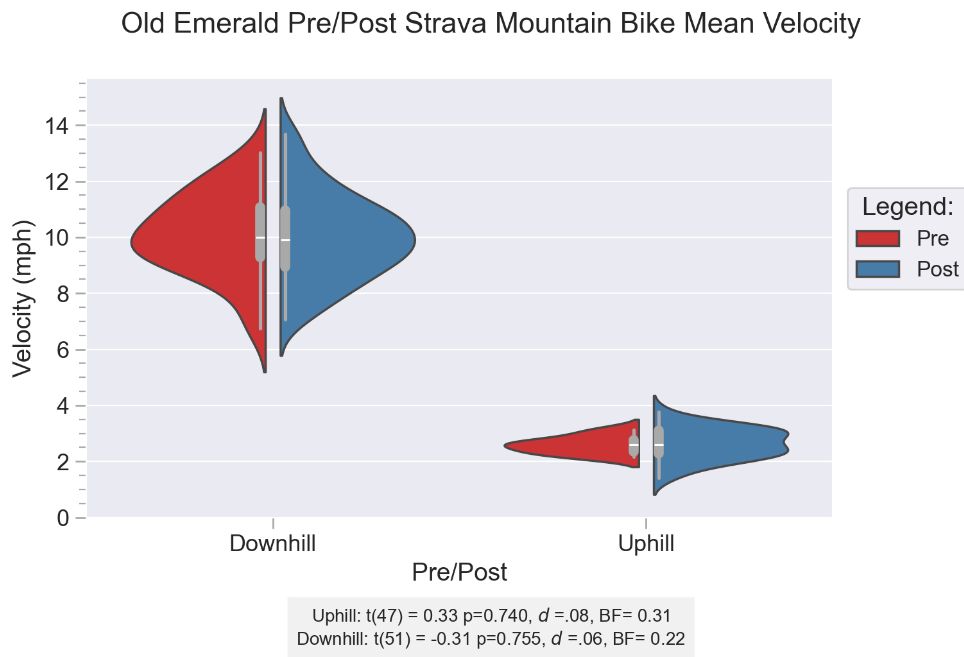

Figure B.8: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Old Emerald Trail

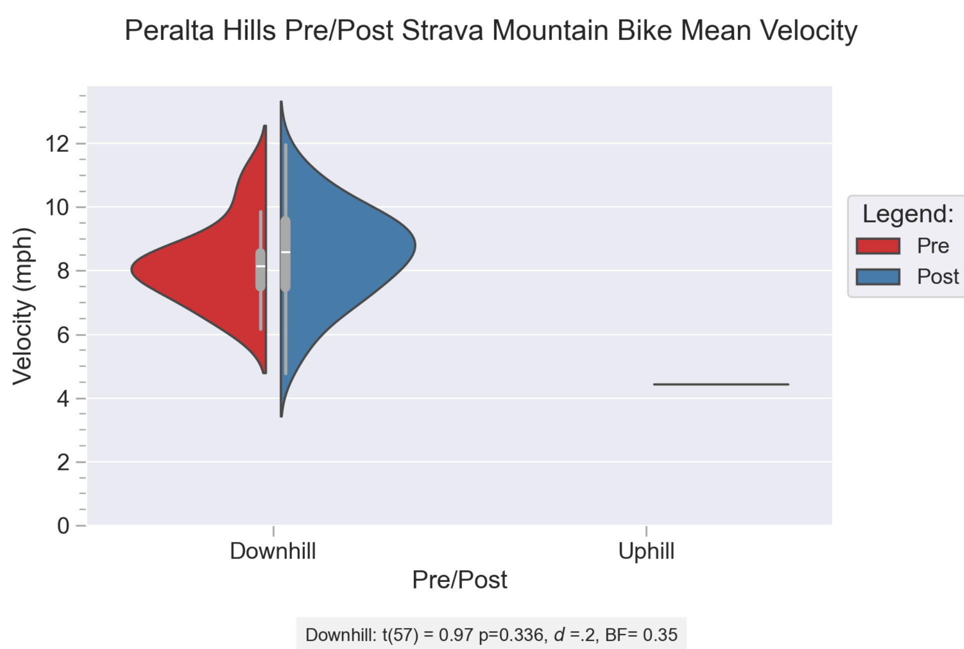

Figure B.9: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Peralta Hills Trail

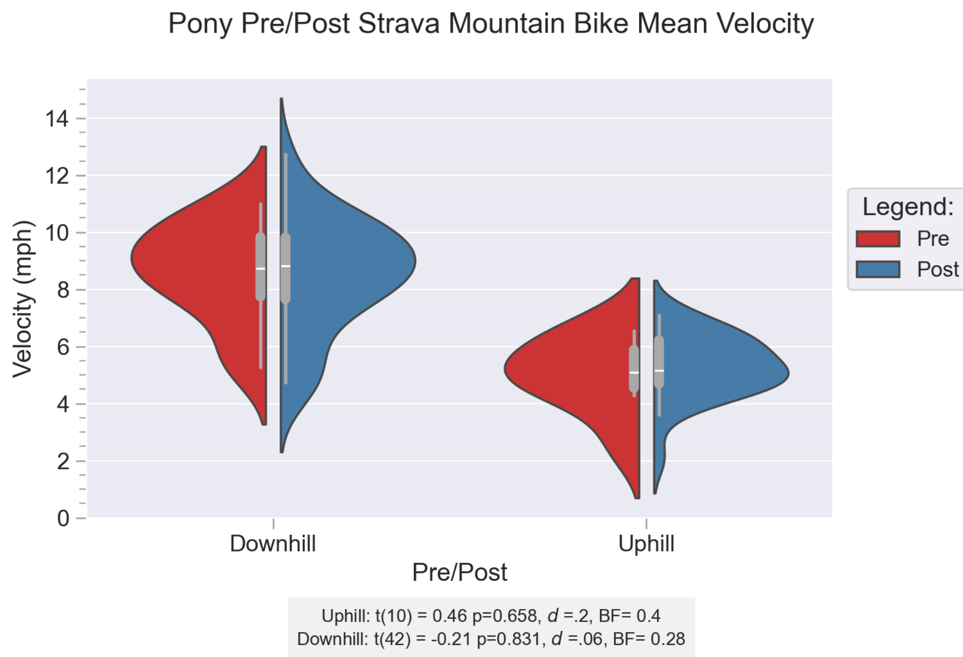

Figure B.10: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Pony Trail

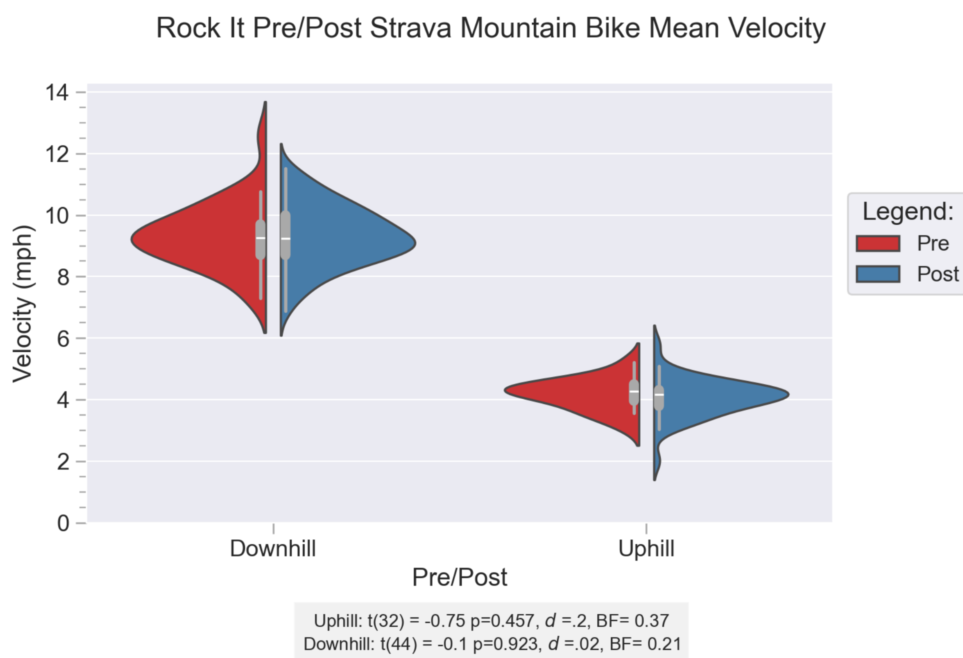

Figure B.11: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Rock It Trail

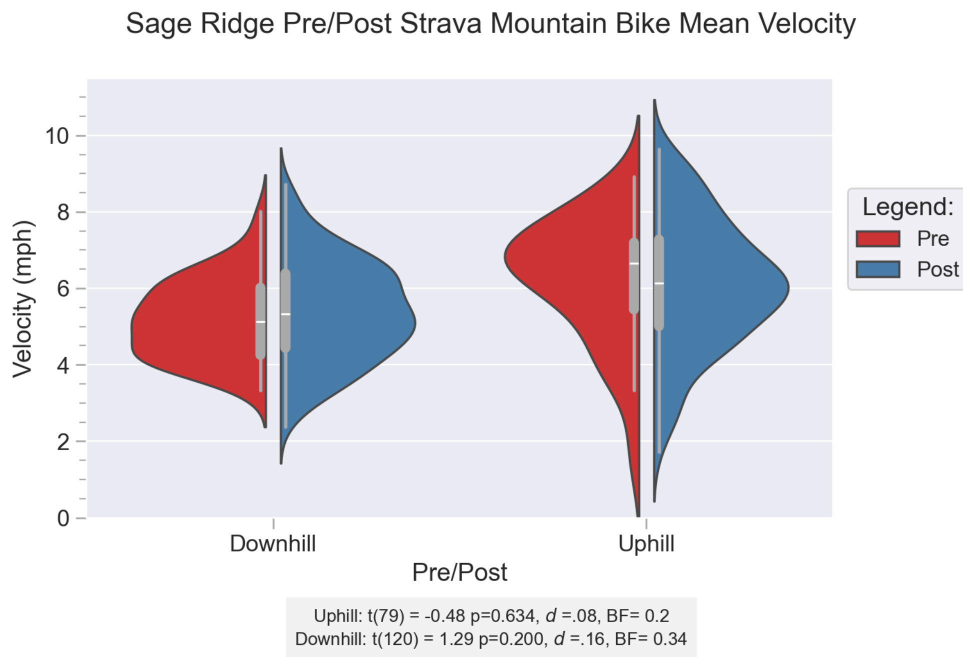

Figure B.12: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Sage Ridge Trail

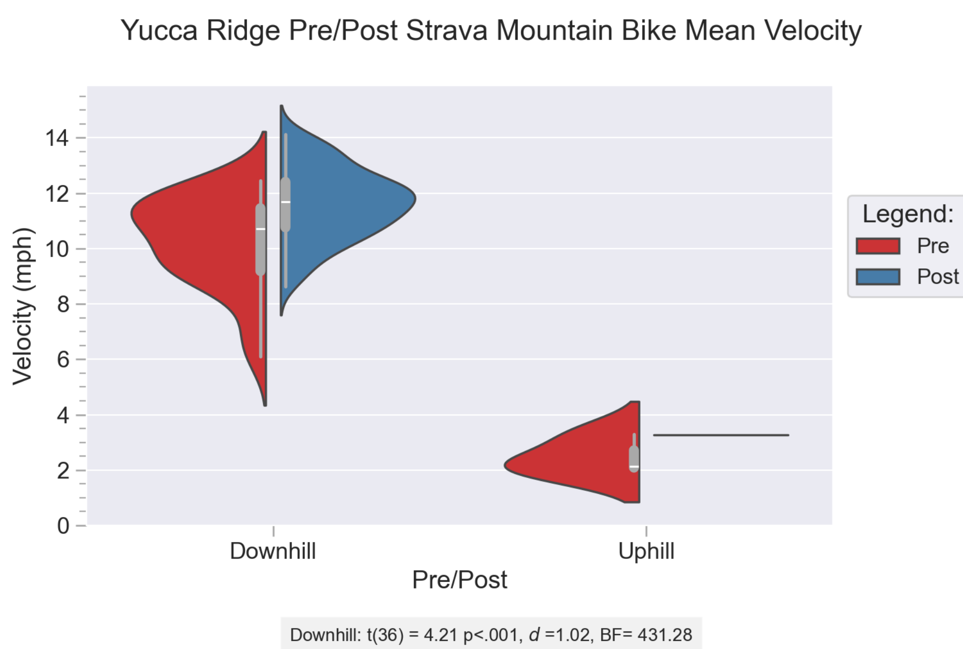

Figure B.13: Pre/Post Trail Pilot Program Strava Metro velocity comparisons on the Yucca Ridge Trail

Noah E Creany

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Education

Utah State University — Logan, UT
PhD Candidate, Ecology — *2020-Present*

- Research Assistant/Instructor of Record
- Dissertation: *Shifting Paradigms in Recreation and Parks and Protected Areas: Advancing Social-Ecological Systems Frameworks in Park and Protected Area Management*
- **Major Professor**: Dr. Christopher A. Monz
- **Supervising Committee**: Dr. Mark Brunson, Dr. Wayne Freimund, Dr. Sarah Klain, Dr. Patrick Singleton.

Utah State University — Logan, UT
M.Sc. Recreation Resource Management — *2019*

- Thesis: *Kudos & KOMs: The Effect of Strava Use on Evaluations of Social and Managerial Conditions, Perceptions of Ecological Impacts, and Mountain Bike Spatial Behavior*
- Research Assistant/Teaching Assistant

Pennsylvania State University — University Park, PA
B.S. Community, Environment & Development — *2012*

- Focus: Rural Sociology, International Development & Agribusiness

Research

Protected Area Conservation & Management

Broadly, my research aims to inform recreation management in protected area settings through the lens of social-ecological systems.

- Recreation Ecology
- Human Dimensions of Wildland Recreation
- Visitor Use Management & Monitoring

Awards

Rocky Mountain Cooperative Ecosystem Studies Unit (CESU)

- Student Researcher (Honorable Mention) (2023)

Utah State University Quinney College of Natural Resources

- Doctoral Student Researcher of the Year (2023)

Peer-Reviewed Articles

- Minehart, K., Antonio, A. D., **Creany, N.**, Monz, C., & Gutzwiller, K. (2024). *Predicting trail condition using random forest models in urban-proximate nature reserves*. **mine**. doi: 10.1016/j.envc.2024.100937.
- Van Deursen, J., **Creany, N.**, Smith, B., Freimund, W., Avgar, T., & Monz, C. A. (2024). *Recreation specialization*. Applied Geography. doi: 10.1016/j.apgeog.2024.103276.
- **Creany, N.**, Monz, C., Esser, S. (2024). *Understanding visitor attitudes towards the timed-entry reservation system in Rocky Mountain National Park*. Journal of Outdoor Recreation and Tourism. doi: 10.1016/j.jort.2024.100736 .

- Tomczyk, A., Ewertowski, M., **Creany, N.**, Ancin-Murguzur, J.A., Monz, C. (2023).*The application of unmanned aerial vehicle (UAV) surveys and GIS to the analysis and monitoring of recreational trail conditions*. International Journal of Applied Earth Observation and Geoinformation[1]. doi: 10.1016/j.jag.2023.103474
- Smith, J.W., Miller, A.B., Spernbauer, B.S., **Creany, N.**, Richards, J.C., Meyer, C., Nesbitt, J., Rempel, W., Wilkins, E. (2021). *Motivations and Spatial Behavior of OHV Recreationists: A Case-Study from Central Utah (USA)*. Journal of Outdoor Recreation and Tourism. doi: 10.1016/j.jort.2021.100426
- **Creany, N.**, Monz, C. A., D'Antonio, A., Sisneros-Kidd, A., Wilkins, E. J., Nesbitt, J., & Mitrovich, M. (2021). *Estimating trail use and visitor spatial distribution using mobile device data: An example from the nature reserve of orange county, California USA.* Environmental Challenges[1]. doi: 10.1016/j.envc.2021.100171
- Wesstrom, S., Monz, C., **Creany, N.**, Miller, A., D'Antonio, A. *The Effect of a Vehicle Diversion Traffic Management Strategy on Spatio-Temporal Park Use: A Study in Rocky Mountain National Park, Colorado*. Journal of Park and Recreation Administration. doi: 10.18666/JPRA-2021-10746
- Monz, C., **Creany, N.**, Nesbitt, J., & Mitrovich, M. (2020). Research Note | *Mobile Device Data Analysis to Determine the Demographics of Park Visitors*. Journal of Park and Recreation Administration. doi: 10.18666/JPRA-2020-10541

Natural Resource & Technical Reports

- Graham, R., **Creany, N.**, & Monz, C. (2021). Spatial Behavior of Backcountry Anglers and Hikers in Rocky Mountain National Park (p. 26) [Natural Resource Report]. National Park Service.
- Sisneros-Kidd, A., D'Antonio, A. L., **Creany, N.**, Monz, C. A., & Shoenleber, C. (2019). Recreation Use and Human Valuation on the Nature Reserve of Orange County, California (p. 52). Orange County, California: Utah State University.

Manuscripts in Review

- Van Deursen, J., **Creany, N.**, Freimund, F., Monz, C., - *Classifications of Recreation Specialization: Attitudinal and Behavioral Differences Across Specialization Types in the Nature Reserve of Orange County, CA*. [In Editorial Review] Submitted 22 Dec 2023 to Journal of Outdoor Recreation and Tourism.

Manuscripts In Preparation

- **Creany, N.**,Monz, C. - *Walk this Way: Intensive Visitor-use Management Strategies for High-use Urban-Proximate Park and Protected Areas*. Target Journal: Journal of Outdoor Recreation and Tourism
- **Creany, N.**,Monz, C. - *Developing a Social-Ecological, Systems Thinking approach to Recreation and Protected Area Management*. Target Journal: Frontiers in Ecology and the Environment.
- **Creany, N.**, Monz, C., Freimund,W., - Leveraging crowd-sourced data for Recreation Use Monitoring: An Application and Evaluation of *Strava Metro* in urban-proximate Park and Protected Areas. Target Journal: Journal of Outdoor Recreation and Tourism.

[1]Open-Access

Presentations

2024

- **Creany, N.** *Elucidating the Social-Ecological Interactions of Direct Trail Management Strategies on Resource Conditions and Visitor Experience and Behavior: Evidence from the Urban-Proximate Protected Areas in Coastal California*.(2024, September). 12th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas. Camp Reinsehlen, Schneverdingen (Germany).
- **Creany, N.** *The Timed-Entry Permit System (TEPS) in Rocky Mountain National Park: A Multi-Year Study of the effects on the Visitor Experience and Visitor Evaluations*.(2024, March). Rocky Mountain National Park Biennial Research Conference. Estes Park, CO

2023

- **Creany, N.** *Contemporary Applications of Managed-Access Reservation Systems: Visitor & Management Perspectives from Acadia, Arches, and Rocky Mountain National Parks*.(2023, June) International Symposium on Society and Resource Management (IASNR). Portland, ME.

2022

- **Creany, N.** *Reservation for Bear Lake at 10am, party of four: A look into the RMNP Timed Entry Permit System from 2020 to 2021*.(2022, March) Presented at Rocky Mountain National Park Biennial Research Conference. Virtual Conference.

2021

- Ancin-Murguzur, F.J., Monz, C., **Creany, N.**, Munoz, L., D'Antonio, A., Sisneros-Kidd, A., Tomczyk, A., Ewertowski, M. *Recreation and tourism monitoring under increased pressure: practical tools and approaches for sustainable management*.(2021, August) Presented at Monitoring and Management of Visitors in Recreation and Protected Areas (MMV10).Virtual Conference.

2020

- **Creany, N.**, Wesstrom, S. *The Effect of a Vehicle Diversion on Spatio-temporal Park Use: A Study in Rocky Mountain National Park*. (2020, March).Presented at the Rocky Mountain National Park Research Conference. Estes Park, CO.
- Monz, C., Sisneros-Kidd, A., D'Antonio, A., **Creany, N.** *Orange County Recreation Management Project Update*.(2020, February) Presented to Park Managers and Project Partners. Irvine, CA.

2019

- Monz, C., Singleton, P., **Creany, N.**, Wesstrom, S. *Bear Lake Road Traffic Study* (2019, April) Presented at Rocky Mountain National Park. Estes Park, CO.

2018

- Monz, C., Sisneros-Kidd, A., **Creany, N.**, Shoenleber, C. *Orange County Recreation Management Project Update* (2018, December) Presented to Park Managers and Project Partners. Irvine, CA.
- **Creany, N.** *Spatial and Behavioral Patterns of Strava Mountain Bike Users*.(2018, June) Presented at the 2018 International Symposium on Society and Resource Management. Snowbird, UT.

Technical Skills

- **Programming Languages**: Python, R, ArcPy, SAS
- **Software**: Google Cloud Compute, Google Earth Engine, ArcMap/ArcGIS, QGIS, Adobe CC, LaTeX, Microsoft Office

Professional Affiliations

- Ecological Society of America (2022-)
- Recreation Ecology Research Network (2019-)

Relevant Certifications

- FAA Part 107 Drone Pilot
- CITI-Responsible Conduct of Research
- CITI-Human Subjects - Social, Behavioral, & Educational Research

Teaching Experience

Instructor of Record

- NR 6580: Data Analysis and Programming for Natural Resource Management. Spring-2024
- ENVS 4500: Wildland Recreation Behavior- Recreation Resource Management. Fall-2022
- ENVS 4500: Wildland Recreation Behavior- Recreation Resource Management. Fall-2021
- ENVS 4500: Wildland Recreation Behavior- Recreation Resource Management. Fall-2020

Teaching Assistant

- ENVS 3300: Fundamentals of Recreation Resource Management. Fall-2018

Guest Lecturer

- Presented a lecture to a graduate-level Active Transportation on recreation ecology in protected area management.(2023).
- Presented a field-based lecture on Recreation Ecology Theory and Monitoring to an Undergraduate/Graduate Disturbance Ecology Class. (2021/2022).
- Presented a lecture on the topics of Technology, Risk, and Social Media in the context of Recreation to a 4th year class of undergraduates. (2019).
- Presented a lecture on Technology, Risk, and Social media with examples from my own original research illustrating changes in recreation behavior and challenges for management. (2018).

Research Experience

Rocky Mountain National Park Day-Use Visitor Access Management, Rocky Mtn. N.P. - (2023-2024)

In this project I worked with collaborators from the National Park Service and Oregon State University to develop an indicator and monitoring program informing adaptive management strategies for visitor use. One aspect of this research lead to the development of new deep-learning visitor use estimation techniques that can reduce administrative burden.

Human and Ecological Dimensions of Recreation Management, Orange County, CA - (2017-2024)

Combined social science and ecology approaches to inform park managers of the human dimensions of the recreation experiences visitors seek and ecological conditions of park resources. This multi-year study has provided a unique opportunity to apply techniques typically used in National Parks in an urban proximate setting and allow opportunities for development of new approaches and methodologies.

Visitor Use & Transportation- Rocky Mtn. N.P.- (2020-Present)

Project focused on understanding the downstream ecological consequences of a management intervention to divert park visitors away from a high-use day area in the park. Using GPS tracking we were able to understand visitor behaviors to inform park management of the direction and magnitude of the diversion's effect on visitor flows and considerations for potential future infrastructure and traffic planning.

USFS National Visitor Use Monitoring (NVUM) - (2019)

Administered surveys to visitors to collect information on satisfaction of visitor experience, economic impact of the Forest on surrounding areas, and demographic information.

String & Leigh Lake Visitor Use Study - Grant Teton N.P. - (2018)

Assisted researchers from Penn State University and Oregon State University in survey and GPS data collection to better understand social and ecological impacts of a high-use day area within the park.

Professional Service

Journal Peer Reviewer-Journal of Park and Recreation Administration. 2021-Present

Provided peer review for manuscripts related to mobile device data for recreation use estimation.

Journal Peer Reviewer- Biodiversity and Conservation. 2021-Present

Provided peer review for manuscripts related to recreation ecology for protected area management.

Journal Peer Reviewer-Landscape and Urban Planning. 2021-Present

Provided peer review for manuscripts related to Park and Protected Area Planning and Management.

Review Workshop Facilitator IPBES. 2021

Assisted in organizing and collecting comments from a North American panel of Reviewers for the International Panel on Biodiversity and Ecosystem Services (IPBES) Values Assessment Report.

Sustainable Trail Design & Monitoring Webinar. Great Basin Institute. 2020

Delivered Webinar to Great Basin Institute/Nevada Conservation Corps AmeriCorps crew leaders on Sustainable Trail Design, Recreation Ecology, and GIS analysis and trail design tools.

Emergency Medical Fund Liaison & Treasurer. Graduate Student Council. 2019-2021

Oversee budget for USU College of Natural Resources Graduate Student Emergency Medical Fund Scholarship which provides financial assistance to graduate students.

Volunteer-Nordic United. 2017-Present

Volunteer trail groomer for Nordic trails in Logan, UT and assisted with preparation and organization of a backcountry ski-mountaineering race. Nordic United advocates for human-powered winter recreation on the Cache National Forest.