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Modeling the Ecological Consequences of Visitor Behavior in Off-Trail Areas of Dispersed Recreation Use

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MODELING THE ECOLOGICAL CONSEQUENCES OF VISITOR BEHAVIOR IN OFF-TRAIL AREAS OF DISPERSED RECREATION USE

by

Ashley L. D'Antonio

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Human Dimensions of Ecosystem Science and Management

Approved:

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ABSTRACT

Modeling the Ecological Consequences of Visitor Behavior in Off-trail Areas of Dispersed Recreation Use

by

Ashley D'Antonio, Doctor of Philosophy

Utah State University, 2015

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Predicting the locations of ecological impacts in a park or protected area, which often results from recreation use, allows managers to be more proactive in their visitor use management. However, the relationships between visitor behavior, visitor use level, the current ecological community, and any resulting ecological consequences are not well understood. Managers are particularly concerned about visitor use in scenarios where visitors disperse off of hardened surfaces. In these off-trail areas there is greater potential for ecological change. This dissertation clarifies the roles of visitor behavior and visitor use levels as drivers of ecological change by developing a social-ecological model of off-trail use.

GPS-based tracking and vegetation survey data from a variety of national park and national forest recreation destinations were used to build these social-ecological models. Results show that visitor behavior is a more important driver of ecological change at certain types of recreation destinations than visitor use levels. When patterns of visitor behavior are combined with measures of the vegetation community at these destinations, the importance of behavior is further emphasized. At some types of recreation destinations, even in very susceptible vegetation communities and during periods of very high levels of use, visitors are behaving in ways that minimize the potential for ecological change.

In order to make the results from these static social-ecological models more predicative and representative of the total visitor use occurring at a recreation destination, a simulation modeling procedure is needed. Agent-based modeling (ABM) is a modeling approach well-suited for representing dynamic social-ecological systems. The GPS-based tracking data that was collected to measure visitor behavior provides ideal ABM inputs. The framework presented here represents a proof-of-concept for ABMs of off-trail use and explores the potential for ABM in examining other recreation use issues. Taken together, these findings inform the sustainable management of parks and protected areas by emphasizing that maintaining desired ecological conditions may require focusing management efforts more on visitor behavior and less on visitor use numbers.

(221 pages)

PUBLIC ABSTRACT

Modeling the Ecological Consequences of Visitor Behavior in Off-trail Areas of Dispersed Recreation Use

Ashley D’Antonio

Parks and protected areas are often created to protect important social, ecological, or cultural resources from impairment. In the United States, a large majority of these parks and protected areas are also public land where recreational activities such as hiking or scenic driving are allowed. Managers of many parks and protected areas must therefore try to protect resources while also allowing for recreation use that may put these resources at risk for damage. The field of recreation ecology is interested in understanding how recreation use in parks and protected areas can sometimes cause ecological impacts to vegetation, soil, wildlife, water, air, and soundscapes. This information is then used to help managers prevent undesirable ecological change. When visitors to parks and protected areas leave designated sites such as trails or roads, there is a greater chance that ecological impacts will occur.

The studies presented here are designed to help managers better understand how visitor behavior off of designated trails may result in damage to plant communities. These studies examine data on both the social aspects of recreation use (such as visitor behavior and the number of visitors recreating) and the ecological aspects (specifically the plant communities found at popular recreation destinations). By looking at social and ecological data together, these studies can predict locations in parks or protected areas where ecological impact may occur as a result of recreation use. Managers can use these predictions to better allocate resources and time to managing recreation use at locations that are most at risk of impairment.

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CHAPTER 1

INTRODUCTION

Visitor use is increasing in parks and protected areas in the United States and worldwide (Balmford et al., 2009; Cordell, 2008; Hammitt et al., 2015). Managers are charged with protecting resources while simultaneously providing quality visitors experiences. Understanding visitor behavior in a park or protected area can help managers effectively provide recreation experiences while protecting natural resources from degradation. Spatial components of visitor behavior – such as movement patterns and distribution across a landscape - have the potential to influence biophysical and social resources. The level of impact to ecological resources is dependent on biotic factors and visitor behavior (Hammitt et al., 2015). The behavior of visitors can also diminish the recreation experience for visitors around them (Manning, 2011; Manning et al., 2000). This dissertation, written in multiple-paper format, represents a three-step approach for building a predictive, social-ecological model of visitor use in recreation settings designed to better understand the biophysical consequences of visitor behavior in off-trail areas of dispersed use.

1. Ecological impacts of recreation use

Recreational activities in wildland areas inevitably have some consequences to ecological conditions. Management decisions as to the level of acceptable and appropriate recreation disturbance to natural systems must be well informed by both ecological and social science. Considerable research conducted over the last 50 years has demonstrated the relationships between recreation use and resource change. Recently, this information has been reviewed and summarized (Cole, 2004; Hammitt et al., 2015; Leung and Marion, 2000; Monz et al., 2010a) and the relatively new discipline of Recreation Ecology has evolved. Several fundamental principles can be generalized from this body of literature.

(1) Recreational activities can directly affect both biotic and abiotic components of an ecosystem including soil, vegetation, wildlife, water, air, and soundscapes.

Trampling is the main mechanism for impacts to vegetation and soil. Disturbance to soil in recreation settings includes impacts such as the loss of organic matter, soil compaction, erosion, and change in the microbial community (Cole, 2004; Hammitt et al., 2015; Zabinski and Gannon, 1997). Loss of vegetation cover and reduced reproductive capacity are examples of vegetation impacts that can occur as a result of recreation use (Cole, 2004). Changes in vegetation community can also occur as well as mechanical impacts such as damaged shrubs, limb breakage, and tree carving (Hammitt et al., 2015).

Recreation use can cause disturbances to wildlife species both directly (harvest, feeding, harassment) and indirectly (habitat modification). The resulting impacts to wildlife can include behavioral changes, changes in reproductive output, reductions in survival, and changes in species composition and distribution (Becker et al., 2012; Hammitt et al., 2015; Smith-Castro and Rodewald, 2010). Both land and water-based recreational activities have the potential to impact aquatic systems. Recreation use can cause decreases in water quality through increased stream bank/shore line erosion (Kidd et al., 2014), input of nutrients pollutants and/or pathogens (Phillip et al., 2009), and changes in water temperature, turbidity and/or flow (Hammitt et al., 2015).

Air quality can be impacted, mostly locally, through the input of pollutants from motorized recreation use such as snowmobiles and off-highway vehicles (Shively et al., 2008). Finally, the impact of visitor-caused noise in parks and protected areas is expanding as an area of research (Hammitt et al., 2015). Noise caused by recreation use has the potential to negatively impact not only the visitor experience, but wildlife species as well (Stack et al., 2011). Visitor-caused noise disrupts the natural soundscape of a park and protected area, acts as a potentially negative stimulus to wildlife, and can disturb wildlife's ability to hear auditory cues important for their survival and fitness (Stack et al., 2011).

The majority of recreation ecology studies have focused on the impacts that recreation use has on vegetation and soil. Trampling is arguably the most commonly researched topic in the field recreation ecology (Monz et al., 2013). A meta-analysis of recreation ecology literature up through 2006 found 145 total published trampling studies (Pescott and Stewart, 2014). Standard experimental trampling methodologies were developed in 1993 by Cole and Bayfield and these methods have been repeated in a number of studies in a variety of ecosystems around the world (e.g. Cole, 1993, 1995a, 1995b; Gallet et al., 2004; Hill and Pickering, 2009; Liddle, 1997; Monz 2002; Monz et al., 2000; Roovers et al., 2004; Yaşar Korkanç, 2014). New technologies such as remote sensing and digital photos analysis, show promise as new methods of examining the influence of trampling on vegetation at different scales (Kim and Daigle, 2012; Kim et al., 2014; Monz et al., 2010b).

(2) Given the interrelationships between ecosystem components, indirect and cascading effects to other ecosystem attributes can occur from direct recreation disturbance.

For example, trampling is a direct recreation impact that can affect numerous aspects of the ecosystem at once or in sequence (Hammitt et al., 2015). Trampling, most directly, leads to soil compaction and a loss of vegetation cover. Once soil has become severely compacted, plant roots can no longer penetrate the soil thus preventing vegetation regrowth. Changes in plant community as a result of changes in vegetation cover and soil compaction can occur which can lead to changes in wildlife habitat use. Vegetation loss can also lead to increased erosion especially on stream banks where plant root structures can help to anchor soil. A soil erosion model built by Kidd et al. (2014) found that increased erosion at recreational stream crossings led to increased sediment delivery in downstream locations. The increased sediment load was associated with changes in macroinvertbrate communities; indicating reduced water quality downstream from recreational stream crossings (Kidd et al., 2014).

(3) The relationship between resource change and recreation use is generally curvilinear with the majority of resource change occurring with initial use.

The relationship between amount of use and the resulting ecological impact is arguably the most studied relationship in recreation ecology (Monz et al., 2013). Findings, mostly from experimental trampling studies, have found that initial use on undisturbed sites results in the most impact (Hammitt et al., 2015; Monz et al., 2013). At high levels of use, the amount of resulting impact begins to plateau. Many visitor management strategies are based on this curvilinear relationship. However, recent discussions in the literature (Monz et al., 2013) suggest that generalized relationship may not hold for all types of resource change. Different relationships, such as linear or step-wise functions, may more accurately reflect the response of soil, wildlife, and water quality to recreation disturbance.

(4) Resistance and resilience to visitor use disturbance is ecosystem specific.

Resistance is the ability of an ecosystem to resist change as a result of recreation disturbance (Cole, 1995b; Hammitt et al., 2015). Resilience is the ability of an ecosystem to recover following the removal of the recreation disturbance (Cole, 1995b; Hammitt et al., 2015). Tolerance, another characteristic of species response to trampling, is a combination of resistance and resilience. Resistance and resilience measures are often quantified based on the response of vegetation observed in experimental trampling studies (Cole and Bayfield, 1993). One standard measure of resistance is the resistance index (RI) (Cole, 1995b). The RI of an ecosystem, community, or species is the number of trampling passes required to reduce vegetation cover by 50% (Hill and Pickering, 2009). Resistance and resilience of a plant community is influenced by individual species characteristics, species composition, total vegetation cover prior to disturbance, and vegetation structure (Hammitt et al., 2015).

Generalization about species resistance are often made across morphological groups and the dominate plant community (e.g. forest understory versus riparian zone). For example, gramminoids are considered to be more resistant to recreation disturbance than woody plants, which are more resistant than forbs or shrubs (Hammitt et al., 2015; Liddle, 1997). Subtropical plant communities are considered to be more resistant than alpine or artic communities (Hill and Pickering, 2009). However, studies are beginning to find that these generalizations of level of resistance across plant morphological groups, or dominant plant community, can be influence by the relative mix of low and high resistant species found in the community (Hill and Pickering, 2009). Species-level analyses of RI may be a more precise way of estimating overall plant community susceptibility to recreation disturbance.

(5) The amount, density, type, and distribution of use and visitor behavior can all influence the level of resource change that occurs.

The amount, density, type and distribution of visitor use can all be influenced by management actions (Leung and Marion, 2000). However, managers must be able to measure these characteristics of visitor use in order to effectively manager visitors in a way that protects natural resources. Methodologies have been developed and established in the literature to accurately count visitors and determine type of use in a given recreation use area (Hollenhorst et al., 1992; Watson et al., 2000). With recent advances in Global Positioning System (GPS) and Geographic Information System (GIS) technology, the field of recreation ecology has begun to better measure visitor density, distribution, and behavior (D'Antonio et al., 2010; Hallo et al. 2005).

2. Modeling visitor behavior in recreation settings

Visitor behavior has traditionally been monitored using visitor counters, trip diaries, visitor surveys, and observational studies (Skov-Petersen and Gimblett, 2008; Walden-Schreiner and Leung, 2013). Recently, GPS-based tracking techniques have proved to be a powerful alternative to these descriptive measurement techniques (Beeco and Brown 2013; D'Antonio et al., 2010; Hallo et al., 2012). Although traditional visitor monitoring techniques provide useful information, the outputs are inherently static. While providing managers with valuable information, traditional data collection techniques do not provide managers with any predictive capacity (Lawson et al., 2003). Traditional survey techniques, and even the newer GPS-based tracking methodologies, require managers to take a reactive approach to addressing management issues which might lead to undesirable changes to resource conditions.

However, beginning in the 1970s, recreation research began to utilize simulation modeling programs to understand visitor movement and distribution through space and time. These simulation models use the static information that is collected through traditional techniques in a more dynamic and predictive way (Lawson et al., 2003; Skov-Petersen and Gimblett, 2008). Simulation modeling provides a stochastic view of recreation that allows managers to "experiment" with different management techniques and visitor use scenarios (Lawson et al., 2003). From a general sense, a simulation model attempts to imitate a complex real-world process or system (Wang and Manning, 1999). Simulation modeling has been used successfully to examine visitor behavior in both terrestrial and aquatic-based recreational systems (i.e. Cole, 2005, Gimblett et al., 2002, 2005a, 2005b; Lawson et al., 2006). Modeling efforts have been used to examine social science questions (i.e. Manning et al., 2002; Valliere et al., 2005; Wang and Manning, 1999) and the outcomes of different management actions (i.e. Itami, 2005; Lawson et al., 2003, 2009).

Since the 1990s, two main simulation modeling approaches have been pursued in the area of recreation management (van Wagtendonk and Cole, 2005; Wang and Manning, 1999). One technique uses a probabilistic modeling approach (Lawson et al., 2003) and the second approach focuses on using a rule-based method (Gimblett et al., 2001). These rule-based models are often referred to as agent-based models (ABM). ABM are comprised of user-created agent rules that allow the behavior of the “agents” in the model to be triggered by changes in the agent’s social or physical environment (Itami, 2005). In ABMs, instead of the “visitor” in the model being assigned a specific route of travel based on a probability, visitors are autonomous agents that have decision making capacities (Gimblett et al., 2001; Itami et al., 2003).

3. Agent-based models of recreation use

Because ABMs afford the agent a form of logic based on the agent’s environment, ABMs build representations of recreation use that are more realistic than probabilistic models (Skov-Petersen and Gimblett, 2008). The rules and actions that drive the agent’s behavior in the ABM are built using a series of assumptions derived from observed visitor behaviors (often using traditional monitoring techniques such as trip diaries or visitor counts). ABMs are excellent tools for modeling human behavior as a variety of agent decisions and actions can be modeling in a single ABM. Additionally, ABMs allow for the behavior of an individual agent in the model to influence the decisions and actions of other agents in the model (O’Sullivan et al., 2012).

ABM techniques have mostly been used in urban settings to examine phenomena such as pedestrian way-finding in cities, crowd dynamics, and evacuation scenarios (Johansson and Kretz, 2012; Torrens et al., 2012). ABMs have not been extensively used to examine pedestrian movement in parks and protected areas. As recreation planning and management becomes more complex, both from a social and a biological perspective, it is predicted that there will be an increased interest in the use of ABM in recreation research (Skov-Petersen, 2008). However, a key constraint to building more sophisticated pedestrian ABMs in recreation settings has been the need for individual based, high-resolution, geo-temporal data. (Taczanowska et al., 2008a). Fortunately, partially due to advances in technology, GPS-based tracking data can provide the details needed to create ABMs of recreation use both on and off-trail (D’Antonio et al., 2010).

4. Social-ecological models of visitor use

While the vast majority of simulation modeling and ABM research has been in the social science realm, there is increasing interest in conducting recreation research that combines social and ecological dimensions (Beeco et al., 2014; D'Antonio et al., 2013; Taczanowska et al., 2008b). Gimblett and colleagues (2014) argue that conventional models of recreation use are "not good enough" and that future models of recreation networks could be greatly improved by focusing on the interactions between both the biological and social systems involved in recreation. Within the field of recreation ecology, very little research has related spatially referenced social science data to biophysical resource conditions (Beeco et al., 2014; Monz et al., 2013). GPS-tracking methodologies combined with ABM and GIS tools can be used to develop social-ecological models of recreation use that inform management decisions (Beeco et al., 2013). Along with social-biological integrated approaches, increased predictive capabilities are essential as managers evaluate the possible outcomes of varying visitor use, density and frequency to visitor experience and resource conditions in wildland settings.

5. Dissertation outline

This dissertation contains three chapters prepared for publication that will address some of the above shortcomings of current social-ecological and simulation modeling efforts in recreation settings. In Chapter 2, more generalizable rules of human behavior are proposed by examining how visitor behavior, specifically behavior of day-use hikers, changes under different use level scenarios. By using GPS-based tracking data of visitor behavior from a variety of parks and protected areas and spatial analysis in GIS, Chapter 2 tests the assumptions of current models that visitor behavior does not change in response to environmental conditions. The results of the analysis of visitor behavior in Chapter 2 provides the static, descriptive information that will be used to develop rules as inputs for an ABM that is described in Chapter 4.

Chapter 3 develops a more precise methodology for combining static models of visitor use patterns and biophysical conditions. Heretofore, the few models that have been developed examining vegetation susceptibility have been based on plant morphological group. However, individual species response to human disturbance varies greatly within a given morphological group. In Chapter 3, for a number of off-trail locations in two national parks, a GIS layer of vegetation susceptibility to resource change is created that is based on species- or genus-level susceptibility gathered from the experimental trampling literature. The GIS model of vegetation susceptibility is then combined with the models of visitor behavior patterns observed under different use level scenarios that were developed in Chapter 2. The resulting social-ecological model highlights areas of potential resource change as a consequence of visitor use in off-trail areas.

Chapters 2 and 3 generate more accurate models of the social and ecological components of recreation use. Both of these steps are static in nature and, although they provide managers with useful information, the resulting model cannot generate predictions under changing visitor use or management scenarios. Therefore, the final component of the project, in Chapter 4, will be to create a framework for developing a more dynamic and predictive model. The rules for an ABM of visitor use in off-trail areas were developed based on data derived from the GPS-tracking points of visitor use from Chapter 2. The potential for using ABMs to examine a variety of recreation management questions is discussed in Chapter 4 as well.

A conceptual model (Fig. 1.1) illustrates the approach of the overall project and the relationship between individual objectives for each dissertation chapter as outlined below.

Chapter 2 Objective: Explore the influence of visitor use level on visitor behavior in off-trail areas of dispersed recreation use.

Chapter 3 Objective: Develop a model of species-specific vegetation susceptibly and potential for future change in areas of dispersed visitor use

Chapter 4 Objective: Build a framework for developing predictive simulation models from GPS-based tracking data to understanding visitor behavior in off-trail areas of dispersed visitor use.

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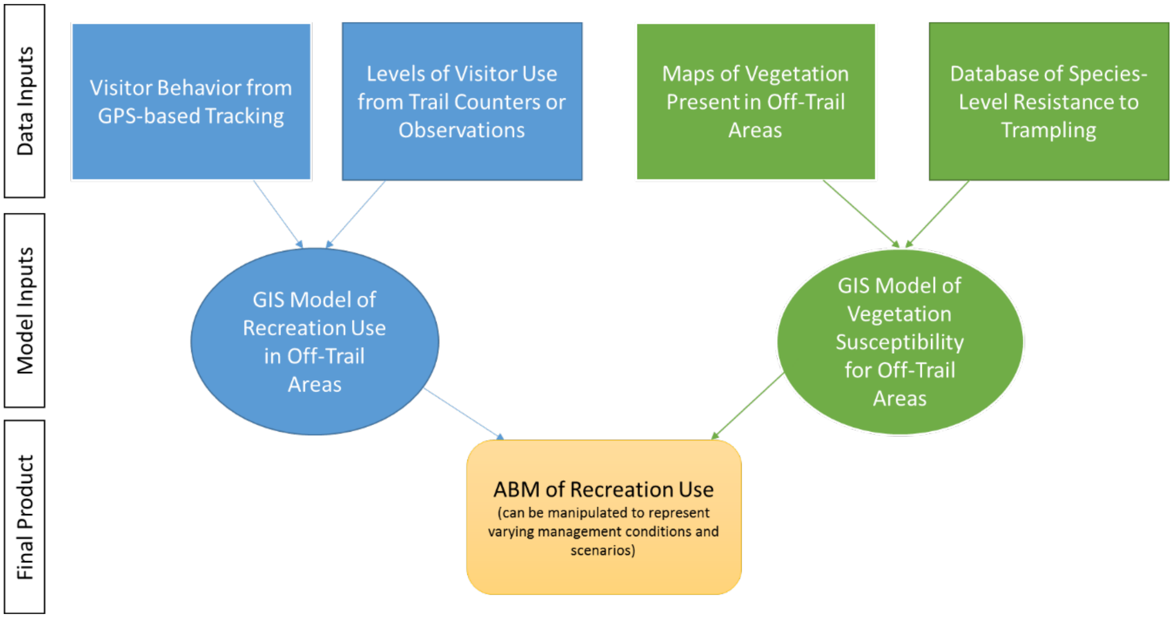

Fig. 1.1. Conceptual model of the dissertation research. Chapter 2's Objective is shown in blue, Chapter 3's Objective is shown in green, and Chapter 4's Objective is shown in yellow.

CHAPTER 2

THE INFLUENCE OF VISITOR USE LEVELS ON VISITOR BEHAVIOR IN OFF-TRAIL AREAS OF DISPERSED RECREATION USE

Abstract

A variety of social and ecological factors influence the level and extent of ecological change that occurs in a park or protected area. Understanding these factors and how they are interrelated can help managers prevent undesirable ecological impacts especially in off-trail areas. This study examines the relationship between levels of visitor use and patterns of visitor behavior at a variety of recreation destinations. Current recreation ecology literature and simulation modeling efforts assume that visitor behavior either does not change with use level or that visitors disperse at high levels of visitor use. Using visitor counts and GPS-tracks of visitor behavior in locations where visitors could disperse off-trail, we found that visitor behavior does vary with visitor use level in some recreation settings. The patterns of visitor behavior observed in this study are contrary to current thinking. In most cases, when visitor behavior varies with use level, visitors are dispersing more in off-trail areas at low levels of visitor use. Overall, these findings suggest that the amount of visitor use at a recreation destination is a less important driver of ecological change than visitor behavior.

1. Introduction

Recreation use in parks and protected areas inevitably leads to some level of ecological change (Hammitt et al., 2015). Managers of parks and protected areas are charged with mitigating these ecological changes while simultaneously providing visitors with opportunities for high quality recreation experiences. The level of resource change that occurs in a park or protected area is influenced by a variety of social and ecological factors including: current environmental conditions, ecosystem type, visitor use levels, the timing of visitor use, the type of visitor use, and visitor behavior (Hammitt et al., 2015; Monz et al., 2013; Pickering, 2010). Managers can influence some of these factors through management actions such as limiting use, hardening the environment against impact, and encouraging low-impact visitor behavior (Cole, 2008). The field of recreation ecology is focused on understanding the factors that drive resource change in an effort to help develop effective management strategies that prevent undesirable ecological impacts (Monz et al., 2013).

Recreation ecologists and park and protected area managers have developed a variety of measurement and monitoring techniques that are used to evaluate the factors that influence the level of resource change. The current environmental conditions of a recreation area can be measured using monitoring and assessment techniques such as ground surveys of the level and extent of visitor use impacts, trampling studies, and trail assessments (D'Antonio et al., 2013; Marion and Leung, 2011; Monz et al., 2010; Wimpey and Marion, 2010). Indirect measurement techniques, such as automatic trail counters and traffic counters, are frequently utilized to quantify visitor use levels and the timing of visitor use (Cessford and Muhar, 2003; Watson et al., 2000). More direct measurement techniques are needed to assess the type of visitor use and visitor behaviors.

Survey methodology is often applied in parks and protected areas to gather specific, descriptive visitor information such as activity type (Manning, 2010). Survey techniques can also be employed to understand visitor behavior through the use of trip logs or diaries or by having the visitor recall their activities (Wolf et al., 2012). However, these survey methods are often inaccurate, subject to bias, and time intensive for the visitor. Unobtrusive observational techniques (Walden-Schreiner and Leung, 2013), where researchers watch and record visitor behavior, may be more accurate than surveys but are often prohibitively expensive and time intensive (Arnberger et al., 2005; Park et al., 2008). Advances in Geographic Information Systems (GIS) and Global Positioning Systems (GPS) technology allows for visitors' spatial behavior to be more accurately and robustly measured (D’Antonio et al., 2010; Hallo et al., 2005).

In many recreation settings, GPS tracking techniques are being employed to measure visitor behavior (Beeco and Brown, 2013; Beeco et al., 2014; D’Antonio et al., 2013; Hallo et al., 2012; Taczanowska et al., 2014). In GPS tracking studies, a representative sample of visitors voluntarily carry GPS units with them during their recreation visit. With little input of time or effort on the part of the visitor, researchers are able to gather a large and detailed record of visitor movement patterns at a particular recreation location (D’Antonio et al., 2010; Wolf et al., 2012). Analysis in GIS can then be used to describe patterns of visitor behavior. Hallo et al. (2012) demonstrated, through the use of GPS-tracks from visitors to the Blueridge Parkway, that spatial statistics in ArcGIS can be used to examine the dispersion and patterns of visitor use. In Acadia National Park, Kidd et al. (2015) explored whether visitor dispersion and off-trail behavior varied in response to interpretative messages by GPS tracking hikers and experimentally exposing hikers to different types of messaging.

The measurement techniques described thus far are useful in describing the current social and ecological components of recreation use but are inherently static. Meaning the descriptive data collected represents a “snapshot in time” and may or may not be representative of future social, ecological, or management conditions. The need for more predictive capacity in recreation management led to the development of simulation modeling techniques (Gimblett and Skov-Petersen, 2008; Lawson et al., 2003). Simulation models use traditional descriptive data, collected through indirect and direct measurement techniques, as model inputs. The output from simulation models provide a means of understanding visitor use data in a way that is not possible through purely survey-based or observational approaches (van Wagtendonk and Cole, 2005). Simulation modeling efforts provide managers with a proactive management tool which allows them to “experiment” with different management techniques and visitor use scenarios (Lawson et al., 2003). For example, simulation modeling was used recently in Yosemite National Park to examine the effects of alternative management strategies on aspects of visitors use at the cables route on Half Dome (Lawson et al., 2011). The simulation modeling at Half Dome was conducted as part of the planning process, so that scenarios could be examined prior to implementation.

Despite their predictive power, current simulation models do have their limitations. For example, models often assume that there is no change in the temporal or spatial distribution of visitor use (Wang and Manning, 1999). However in reality visitor behavior, such as travel routes or dispersion, may be influenced by the social, ecological, and/or managerial conditions at the recreation site. Most simulation models of recreation use assume that visitor travel routes do not change under different use levels (Wang and Manning, 1999); meaning that visitors do not change their behavior in response to the visitors (or lack of visitors) around them. Yet, conventional thought in recreation ecology and park and protected area management assumes that as visitor use increases visitors spread out; potentially increasing the extent of ecological change (Cole, 1994). But the interrelationship between visitor behavior and other social factors of ecological change has never been empirically examined. By operating under the assumption that visitor behavior is constant, even during varying social settings, current simulation models and lines of thought in the field of recreation ecology may inaccurately predict future levels of ecological change.

Another limitation of current simulation modeling, is that these models to focus solely on visitor use and behavior that occurs on hardened surfaces such as trail networks or visitor sites. The majority of models have been designed to predict how visitors will behave within a trail network (Lawson et al., 2003, 2008; Gimblett and Skov-Petersen, 2008). Visitor use on hardened surfaces is important from a social and managerial standpoint but these hardened areas are designed to be buffered against undesirable ecological change. However, many of the recreation impacts that are of concern to managers are occurring off of hardened surfaces and in areas where visitors disperse off-trail. The relationship between visitor use and ecological change is generally considered curvilinear; meaning initial use causes a disproportionate amount of ecological change (Hammitt et al., 2015; Monz et al., 2013). Therefore, visitor behavior that results in visitors leaving hardening surfaces and entering disperse use areas, where visitor use rarely or never occurs, can have significant ecological consequences (Hammitt et al., 2015).

Visitor spatial behavior is an important driver of ecological change in parks and protected areas and a more complete understanding how visitors behave, especially in off-trail locations, can help managers better protect ecological conditions. Current models have not examined visitor behavior in off-trail areas in a quantitative manner. Previous studies have been descriptive in nature and many of the theoretical frameworks driving management decisions related to visitor use are based on assumptions of visitor behavior that have not been tested. Additionally, the interrelatedness between the social factors that influence ecological change have never been empirically examined. As such, this study addresses the following question: does visitor behavior, specifically behavior of day-use hikers, in off-trail areas of disperse use vary with visitor use level and/or setting characteristics? By combining indirect measures of visitor use (visitor counts) with direct measures of visitor behavior (GPS-tracks of hikers) across a variety of recreational and managerial settings we hope to better understand how visitor dispersion in off-trail areas varies by use level. The result of this study will test current assumptions about visitor behavior, inform future simulation modeling efforts, and provide a better understanding of the interrelatedness of the factors that influence resource change.

2. Methods

2.1. Study sites

2.1.1. Study sites as a spectrum

Given that the social, ecological, and managerial aspects of a recreation area can influence visitor behavior, a variety of recreation locations were chosen to include in this study (Table 2.1). This series of study sites represents popular hiking destinations across a spectrum of recreational opportunities, visitor use levels, and levels of visitor management. The specific recreation destinations where chosen for inclusion in this study because at all locations visitors have the potential to disperse into off-trail areas once they reach the recreation destination (Table 2.2). Each study site and recreation destination will be described in detail here in order to outline the unique ecological, social, and/or managerial setting of each location.

2.1.2. Yosemite National Park, CA: El Capitan Meadow and Tuolumne Meadows

Yosemite National Park (YOSE) is located in the Sierra Nevada region of California and is only a few hours from the San Francisco Bay, Sacramento, and San Jose metropolitan areas. YOSE's proximity to city centers makes it one of the most visited national parks in the United States. In 2014, YOSE received approximately 3.8 million visitors (National Park Service, 2015a). The majority of these visitors remain within the 8 miles that make up Yosemite Valley. Yosemite Valley is home to the Merced River, a federally designated Wild and Scenic River, as well as a variety of sensitive meadow habitat. The acreage of meadow habitat in YOSE has been cut in half since the late 1800s due to both ecological and anthropogenic forces (Walden-Schreiner and Leung, 2013). The remaining meadows provide ecological services such as water filters for San Francisco's water supply, recreation value, and important habitat for wildlife and plant species. As such, YOSE has begun to actively monitor the remaining meadows in Yosemite

Valley. However, the level of management varies by individual meadow (Walden-Schreiner and Leung, 2013).

One of the least managed meadows in YOSE is El Capitan Meadow. El Capitan Meadow is located at the west end of Yosemite Valley and provides views of El Capitan for photography or scoping climbing routes. Visitors can also access a section of the Merced River from El Capitan Meadow. El Capitan Meadow is often one of the last stops visitors make as they leave Yosemite Valley. The meadow does not contain any formal trails or interpretative signs and does not have any formal parking capacity. Visitors use road shoulders for parking or ride the YOSE shuttle bus to access the El Capitan Meadow area. In 2011 when GPS tracking occurred in the meadow, El Capitan Meadow received approximately 300 visitors per day (Table 2.1) (Monz et al., 2012).

Another popular recreation corridor in YOSE is Tioga Pass. Tioga Pass (also State Route 120) provides access to YOSE from the East. Tioga Pass bisects Tuolumne Meadows; one of the highest elevation meadows in the Sierra Nevadas (NPS, 2015b). Visitors can access the Tuolumne Meadows region at various points along Tioga Pass. Two of the most popular access points for Tuolumne Meadows are from the Tuolumne Meadows Store and the Tuolumne Meadows Visitor Center. These facilities are located about 20 miles from the Tioga Pass Entrance Station. Both facilities provide short-term parking for visitors wanting to explore the meadows. The Tuolumne Meadows Store also includes a grill and resupply/stopping location for John Muir Trail and Pacific Crest Trail through-hikers. During 2011, Tuolumne Meadows received approximately 120 visitors entering the meadow areas per day (Table 2.1). Tuolumne Meadows is used as a “picnic” or resting spot for those patronizing the Tuolumne Meadows Store. A few designated trails can be accessed from the Tuolumne Meadows Visitors Center and Tuolumne Meadows Store. However, there is minimal interpretative or informative material at these trailheads.

2.1.3. Rocky Mountain National Park, CO: Alberta Falls and Emerald Lake, Bear Lake Road Corridor

Rocky Mountain National Park (ROMO) is located in the Front Range of Colorado. Like YOSE, ROMO is also located relatively close to metropolitan areas (Denver, Boulder, and Fort Collins). In 2014, ROMO received approximately 3.4 million visitors (NPS, 2015a). ROMO utilizes a shuttle bus system to provide alternative transportation access to one of the more popular hiking destinations in the park; the Bear Lake Road Corridor. The Bear Lake Road Corridor provides access to a variety of subalpine lakes and waterfalls. The trail system in the Bear Lake Road Corridor contains trails of varying difficulty and length which makes it an especially attractive destination to many visitors. Previous studies (Newman et al., 2010) found that the shuttle bus system to the Bear Lake Road Corridor was being utilized in a manner that was delivering large numbers of visitors to high capacity trails leading to low capacity destinations. This study also found that at many destinations in the Bear Lake Road Corridor, visitor standards for crowing and resource conditions were exceeded (D'Antonio et al., 2013; Newman et al., 2010).

Two of these relatively low capacity sites in the Bear Lake Road Corridor are Alberta Falls and Emerald Lake. Alberta Falls is a 30-foot waterfall on Glacier Creek located about 1 mile from the Granite Gorge Trailhead (serviced by the shuttle bus). In 2008 when GPS tracking occurred in the Bear Lake Road Corridor, Alberta Falls received approximately 1,300 visitors per day (Table 2.1) (Newman et al., 2010). The falls is located directly adjacent to the designated trail and is a popular destination for visitors looking for a short hike in the Bear Lake Road Corridor. Visitors often leave the designated trail at Alberta Falls to have better views of the falls, to picnic, or rest or explore near the falls. Although some of the area around the falls is bare rock, visitors also disperse into the forest understory and riparian areas near Alberta Falls. There is a moderate amount of management at Alberta Falls including rocks lining the edge of the designated trail as subtle reminders to stay on-trail. There is also a sign asking visitors to stay on the trail at one of the most popular view sites at Alberta Falls. Interpretative rangers occasionally hike to Alberta Falls but are not necessarily directed to provide minimum-impact information to visitors.

Compared to the hike to Alberta Falls, Emerald Lake is one of the more difficult day hikes in the Bear Lake Road Corridor. Emerald Lake is located 1.8 miles from the Bear Lake Trailhead (the terminus of the shuttle bus) and much of the trail is steep and rocky. The trail ends abruptly at the shore of Emerald Lake where visitors disperse onto the rocky shoreline to rest, take photos, and/or picnic. Emerald Lake is a high alpine lake located at approximately 10,000 ft. Although much of the lakeshore is rocky there is potential for visitors to disperse into sensitive, and often wet, alpine habitat. During 2008, approximately 1,000 visitors per day hiked to Emerald Lake (Table 2.1). There is very little management at Emerald Lake; although visitors are presented with a Leave-No-Trace focused interpretative sign at the Bear Lake Trailhead and pass a variety of "stay on the trail" signs as they hike to Emerald Lake.

2.1.4. Arapaho-Roosevelt National Forest, CO: Mt. Evans and Mt. Bierstadt, Mt. Evans Wilderness Area

Arapaho-Roosevelt National Forest (ARNF) is also located in the Front Range of Colorado. The Mt. Evans Wilderness Area and Guanella Pass are popular recreation areas in ARNF. These locations are easily accessed from population centers of the Colorado Front Range. Mt. Evans is one of 54 "Fourteeners" found in Colorado and is located very close to Denver. The highly managed Mount Evans Scenic Byway, the highest paved road in the North America, allows vehicular traffic to reach the peak of the mountain during the summer months when the road is opened. A fee station is positioned at the beginning of the 14-mile Mount Evans Scenic Byway and the road itself ends at the trailhead to Mt. Evans (14,265'). Approximately 120,000 visitors use the Mount Evans Scenic Byway each year (USDA Forest Service, 2014) and, in 2012, approximately 650 visitors per day hiked the short trail to the peak of Mt. Evans (Table 2.1) (Resource Systems Group, Inc., 2013a). The trailhead area includes a large parking lot with restroom facilities. From there the hike to the peak of Mt. Evans only take a few minutes. Mount Evans Scenic Byway also provides one access point into the Mt. Evans Wilderness Area.

The Guanella Pass Scenic Byway is also in the Mt. Evans Wilderness Area and originates in the town of Georgetown, Colorado. The Guanella Pass Scenic Byway takes visitors on a vehicular tour through the Rocky Mountains. The road is bordered on both sides by the Mt. Evans Wilderness Area and various hiking trails and other points of interest can be found along the bypass. One popular hiking destination is Mt. Bierstadt. Mt. Bierstadt (14,065') is another easily accessible "Fourteener". The summit of Mt. Bierstadt is only 3 miles from the trailhead parking lot at Guanella Pass. When GPS tracking occurred in ARNF in 2012, approximately 300 visitors hiked to Mt. Bierstadt per day (Table 2.1) (RSG, 2013b). The trail to the summit passes through wetland habitat where boardwalks have been installed to prevent vegetation damage. The trail then crosses above tree line into sensitive alpine tundra habitat. Visitor use on the Mt. Bierstadt trail and nearby Square Top Lakes Trailhead often greatly exceeds parking lot capacity. On busy weekends, as many as 100 cars can be observed parking on the shoulder of Guanella Pass because the Mt. Bierstadt and Square Top Lakes parking areas are full.

2.1.5. Grand Teton National Park, WY: Phelps Lake, Laurence S. Rockefeller Preserve, Moose-Wilson Road Corridor

Grand Teton National Park (GRTE) is located in northwestern Wyoming just south of Yellowstone National Park and north of Jackson, Wyoming. In 2014, Grand Teton National Park received approximately 2.8 million visitors (NPS, 2015a). That same year, approximately 5,400 visitors per day accessed the Moose-Wilson corridor (MWC) of GRTE (Monz et al., 2014). The MWC, in the southwest corner of GRTE, is an outstanding representation of the park's major natural ecological communities, all of which are located within a geographical area that is about seven miles in length, five miles in width, and about 10,300 acres in size. The corridor contains several primary visitor use areas, including Death Canyon and Granite Canyon trailhead parking areas, Laurance S. Rockefeller (LSR) Preserve. The Moose-Wilson Road is the primary access point to destinations within the corridor. With increasing vehicle traffic volumes, congestion along this narrow, rustic country road has become common. This observation has raised concerns about the protection of wildlife and other resources, visitor safety, visitor experience, and the effectiveness of park operations.

The most popular destination in the MWC is the LSR Preserve (Monz et al., 2014). Until 2001, the LSR Preserve was a private ranch owned by the Rockefeller family. In 2001 the ranch was donated to GRTE and in 2008 a LEED certified visitor center was built on the LSR Preserve (NPS, 2015c). The LSR Preserve is highly managed and includes a parking lot that is maintained at a capacity of approximately 50 vehicles. When the parking lot is full, visitors must queue and a "one-in, one-out" strategy is implemented by NPS staff and volunteers. Roadside parking on the LSR Preserve is prohibited, so visitors wishing to recreate on the LSR Preserve must park in the LSR Preserve parking lot or park outside of the LSR Preserve boundary and hike in using a more difficult access trail.

Phelps Lake is a key destination that can be accessed from the LSR Preserve and during the summer of 2013 approximately 300 visitors reach the shore of Phelps Lake per day (Table 2.1). There are multiple trails that can be used to access the shore of Phelps Lake and there are restroom facilities located at the end of these trails. The southern shore of Phelps Lake can be accessed by multiple relatively easy, short, and flat hikes. From the southern shore, these trails can then be used to access longer loop hikes as well as more difficult hikes into various side canyons of the Teton Range. As such, the Phelps Lake shoreline is visited by a variety of visitor types. The shore of Phelps Lake has been hardened to prevent visitor impacts to the southern lakeshore. However, any use off of these hardened surfaces has the potential to lead to ecological changes to sensitive lakeshore vegetation.

2.2. Dispersion analysis

A GPS tracking methodology was utilized at all study sites (Table 2.1) to measure visitor behavior in both on and off-trail locations (D'Antonio et al., 2010). A representative, random sample of visitors was collected at each study site and sampling occurred throughout the day and on both weekdays and weekend days. GPS-tracks were saved as point features for analysis in ArcGIS so that each visitor's hiking path is represented by a series of points. Standard visitor estimation techniques using infra-red counters (Pettebone et al., 2009) or observational techniques (in YOSE only) were used to determine levels of visitor use at all recreation destinations from each study site. Only those visitors who traveled to the specific recreation destinations were included in the final dataset of GPS tracks collected at each study site. At most study sites, full GPS-tracks were truncated to include only visitor behavior that occurred at the recreation destination where dispersed, off trail behavior was occurring.

A series of analysis steps were taken at each recreation destination to examine how visitor behavior in off-trail areas of dispersed use varies by use levels (Fig. 2.1). First, visitor use levels were examined and destination-specific periods of relatively "high use" and "low use" were determined. For ARNF, only daily visitor use counts were available. For ROMO, YOSE, and GRTE, both daily and hourly visitor counts were available but at both of these locations weekend and weekday use levels were equal. Therefore, at ROMO, YOSE, and GRTE, hourly counts were used to identify periods of high and low use. Once times of high visitor use and low visitor use were determined, then visitor GPS tracking points were separated into those points collected during periods of high use, or "High Load Points," and points collected during periods of low use or "Low Load Points."

This separation resulted in two datasets per recreation destination. These two datasets were then the inputs for subsequent analyses. Tools in ArcGIS were then used to examine the dispersion characteristics of both the High Load Point and Low Load Points at each recreation destination. In this case dispersion was defined as the pattern of visitor behavior as visitors spread out (or did not spread out) across the recreation destination area. For each dataset and using built-in tools in ArcGIS, the median center point was calculated and then a one standard deviation standard deviational ellipse was generated (Hallo et al., 2012). The median center point identifies where the visitor tracking points are most concentrated; visually identifying the geographic center of the point cloud that represents visitor behavior. The standard deviational ellipse is used to display the overall dispersion of the point cloud of visitor tracking data as well as any directional tendencies of the data. The area and perimeter of each standard deviational ellipse was calculated to compare size and shape of the ellipses. Both the median center point and the standard deviational ellipse provide visual indicators of any differences in dispersion between the High Load Points and the Low Load Points.

In order to quantitatively examine visitor dispersion in response to visitor use levels, Euclidean distance measures were calculated in ArcGIS. Euclidean distances describe how far visitors traveled from a point of interest. For each of the two datasets at each recreation destination, Euclidean distance measures were calculated from all data points in the dataset to the median center point of that dataset. Additionally, Euclidean distance measures were calculated to determine the distance visitors dispersed from hardened surfaces such as designated trails or sites. The average Euclidean distance from hardened surfaces indicates the potential for ecological consequences as a result of visitor dispersion into off-trail areas. At some of the study sites, the positional error associated with the GPS tracks was estimated (Table 2.3). In order to correct for positional error, an error buffer was generated around the hardened surface layer in GIS and Euclidean distances were calculated to the buffer edge.

The average Euclidean distances from the median center point and hardened sites were calculated. These averages were compared using two-sample t-tests (p-value ≤ 0.05) conducted in the open-source software and programming language R. After these statistical analysis, Euclidean distance measures were standardized for the purposes of comparison across sites. The result of the destination-level dispersion analyses described here were compared across study sites to see if the level of management action or other setting characteristics may be influencing how visitor behavior changes in response to visitor use levels. The average Euclidean distance to the median center point describes overall visitor dispersion in response to use levels.

3. Results

3.1. Response rate, sampling effort, and sample size

Response rates for the collection of GPS-based tracking methodology at the various study sites varied from a lowest value of 65% in Tuolumne Meadows to 97% at both sites in ARNF (Table 2.4). The total number of GPS tracks collected at each study varied from a low of 98 in El Capitan Meadow to over 2,000 at Mt. Evans (Table 2.4).

The total number of visitor tracks collected during periods of low use varied from 14 at Emerald Lake to 98 at Phelps Lake. The total number of visitor tracks collected during periods of high use varied from 23 at Emerald Lake to 113 at Phelps Lake. The final sample size for each dataset is a reflection of overall sampling effort at each study location and well as a reflection of the amount of visitor use that occurs at each recreation destination.

3.2. Differences in overall dispersion

There was not a statistically significant difference in overall visitor dispersion in response to visitor use level observed at the summit of Mt Evans (t (145) = -0.0007, p = 0.999), the summit of Mt. Bierstadt (t (183) = -0.6409, p = 0.522), in Tuolumne Meadows (t (18) = 0.4373, p = 0.667), or at Emerald Lake (t (17) = 0.0401, p = 0.968) (Fig. 2.2). At all of these recreation destinations, no difference was found between the average Euclidean distance from the median center point of the High Load Points and the Low Load Points.

For Mt. Evans, Mt. Bierstadt, and Tuolumne Meadows the size, shape, and location of the standard deviational ellipse was similar for both High Load Points and Low Load Points. The location of the median center point for the High Load Points and Low Load Points was also very similar for these three locations. In the case of Tuolumne Meadows, the two median center points were located in the exact same location (Fig. 2.3).

At Emerald Lake, although there was no difference found between the average Euclidean distance from the median center point for the High Load Points and the Low Load Points, the location, size and shape of the standard deviational ellipse differed (Fig. 2.2 and Fig. 2.4). During periods of low use, visitors tended to disperse more to the north of the designated trail. More “outlier” visitor behavior, where a few visitors traveled unusually far from the median, occurred during periods of low use (Fig. 2.2). During periods of high use, visitors tended to disperse more to the south of the designated trail.

At El Capitan Meadow (t (27) = -2.874, p = 0.008), Alberta Falls (t (79) = 2.8685, p = 0.005), and Phelps Lake (t (204) = -2.1907, p = 0.029), a statistically significant difference was found in average dispersion away from the median center point between the High Load Points and the Low Load Points (Fig. 2.2). At El Capitan Meadow and Phelps Lake visitors tended to disperse less during periods of high visitor use; contrary to conventional thinking about how visitors react to crowding. In other words, GPS-tracked visitors tended to clump more at these sites when there were other visitors present at the recreation destination. At El Capitan Meadow and Phelps Lake, visitors disperse more overall during periods of low visitor use. Meaning, when there were potentially fewer other visitors around, GPS-tracked visitors tended to wander farther overall. However, at Alberta Falls, the opposite trend was observed with visitors dispersing more during periods of high use as compared to periods of low use. Visitor dispersion at Alberta Falls is more in-line with current assumptions about how visitors behave in response to visitor use.

The median center point locations as well as the geometry of the standard deviational ellipses also indicate differences in dispersion at different use levels at El Captain Meadow, Alberta Falls, and Phelps Lake. At El Capitan, the High Load and Low Load median center points were in different locations within the meadow boundary and the size, shape, and orientation of the standard deviational ellipses differed (Fig. 2.5). The standard deviational ellipse for the Low Load Points was larger than the standard deviational ellipse of the High Load Points. At Phelps Lake, the standard deviational ellipses were of similar size and orientation but the median center points were in different locations along the lakeshore. The standard deviational ellipses were also of similar geometry and orientation at Alberta Falls, but like Phelps Lake, the median center points were in different locations (Fig. 2.6).

3.3. Differences in dispersion from hardened surfaces

As with the overall dispersion analysis, there was no statistically significant difference in visitor dispersion away from hardened surfaces in response to visitor use level observed at the summit of Mt. Bierstadt (t (119) = 0.2529, p = 0.800), in Tuolumne Meadows (t (46) = 1.8439, p = 0.071), in El Capitan Meadows (t (114) = -0.0417, p = 0.966), at Alberta Falls (t (65) = -0.0262, p = 0.979), or at Emerald Lake (t (21) = -0.2155, p = 0.831) (Fig. 2.7). Mt. Evans was not included in the analysis of dispersion from hardened surfaces as accurate trail layers were not available. The only site where the average Euclidean distance dispersed off of hardened surfaces varied with use levels was at Phelps Lake (t (201) = -2.1155, p = 0.036). During periods of low visitor use, GPS-tracked visitors dispersed farther from hardened surfaces than during periods of high visitor use.

The total distances that visitors dispersed from hardened surfaces and into off-trail areas varied by study site and was influenced by the size and location of the study site (Fig. 2.8). The greatest dispersion distances were observed in the two meadow recreation destinations, Tuolumne and El Capitan Meadow. Visitors also dispersed an average of approximately 35 meters away from the designated trail at Alberta Falls. At Mt. Bierstadt and Emerald Lake, visitors dispersed an average of approximately 8 to 9 meters away from designated trails. The lowest dispersion distance off of hardened surfaces was observed at Phelps Lake (Fig. 2.9). Phelps Lake was the only site which contained hardened visitor sites in addition to hardened trails, with visitors on average dispersing approximately 4–5 meters off of these hardened areas.

4. Discussion

4.1. Overall findings

Results from this study indicate that: 1) visitor behavior in off-trail areas does vary with visitor use level in some recreation settings, 2) visitor behavior varies in ways that are counterintuitive to what is currently assumed in the literature, and 3) visitor behavior in response to use level varies in ways that are ecologically important. Each of these points will be discussed in greater detail followed by the proposal of a psychological theory that may help explain the results, and finally the management implications of these findings will be discussed.

4.2. Visitor behavior: Use levels and recreation sites

Whether or not visitor behavior varies with use level is dependent on the recreation location (Fig. 2.10). Overall dispersion, as measured and analyzed in this study, serves as an indicator of how visitors respond to the social setting at the recreation destination (the presence of other visitors around them). Measures of dispersion away from hardened surfaces indicates how visitors respond to one component of the managerial setting of the recreation destination. Our results suggest that visitor use level does not influence how far visitors travel off-trail into areas of disperse use. However, once off-trail, visitor dispersion appears to be influenced by visitor use level in some recreation settings.

Overall visitor dispersion and dispersion away from hardened surfaces did not vary with use level at Tuolumne Meadows, Mt. Evans, Mt. Bierstadt, or at Emerald Lake. At Emerald Lake, although differences in dispersion were not statistically significant the standard deviational ellipses suggest the direction that visitors disperse may vary with use level. At El Capitan Meadow, Alberta Falls, and Phelps Lake overall visitor dispersion varied with use levels. Dispersion away from hardened surfaces only varied with use levels at Phelps Lake; the site with the highest level of management action related to hardened surfaces.

More generally, the recreation destinations where visitor behavior did not vary with use levels were one of the two meadow locations and the two mountain summit locations. The destinations where visitor behavior did vary with use levels could all be considered “viewsites” or destinations that had a single feature that was the attraction point for visitors. At El Capitan Meadow many visitors went to the meadow to view and photograph El Capitan. At Alberta Falls, visitors were drawn to the destination to view and photograph the falls. At Emerald Lake, visitors are drawn to the lake shore and the view of Hallett’s Peaks. At Phelps Lake, the southern shore provides one of the best views of the lake and associated canyons.

4.3. Visitor behavior and current thinking

The patterns of dispersion observed in this study are contradictory to the current assumptions of visitor behavior held in both simulation modeling efforts and the recreation ecology literature. Current simulation modeling efforts assume that visitor use is constant in space (Lawson et al., 2003). Results from this study indicate that this assumption is only valid for some recreation settings such as mountain summits and some meadow locations. At the lakeshore and viewsite examined in this study visitor behavior varied with use level. Simulation models that are modeling visitor behavior at lakeshores or viewsites may be building models that are inaccurate representations of visitor behavior at these recreation destinations. The level of importance of this inaccuracy will depend on the management questions being examined in the simulation model.

Unlike in simulation modeling, conventional thinking in recreation ecology and parks and protected area management assumes that visitor use is not constant. The assumption has been that as visitor use increases and recreation destinations become more crowded with visitors, visitor use will spread out (Cole, 1994). As visitor use spreads out, then the extent of ecological change increases. At only one site in this study, Alberta Falls, were visitors observed to disperse more at levels of high visitor use. At all other sites, visitor dispersion either did not change in response to use level or the opposite pattern was observed. A more complete understanding of the relationship between visitor use level and visitor behavior will help recreation ecologists and managers better predict the potential for resource change.

4.4 Visitor behavior and ecological significance

Visitor use is arguably the most studied factor influencing ecological change (Monz et al., 2013). The relationship between the level of visitor use and the amount of ecological change is characterized by various models, but is often described as a curvilinear response, i.e., that low levels of use cause a disproportionate amount of resource change in a given area. At high use levels there is proportionally less impact as compared to initial disturbance. Overall, the use-impact relationship indicates that initial disturbance in undisturbed sites causes proportionally more resource change. Results from this study indicate that at certain recreation locations, low use may have the potential to lead to increases in the spatial extent of ecological change. At low use levels, as visitors tend to disperse more overall, visitors may be more likely to enter previously undisturbed areas.

There is potential to combine these results with ecological data that describes current resource conditions in a way that is predictive in nature. The findings from this study suggest that visitor behavior is an important driver of ecological change but that the amount of impact that may result from visitor behavior is site-specific. Combining social science methodologies, like those presented here, with ecological data—such as vegetation susceptibility—would create a social-ecological model of recreation use. This model could then clarify the ecological significance of the differences of visitor dispersion in response to visitor use level that are observed in this study. A social-ecological model of recreation use could not only inform management actions but also potentially provide insight into the use-impact relationship.

4.5. Affordance theory as an explanation

Affordance theory, which has been suggested as a way inform recreation site design and to understand visitor behavior in landscapes and in simulations, may help explain why visitor behavior in off-trail areas varies by use level and recreational destination type (Doxtater, 2008; Pierskalla and Lee, 1998). Affordance theory was first described by psychologist J.J. Gibson as a way to understand how animals perceive their environment (Gibson, 1977). Gibson's theory explains that cues in the physical environment tell individuals what opportunities (or affordances) that environment provides (Gibson, 1977). As a recreation example, the presence of a fire ring and a picnic table in the same location would indicate to a visitor that one affordance for this location would be camping. Management actions, such as signs or the installation of facilities, can provide clues to visitors about the range of affordances a recreation locations provides and what affordances are appropriate at a particular location.

We hypothesize that when specific affordances are made obvious to visitors, either through management actions or infrastructure, visitor behavior will not vary with use level. We see this manifest in the mountain summit locations examined in this study. The affordance of a mountain summit is relatively obvious; the goal for most visitors is to summit the mountain. At both Mt. Evans and Mt. Bierstadt, due to high use levels at these destinations, the designated trails which lead directly to the mountain summits were easy to find, hardened, and well maintained. Once reaching the summit area, which are easy to identify at these sites, visitors do disperse into off-trail areas but dispersion is not influenced by the level of visitor use at the summit location.

When affordances are not obviously communicated by the environment itself or management action, then visitors look for clues about the recreation opportunities based on observations of the behavior of visitors around them. When visitor use is low at a recreation destination with cryptic affordances, new visitors to the recreation site may not have either physical or social cues to guide their behavior and may "wander" in search of recreation opportunities. Patterns of visitor behavior at sites with less obvious affordances appear to be driven by the social setting or by a normative response.

This hypothesized phenomenon is most obvious at El Capitan Meadow. El Capitan Meadow does not have any obvious affordances; there is very little management presence besides parking barriers. At times of high use levels, visitors to El Capitan Meadow clump together at the meadow locations that have the most clear and direct view of El Capitan. The presence of other visitors taking photographs or with binoculars looking at El Capitan, cues new visitors that arrive at the meadow to one of the affordances of the location. Visitors that arrive at the meadow during low use periods, may not have other visitors around to provide such clues. As such, during periods of low use, visitors in El Capitan meadow appear to disperse more into the meadow possibly in search of recreation opportunities.

Visitor behavior at Alberta Falls provides a bit of an exception to the application of affordance theory to visitor behavior in response to use levels. At Alberta Falls, visitors dispersed more during periods of high use as compared to periods of low use. The topography of the Alberta Falls location may influence visitor behavior. A sign is located on the Glacier Gorge trail marking the location of Alberta Falls. The majority of visitor use occurs at this sign but the area around the sign is fairly small. Dispersion away from the sign would require leaving the area and hiking up steep, slick rock adjacent to the falls or down a steep embankment to the river. During periods of low use, viewing the falls at this location may be the only affordance or opportunity that visitors seek and there is no incentive to disperse onto steep terrain. However, during periods of high visitor use, the area around the sign becomes too crowded for all visitors to view the falls at this location and the steeper areas nearby provides a substitute location for viewing the falls.

As demonstrated, affordance theory may help explain the spatial patterns of visitor behavior observed in this study. However, site affordances are not the only factors that influence visitor movement and behavior. Visitor motivations, attitudes, personal norms and descriptive norms also influence how visitors recreate at a recreation destination (Manning, 2010). Combing GPS-based tracking techniques with social science surveys may help to clarify the impact of affordances and social-psychological influences on visitor behavior in off-trail areas.

4.6. Management implications and modeling efforts

Whether or not visitors disperse under different use levels appears to be dependent on the managerial conditions of the study site. At some recreation destinations current management and simulation modeling assumptions were supported but at other recreation destinations these assumptions were violated. Visitor behavior is not uniform in time and space, even at a single recreation destination, but from these findings some reasonable generalizations can be made and incorporated into future simulation modeling efforts and management strategies. Identifying the type of recreation destination, level of management action at the destination, and the obviousness of the affordances provided by that location can help managers and simulation modelers predict how visitor behavior may vary with use level at that site. Management actions that make the affordances of a location clear may be effective at reducing undesirable ecological change by reducing visitor dispersion in response to use level.

5. Conclusions

Overall the findings from this study show that, in terms of ecological change, visitor behavior is a much more important driver than the levels of visitor use. Certain recreation destinations may be able to support high levels of visitor use without an increase in the extent of level of ecological change in off-trail areas. Additionally, the factors that influence the level of resource change at a recreation destination may be interrelated and feedback on one another. This study represents a first step at exploring the influence of social and managerial factors on visitor behavior in disperse use areas. Findings from studies examining patterns of visitor behavior and their interrelatedness with other drivers of resource change can be incorporated into ecological modeling efforts that predict where and to what extent resource change may occur in off-trail areas. Additionally, current simulation models may not be sophisticated enough to accurate reflect the relationship between visitor use and visitor behavior. Advances in agent-based modeling techniques may prove useful for modeling visitor behavior that responses to social and ecological conditions.

Future studies at additional types of recreation destinations are needed to solidify these generalizations and clarify the role and importance of affordances and normative responses in driving visitor behavior. The combined use of indirect and direct measurement techniques, especially GPS tracking, allows for the exploration of the interrelatedness of the factors that influence ecological change (Beeco and Brown, 2013). A better understanding of how visitors behave in off-trail areas can help managers, recreation ecologists, and simulation modelers make more accurate predictions about the potential for undesirable ecological change to occur at a recreation destination.

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Table 2.1.
Summary of study site locations, overall estimated use level at these locations, and the types of management actions observed at the recreation destinations.

Park or Protected Area	Recreation Destination	Estimated Average Total Use Level*	Management Actions
Yosemite NP	El Capitan Meadow	300 visitors/day	None
Yosemite NP	Tuolumne Meadows	120 visitors/day	Designated Trails and Signage
Rocky Mountain NP	Alberta Falls	1,300 visitors/day	Designated Trail Adjacent to Site
Rocky Mountain NP	Emerald Lake	1,000 visitors/day	Designated Trail to Destination Site
Arapaho-Roosevelt NF	Mt. Evans	650 visitors/day	Parking Lot, Hardened Trail, "Frontcountry"
Arapaho-Roosevelt NF	Mt. Bierstadt	300 visitors/day	Designated Trail to Destination Site, Cairns
Grand Teton NP	Phelps Lake	300 visitors/day	Designated Trail to Hardened sites on Lakeshore

*Estimations determined using visitor counters put in place during GPS tracking studies or observational counts of visitors at sites during GPS tracking studies.

Table 2.2.
Matrix of recreation destinations based on the level of management actions at each site and the average number of visitors per day at these locations.

	Level of Management			
Use Levels	None	Low	Medium	High
Low		Tuolumne Meadows		
Medium	El Capitan Meadow		Mt. Bierstadt	Phelps Lake
High		Emerald Lake	Alberta Falls	Mt. Evans

Table 2.3.
Summary of data collection and the use level periods that were used in separating the GPS-tracks into period of "High Load" tracks and "Low Load" tracks.

Park or Protected Area	Rec Destination	Data Collected	Temporal Scale	Average Use Level at Study Site (visitors/temporal scale)	
				High Use	Low Use
Yosemite NP	El Capitan Meadow	July/Aug 2011	Hourly	472	237
Yosemite NP	Tuolumne Meadows	July/Aug 2011	Hourly	177	65
Rocky Mountain NP	Alberta Falls	July/Aug 2008	Hourly	203	131
Rocky Mountain NP	Emerald Lake	July/Aug 2008	Hourly	181	84
Arapaho-Roosevelt NF	Mt. Evans	June - September 2012	Daily	1,018	476
Arapaho-Roosevelt NF	Mt. Bierstadt	June - September 2012	Daily	579	187
Grand Teton NP	Phelps Lake	July/Aug 2013	Hourly	31	17

Table 2.4.
Data collection efforts at each recreation destination. Only GPS tracks of visitors that visited the recreation destination were included in the analysis. Therefore, the number of high use and low use tracks does not equal the total number of GPS tracks collected at each study site.

				Number of Visitor GPS Tracks		
Park or Protected Area	Rec Destination	Response Rate	Average GPS Positional Error (m)	Total Collected in Overall Study	High Use	Low Use
Yosemite NP	El Capitan Meadow	71%	1.7	98	45	45
Yosemite NP	Tuolumne Meadows	65%	0.7	108	25	25
Rocky Mountain NP	Alberta Falls	80%	6.4	301	68	37
Rocky Mountain NP	Emerald Lake	80%	6.4	301	23	14
Arapaho-Roosevelt NF	Mt. Evans	97%	N/A	2,248	76	93
Arapaho-Roosevelt NF	Mt. Bierstadt	97%	N/A	1,051	105	80
Grand Teton NP	Phelps Lake	93%	1.7	500	113	98

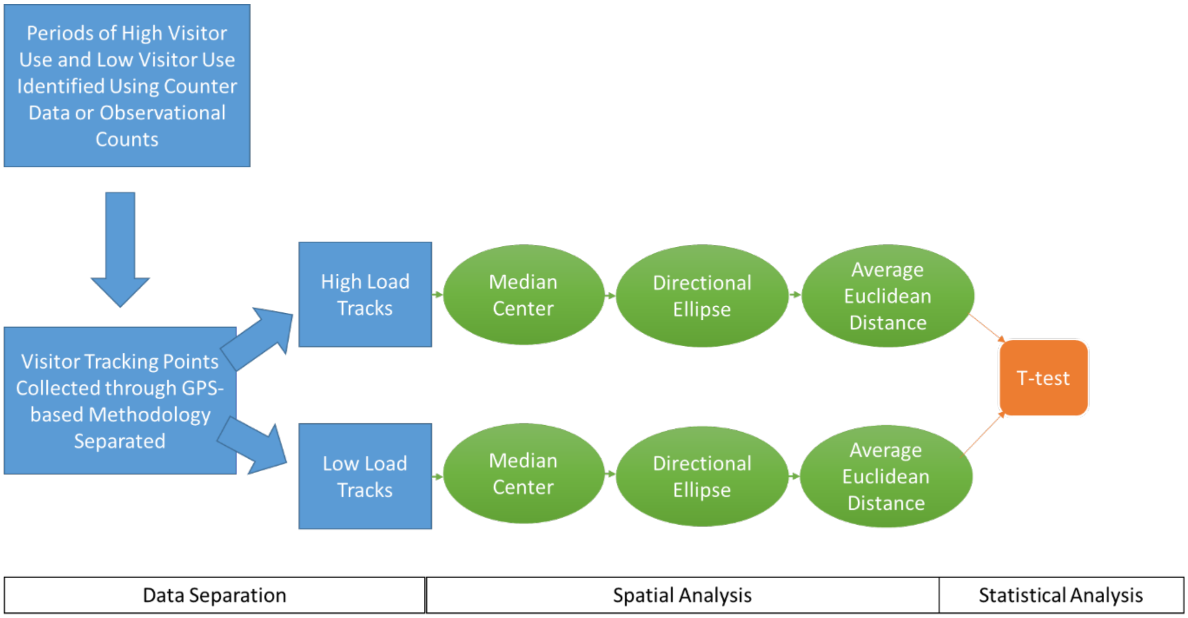


Fig. 2.1. Conceptual diagram of the analysis steps taken in this study. Each step was repeated at each recreation destination listed in Table 2.1.

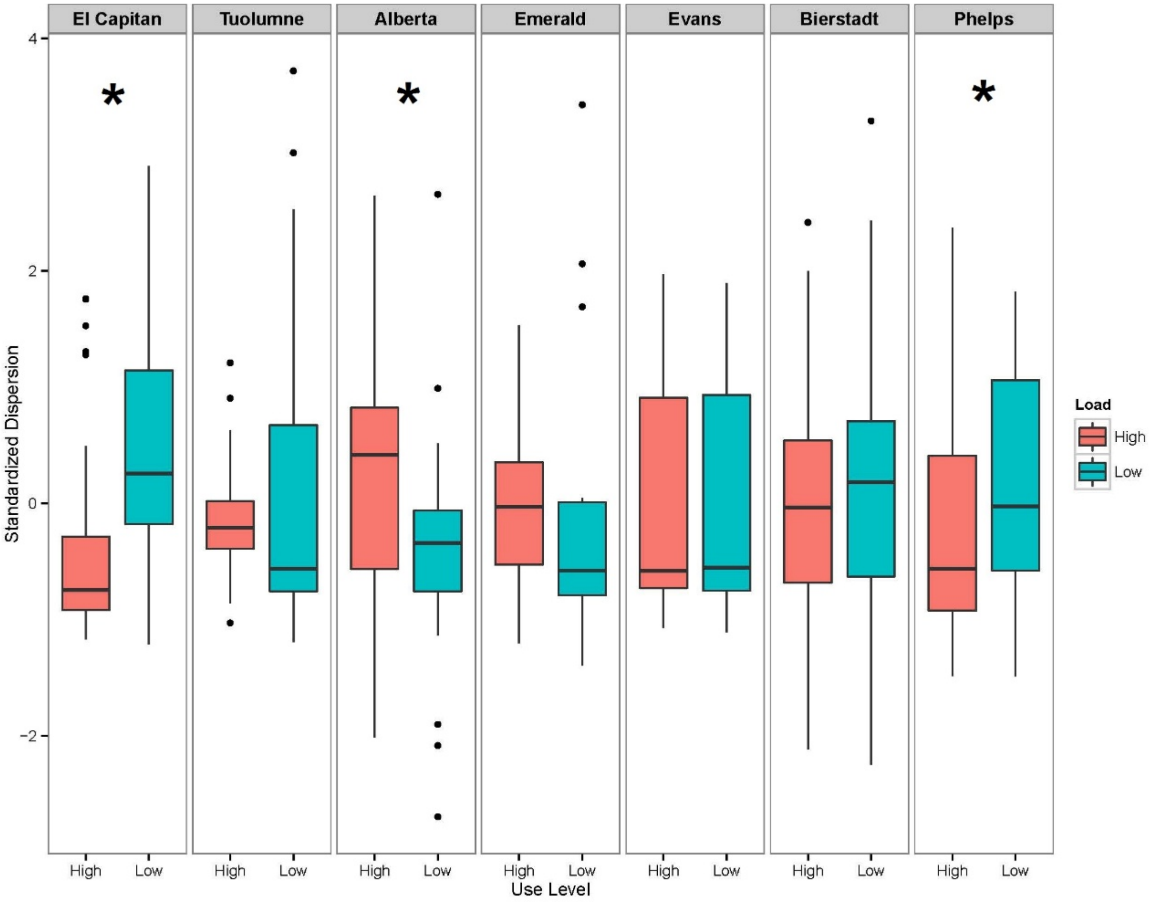


Fig. 2.2. Standardized, average, overall visitor dispersion at each recreation destination. Asterisks indicate recreation destinations where a statistically significant ($p \leq 0.05$) difference was observed between overall visitor dispersion at high and low levels of visitor use.

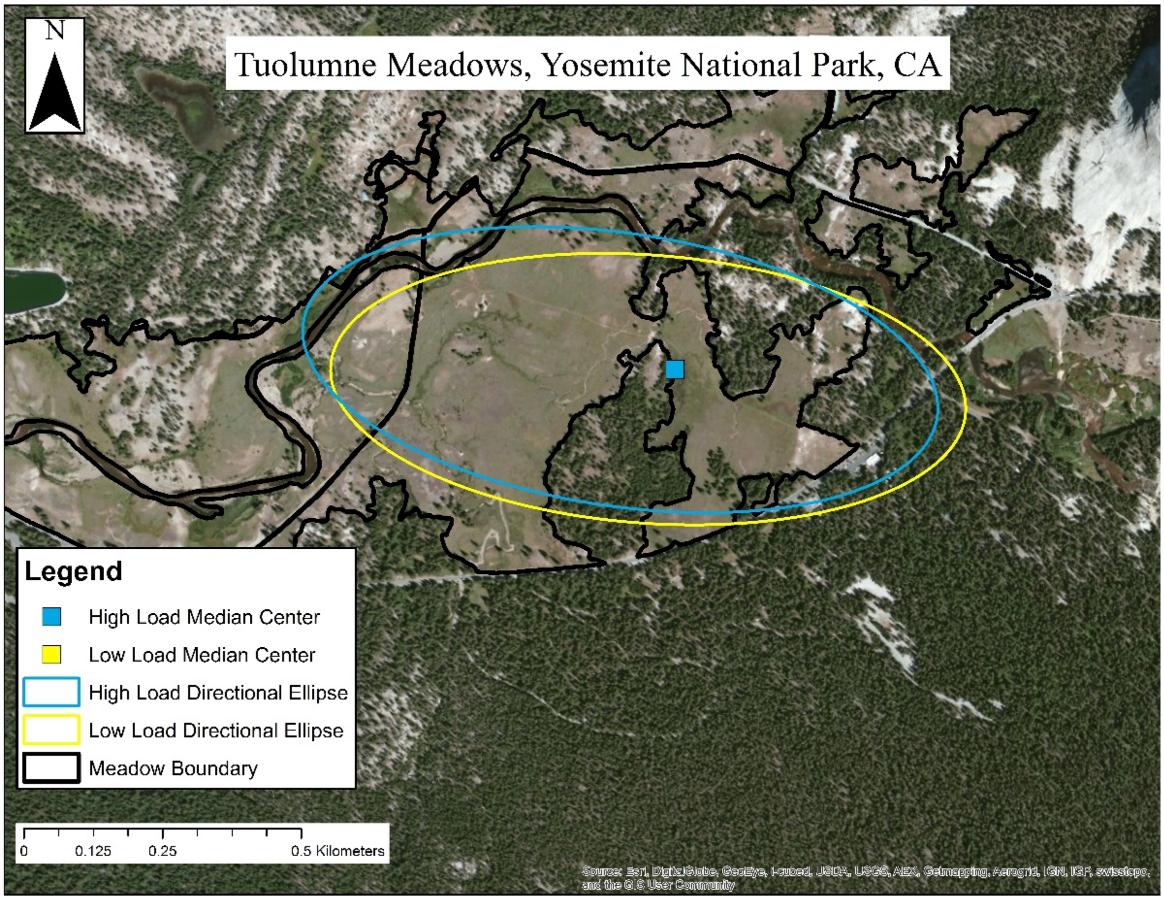
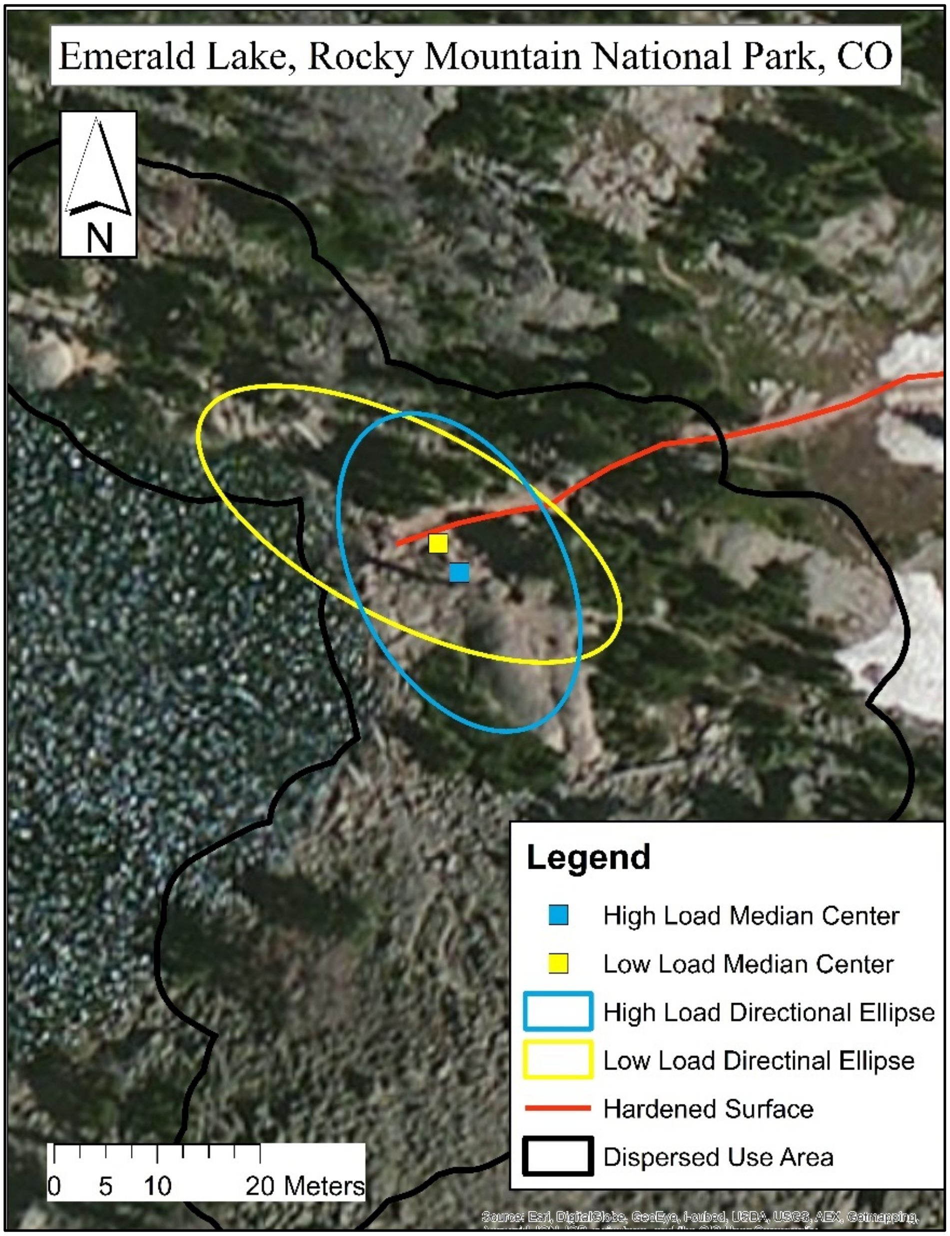


Fig. 2.3. Descriptive metrics of overall visitor dispersion at Tuolumne Meadows. Here the high load median center point and low load median center point are located in the exact same location. The standard deviational ellipses are of almost equal location, size, and shape.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping,

Fig. 2.4. Descriptive metrics of overall visitor dispersion at Emerald Lake. Although no statistical difference was found in overall visitor dispersion, the standard deviational ellipses are showing that during periods of low use visitors disperse more to the north and during periods of high dispersion visitors disperse more to the south.

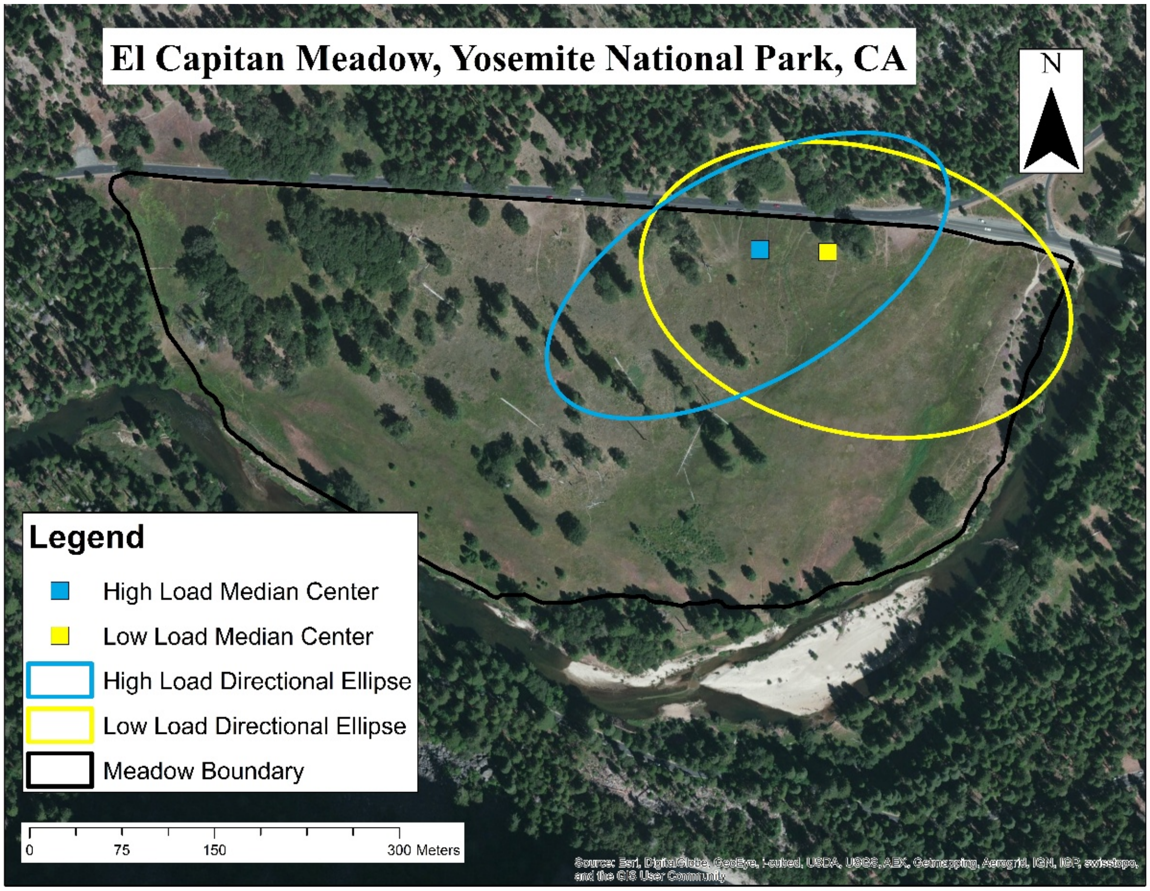


Fig. 2.5. Descriptive metrics of overall visitor dispersion at El Capitan Meadow. Here the high load median center point and low load median center point are located in different locations. The standard deviational ellipses are of very difference size, shape, and orientation.

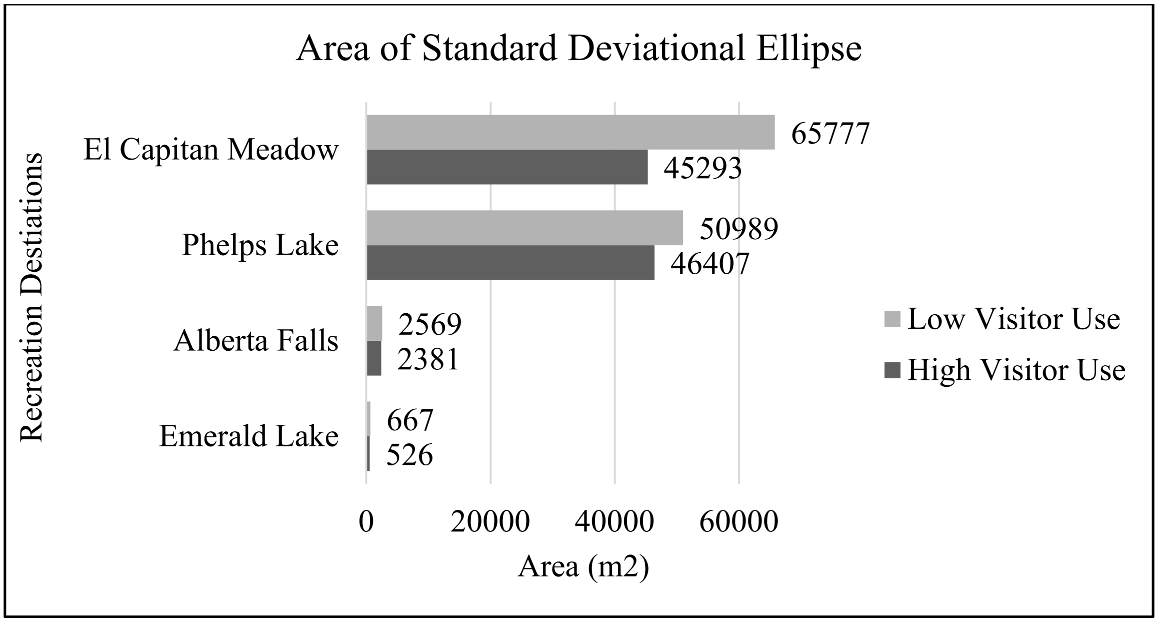


Fig. 2.6. Summary of the area of the standard deviational ellipses calculated for each recreation destination at each visitor use level. Larger standard deviational ellipses indicated greater overall visitor dispersion.

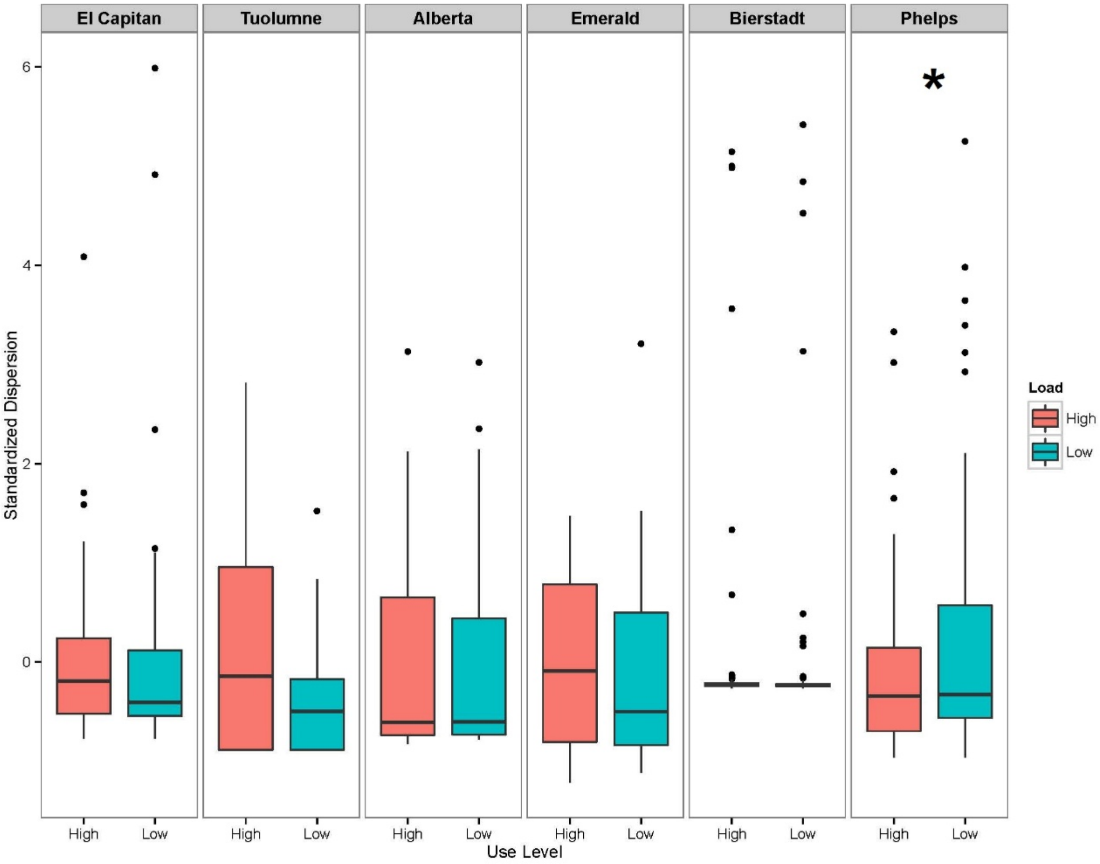


Fig. 2.7. Standardized, average, overall visitor dispersion away from hardened surfaces at each recreation destination. Asterisks indicate recreation destinations where a statistically significant ($p \leq 0.05$) difference was observed between dispersion away from hardened surfaces at high and low levels of visitor use.

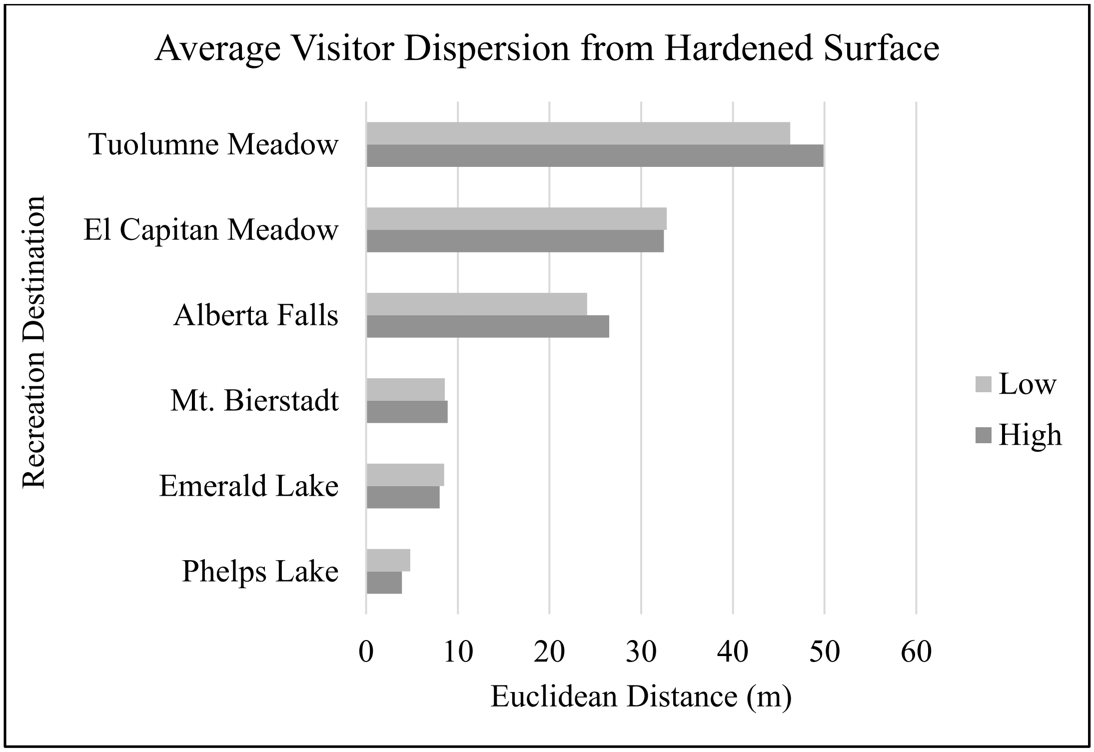


Fig. 2.8. Summary of average Euclidean distance traveled away from hardened surfaces at each recreation destination during periods of low and high use.

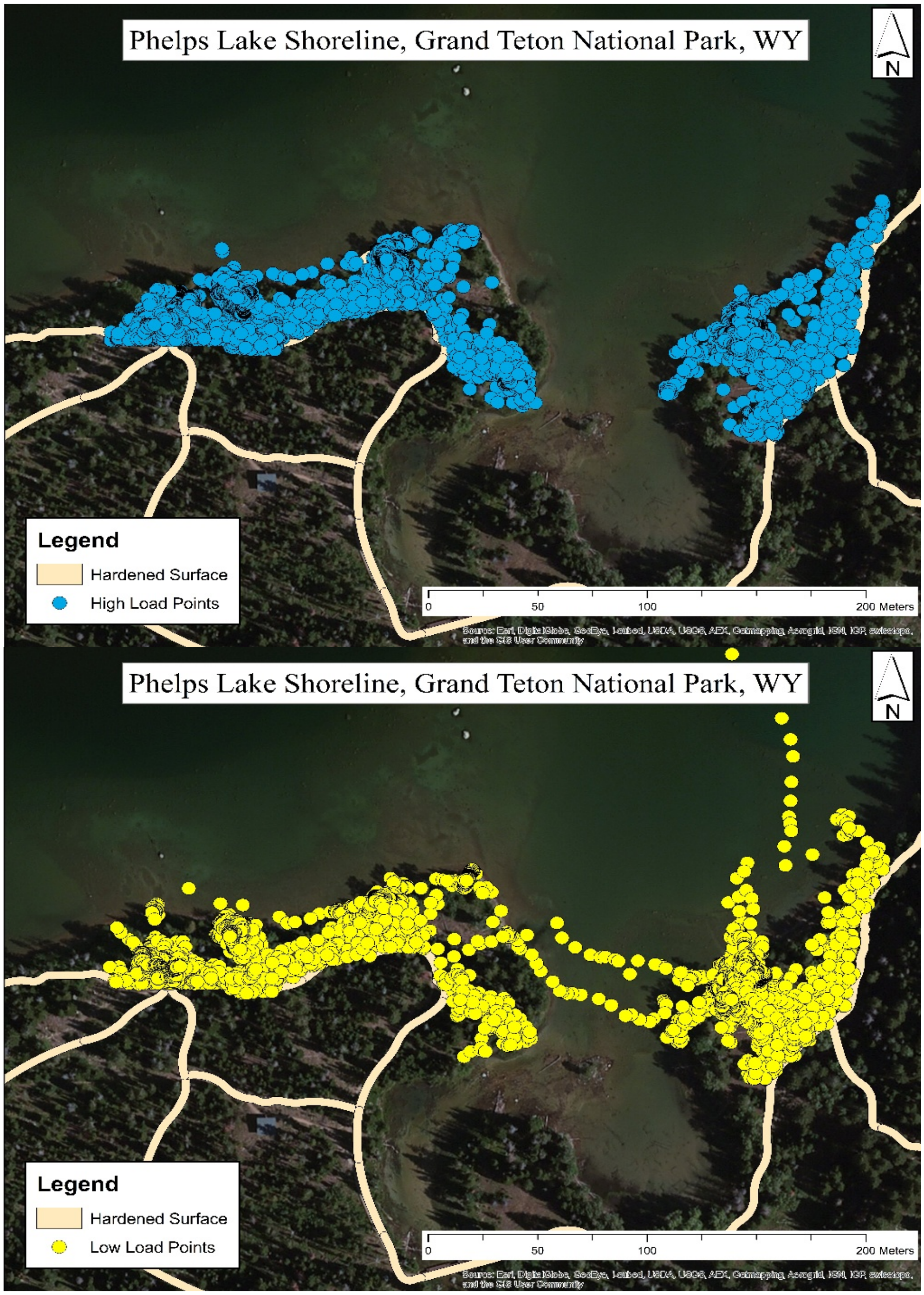


Fig. 2.9. Distribution of visitor GPS-based tracking points for visitors that recreated on the shoreline of Phelps Lake during periods of high use (top) and low use (bottom). Visitors dispersed further from hardened surfaces during periods of low use.

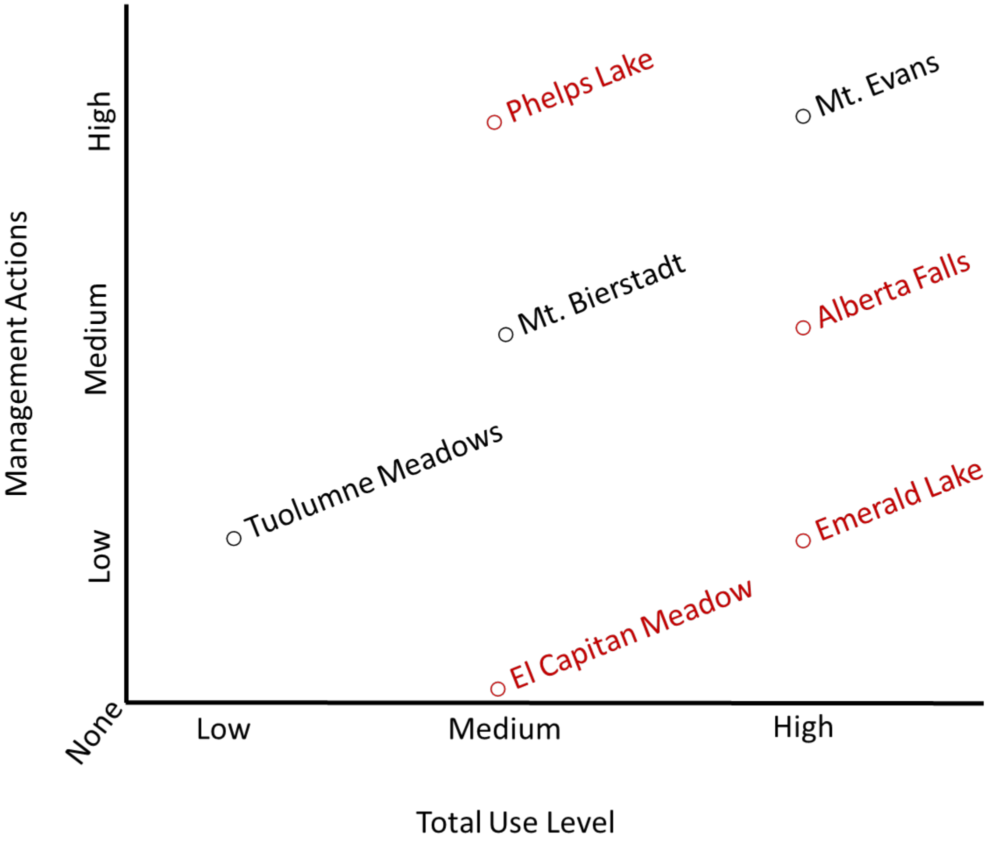


Fig. 2.10. Graph of matrix from Table 2.2. Locations where a statistically significant difference was found between overall visitor dispersion during periods of high and overall visitor dispersion during periods of low use are shown in red.

See Appendix A for additional figures of study sites, GPS-tracking points during high and low use loads, and dispersion analyses.

CHAPTER 3

A SOCIAL-ECOLOGICAL MODEL OF ENVIRONMENTAL DISTURBANCE IN OFF-TRAIL AREAS OF DISPERSED RECREATION USE

Abstract

Sustainable management of parks and protected areas requires an understanding of the relationship between recreation use and resulting ecological impact. This study presents a methodology for combining GPS-based tracking data of visitor use and vegetation susceptibility to trampling into a single social-ecological model. The result provides a prediction of potential ecological change as a result of recreation in off-trail areas of dispersed use. Findings show that the potential for ecological change is largely driven by visitor behavior and that recreation activities in areas of dispersed use with susceptible vegetation does not necessarily lead to more ecological change. Overall, this study highlights the importance of site-specific, social-ecological models for informing management decisions to minimize ecological impacts from recreation use.

1. Introduction

Visitor use of parks and protected areas, both in the United States and worldwide, is increasing (Balmford et al., 2009; Cordell et al., 2008; Hammitt et al., 2015). There will inevitably be some level of environmental disturbance as a result of visitor use. In order to manage parks and protected areas sustainably, it is important for managers and researchers to understand the relationship between visitor use and resulting ecological impacts. The field of recreation ecology, as defined by Monz et al. (2013), is “the study of the environmental consequences of outdoor recreation and nature-based tourism activities and their effective management.” Over the past 50 years, this relatively new field has produced some generalizations about the ecological impacts of recreation use in parks and protected areas (Cole, 2004a; Hammitt et al., 2015; Leung and Marion, 2000; Monz et al., 2010).

These generalizations include: (1) Recreational activities can directly affect both biotic and abiotic components of an ecosystem including soil, vegetation, wildlife, water, air, and soundscapes. (2) Indirect and cascading effects to other ecosystem attributes can occur from direct recreation disturbance as a result of the interrelationships between ecosystem components. (3) Although alternative response functions have been identified, in many case the relationship between use and disturbance is curvilinear with the majority of resource change occurring with initial use. This is often referred to as the use-impact theory. (4) Resistance and resilience to visitor use disturbance is ecosystem specific. (5) The amount, density, type, and distribution of use and aspects of visitor behavior can all influence the level of resource change that occurs as a result of recreation use (Cole, 2004a; Hammitt et al., 2015; Liddle, 1997; Monz et al., 2013).

1.1 Recreation use as a social-ecological system

Taken together, these generalizations imply that the overall level of ecological impact that results from recreation use is dependent on both environmental, or biotic, factors as well as social factors (Hammitt et al., 2015). Recreation use in parks or protected areas can therefore be thought of as a coupled social-ecological system (Cumming et al., 2014). However, the majority of studies that examine the ecological consequences of recreation use only examine either the social *or* ecological components of the system (D'Antonio et al., 2013). Very few studies examine both the social and biological factors that drive ecological change in recreation settings (Beeco et al., 2013; D'Antonio et al., 2013; Goonan et al., 2012).

By combining social science techniques with traditional recreation ecology measures, the field of recreation ecology may be able to provide managers with a more complete and comprehensive understanding of the relationship between visitor use and impact (D'Antonio et al., 2013). Additionally, social-ecological models could help recreation ecologists better understand the non-linear relationship between use and impact (Cole, 2005; Gimblett et al., 2001). This study combines traditional recreation ecology measures of vegetation resistance with new social science methodologies examining visitor behavior under different use level scenarios. The overall objective of the study is to create a social-ecological model that will help managers more accurately predict where, and to what level, ecological impacts may occur as a result of recreation use.

1.2 Biotic component of the social-ecological model

Recreation ecology studies have examined the impacts of recreation to soil, wildlife, water, air, and soundscapes. However, the impacts to vegetation as a result of trampling from recreation use is the most widely-studied mechanism of ecological change (Hammitt et al., 2015; Monz et al., 2010, 2013). A recent meta-analysis found 145 studies that examined the response of vegetation to trampling disturbance (Pescott and Stewart, 2014). Standard experimental trampling protocols have been established in the field since the early 90s (Cole and Bayfield, 1993) and the majority of trampling studies report similar response variables; resistance, resilience, and tolerance (Hammitt et al., 2015). Resistance is the ability of a particular vegetation type or community to resist being disturbed by trampling. Resilience describes the ability of a vegetation type or community to recover from trampling disturbance. Tolerance is a measure that combines both resistance and resilience (Cole and Bayfield, 1993). How resistant a particular vegetation community is to recreation disturbance depends on characteristics of that community, of the vegetation present, and of the soil (Hill and Pickering, 2009). A commonly used index to compare vegetation response across experimental trampling studies is the resistance index (RI) (Hill and Pickering, 2009; Liddle, 1997). RI is an indicator of the short-term response of vegetation to trampling disturbance.

Several attempts have been made to generalize vegetation resistance to trampling disturbance. Cole (1995a, 1995b) modeled the response of vegetation cover to trampling disturbance for a variety of vegetation species in a variety of ecosystem types (Monz et al., 2010). Through this series of experimental trampling studies, Cole was able to generalize the response of vegetation types across morphological groups. In general, grammanoids are more resistance to trampling than trees, followed by forbs, and finally shrubs have the lowest resistance to trampling (Cole, 1995b; Hammitt et al., 2015, Hill and Pickering, 2009).

Despite these morphological group generalizations being widely applied in the field of recreation ecology (Cole, 2004b; Hammitt et al., 2015; Pickering and Hill, 2007; Whinam and Chilcott, 2003), Hill and Pickering (2009) found a large amount of variability in the RIs of species within the same morphological group. And recent observations in the field of recreation ecology have emphasized the importance of species-specific susceptibility to understand recreation impacts (Buckley, 2013). Moving away from the morphological group generalizations suggested by Cole (1993), and towards a species- or genus-level understandings of vegetation resistance may provide a more accurate picture of how vegetation communities response to trampling disturbance.

From a management perspective, not only is it important to know how particular species may response to trampling disturbance but it is important to also know where those species are located within a particular park or protected areas. In 1997, Liddle suggested that there was a need in the field of recreation ecology for the development of low-cost, quick methodologies for creating “vulnerability maps.” Recent advances in Geographic Information Systems (GIS) and Global Positions Systems (GPS) methodologies provide the means to create these maps in a low-cost and efficient manner. Vulnerabilities maps would be useful to managers as they would highlight locations where communities are more susceptible to impacts as a result of recreation disturbance (Liddle, 1997). Vulnerability, or susceptibility, mapping based on existing experimental trampling protocols and species- or genus-level RIs provide a basis for creating such maps.

1.2 Social component of the social-ecological model

Alone, susceptibility maps provide only the ecological component of a coupled social-ecological system. Social factors, such as visitor use levels and visitor behavior, are known to be important drivers of ecological impacts in recreation settings (Hammitt et al., 2015). Recently, GPS-based tracking methodologies have become a common way to gather information on the behavior of visitors to parks and protected areas (Beeco and Brown, 2013; Beeco et al., 2014; D'Antonio et al., 2010; Hallo et al., 2012; Kidd et al., 2015; Taczanowska et al., 2014). Although visitor surveys and trip diaries can be used to gather information on visitor behavior, GPS tracking provides more reliable and robust data that is automatically georeferenced (Hallo et al., 2005). GPS tracking is an especially powerful tool when gathering information about visitor behavior in areas of off-trail use, where visitors disperse away from known and established recreation networks (D'Antonio et al., 2010; Kidd et al., 2015).

Chapter 2 of this dissertation used GPS-based tracking methodologies to understand the role of visitor use level in driving visitor dispersion in off-trail areas of visitor use. Results from Chapter 2 indicate that in some recreation settings, visitor behavior varies under different use levels in ways that are counterintuitive and important to managers. In some areas of dispersed visitor use, visitors actually cluster together during periods of high visitor use levels and spread out during periods of low visitor use levels. These findings have a variety of social implications in terms of visitor crowding and visitor capacity issues. However, the ecological implications of these differences in use patterns in response to visitor use levels has yet to be examined.

1.3 Predictive capacities in social-ecological models

In addition to increasing our understanding of species-level responses to recreation, suggestions have been made in the recreation literature that the field needs increased predictive capacity (Monz et al., 2010). One way in which the field of recreation ecology can be more predictive is through the use of the previously mentioned susceptibility maps. Little research has related spatially referenced social science data, such as that collected using GPS-tracking methodologies, to biophysical resource conditions (Beeco et al., 2014; D'Antonio et al., 2010; Monz et al., 2013). The integration of spatially-referenced social science with maps of community susceptibility to recreation disturbance could provide managers with the capacity to predict the location of impacts across space.

In 2010, in a paper emphasizing the gaps in current recreation ecology literature, Monz and colleagues suggested ways of increasing predictability in the field. One suggestion was to use spatially-based models of ecosystem susceptibility and examine ecosystem response under different use levels. At the time of that papers publication, little spatially-based visitor use data was available. Now with more extensive use and better development of GPS-based tracking methodologies there is opportunity to build predictive social-ecological models of recreation use.

This paper builds on previous attempts at constructing vulnerability maps by using species- or genus-level RIs, instead of relative morphological group rankings, to create more accurate, spatially-based models of vegetation community response to trampling. These vulnerability, or susceptibility maps, are then integrated with GPS-based tracking data from Chapter 2. The potential for ecological consequences as a result of recreation use is examined under varying use level to create a predictive social-ecological model.

2. Methods

2.1 Study sites

Three different study sites from two different national parks were selected for this social-ecological analysis. All study sites are day use locations that receive high levels of recreation use. Each study site represents a unique type of visitor destination where visitors have the potential to travel off-trail into vegetated areas of dispersed visitor use. Results from Chapter 2 indicate that at all study sites included in this paper, visitor behavior varied in response to visitor use levels.

2.1.1 Alberta Falls, Rocky Mountain National Park, CO

Alberta Falls is located in Rocky Mountain National Park, Colorado (ROMO) in the Bear Lake Road Corridor. Alberta Falls is a short, one mile hike from the Glacier Gorge Trailhead. The main attraction to this recreation site is the 30-foot waterfall on Glacier Creek that lies adjacent to the designated trail. During the busy season, an average of approximately 1,300 visitors per day will visit Alberta Falls and a portion of those visitors will also disperse off-trail into the forest understory and riparian areas near the falls (Newman et al., 2010). Results from Chapter 2 indicate that visitor behavior into off-trail areas of dispersed use at Alberta Falls varies with use level. During periods of high use, visitors dispersed more into off-trails areas as compared to dispersion during periods of low visitor use.

2.2.2 Emerald Lake, Rocky Mountain National Park, CO

Emerald Lake, a high alpine lake located at 10,000 ft., is also located ROMO. Emerald Lake is located 1.8 miles from the Bear Lake Trailhead. Despite being considered one of the more difficult day hikes in the Bear Lake Road Corridor, Emerald Lake still receives, on average, approximately 1,000 visitors per day to the lakeshore (Newman et al., 2010). Much of the lakeshore at Emerald Lake is rocky however there is potential for visitors to disperse into sensitive, and often wet, alpine habitat both as they approach Emerald Lake and at the lake itself. Results from Chapter 2 indicate that overall visitor dispersion into off-trail areas at Emerald Lake did not vary with use level. However, descriptively, during periods of high visitor use, visitors were more likely to disperse into the south lakeshore area with very little dispersion north of the designated trail. During periods of low visitor use, visitors were more likely to disperse into the north lakeshore area with very little dispersion to the south of the designated trail.

2.2.3 El Capitan Meadow, Yosemite National Park, CA

El Capitan Meadow is located in Yosemite National Park, California (YOSE) at the west end of Yosemite Valley. El Capitan Meadow is bordered to the north by the road out of Yosemite Valley and to the south by the Merced River. The meadow area has no formal parking for recreationists, so visitors must take the free park shuttle bus to the meadow or park their vehicle along the shoulder of the road. El Capitan Meadow provides views of El Capitan, a popular climbing wall, and access to the Merced River. El Capitan Meadow is often one of the last stops visitors make as they leave Yosemite Valley and on average, 300 visitors per day will enter the meadow to recreate for a short period of time. Result from Chapter 2 show that visitor behavior at El Capitan Meadow varies with use levels in ways that are counter-intuitive. During periods of high visitor use, recreationists in El Capitan meadow tend to disperse less and clump together. During periods of low visitor use, recreationists in the meadow disperse farther into the meadow, wandering closer to meadow edges.

2.2 Visitor densities

At each study site, GPS-based tracking methodology was utilized to measure visitor behavior (D’Antonio et al., 2010). Visitors were randomly intercepted before reaching the study site and asked to voluntarily carry a GPS unit with them during their visit. The GPS units were returned to researchers at the end of the recreationist’s visit. The subsequent GPS tracks were uploaded into ArcGIS as point features, cleaned, and separated into visitor behavior observed during periods of high visitor use and low visitor use at the study site (see Chapter 2).

Visitor tracking points were separated into two subsets: those collected during periods of “High Load Points” and “Low Load Points”. A kernel density estimation (KDE) was calculated for each of the two datasets. The resulting KDEs highlight the key “visitor use areas” in the overall areas of dispersed use that were mapped (see section *2.3.1*). In order to better visualize where visitor behavior varied between use levels, the raster calculator tool in ArcGIS was then used to compare these two KDE maps to highlight locations where visitor densities differed between the two use levels. At each study site, locations were identified where the Low Load density values were higher or lower than the High Load density values.

2.3 Vegetation susceptibility to trampling

2.3.1 Vegetation mapping

Areas of dispersed visitor use were identified using foot searches and mapped using high accuracy Trimble GPS units at both Alberta Falls and Emerald Lake. A 30-meter buffer was generated around each area of dispersed use to account for any error in estimating the extent of visitor dispersion at these study sites. Within these buffered areas of dispersed use a system of points was generated randomly within a grid system (N = 179 points for Alberta Falls and N = 131 points for Emerald Lake; Fig. 3.1). Each point was navigated to and a 1-meter quadrat was used to estimate percent vegetation cover by species or genus for that location (Monz et al., 2010). The percentage of bare ground, vegetation litter, and bare rock surface was also noted at each quadrat location.

At El Capitan Meadow, Yosemite National Park staff provided a polygon delineating the El Capitan Meadow management area. Yosemite National Park staff also completed a vegetation survey of El Capitan Meadow. A regular grid of points was generated for the entire meadow area and a 1-meter quadrat was used to estimate percent vegetation cover of the three most dominate species at each point location (N = 183 points). Ocular estimates were utilized in El Capitan Meadow and the percentage of bare ground, vegetation litter, and rock were also recorded at each quadrat location.

2.3.2 Resistance index

The measure of vegetation susceptibility to trampling used in this study was resistance index (RI) (Hill and Pickering, 2009). RI is the number of trampling passes required to cause a 50% reduction in vegetation cover (Liddle, 1997). RI was chosen as an index of susceptibility because it is consistently reported in the results of the experimental trampling literature. In ROMO, due to permitting constraints, an experimental trampling study was not conducted to determine site-specific RIs. In 2011, in YOSE, an experimental trampling study following methods outlined in Cole and Bayfield (1993) was conducted by researchers from Utah State University in a meadow with a similar vegetation community to El Capitan Meadow. Site-specific RIs were calculated for the species in this nearby meadow.

An RI was assigned to each species that was identified in the areas of dispersed visitor use during the vegetation mapping component of the study. The best available information was utilized to determine an RI for each species. In YOSE, the first source for RIs was the experimental trampling study conducted in 2011. If the species in question was not found in the data from the experimental trampling study in YOSE, then the broader experimental tramping literature was searched for a species or genus level RI (Hill and Pickering, 2009; Appendix C). If no RI value for that species could be found in the experimental trampling literature at either the species or genus level, then the average RI for morphological groups, as summarized in Hill and Pickering (2009), was used. For both ROMO sites, the first source for RIs was the experimental trampling literature followed by the morphological group averages found in Hill and Pickering (2009). Areas of bare ground and bare rock were assigned an RI that was double the highest vegetation RI observed in the experimental trampling literature. Given that 1) there is currently a lack of literature discussing the RI of vegetation litter and 2) vegetation litter made up a very small percentage of ground cover at any of the sites, vegetation litter was noticed included in this study. See Appendix C for list of species, resistance indices, and the source for the RIs.

2.3.2 Resistance index interpolation

Each 1-meter quadrat location mapped and summarized during the vegetation mapping component of the study was assigned an average RI in ArcGIS. The RI for the quadrat location was a calculated as a weighted average based on the species composition of that 1-meter quadrat (see equation below). Once an overall average RI was calculated for each quadrat location, a kriging procedure was used in ArcGIS to create an interpolated, continuous surface of RIs for the entire area of dispersed use. This RI surface spatially represents the vegetation susceptibility to trampling for each study site.

$$\text{Average RI} = \frac{\sum_{i=0}^{n} species\ \%\ cover_i \text{ x } RI_i}{n}$$

2.4 Potential for ecological change

At all study sides the Low Load and High Load KDEs were reclassified into 5 categories and each raster cell was assigned a value from 0 (no visitor use) to 5 (high visitor use densities). The vegetation susceptibility map from the RI calculations and interpolation was also reclassified into 5 categories and each cell was assigned a value from 1 (low resistance to trampling) to 5 (high resistance to trampling). These two data layers were then combined and the resulting database assigned each raster cell two values; one for visitor density at that location and one for the vegetation resistance at that location. Use-impact theory, the curvilinear relationship between visitor use and the level of impact (Monz et al., 2013), was used to then assign each combination of values a score representing the potential for ecological change at that location. For example, if a cell had a “5” for vegetation resistance and a “2” for visitor density, then the potential for ecological change at that location would be low. See Table 3.1 for a complete list of all visitor density and vegetation resistance combinations. For each study site, and under both High Load and Low Load visitor use levels, a surface was generated in GIS that represents three levels of the potential for ecological change (high, medium, low) that may result from recreation use.

3. Results

3.1 Visitor densities

In ROMO, the response rate for the GPS-tracking component of the study was 80% with 301 GPS tracks collected overall (Table 3.2). Of the 301 GPS tracks collected, 37 of the tracks were from visitors that entered the area of dispersed use at Emerald Lake and 105 of the tracks were collected from visitors that entered the area of dispersed use at Alberta Falls. In YOSE, the overall response rate for the GPS-tracking component of the study was 71% with 98 GPS tracks collected overall (Table 3.1). Of these 98 tracks, 90 were from visitors that dispersed off of the road and into El Capitan Meadow.

At Alberta Falls during periods of Low Load visitor use levels, the highest densities of visitor tracking points occurred very close to the designated trail. During periods of High Load visitor use levels, high densities of visitor tracking points occurred very close to the designated trail as well as along the edge of areas of dispersed use (closest to Alberta Falls and Glacier Creek). At Emerald Lake, during both periods High and Low Load, high densities of visitor tracking points occurred near the where the designated trail ended at the shore of Emerald Lake (Fig. 3.2 and Fig. 3.3). However, during periods of High Load, high densities of visitor tracking points also occurred away from the designated trail. At El Capitan Meadow, high densities of visitor tracking points occurred at the northeast edge of the meadow during periods of both High and Low Loads. This location affords the best views of El Capitan. However, during periods of Low Load visitor use levels, higher densities of visitor tracking points were observed along the southern edge of El Capitan Meadow along the Merced River.

3.2 Vegetation susceptibility

In ROMO, 30 different species were identified at the two study sites during the vegetation mapping component of the study. These 30 species were from 12 different genera. The majority of the RIs assigned to these species were assigned at the genus level. Only four species-level RIs were found in the experimental trampling literature for ROMO. In El Capitan Meadow, 50 species from 32 different genera were identified and 95% of the 1-meter quadrats contained at least one invasive species; usually *Poa pratensis*. At El Capitan Meadow, the majority of species were assigned at the genus or morphological group level. Only 5 species-level RIs were found in the experimental trampling literature or able to be determined from the experimental trampling study.

At Alberta Falls, the location within the area of dispersed use with the highest resistance to trampling disturbance were found to be directly adjacent to Alberta Falls. This location is mostly bare rock surface. The majority of the area of dispersed use at Alberta Falls contains vegetation communities that have medium (10% of the area) to low (71% of the area) resistance to trampling (Fig 3.4). At Emerald Lake, the majority (44%) of the areas of dispersed use has high resistance to trampling disturbance as much of the lake shore is bare rock. However, areas of high susceptibility occur directly adjacent to where the designated trail meets the lakeshore (Fig. 3.5). The majority of El Capitan Meadow contains vegetation communities which have medium (10% of the area) to low (85% of the area) resistance (Fig. 3.6). Areas of high resistance to trampling (1% of the area) and low susceptibility to disturbance are found in the northeast corner of the meadow and directly adjacent to the park road (north edge of the meadow).

3.3 Potential for ecological change

At Alberta Falls, regardless of visitor use levels, the areas that have high potential for ecological change occur in the center of the area of dispersed use and directly adjacent to the designated trail. These areas of high potential for ecological change occur away from the bare rock directly adjacent to Alberta Falls. During High Load periods, there is a greater proportion (31%) of total visitor use area that has a high potential for ecological change than during periods of low visitor use (15%). There is also a greater proportion of area that has a medium potential for ecological change during High Load periods (9%) compared to periods of Low Load visitor use (3%). During periods of Low Load, 83% of the overall area of visitor use has a low potential for ecological change as a result recreation activity.

At Emerald Lake, there is very little potential for ecological change as the majority of the lakeshore is bare rock and skree which has a high resistance to trampling. Overall, regardless of visitor use levels, 95% of the area of visitor use at Emerald Lake has a low potential for ecological change. However, during both High and Low Load visitor use levels, there is high potential for change directly adjacent to the designated trail where visitors first leave the hardened surface of the trail to enter the area of dispersed use. The area of high potential for ecological change covers approximately 2% of the total visitor use area during High Load periods and 3% during periods of Low Load periods.

At El Capitan Meadow, during High Load visitor use levels, areas that have a high potential for ecological change as a result of recreation use occur on the northern edge of the meadow and in the core of the meadow area (Fig. 3.7). During Low Load periods, there are still areas of high potential for ecological change on the northern edge of the meadow and in the core meadow area (Fig 3.8). During Low Load periods, there are additional areas that have a high potential for ecological change along the Merced River (south edge of the meadow). However, the proportion of areas of potential ecological change are approximately equal regardless of visitor use level. During periods of both High and Low Load of visitor uses, there is low potential for ecological change in approximately 73% of the area of visitor use in El Capitan Meadow.

4. Discussion

Through the more widespread use of GPS-based tracking methodologies, the field of recreation ecology has become better at understanding patterns of visitor use and behavior. However, in order to fully grasp the relationship between visitor use and resulting environmental consequences, measurements of visitor behavior need to be examined within an ecological context. For example, Chapter 2 of this dissertation found that visitor use level is an important driver of visitor behavior. However, without understanding the ecological environment in which visitor use is occurring, few conclusions can be made regarding the ecological implications of visitor use. GPS tracking of visitors allows for a thorough understanding of where visitors are going but social-ecological modeling provides a means for understanding how recreationists are interacting with their environment and the potential ecological implications of that interaction.

4.1 Site specific findings and management implications

The social-ecological modeling procedure suggested here combined georeferenced visitor behavior and vegetation susceptibility to successfully predict areas of potential ecological change under two use level scenarios. At Alberta Falls, during Low Load periods of visitor use, visitors were largely recreating on highly resistance surfaces (base rock). Therefore, the greatest potential for ecological change at Alberta Falls occurs during periods of high visitor use when visitors are dispersing into areas of susceptible, forest understory (Fig. 3.9). These findings indicate that in order to reduce potential for ecological change, managers could encourage confinement of off-trail use to the less susceptible surfaces directly adjacent to Alberta Falls.

At Emerald Lake, despite high levels of visitor use in off-trail areas along the lakeshore, there is very little potential for ecological change at either High or Low Loads of visitor use. The majority of the shore of Emerald Lake is bare rock and the most highly susceptible vegetation is located along the designated trail as it approaches the lakeshore (Fig. 3.5). The social-ecological model at Emerald Lake suggests that high visitor use can be accommodated as long as visitors do not disperse into off-trail areas until they reach bare rock. Minimal containment strategies could be used at Emerald Lake to further reduce the potential for ecological change.

At El Capitan Meadow, very susceptible vegetation communities were found throughout the disperse use area (Fig. 3.6). Additionally, marked differences were observed between visitor behavior during periods of Low and High Loads of visitor use. Despite these differences in behavior, the total amount of area that had a high potential for ecological change was the same during periods of High Loads and Low Loads. What differed between visitor use levels was the location of these areas of high potential for ecological change. During Low Loads of visitor use, areas of high potential for ecological change occurred mostly around the perimeter of the meadow and close to the Merced River (see Chapter 2). Given these patterns of use, containment strategies may be of particular importance during periods of low visitor use at El Capitan Meadow. There are locations of highly resistant vegetation communities located at key view areas along the northern edge of El Capitan Meadow. Managers could encourage visitor use, during periods of both High and Low Load, at these more resistant locations to reduce visitor use in more susceptible areas of the meadow.

Together these site-specific findings indicate that the relationship between visitor use and ecological impacts is conditional on a variety of setting characteristics. Some of these characteristics are known factors that are discussed in the recreation literature such as visitor use patterns and visitor use levels (Hammitt et al., 2015). However, this social-ecological model emphasizes the importance of the interrelationship between visitor use level and visitor behavior in driving potential ecological change. In the case of El Capitan and Emerald Lake, visitors do not appear to be drawn to areas of sensitive vegetation; a phenomena suggested by Tomczyk (2011). Visitors may find more recreation amenities or affordances (such as view areas or flat locations for sitting) in locations that naturally have more highly resistant surfaces (Tomczyk, 2011). Counter to current thinking, in some situations – such at El Capitan Meadow – high levels of visitor use can be accommodated in a location with highly susceptible vegetation with little ecological consequences to vegetation.

4.2 Vegetation susceptibility mapping

Until recent advances in GIS technologies, the creation of susceptibility mapping was time and cost prohibitive. Attempts have been made at large scales to map vegetation susceptibility. Tomczyk (2011) created a landscape-level susceptibility map for Gorce National Park in Poland. One of the findings of this work was that such broad-scale mapping procedures, while useful, may not be appropriate for site-level management especially in very sensitive ecosystem types (Tomczyk, 2011).

The susceptibility mapping procedure presented here is designed to be applicable at the site-level. All three study sites contained sensitive habitats (a meadow, a lakeshore, and a riparian area) where visitor use was dispersed off of hardened surfaces into areas where managers may or may not want recreation use to occur. Generally, vegetation susceptibility at the site or landscape scale is modeled at the community or morphological group level and relative rankings are used (e.g. 1 = shrub, 2 = forb, 3 = gramminoid, 4 = bare ground, etc.) (Hill and Pickering, 2009; Tomczyk, 2011). In a previous study, and as a first attempt at building vulnerability models of vegetation response to trampling, common morphological group rankings were used to build vegetation susceptibility maps at Alberta Falls and Emerald Lake (D’Antonio, 2010).

When compared to the morphological group-based maps built with relative rankings, the species- or genus- level susceptibility maps built with RI values resulted in different levels of resistance. The morphological group maps resulted in an underestimate of susceptibility at Alberta Falls and an overestimate of susceptibility at Emerald Lake. For example, the rocky shoreline of Emerald Lake, which should have a very high resistant to trampling, was identified as medium resistance in the susceptibility map built from morphological group rankings. These observed differences are likely the result of 1) widely different RIs reported within a single morphological group (Hill and Pickering, 2009) and 2) the ordinal ranking used in the morphological group analysis versus the ratio variables used in the RI analysis.

Species resistance is considered to be relatively consistent across geographic locations while even at a single geographic location, resistance can vary widely within a morphological group (Cole, 1993; Hill and Pickering, 2009). The use of species- or genus- specific RI values, which are a continuous value, seems to provide a more accurate model of vegetation susceptibility at the site-level where individual species can be reasonably identified. This approach may not be appropriate at larger scales such as the scale of a national park, where vegetation community level or morphological group rankings may be a more feasible. At such large scale, the location and percent cover of individual species may not be available.

The use of RI values do have some limitations. Specifically, RI values are in a way a “worst-case scenario” index. During trampling studies, researchers are purposefully trampling vegetation in a way that is akin to but not identical to the way in which hiker trampling may actually occur. Trampling is done with purpose during experimental trampling studies. Therefore, the RI values obtained from trampling studies may be seen as more representative of an extreme trampling event. Additionally, trampling studies occur with discrete trampling categories (0 passes, 25 passes, 75 passes, etc). So the exact RI value is often interpolated from graphs and therefore is subject to some error. Despite these limitations, RI values are the most robust measure available at the time for examining vegetation response to trampling disturbance and does appear to be more accurate to morphological group rankings.

4.3 Social-ecological model

Singularly, KDEs of visitor use can tell managers and researchers where visitors are going (D’Antonio et al., 2010). Susceptibility maps can inform managers and researchers about where the vegetation that is sensitive to recreation use is located. However, without combining these social and ecological data, predictions about ecological impacts cannot be made. Building social-ecological models of visitor use, especially under difference use level scenarios, can inform fine-scale management decisions related to the sustainable visitor use in parks and protected areas.

Currently, one of the few social-ecological models of recreation use that has been developed examined the relationship between visitor use densities and existing recreation impacts on trails (Beeco et al., 2013). The management of trail conditions and visitor use on trails is an important component of managing recreation use. However, managers are often more concerned about ecological impacts that occur when visitors move away from existing recreation networks such as trails. The model suggested in this study, is a methodology for predicting where ecological consequences of visitor use may occur *before* the impact happen. Overall, this social-ecological model highlights areas of concern where managers may want to concentrate their management efforts to reduce potential, future impacts to ecosystem components. Additionally, by examining and comparing the potential for ecological change at different visitor use levels this social-ecological model allows for some predictive capacity under different management scenarios.

4.4 Future directions

During the process of building this social-ecological model, several areas for future research were revealed. First, there is very limited species-level RIs reported in the literature. Species-level measurements are consistently taken as part of the standard experimental trampling study protocols (Cole and Bayfield, 1993). However, when final results are published resistance and RI is often either reported at the community level, only a few species-level RIs are reported, or relative resistance rankings are reported for individual species (such as low, medium, or high). The power of susceptibility mapping would be greatly enhanced if a database of species- and genus-level RIs existed.

Tables and supplementary material from Hill and Pickering (2009), as well as Appendix C from this study, provide a starting point for the creation of such a database. However, in order to produce a more comprehensive and complete database of specie- and genus- level RI values, historical and raw data from experimental trampling studies would need to be compiled and potentially reanalyzed. Additionally, little literature was found on the response of vegetation litter, lichen species, or moss species to trampling disturbance. Although vegetation litter does not appear to be an important component to the susceptibility of the vegetation communities examined in this study, lichen and moss species responses to trampling could be important at lakeshores such as Emerald Lake.

Overall, the potential for ecological change in areas of dispersed visitor use is largely driven by visitor behavior. The predictions made in our social-ecological model are accurate as long as patterns of visitor use do not change. As such, these results are a "snapshot" in time representing visitor use patterns as they existed when the GPS tracking of visitors occurred (Lawson et al., 2003). Simulation modeling exercises, specifically agent-based models, can provide a way to model the relationship between visitor use and ecological consequences under changing use or management scenarios (Lawson et al., 2008). Heretofore, agent-based models of visitor use have not been used extensively in recreation ecology or visitor management (Gimblett et al., 2014). However, the static information produced in this social-ecological model provide the inputs that could be used to create a predictive, agent-based model of visitor use.

5. Conclusions

Gimblett and colleagues (2014) argue that conventional models of recreation use are "not good enough" and that future models of recreation networks could be greatly improved by focusing on the interactions between both the biological and social systems involved in recreation. Presented here is a methodology for building a social-ecological model that examines how visitor behavior varies under different use level scenarios and the potential ecological consequences of those behaviors. Results indicate that visitor behavior is an important driver of ecological impacts and that in some cases, despite the presence of highly susceptible vegetation, recreation use has little potential for ecological impacts to vegetation. Such social-ecological models can help inform management decisions that allow for quality recreation experiences, even in off-trail areas of dispersed use, while still sustainably managing resource conditions for future generations.

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Table 3.1.
Combination scheme that was used to determine the level of potential for ecological change as a result of recreation use. KDEs of visitor density and RI scores were reclassified to a 1-5 scale prior to data combination.

Visitor Density Class	Vegetation Resistance Class	Potential for Ecological Change
1	1-2	High
1	3	Medium
1	4-5	Low
2	1-2	High
2	3	Medium
2	4-5	Low
3	1-2	High
3	3	Medium
3	4-5	Low
4	1-2	High
4	3	Medium
4	4-5	Low
5	1-2	High
5	3	Medium
5	4-5	Low

Table 3.2.
Summary of GPS tracking data collection efforts at the three study site locations.

				Number of Visitor GPS Tracks		
Park or Protected Area	Study Site	Response Rate	Average GPS Positional Error (m)	Total Collected in Overall Study	High Use	Low Use
YOSE	El Capitan Meadow	71%	1.7	98	45	45
ROMO	Alberta Falls	80%	6.4	301	68	37
ROMO	Emerald Lake	80%	6.4	301	23	14

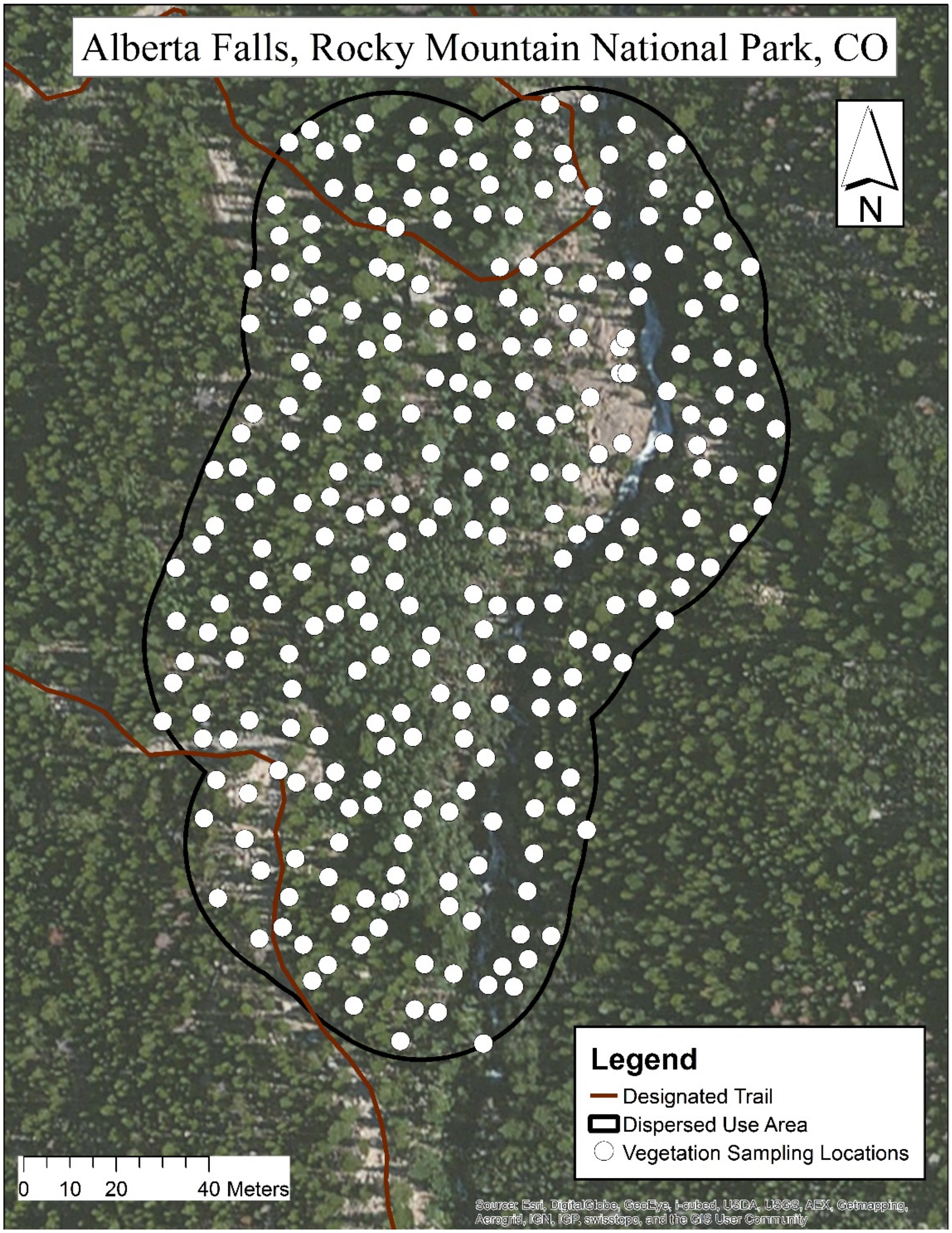


Fig. 3.1. Overall area of dispersed visitor use at Alberta Falls. White dots represent 1-meter quadrat sampling locations from which vegetation resistance was interpolated.

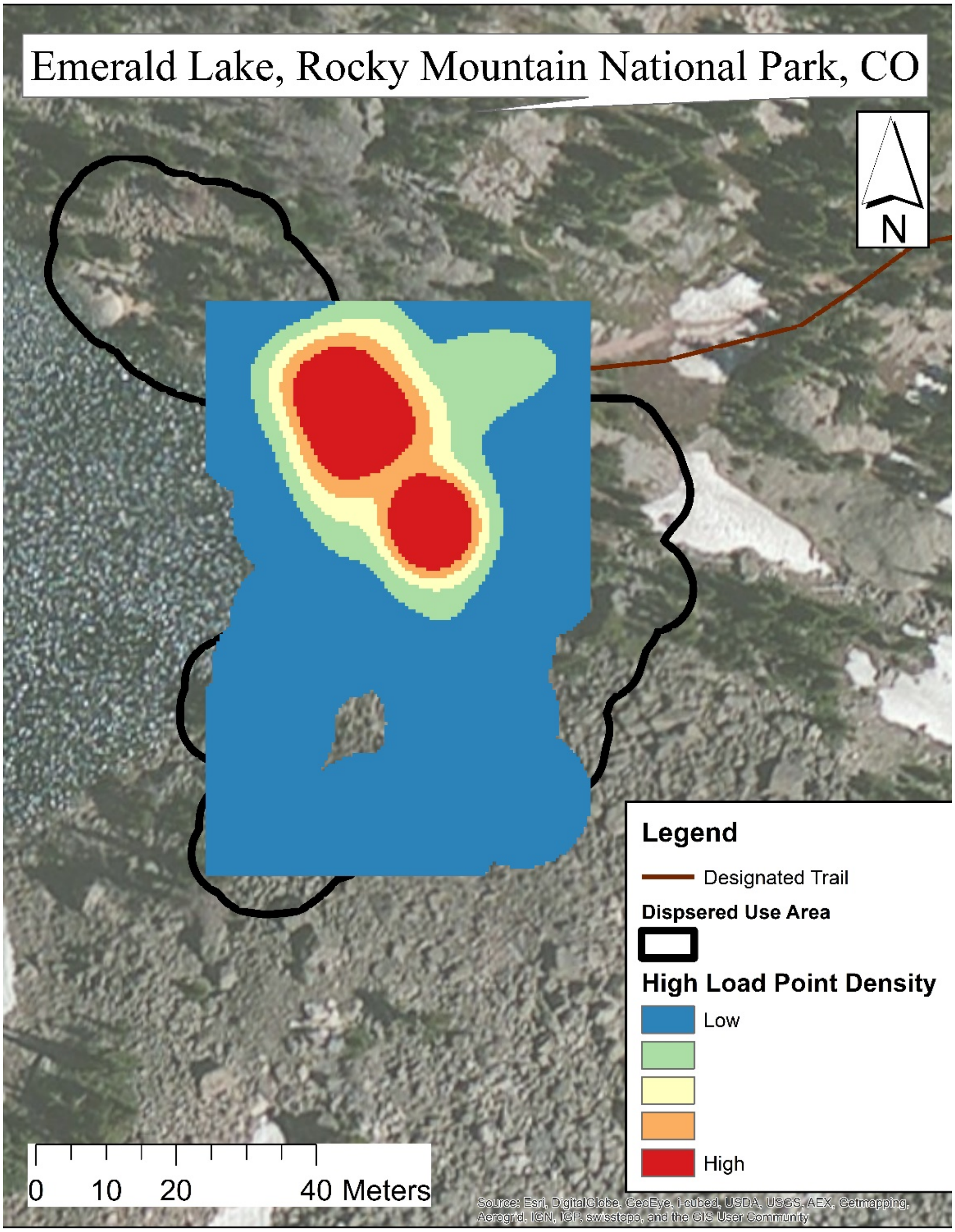


Fig. 3.2. Density of visitor tracking points at Emerald Lake during periods of high visitor use levels.

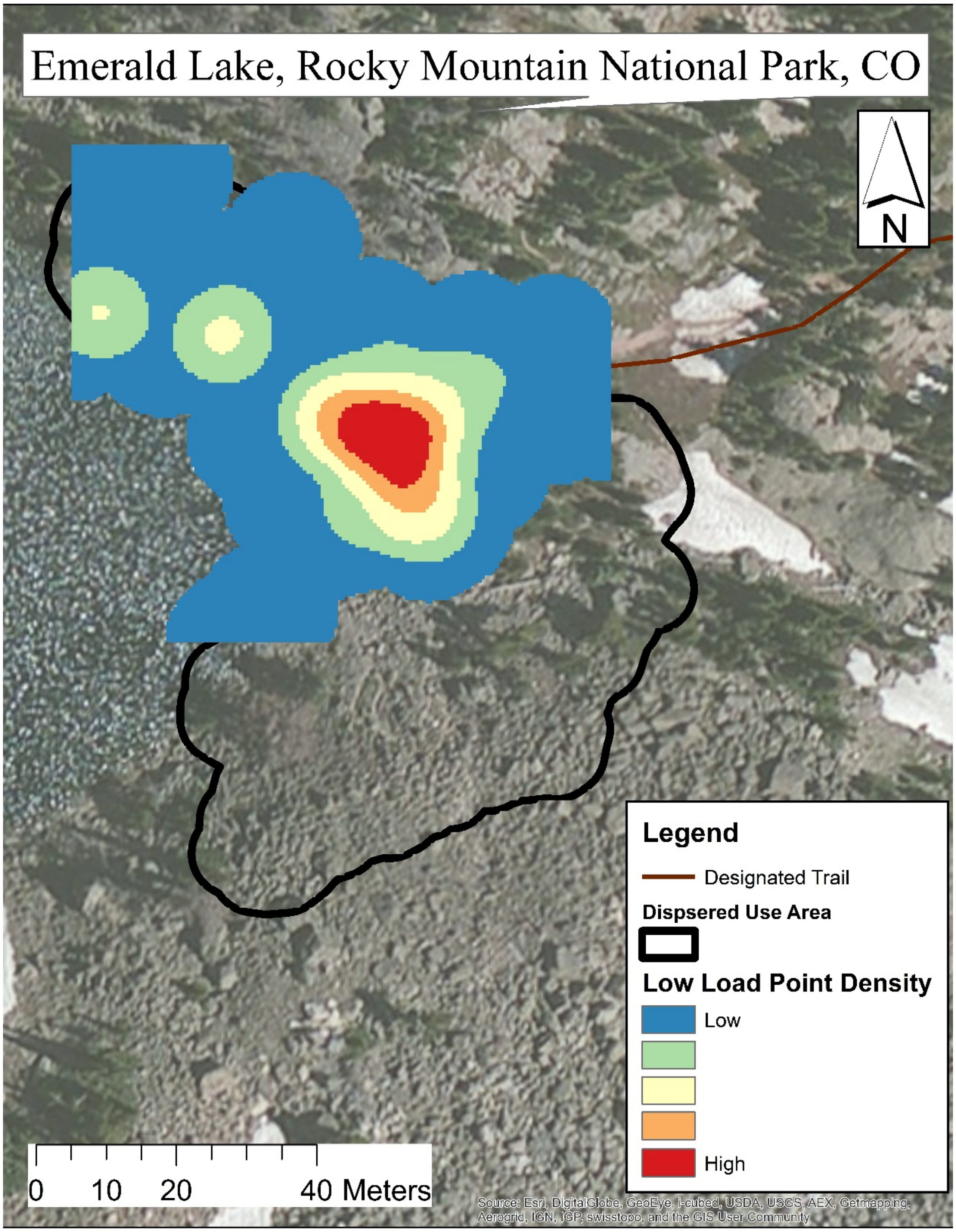
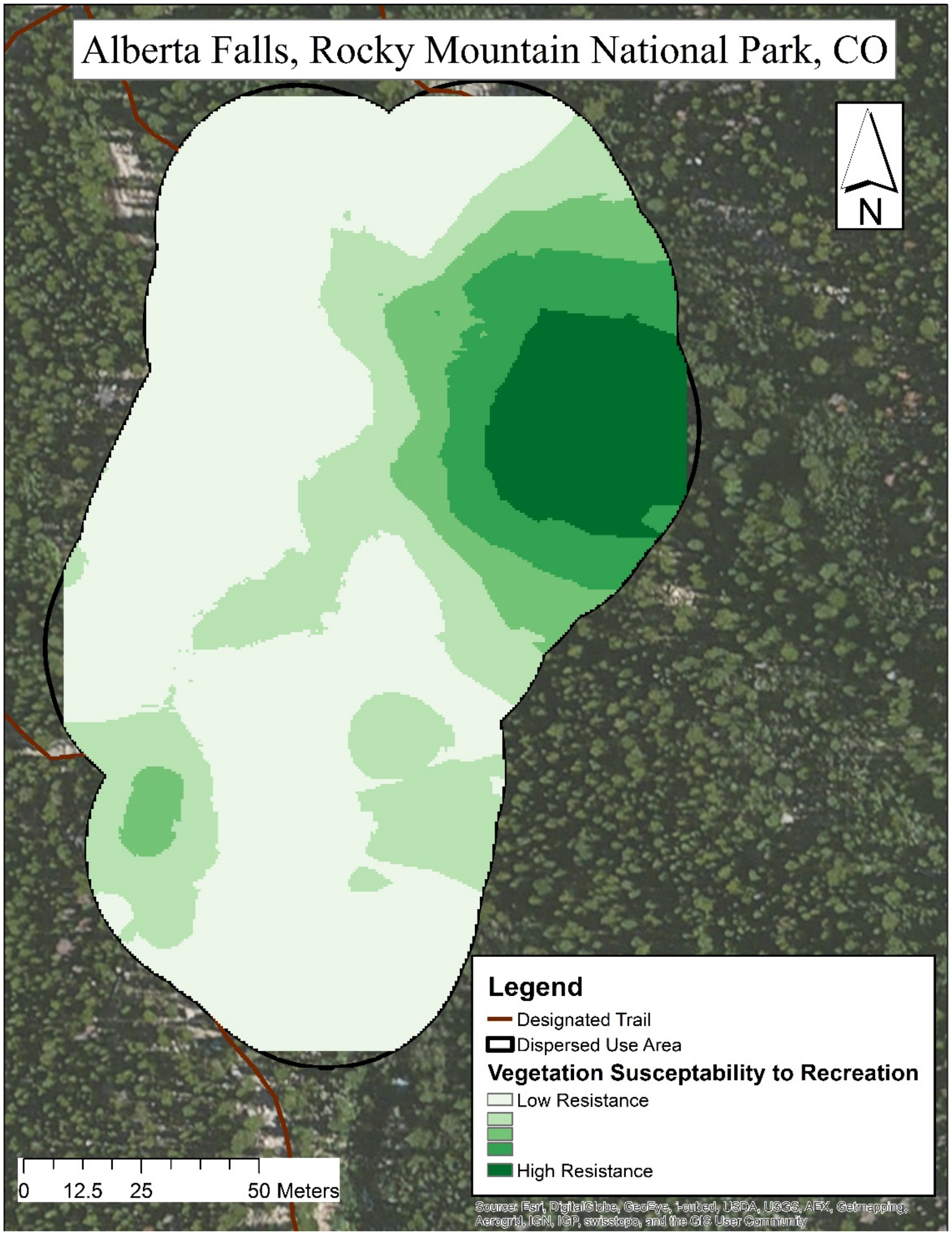


Fig. 3.3. Density of visitor tracking points at Emerald Lake during periods of low visitor use levels.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 3.4. Vegetation susceptibility, as measured by resistance to trampling disturbance, in the area of dispersed visitor use at Alberta Falls. RI ranges at Alberta Falls from a low of 600 to a high of 2,897 trampling passes.

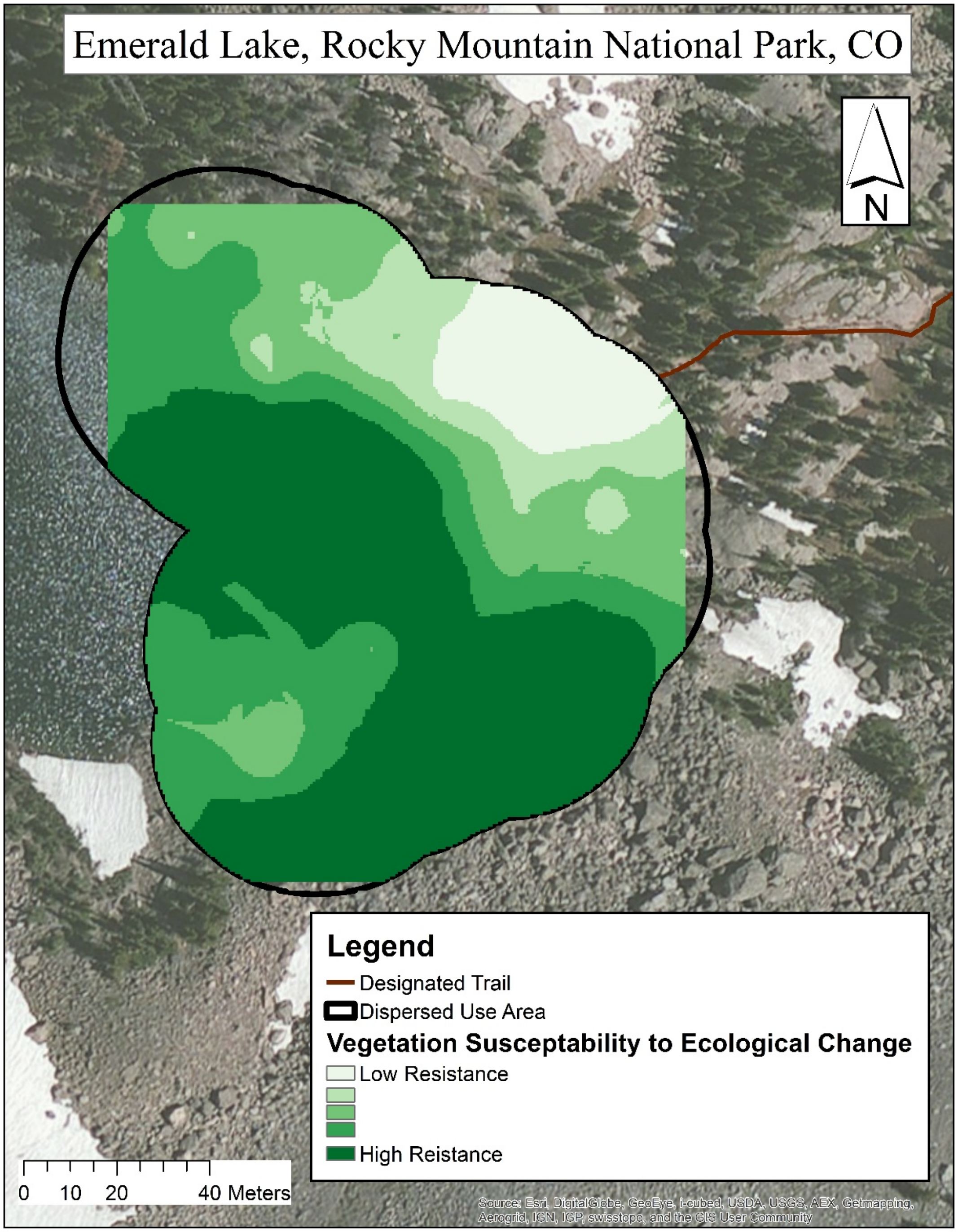
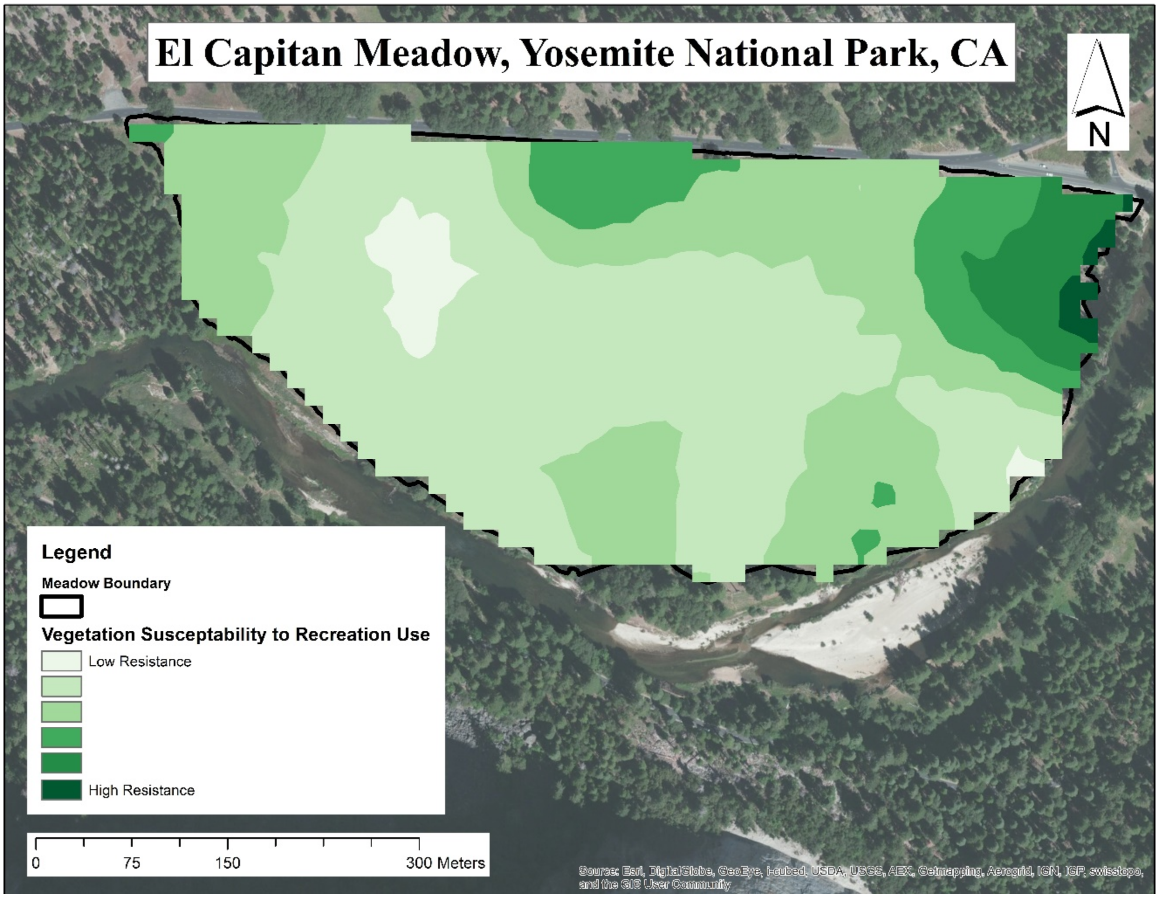
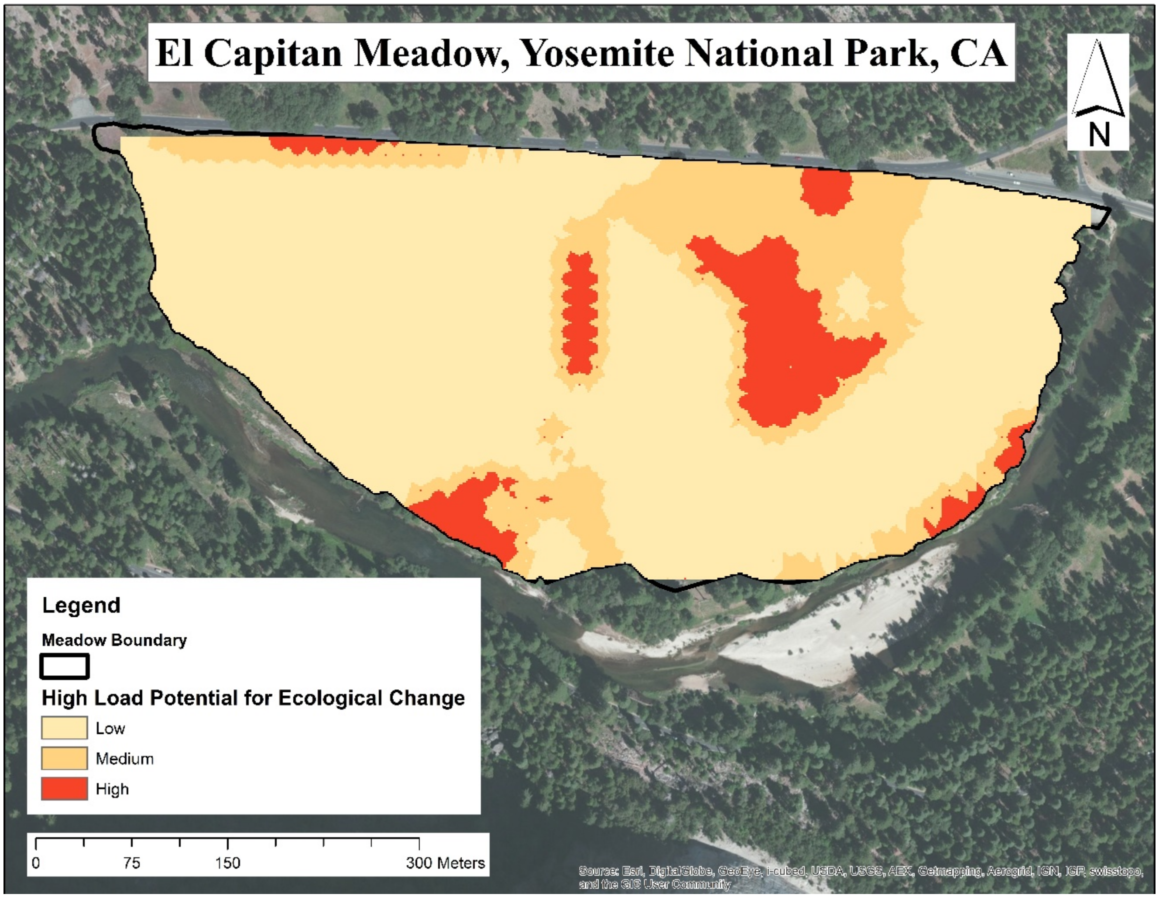


Fig. 3.5. Vegetation susceptibility, as measured by resistance to trampling disturbance, in the area of dispersed visitor use at Emerald Lake. RI ranges at Emerald Lake from a low of 600 to a high of 2,897 trampling passes.



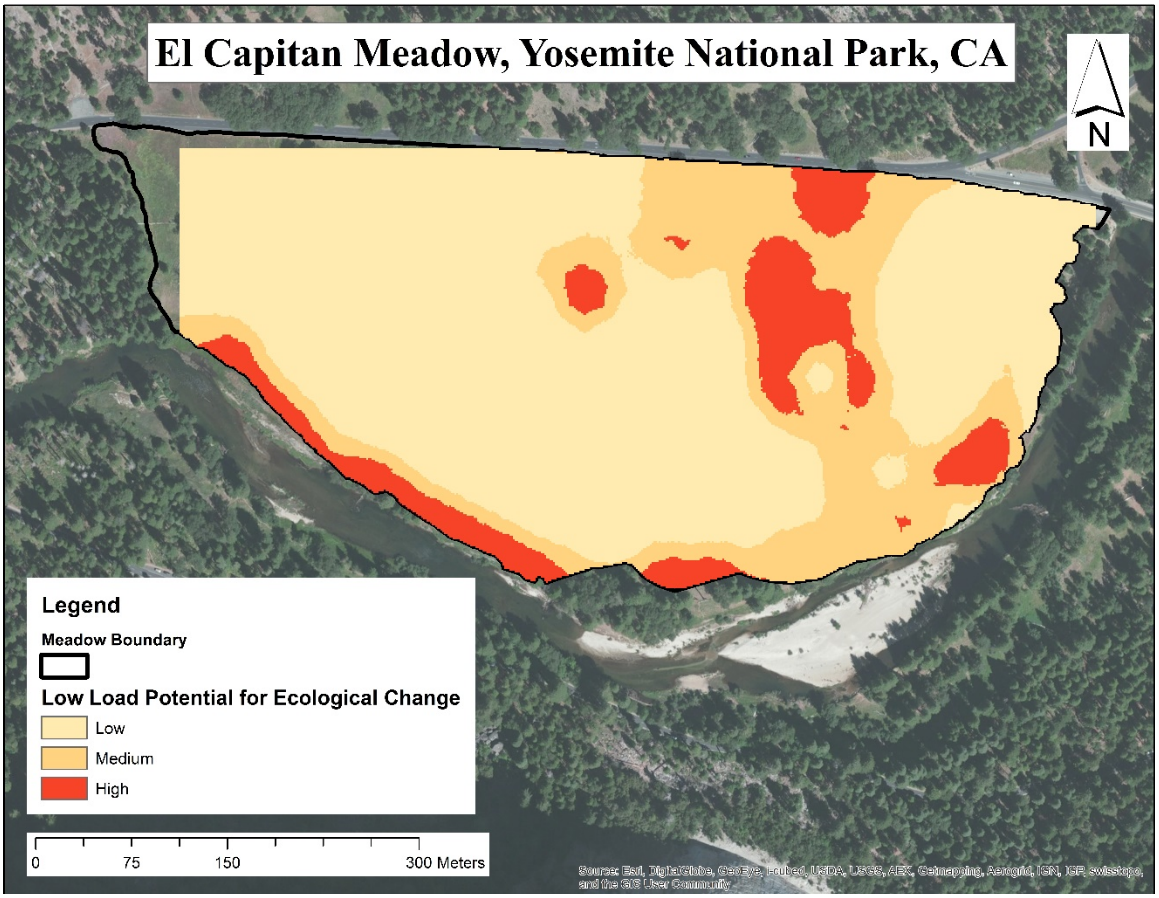
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 3.6. Vegetation susceptibility, as measured by resistance to trampling disturbance, in the area of dispersed visitor use at El Capitan Meadow. RI ranges at El Capitan Meadow from a low of 136 to a high of 1,341 trampling passes.



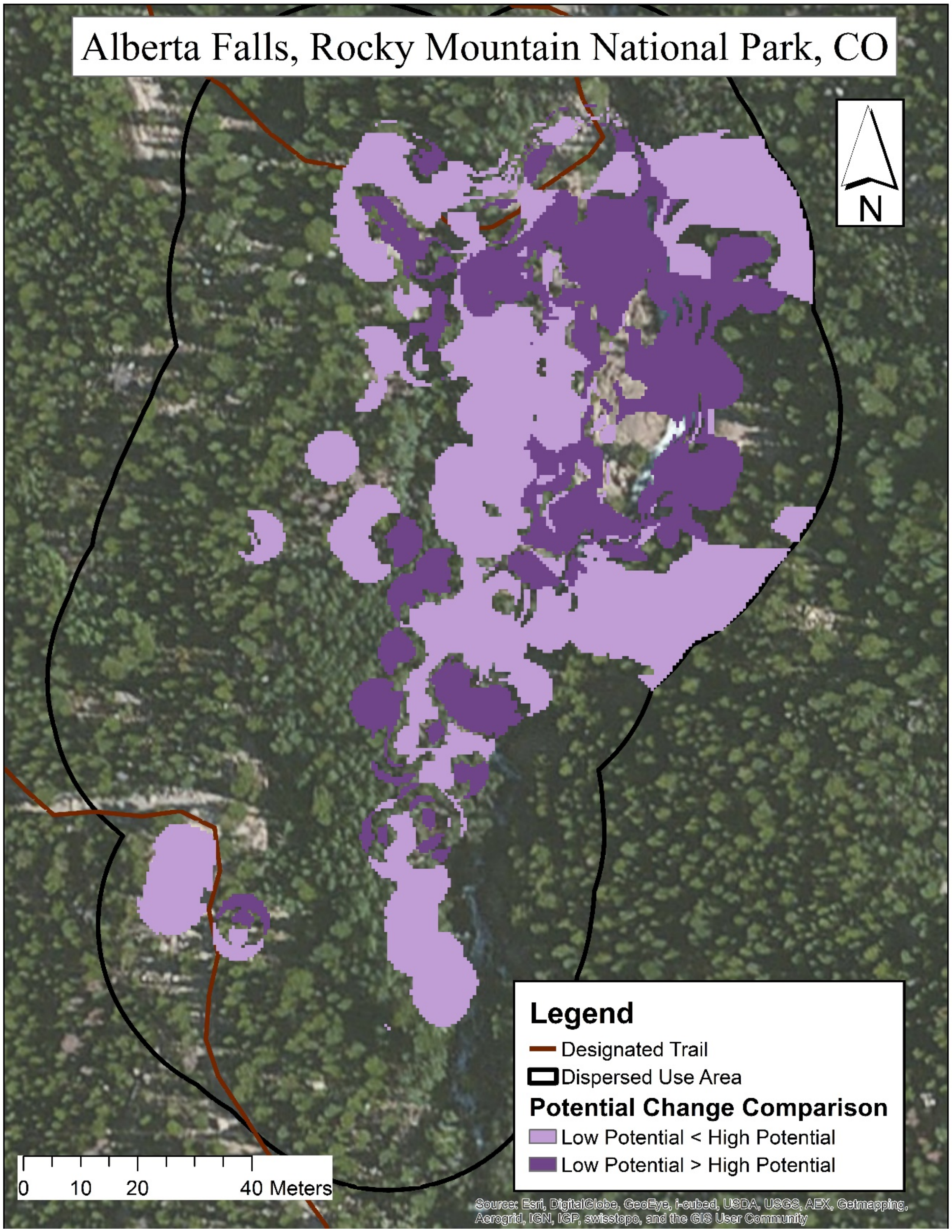
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 3.7. Areas of potential for ecological change as a result of recreation use at El Capitan Meadow during periods of high visitor use.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 3.8. Areas of potential for ecological change as a result of recreation use at El Capitan Meadow during periods of low visitor use.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 3.9. Comparison of potential for ecological change as a result of recreation use during different visitor use level scenarios.

See Appendix B for additional tables and figures showing GPS-tracking point densities, areas of potential ecological change, and comparisons for all study sites.

CHAPTER 4

USING GPS-BASED TRACKING DATA TO BUILD AN AGENT-BASED MODEL OF VISITOR BEHAVIOR IN AREAS OF DISPERSED RECREATION USE

Abstract

Simulation modeling techniques have been used in recreation settings to help managers become more proactive in their management decision-making. However, managing parks and protected areas in a way that both protects natural resources and provides quality recreation experiences is becoming increasing complex as visitor use increases. Agent-based models (ABM) are often considered the most accurate technique for representing complex human behavior such as visitor use. ABM are also capable of integrating seamlessly with Geographic Information Systems; possibly making them a superior modeling technique for social-ecological systems. The lack of detailed, individually-based, georeferenced data on visitor use has hindered the developed of ABMs in recreation settings. This paper demonstrates how GPS-based tracking methodologies, which are becoming more common in recreation management studies, can be used to build the agent groups and the rules needed to develop an ABM. Off-trail, dispersed visitor use in El Capitan Meadow is utilized as a case study to develop this framework.

1. Introduction

Understanding visitor distribution, movement, and interactions across a landscape can help inform management decisions regarding resource protection and visitor management. Spatial components of visitor behavior have the potential to influence not only the biophysical environment but the experiential environment as well. Level of impact to biophysical resources is dependent on ecological factors as well as visitor behavior (Hammitt et al., 2015). The quality of a visitor experience can be influenced by the behavior of other visitors. For example, perceptions of crowding have been shown to be influenced by the characteristics of “others” that are encountered while recreating as well as the location where the interactions occurs (Manning, 2011; Manning et al., 2000).

The role of visitor behavior in both social and biophysical recreation impacts emphasizes how it important it is that managers understand how visitors move within a park or protected area. Traditionally, visitor behavior has been monitored using descriptive techniques such as visitor counters, trip diaries, visitor surveys, and observational studies (Skov-Petersen and Gimblett, 2008). More recently, GPS-based tracking techniques have proved to be a reasonable and robust alternative to paper-based measurement techniques (D'Antonio et al., 2010; Hallo et al., 2005). While providing managers with valuable information, traditional data collection techniques are static in nature, represent a "snapshot in time," and do not provide managers with any predictive capacity. Survey techniques and GPS-based tracking data, when used on their own, require managers to take a reactive approach to management. However, advances in computer technology since the 1970s have led to the creation of simulation modeling programs that use the static information collected through traditional techniques to create more dynamic and predictive modeling results (Lawson et al., 2003; Skov-Petersen and Gimblett, 2008).

1.1 Simulation modeling in recreation management

A simulation model attempts to imitate the operations involved in a real-world process or system over-time (Wang and Manning, 1999). Simulation models are most useful in understanding systems that are particularly complex and therefore cannot be accurately understood through direct observations (Lawson et al., 2003; Wang and Manning, 1999). Unlike traditional techniques to understand visitor behavior, simulation modeling provides a dynamic and stochastic view of recreation. As such, simulation modeling efforts provide managers with a proactive management tool which can allow them to "experiment" with different management techniques and visitor use scenarios (Lawson et al., 2003).

Cole (2005) provides a thorough review of studies that used simulation modeling approaches to answer a menagerie of management questions. Simulation modeling has successfully been used to examine simple patterns and distributions of visitor use for both terrestrial and aquatic-based recreational activities (i.e., Gimblett et al., 2002, 2005a, 2005b; Lawson et al., 2006). Modeling efforts have been used to examine visitor standards for people per view and people at one time (i.e. Manning et al., 2002; Valliere et al., 2005; Wang and Manning, 1999). Recently, modeling has been used to examine the result of different management actions and scenarios (i.e. Itami, 2005; Lawson et al., 2003, 2009, 2011; Newman et al., 2010).

There are a variety of simulation modeling programs applicable to park and protected area settings. The first simulation modeling effort was made in the 1970s through the combined efforts of the Forest Service and IBM (Gimblett et al., 2001; Lawson et al., 2003; van Wagtendonk and Cole, 2005). The model was called the Wilderness Use Simulation Model (WUSM) and was designed to examine visitor encounters in wilderness settings. The WUSM was costly and difficult for managers to run on their own; modeling efforts stopped after the early 1980s (van Wagtendonk and Cole, 2005). As technology improved there was a resurgence of interest in simulation modeling in the 1990s.

Since the 1990s, two main simulation modeling approaches have been pursued in the area of recreation management (van Wagtendonk and Cole, 2005; Wang and Manning, 1999). One effort uses a general purpose simulation modeling software called Extend which takes a *probabilistic modeling* approach (Lawson et al., 2003). The second effort focuses on using a rule-based approach to create a model where, instead of being assigned a specific route of travel, visitors are autonomous "agents” in the simulated environment; these models are referred to as *agent-based models* (Gimblett et al., 2001; Itami et al., 2003). A third type of modeling, *trace modeling*, also exists but is rarely used in examining visitor behavior. Trace-based models require the agent in the model to follow an entire, pre-programmed route without deviation (Skov-Petersen and Gimblett, 2008). Probabilistic models are an improvement on trace models in that agents do follow a programmed route but can make spatial choices at certain locations such as trail intersections (Skov-Petersen and Gimblett, 2008).

1.2. Agent-based models

Unlike probabilistic models, which assign agents to a particular travel route based on probabilities, agent-based models (ABM) are comprised of user-created agent rules. ABMs provide the means to build representations of visitor use that are more realistic than traditional probabilistic simulation models. ABMs use a series of assumptions that can be derived from observed visitor behaviors to define the actions of the agents (Crooks and Heppenstall, 2012). These ABM rules, often formed as "if-then" statements, govern the behavior of the agents in the model and certain rules can be triggered by changes in the agent's social or physical environment (Crooks and Heppenstall, 2012; Itami, 2005). The behavior of agents in the model is also driven by the agents being "attracted to" or "repelled by" other agents or aspects of the environment (Torrens, 2012). Overall, ABMs afford the agent (i.e. visitor) way-finding logic based on environmental characteristics (Skov-Petersen and Gimblett, 2008).

ABMs are especially appropriate when agent decisions and actions vary greatly and when an individual agent's actions influence the decisions/actions of other agents in the model or by the environment (O'Sullivan et al., 2012). As such, ABMs are excellent tools for modeling human behavior, especially in recreation use scenarios where visitors are interacting with each other as well as the surrounding environment (Crooks and Heppenstall, 2012). The result of an ABM is simulated data that can be analyzed and then used to inform recreation management decisions (An, 2012). In many recreation management scenarios, experimentation with management actions is undesirable as it can result in unintended recreation resource impacts. ABMs are also a powerful modeling tool that allows for experimentation in situations where conducting actual experiments are undesirable or impossible (Abdou et al., 2012).

Pedestrian models have been built using ABM tools but the majority have examined more urban-based phenomena such as way-finding in cities, the dynamics of crowds, and evacuation scenarios (Johansson and Kretz, 2012; Torrens et al., 2012). Skov-Petersen (2008) predicted an increase in the use of ABM in recreation planning and management as technology improved. The few ABMs that have been built to examine visitor use in natural areas have focused on pedestrian models with inputs derived from visitor counts obtained by automatic cameras and/or automatic trail counters placed on recreation networks such as trails (Gimblett and Skov-Petersen, 2008). As such, the agents in these early ABMs models must remain "fixed" to established recreation trail networks.

Although modeling on-trail behavior is important for recreation managers, the majority of recreation impacts occur when visitors travel off of hardened surfaces such as trails. The main constraint to more sophisticated pedestrian simulation models, that incorporate off-trail behavior in recreation settings, has been the need for higher-resolution, geo-temporal data from visitors in parks and protected areas (Taczanowska et al., 2008a). ABM may provide a more accurate representation of recreation use when compared to other simulation modeling techniques but any simulation is only valid if the rules of human behavior are specified correctly. Many ABMs of pedestrians are developed using rules derived from particle physics instead of actual measures of human behavior (Lawson et al., 2009; Torrens et al., 2012). More research is needed to accurately define generalizable rules for human behavior that could then be incorporated into an ABM (Lawson et al., 2009).

Studies that have explored the use of ABMs in recreation settings have emphasized that individual-level visitor data is incredibly important for accurate rule generation and model building (Garthe, 2010). Heretofore, such detailed data has been unavailable. GPS-tracking methodologies, which have not been used extensively in other ABM exercises, provide a means of gathering individual visitor behavior data that can serve as an input for the ABM (Taczanowska et al., 2008a). Fortunately, GPS-based tracking methodologies are becoming increasingly common in recreation management (Beeco et al., 2013, 2014; D'Antonio et al., 2013; Hallo et al., 2012; Kidd et al., 2015). Yet, no studies have attempted to use GPS-based tracking data to build ABMs of recreation use. Robust GPS-based tracking data of visitor behavior provides the level of detail needed to generate accurate agent rules that can serve as input for ABMs of recreation use both on and off-trail (D'Antonio et al., 2010).

1.3. Social-ecological simulation models

Simulation models, including ABMs, have also not been used in many integration exercises. There is potential to combine simulation modeling with resource level information to better understand how visitors are interacting with biophysical resources (Lawson et al., 2003). A few static, social-ecological models of recreation use have been created recently (Beeco et al., 2014; D'Antonio et al., 2013). However, recreation planning and management has become increasingly complex as visitor use has increased in many parks and protected areas. ABMs, more so than other simulation modeling techniques, are capable of handling the social and biological complexities of modern recreation management (Skov-Petersen, 2008). Advances in GIS technology make the possibility of a linkage between simulation models and biophysical impacts feasible (Skov-Petersen and Gimblett, 2008). There has been an increasing interest in the ability to link ABM, specifically, to GIS environments (Crooks, 2015; Crooks and Castle, 2012; Torrens, 2012).

Most simulation modeling exercising thus far have examined large scale visitor movements and have not been designed in a way that allows the models to examine site-specific, visitor use patterns at smaller scales (Garthe, 2010). ABMs, although capable of modeling across a variety of spatial scales, are well-suited for simulation modeling exercises where visitors respond to the surrounding environment at specific visitor sites (Crooks, 2015; Garthe, 2010). Chapter 2 of this dissertation indicated that site-specific characteristics and levels of visitor use are important drivers of visitor behavior in off-trail areas of dispersed use. By incorporating these visitor behaviors into a social-ecological model of recreation disturbance, Chapter 3 showed that visitor behavior can be an important driver of ecological change in off-trail areas. However, both of these models were static in nature and were limited in their predictive capacity.

Therefore, this study aims to 1) demonstrate that GPS-based tracking methodologies can be used to generate the level of data needed to create rules for an ABM of recreation use and 2) demonstrate how an ABM could be used to "ramp-up" the data from the GPS-based tracking sample to represent the total use observed at a single recreation site in a single day. Overall, this study represents a proof-of-concept exercise that GPS-based tracking methodologies are ideal for creating, predictive social-ecological ABMs of visitor behavior in off-trails areas of disperse recreation use.

2. Methods

2.1 Study site

El Capitan Meadow in Yosemite National Park (YOSE), California was chosen as the case study location. YOSE is located in close proximity to the San Francisco Bay Area; making it one of the most visited national parks in the United States. In 2014, YOSE received over 3.9 million visitors to the park. El Capitan Meadow is located in Yosemite Valley, one the busiest parts of YOSE, at the base of El Capitan. The meadow is a popular stopping location for visitors to YOSE as they leave Yosemite Valley and a favorite location for photographers. El Capitan Meadow is bordered on its north edge by the park road and on its southern edge by the Merced River. El Capitan Meadow contains no designated trails and very little park infrastructure (Fig. 4.1). To recreate at El Capitan Meadow visitors must park along the shoulder of the road or take the park shuttle bus to a stop near the meadow. Results from Chapter 2 suggest that visitor use patterns at El Capitan Meadow are counter-intuitive. During periods of high visitor use, visitor tend to congregate together while during periods of low visitor use visitors tend to spread out further into El Capitan Meadow.

El Capitan Meadow was chosen as an appropriate study site for demonstrating the utility of GPS-based tracking methodology for building ABMs for a variety of reasons. All recreation in El Capitan Meadow is considered off-trail, dispersed visitor use; a type of use often ignored in simulation modeling exercises. Additionally, El Capitan Meadow is a flat meadow with almost no topography to influence visitor movement. Visitor dispersion out of the meadow is constrained by the presence of the park road and the Merced River. Finally, the protection of El Capitan Meadow from degradation is a priority for managers in YOSE, making the location important from an ecological and managerial standpoint.

2.2 Data collection at study site

In 2011, a GPS tracking study was conducted at El Capitan Meadow (D'Antonio et al., 2010). When visitors arrived at El Capitan Meadow in their vehicle or by the shuttle bus, they were randomly intercepted at the meadow's edge and asked to participate in the study. Visitors who were willing to participate were then asked what their anticipated recreational activity was at the meadow and then handed a Garmin 60x GPS unit. The question about recreational activity type was used to ensure that the intercepted visitor was part of the sample population (visitors to El Capitan Meadow) and that they were planning on leaving their vehicle to recreate at the meadow. Visitors carried the GPS unit with them while they recreated in or near El Capitan Meadow. The GPS units recorded the visitor's location every 15 seconds and the units were returned to researchers as visitors left the El Capitan Meadow area. GPS tracking occurring in July and August, the busiest times in YOSE, and sampling was conducted on random weekend days and weekdays. Sampling was also split up into A.M. and P.M. sampling periods.

While GPS tracking occurred, observations of visitor use levels and behaviors were also recorded. Researchers recorded the number of vehicles parked along the edge of El Capitan Meadow, the number of visitors recreating along the shoulder of the road, and the number of visitors recreating in the meadow proper. These observational counts were used to identify periods of high visitor use and low visitor use at the El Capitan Meadow. Finally, a calibration procedure was used to determine the site-specific accuracy of the Garmin 60x GPS units. This calibration procedure involved comparing a random sample of tracks from Garmin 60x units from those used for tracking on that day with a known high accuracy track assessed to sub-meter accuracy with a Trimble Geo XT.

2.3 Generating agent groups

The subsequent GPS tracks that were collected at El Capitan Meadow were uploaded into ArcGIS as point features. Each GPS track (visualized as a series of points) was assigned a unique ID number based on the date the track was collected and the GPS unit number used to record the track. This ID number allows for each unique visitor track to be separated from the overall dataset and examined individually. The GPS-based tracking data from El Capitan Meadow was split into two datasets; one containing the points that were collected during periods of high visitor use and one containing the points that were collected during periods of low visitor use. The same agent group generating procedure (as outline below) was used for both datasets resulting in two sets of agent rules and two sets of agent groups – one to be used to model periods of high visitor use and one to be used to model periods of low visitor use.

In addition to the unique ID number, each GPS track was assigned an ID that represents the activity type that the visitor reported they were participating in at El Capitan Meadow that day. Activity types were grouped into the following categories and IDs:

- M = general meadow users (includes the response “I do not know”)
- P = general photographers

- PM = photographers that said they were going to photograph from the meadow
- PR = photographers that said they were going to photograph from the road
- V = El Capitan viewers (no mention of photography)
- W = meadow wanderers (i.e. "I am going to walk in the meadow")
- O = other activities (i.e. picnicking, climbers scoping routes on El Capitan, etc.)

The first step in generating rules for an ABM of recreation use at El Capitan Meadow was to determine what proportion of the visitors tracked with GPS units left the roadside and entered the meadow (see green box in Fig 4.2). From a recreation management stand-point, we are most concerned about modeling visitor use *in* the meadow because that is where visitor use is likely to result in the most ecological impact. The "off-trail" visitor tracks were separated from the overall dataset and only these off-trail tracks were used to generate the overall rules. From this subset of off-trail meadow users, the next step was to determine what proportion of activity types occurred in the meadow during periods of high and low visitor use. The activity ID codes were used to determine a frequency of activity types that occurred in the meadow during each use level period. Once the activity type proportions were determined the next step was to examine the spatial distribution of these activity types in El Capitan Meadow.

El Capitan Meadow was divided into 5 "visitor use zones." This delineation of the meadow provided a better visualization of visitor movement throughout the meadow and created locations in the meadow that the agents could be "attracted" to while moving in the model. These zones were generated using the median center of all of the GPS-based tracking data from El Capitan Meadow (see Chapter 1) and then a Euclidean distance surface was created in ArcGIS from this median center point. The Euclidean distance surface was separated into 5 "zones" that represent different distances and visitor use areas emanating from the core visitor use area in El Capitan Meadow (Fig. 4.3). The visitor use zones data layer is a raster with a grid size of 3-meters by 3-meters. This size was chosen based on the average distance that visitors moved between GPS-based tracking points. On average, visitors moved 3-meters in the 15-seconds between GPS points being recorded at El Capitan Meadow.

Once the visitor use zones were created, the next step was to determine the proportion of different visitor activity types that occurred in those visitor use zones and how long visitors lingered in these visitor use zones while recreating. An average time spent in each of the different visitor use zones, by activity type, was calculated as was a standard deviation. These values (extracted as hours and minutes) were then converted to “time steps” or the number of 15-second time chunks that visitors spent within each visitor use zone. This conversion allows for model simplification; instead of modeling visitor speed, the agents will simply move one cell per time step and time in the model will be recorded in terms of the number of time steps (or number of 15-second chunks).

Once all of this descriptive information was gleaned from the GPS-based tracking point datasets, the information was used to create two agent groups: one that would represent visitor behavior during periods of low visitor use (the low use agent group) and one that would represent visitor behavior during periods of high visitor use (the high use agent group). One simple way to use an ABM of recreation use is to extrapolate from the sample of GPS-based track collected at El Captain Meadow to total visitor use levels for an average day at El Capitan Meadow. Therefore, the number of agents in each agent group is equal to the average number of visitors actually observed off-trail in El Capitan Meadow during periods of high and low visitor use.

To build the agent groups, each agent in the model was assigned an activity type based on the proportion of activity types observed in the GPS-based tracking data. Then each agent was assigned a visitor use zone that would serve as that agent’s attractant in the model (the area the agent would want to move towards). These zone assignments were based on the proportion of that agent’s activity type that recreated in the different visitor use zones. The next step was to assign the agent a number of model time steps to spend in its assigned visitor use zone. For each activity type and visitor use zone combination, a normal distribution was created using the mean and standard deviation of time spent in the assigned visitor activity zone. The mean and standard deviation used were those extracted from the GPS-based tracking data. Then, for each agent, a random time was selected from the appropriate activity type/visitor use zone distribution and assigned to that agent. The times were then converted to a number of 15-second time steps. All of this information was stored in a spreadsheet that would then be brought into ArcGIS as an attribute table for the agents in the ABM (see blue boxes in Fig 4.2).

2.4 Rule building

Two agent groups were created—one generated using the GPS-based tracking data collected during periods of low visitor use and one generated using the GPS-based tracking data collected during periods of high visitor use. The first step in building rules for agent movement in an ABM is to generate starting locations for all of the agents in the two agent groups. An examination of the GPS-based tracking data indicates that the majority of visitors begin their visit at El Capitan Meadow along its northeastern edge. This area was highlighted and identified as the "agent input area." Each agent was assigned random X and Y coordinate within this agent input area as their starting location in the ABM. Then the agents move within El Capitan Meadow following the rules outlined and justified in Table 4.1 (also see orange boxes in Fig 4.2).
The two agent groups created and the rules from Table 4.1 were then coded in program R to build the ABM. The two output files (one for each agent group) from the model were saved as line features and exported into ArcGIS for visual analysis.

3. Results

3.1. Study site data collection

Overall, there was a 71% response rate at El Capitan Meadow for the GPS-based tracking component of the study. This response rate indicates that a representative sample of visitor use was collected in the study. In total, 122 GPS tracks were collected at El Capitan Meadow in 2011. However, after removing tracks that contained high levels of error, there were 98 useable tracks. Positional error at El Capitan Meadow was calculated to be 1.7 meters. Of these 98 tracks, 45 tracks were collected during periods of high visitor use and 45 tracks were collected during periods of low visitor use. The remaining 8 tracks were given to visitors that recreated north of El Capitan Meadow and therefore were not included in this analysis.

During periods of high visitor use, which occurred daily between 2:00pm – 6:00pm, there were on average 472 visitors observed recreating at the meadow. During periods of low visitor use, which occurred between 9:00am – 2:00pm, there were on average 237 visitors recreating at El Capitan Meadow. During periods of low visitor use 65% of visitors observed left the road shoulder and traveled off-trail to enter El Capitan Meadow. During periods of high visitor use, 80% of visitors observed left the road and traveled off-trail to enter El Capitan Meadow.

3.2 Agent groups

The low use agent group, which represented off-trail visitor use in El Capitan Meadow during low use periods, consisted of 155 agents. The high use agent group, which represented off-trail visitor use in El Capitan Meadow during high use periods, consisted of 378 agents. In the low use agent group the majority of agents were categorized as general meadow users (24%), individuals planning on taking photographs along the road (22%), or visitors wanting to view El Capitan (26%). In the high use agent group the majority of agents were categorized as visitors planning on taking photographs from the meadow (46%) or from the road (23%). During periods of high visitor use, the majority of the agents were attracted to visitor use zone 1 (40%) or zone 2 (48%) (see Fig. 4.3). During periods of low visitor use, the majority of agents were attracted to zone 2 (37%) or zone 3 (33%).

The number of time steps agents spent in each visitor use zone varied by use level and activity type. Analysis of the GPS-based tracking data indicates that, on average, general meadow users, visitors who fell into the “other” category, and meadow wanderers spent more time in El Capitan Meadow as compared to the other visitor activity types. There was almost no difference in average time spent in El Capitan Meadow between visitors that were GPS tracked during high use periods (11 minutes 4 seconds) and visitors that were GPS tracked during low use periods (12 minutes and 30 seconds). However, the low visitor use period tracks had greater variability overall in time spent recreating in El Capitan Meadow. These observations about the amount of time spent in El Capitan Meadow are reflected in the agent groups built from the GPS-based tracking data. For the low use agent group, the range of time steps that agents spent in their assigned visitor use zone varied from 1 time step (15-seconds) to 382 time steps (1 hour 35 minutes and 30 seconds). The range of time steps for the high use agent group varied from 1 time step (15 seconds) to 130 time steps (32 minutes and 30 seconds). See Table 4.2 for an examples extracted from the agent group databases.

3.3 ABM output

Fig 4.4 shows the output for both the High Use and Low Use agent groups from the ABM built based on the rules from Table 4.1. Under the assigned rules, the ABM shows that the majority of simulated visitor use is occurring in close proximity to the road. The geometry of the dispersed use area of El Capitan Meadow (almost a half-circle) and the rules that require the agent to take the shortest available path to their assigned visitor use zone, is resulting in a pattern of dispersion that shows less dispersion than is expected at El Capitan Meadow (see Chapter 3). Fig 4.4 also shows that the ABM is not accurately capturing the visitor use that is known to be occurring in close proximity to the river on the southern border of El Capitan Meadow.

Given this output, a second model run was conducted with slightly adjusted ABM rules. In this second model run, a “river use zone” was added as an attractant. All agents in the agent groups that were assigned to visitor use zones 4 and 5 were reassigned to the river use zone. Additionally, instead of having the agents in the model take the shortest path to their attractant zone, each agent was assigned a random location in the attractant zone at their “destination”. Once an agent reached their destination then the same rules were following as the first model run with the agent moving randomly within that zone for the assigned number of time steps. The output from this second model run can be seen in Fig 4.5. The second run of the ABM shows that the new rules imposed on the agent groups results in greater dispersion in the meadow. In Fig 4.5 there is now visitor use occurring adjacent to the Merced River. In the second ABM, the simulated visitor use appears to be more evenly distributed in El Capitan Meadow that was observed during data collection (see Chapter 3).

4. Discussion

One of the first theoretical frameworks of a social-ecological ABM was developed to examine recreation use in a forest system (Deadman and Gimblett, 1994). At the time, the authors noted that to advance ABM efforts in the field of recreation, researchers would need to have a solid theory of how recreationists interact with each other and their environment. A lack of understanding of visitor behavior in recreation settings halted the advancement of ABM in recreation use planning. Recent advances in GPS-based tracking methodologies and the analysis of GPS tracking data has elucidated many aspects of visitor behavior. Such advancements have provided the knowledge and resources for creating meaningful ABM of recreation use that can help inform management decisions.

ABMS are particularly useful in examining systems where the agents themselves and the interactions between agents are heterogeneous and complex. ABMs are also perfectly suited for modeling system interactions, such as the relationships in social-ecological systems, within a geospatial environment (Crooks and Heppenstall, 2012; Filatova et al., 2013). Recreation use in a park or protected area fits all of these criteria. Visitors are heterogeneous and their interactions with the environment and each other is both varied and complex. Recreation takes place in natural areas and it is assumed that visitors behave in response to their environment (Taczanowska et al., 2008b). However, traditional simulation modeling techniques are not well equipped to examine the interplay between visitor behavior and the environment. Geospatial modeling, and ABMs in particular, may be the best methodology for building predictive social-ecological models of recreation use; especially in areas of dispersed use where visitors are not confined to hardened surfaces or known networks.

The agent groups and rules created in this chapter were used to create an ABM of visitor use in off-trail areas of dispersed recreation use. The results from the two ABM runs conducted in this study show that we can use GPS-based tracking data to create rules for visitor behavior and create models of visitor dispersion in off-trail areas. The differences between the model outputs (Figs. 4.4 and 4.5) show that simple changes to the rules that the agents follow in the ABM can result in significant changes in how the agents behavior and the level of dispersion that results. These findings emphasize the important of visitor behavior in overall patterns of visitor use and the importance of exploring further the details of visitor movement is off-trail areas of dispersed visitor use.

The agent groups presented here are meant to show that GPS-based tracking data can also be scaled-up to the level of total use, instead of just examining visitor behavior at the level of a sample of the total population. As demonstrated, ABMs are capable of storing and outputting the behavior of the agents from the model run. Therefore, the behavior of the two agent groups presented in this paper could be used to build density layers of visitor use (as demonstrated in Chapter 3). These density layers could then be combined with maps of vegetation susceptibility (also developed in Chapter 3). By combing ABM outputs with an ecological model of current resource conditions a more predictive social-ecological model of visitor use in areas of dispersed recreation use could be created.

4.1. Key model assumptions

One of the powers of agent-based modeling approaches is that agents can interact with each other in space and time. However, the ABM rules presented here do not include any interaction between agents. The ABM rules assume that agents are neither attracted nor repelled by each other. The use of GPS-based tracking techniques and development of new ways to analyze GPS tracking data are allowing us to just begin to understand the complex interactions between visitors and between visitors and their environment (see Chapter 1 and Chapter 2 of this dissertation). Results from Chapter 1 indicate that these interactions are site-specific. Further research is needed to be able to make generalizations or reasonable assumptions about how visitors interact with each other in areas of dispersed recreation use.

Since the ABM rules do not incorporate interactions between agents, it also does not include an explicit temporal component. The model behaves as if all agents arrived at the meadow at the same time. In other word, this proposed ABM does not include visitor "delivery" to El Capitan Meadow across a day. An ABM created from this data would not show use over the course of one day, but rather the summation of use in the meadow during one average day during the summer by combing models of periods of high and low use. Since the focus of this study was to explore how GPS-based tracking data can be used to build rules for an ABM, for simplicity, the temporal delivery of visitors to the areas of dispersed visitor use was ignored. However, future ABMs efforts could include this temporal component by using observational counts of visitor arrivals or data from infrared trail counters to determine arrival times and delivery amounts.

4.2. Model validation

One limitation to the use of ABMs is that there is no censuses in the literature pertaining to the best methods for validation or verification of ABMs (Crooks and Heppenstall, 2012; Filatova et al., 2013). ABMs have generally been validated by comparing the model output to real-world observations (Filatova et al., 2013; Rivers et al., 2014; Torrens, 2012; Vizzari et al., 2014). For example, Torrens (2012) validated two different ABMs of pedestrian use using observations of human movement and a sample of GPS based tracks. In the case of the ABM of recreation use conceptualized here, observational data and GPS-based tracking techniques provided the inputs to the model and therefore should not be used for validation.

Had the sample size of GPS tracks been larger, a subset of tracks could have been set aside from the data used to generate agent groups and rules then this subset could have been used in a validation set. Model validation in recreation settings could also be achieved by combining visitor behavior mapping techniques with GPS-based tracking methodologies (Walden-Schreiner and Leung, 2013). Visitor behavior mapping techniques could be used to validate ABMs built from GPS-based tracking data. However, Filatova and colleagues (2013) argue that validation in ABMs needs to move away from simple comparisons of real-world observations and move towards more objective sensitivity analyses. Overall, there is much room for advancement and development of ABM validation and verification procedures, especially in the realm of recreation use management.

4.3. Model improvement

The agent groups and rules presented here are a proof-of-concept that GPS-based tracking data can be used as inputs for creating ABMs of recreation use. There are a number of areas where the application of ABMs to recreation use could be improved. Most importantly, ABMs of recreation use could be greatly enhanced with a better understanding of how visitors behave in response to other recreationists. GPS-based tracking techniques, observational techniques, and/or motion-activated cameras could be utilized to determine under what conditions other visitors act as attractants or repellants (D’Antonio et al., 2010; Walden-Schreiner and Leung, 2013). Results from Chapter 1 hypothesize that during periods of high visitor use at El Capitan Meadow, visitors are attracted to other visitors which results in a clustering behavior.

However, at other recreation settings visitors tend to disperse more during periods of high visitor use which would be considered a repelling behavior in an ABM.

Empirically examining the finer details of visitor interactions (such as how far visitors prefer to be from other visitors or if there is a threshold where repellant or attractant behaviors switch) would allow for more finely tuned rules for an ABM of recreation use. Additionally, a better understanding of visitor attraction to specific features in the environment (such a viewpoints or groundcover vegetation types) would also help to refine future ABMs. Social science methodologies, specifically surveys, could be paired with GPS-based tracking techniques to better understand visitor's perceptions of their environment, their motivations, and their way-finding behaviors.

One aspect of ABMs that may have great potential in the realm of recreation management is that the agents are capable of learning, having memory, and gathering information from other agents and the environment (Crooks and Heppenstall, 2012). Agents can store information from their GIS environment such as where they have recreated or what vegetation communities they interacted with. Agents can also retain memories of interactions with other agents; such as numbers of encounters or "feelings" of crowdedness. The adaptive characteristic of the agents means that ABMS could be used to answer a variety of both social and ecological questions related to recreation management.

Possibly the most powerful aspect of ABMs is that the approach provides the means to examine different management scenarios at a specific recreation site using the same agent rules. Management activities - such as trail or road closures, visitor use limits, or changes in transportation infrastructure – can be examined in a more proactive way with the use of ABMs. As a simplistic example, if use levels doubled at El Capitan Meadow, the same rules generated in this study could be used to examine the social and ecological consequences of increased use by simply modeling twice as many agents per agent group. However, ABMs are capable of examining much more complex scenarios. By examining a variety of management scenarios, emergent behaviors of visitor use would be captured and potentially highlight any unintended consequences of these management actions.

5. Conclusions

In general, simulation modeling provides a tool that is useful for answering various management questions. At the most basic level, simulation modeling can provide a better understanding of visitor numbers and visitor distribution across the landscape (Skov-Petersen and Gimblett, 2008). Simulation modeling is especially informative when managers require the prediction of outcomes under changing management scenarios or changes to a system that are outside manager control; such as changes to use levels or visitor demographics (Skov-Petersen and Gimblett, 2008). ABMs allow for simulations that can incorporate visitor responses to changing conditions – both social and biophysical. When tied to GIS environments, ABMs can provide a visual component to the simulation and afford models that combine both social and ecological components. Along with social-ecological modeling approaches, increased predictive capabilities are essential as managers evaluate the possible outcomes of varying visitor use, density and frequency to visitor experience and resource conditions in wildland settings.

ABMs, built from rules generated from GPS-based tracking data, provide a new tool that can help park and protected areas managers plan sustainably in an increasing complex system. This conceptual exercise demonstrates the utility of using GPS-based tracking methodologies to generate agents groups and rules for these agents. By using descriptive information gathered from the GPS tracks of visitors, sampling-level data can be extrapolated so that an ABM could represent the total visitor use observed at El Capitan Meadow for an average summer day. The study presented here represents a proof-of-concept that GPS-based tracking methodologies, when paired with ABM techniques and GIS, have great potential to make the field of parks and protected area management more proactive and predictive. The framework for examining GPS-based tracking data and methodology for rule generation presented here can be applied to additional recreation sites and future ABM development.

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Table 4.1.
Summary of the ABM rules that the agents will follow and justification for those rules.

Movement Order	Rule	Justification
1	The agent will move only one cell per time step in the model.	Each cell size represents the average distance GPS tracked visitors moved in 15 seconds. Time steps represent 15 seconds.
2	The agent will be attracted to the particular zone in El Capitan Meadow that is was assigned.	Assumed that different recreation activity types will be attracted to different areas of the meadow for recreation. Attractant zone proportions were determined from the GPS tracks.
3	The agent will move through the meadow by taking the shortest distance to that attractant zone.	Assumed for model simplicity since very little is understood about the small-scale movement of visitors towards destinations in dispersed use areas.
4	Once the agent reaches its attractant zone it will move randomly (staying within that attractant zone) by either “choosing” to stay in its current cell or move into a neighboring cell.	Assumed for model simplicity. Little is known about small-scale movements of visitors once they reach an attractant. Some visitors may stay put while others wander slightly.
5	The agent will remain in the attractant zone for the number of time steps assigned to that particular agent.	Assumed that different recreation activity types will spend different amounts of time in the meadow for recreation. Time spent in attractant zone proportions were determined from the GPS tracks
6	Once the agent has lingered in the attractant zone for the assigned number of time steps, the agent will move out of the zone.	Represents a visitor beginning to end their recreation activity in the dispersed use area.
7	The agent will travel back through the meadow to its starting X and Y coordinates by taking the shortest distance possible based off of its final location in the attractant zone.	Assumed for model simplicitiy since very little is understood about the small-scale movement of visitors as they leave dispersed use areas.
8	Once an agent reaches its starting X and Y coordinates then the run of that agent is complete.	Represents a visitor leaving the dispersed use area and the recreation destination.

Table 4.2.
Examples of agents in each agent group database including their attractant visitor use zone and the number time steps assigned to that agent to spend in the attractant zone.

Agent Group	Agent Activity Type	Agent ID	Attractant Zone	Time Steps in Zone	Time in Zone
High Use	M	M1H	1	36	0:09:03
High Use	P	P1H	1	12	0:03:07
High Use	PM	PM1H	1	4	0:00:54
High Use	PR	PR1H	1	21	0:05:17
High Use	V	V1H	2	1	0:00:15
High Use	W	W1H	1	47	0:11:50
High Use	M	M2H	1	68	0:16:54
High Use	P	P2H	1	47	0:11:46
High Use	PM	PM2H	1	29	0:07:13
High Use	PR	PR2H	1	46	0:11:34
Low Use	M	M1L	1	59	0:14:45
Low Use	W	W1L	2	32	0:08:00
Low Use	O	O1L	1	24	0:06:00
Low Use	PR	PR1L	1	16	0:04:00
Low Use	PM	PM1L	1	20	0:05:00
Low Use	P	P1L	1	1	0:00:15
Low Use	V	V1L	1	7	0:01:45
Low Use	M	M2L	1	59	0:14:45
Low Use	W	W2L	2	24	0:06:00
Low Use	O	O2L	1	25	0:06:15

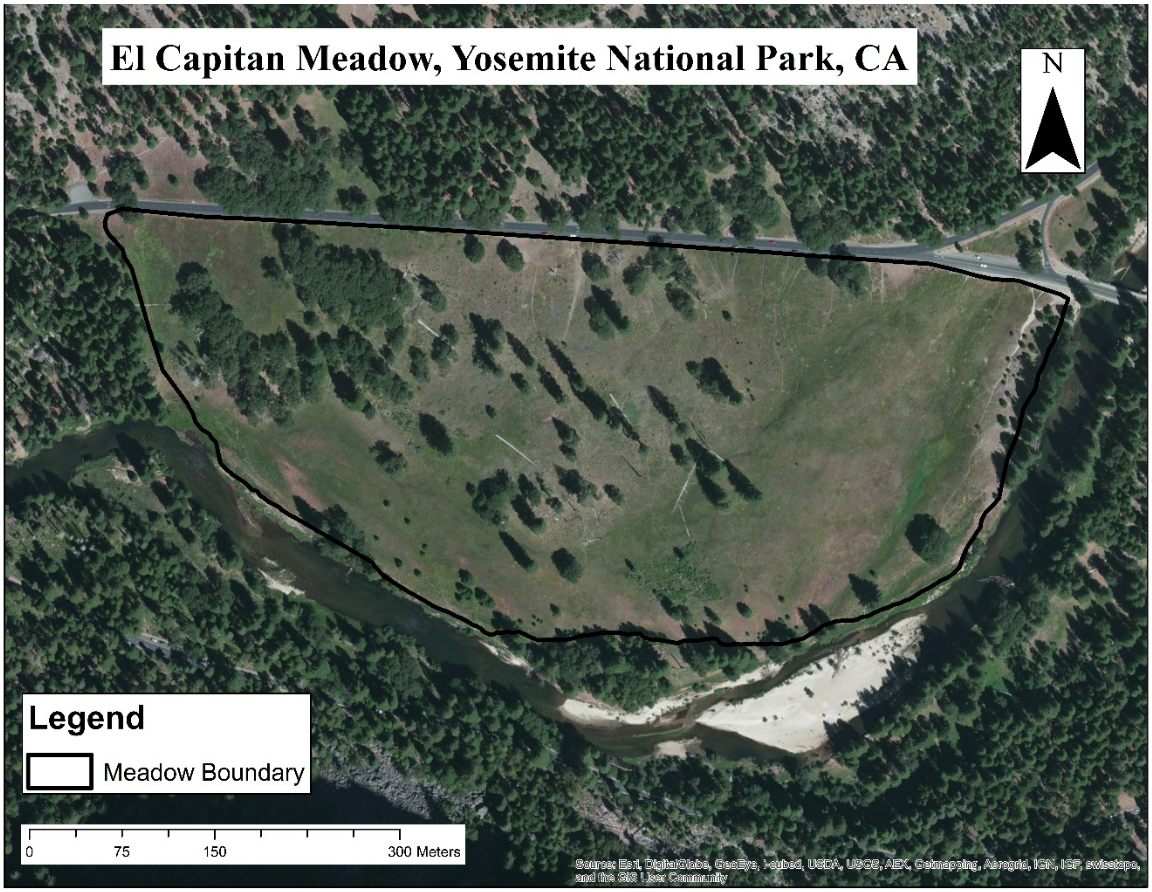


Fig. 4.1. Study area showing El Capitan Meadow management boundary which is bordered to the north by the park road out of Yosemite Valley and to the south by the Merced River.

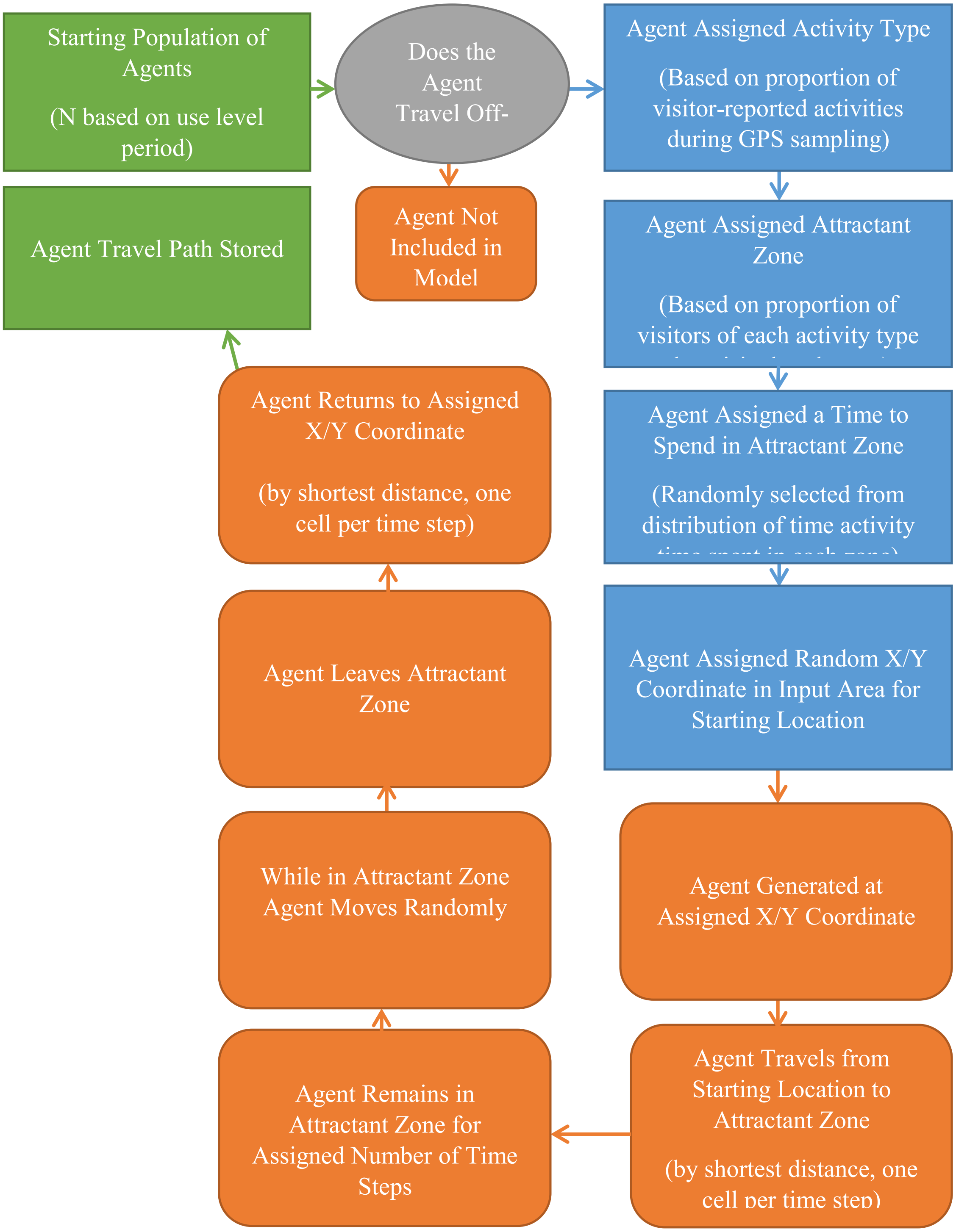
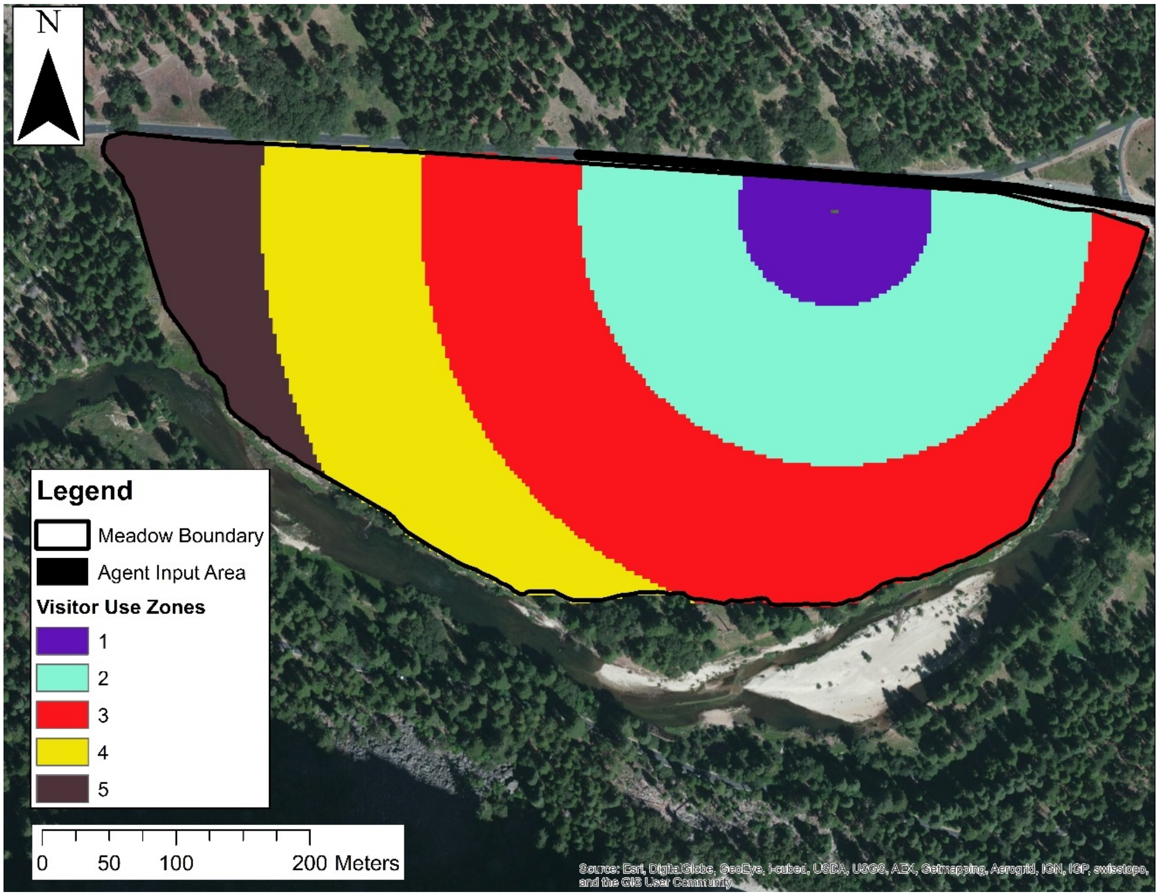
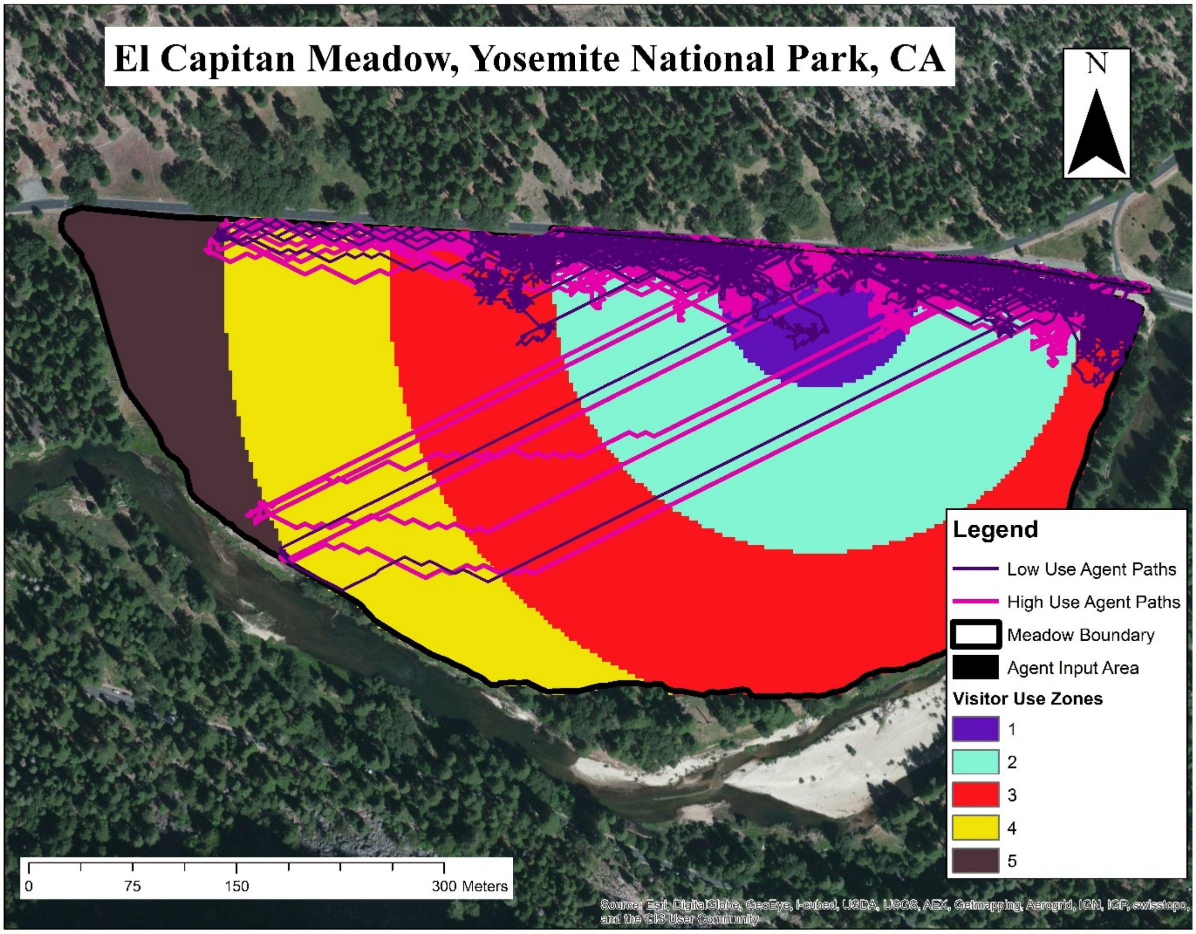


Fig. 4.2. Framework for developing agent groups and the rules for the agents in an ABM.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 4.3. El Capitan Meadow was split into 5 visitor use zones that would serve as attractants for the agents in the ABM. The black polygon on the northeastern edge of the meadow shows the input area where all agents started in the ABM. The zones were generated using Euclidean distance measures from the median center of the overall GPS-based tracking dataset.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 4.4. ABM output using rules from Table 4.1 for both agent groups.

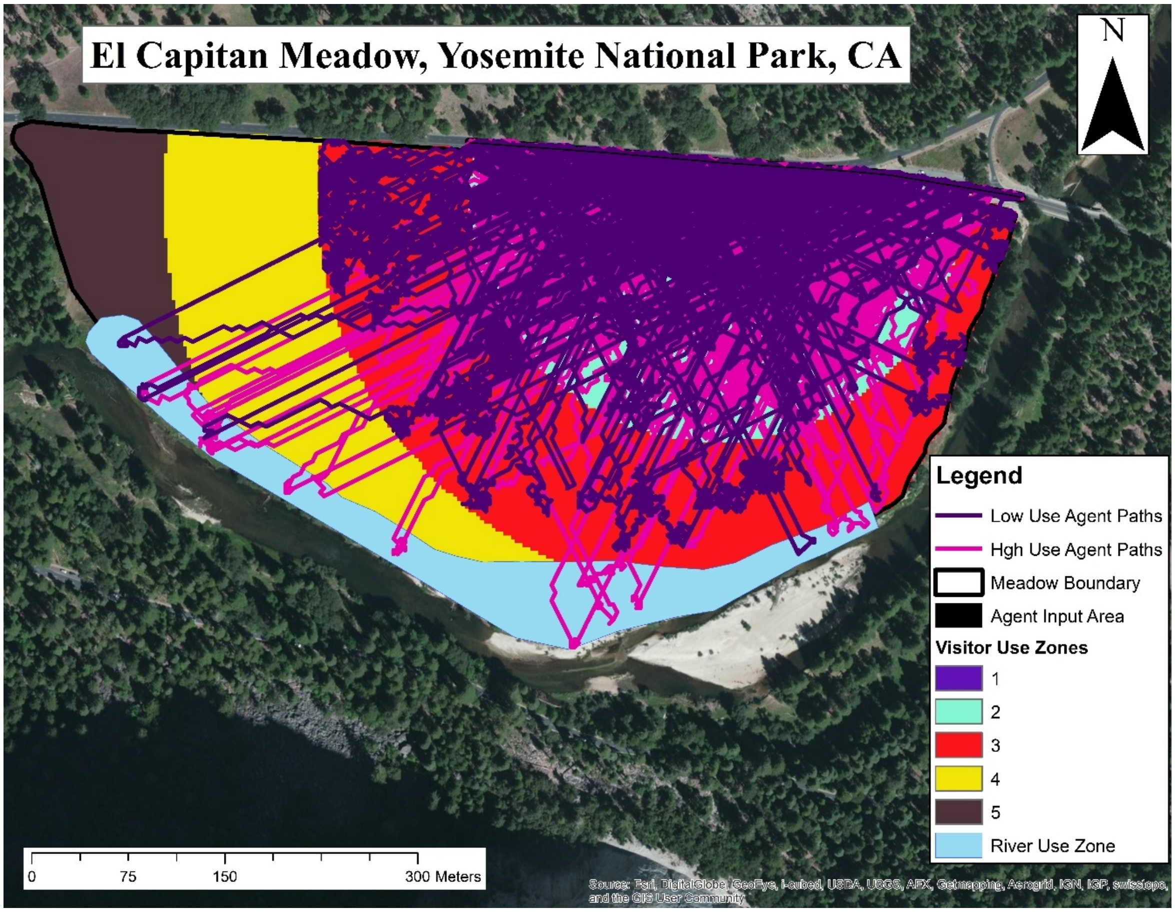


Fig. 4.5. ABM output for both agent groups using random attraction points in each assigned zone and adding a “River Use Zone” as an attractant.

CHAPTER 5

CONCLUSIONS

1. Introduction

It is well understood in the field of recreation ecology that a variety of social and biological factors influence the level of ecological change that results from recreation use (Hammitt et al., 2015). While the relationship between these factors and ecological impact is broadly understood, there is less understanding about the interactions between these social and biological factors. As such, a variety of assumptions have been made about how recreation use in parks and protected areas leads to ecological impacts. These assumptions have hindered the ability of researchers and managers to build accurate social-ecological models of recreation use; especially in off-trail areas of dispersed use. Current models are too simplistic to be able to make predictions about how and where recreation-related impacts may occur (Gimblett et al., 2014). The three papers presented in this dissertation are an attempt to clarify the interactions between the social factors that influence ecological change and develop methodologies for building more accurate and predictive social-ecological models of visitor behavior in areas of dispersed recreation use.

2. Visitor behavior

Chapter 2 explored the relationship between visitor use levels and visitor behavior using newly developed GIS methods to measure visitor dispersion in off-trail areas of dispersed recreation use. At certain types of recreation destinations, current assumptions about how visitor use levels influence visitor behavior and dispersion may be incorrect. Findings from Chapter 2 show that in some recreation settings, visitor behavior may be a more important driver of ecological change than visitor use levels. Chapter 3 echoes the importance of visitor behavior as an influencing factor on the level and extent of ecological change. Chapter 3 found that even at recreation destinations that have highly susceptible vegetation, the potential level of ecological impact is highly dependent on visitor behavior at those locations. Overall, at certain types of recreation destinations, high use levels and the presence of highly susceptible vegetation does not necessarily translate into high levels of ecological impact.

3. Social-ecological modeling

Visitor behavior may be a more important driver of ecological change than visitor use levels. However, in order to fully understand the ecological consequences of visitor behavior in areas of off-trail recreation use, parks and protected area sites need be viewed as a social-ecological system. Current models of recreation use are inadequate and do not fully capture the complexities of recreation use. The majority of simulation modeling efforts in recreation settings are focused on the built environment (trails, roads, park infrastructure) or visitor experience impacts (crowding, safety, etc.). However, recreationists not only interact with just the built and social environments; outdoor recreation use occurs in natural settings (Taczanowska et al., 2008). Building social-ecological models of recreation use is a first step in accurately representing parks and protected areas as the coupled social-ecological systems that they are.

Chapter 3 demonstrated a more sophisticated and precise methodology for exploring recreation use as a couple social-ecological system. The model presented built on previous models by looking at species- or genus-level susceptibility to trampling and incorporated findings from Chapter 2 to more accurately represent visitor use in off-trail areas. Overall, the social-ecological model that was developed highlights the importance of providing an ecological context to models of visitor behavior. Chapter 2 found that visitors do disperse far distances from hardened surfaces into off-trail areas and, at even at low use levels, conventional thought would conclude that this dispersion has the potential to cause high levels of ecological impact (Monz et al., 2013). In Chapter 3, in fact visitors were found to be dispersing at recreation sites that contained highly susceptible vegetation communities. However, in very few cases was recreation use leading to a high potential for ecological change. Most visitors were found to be dispersing in a way that, at most recreation destinations, was minimizing their potential impact to groundcover vegetation. An alternative explanation might be that visitors were dispersing into areas that had historically high levels of dispersed visitor use and previous recreation impact and therefore, there was little potential for further impact to occur.

4. Predictability

Chapter 3 presented a static model that predicted where ecological impact may occur as a result of recreation use. Although the model is an improvement on many social-ecological models in recreation settings, the model is still limited in that it is a snap-shot in time built from a sample of recreation behavior. Even greater predictable could be achieved in the field of recreation research through the use of agent-based models (ABM). ABMs, more so than any other simulation modeling technique use in recreation, are perfectly equipped to model the complex social-ecological interactions that occur in recreation settings (Crooks and Heppenstall, 2012; Filatova et al., 2013). The potential for using ABM in recreation use settings has been known since the early 1990s (Deadman and Gimblett, 1994). Early attempts at building predictive ABMs of recreation use were halted when it was realized that the data needed to build such models was not available.

Chapter 4 shows that this data is now available through the use of GPS-based tracking methodologies. A proof-of-concept exercise and framework was developed for utilizing GPS tracking data to build an ABM of visitor behavior in off-trail areas of dispersed recreation use. ABMs can also be used to scale up sample-level information from GPS-based tracking data to a population-level model of visitor behavior; thus providing models that are more representative of actual use at recreation destinations. Findings from Chapter 2 and the susceptibility map from Chapter 3 could be incorporated into future modeling effort to demonstrate the utility of ABM in modeling recreation use as a social-ecological system.

5. Management implications

In order to sustainably manage parks and protected areas for future generations, managers must balance visitor use with resource protection. In many situations, especially in highly visited public lands, park and protected area managers take a *capacity planning* approach to protecting resource conditions. Capacity planning focuses on visitor capacity or "the maximum amounts and types of visitor use that an area can accommodate while achieving and maintaining desired resource conditions" (Interagency Visitor Use Management Council, 2015). However, findings from this dissertation indicate that maintaining desired resource conditions may be more dependent on visitor behavior than the amount of visitors in an area.

Capacity planning maybe more effective at protecting resource conditions, in certain recreation settings, if planning efforts focused on managing visitor behavior and less on limiting amounts of use. These findings also highlight the importance of interpretive and education programs, such as Leave No Trace and Tread Lightly, which focus on minimum-impact behaviors that recreationists can apply to a variety of park and protected area settings. Many of the patterns of behavior that may result in ecological impact appear to be site-specific. Therefore, managers that are interested in maintaining resource conditions at an ecologically important visitor site, may want to focus efforts on site-specific messaging and making location affordances more obvious to visitors.

For example, at El Capitan Meadow, there is no messaging related to proper behavior when recreating at the meadow. In order to reduce impact at El Capitan Meadow, managers may want to confine visitor use to areas of less susceptible vegetation communities. These vegetation communities also happen to be located where visitors will receive the clearest view of El Capitan. Directing visitors to these more resistant areas using interpretative messaging, especially during periods of low visitor use, could reduce the potential for undesirable ecological change at El Capitan Meadow. If messaging does not want to be used, infrastructure such as hardening the best photography location, could cue to visitors the minimum-impact location for visitor use in El Capitan Meadow.

Visitor use management in parks and protected areas, which includes capacity planning, is defined as being “a proactive and adaptive process for managing characteristics of visitor use and the natural and managerial setting” (Interagency Visitor Use Management Council, 2015). However, the majority of research examining the ecological consequences of recreation use is reactive in nature. In other words, managers usually act only after ecological resources have begun to be degraded. The use of social-ecological modeling approaches, specifically simulation modeling techniques, can make visitor use management more proactive. ABMs can be used to model visitor behavior in response to management scenarios or changes is visitor use and predict the potential for ecological impacts before they occur. Such models would allow park and protected area managers the ability to concentrate their efforts and resources in locations that are most at risk for undesirable ecological change.

Taken together, results from these three papers indicate that some recreation locations - even in the busiest parks and protected areas - could have greater visitation with potentially less impact to ecological resources if visitor behavior is managed effectively. Many parks and protected areas are attempting to increase visitation number as visitation often translates to more funds for management and more support of public lands. Social-ecological models of recreation use can be used to predict the consequences of increased visitor use, the management scenarios used to manage use, and/or the techniques used to change visitor behavior in advance of the impacts occurring. Thus allowing for visitor use management in public land management agencies to truly be a proactive process.

6. Future directions

6.1 Visitor behavior

The counter-intuitive patterns of visitor behavior in response to use level that were observed in Chapter 2 appear to be site-specific. Before generalizations about the relationship between visitor use level and visitor dispersion can be made, the same methodologies for examining visitor dispersion using in this dissertation need to be examined at additional types of recreation sites. Additionally, the mechanisms behind these patterns of dispersion is not fully understood. Research has hypothesized that at some recreation destinations, visitors are mimicking the behavior of the visitors around them during periods of high visitor use causing a "grouping" of visitors. However, this has not been empirically tested.

GPS-based tracking or observational techniques could be used to better understand the mechanisms which are causing these observed dispersion patterns. ABMs could also be employed to test the hypothesis that in some settings, during periods of high use, visitors tend to recreate near where other visitors are recreating. An ABM could be created with rules built around this hypothesis and if the hypothesis was true, then the emergent behavior in the model would resemble patterns observed in the real-world. Overall, understanding the behaviors that drive visitor interactions in off-trail areas of dispersed recreation use would also allow researchers to create more accurate and precise rules for future ABMs.

Finally there is an issue of scale. Only examining site-specific, small scale phenomena has often been a criticism of recreation ecology and recreation research (Monz et al., 2010). Despite the drawbacks of site-specific work, small-scale research is important for managers especially when sensitive habitats or ecosystems occur at a small scale (such as meadows in Yosemite National Park). Additionally, site-specific studies examine issues at the "scale of the human experience" or the scale at which recreationists interact with their environment. As such, these human-scale level phenomena are important from a visitor use perspective as well.

However, as a field, recreation ecology does not have a great understanding of how visitor behavior manifests even at small-scales. The results from this dissertation is a first step at understanding visitor behavior at the site-level. The methodologies employed in this study could be used at larger scales if park-level visitor behavior data was available. There are opportunities with future studies to scale-up examinations of visitor behavior and dispersion to the park-wide level.

6.2 Social-ecological modeling

Modeling recreation as a coupled social-ecological system successfully requires sufficient and accurate data for both the social and ecological components. Susceptibility mapping of vegetation at the species- and genus- scale is in its infancy. This limits the ability to use susceptibility mapping more widely in social-ecological modeling and at a variety of scales. Despite the majority of trampling studies using the same methodologies (Cole and Bayfield, 1993), the way in which resistance index (RI) is reported varies. Overall, to be more ecologically relevant and to be utilized in social-ecological models, trampling studies need to move away from a focus on morphological groups. Those trampling studies that do report specie- or genus-level RIs often only report results from one or two key vegetation species. Reporting consistent RI values for all species and/or genera examined would provide the information needed to build a database of RIs for all species examined in trampling studies. An open-source database of species and genera response to trampling would be incredibly valuable to managers and researchers and make the construction of susceptibility maps cheaper and more streamlined.

By limiting the scope of the results to only morphological groups or the responses of only a couple of species, trampling studies become limited in their utility from a more general ecological standpoint. Loss of vegetation cover, which has become a focus of many trampling studies, is not the only type of ecological impact that recreation can have on a vegetation community. Species- and genus-level responses to trampling disturbance are important indicators of larger ecological processes. More precise and consistent measures of species-level responses can help clarify how recreation impacts other aspects of plant ecology. More comprehensive, species-level reporting of vegetation cover loss, and possibly even individual plant responses, from trampling disturbance would allow generalizations to be made about how recreation influences community composition, ecosystem function, and biodiversity measures. The methods used in trampling studies have not changed much since 1993, further research could update these methodologies to include additional measures borrowed from the plant community ecology literature.

Scaling up from the site-level to the park-wide unit of analysis is also important from an ecological standpoint. However, in some scenarios, site-level studies are needed by managers to properly prevent undesirable resource change to ecosystem types that are limited in scale (mountain summits in the East, meadows in Yosemite). Like the behavior measures from Chapter 2, there is potential to scale up the susceptibility mapping from the site-level to the park-wide level. However, such advancements would require a better understanding of how different vegetation communities respond to recreation disturbance and sufficient measures of vegetation communities' at large scales. Combining these measures with large-scale measures of visitor behavior could lead to the creation of park-level social-ecological models of recreation use. Larger-scale models would highlight locations in the park or protected areas as a whole where managers may need to focus their visitor use planning efforts.

6.3 Predictability and ABM models

ABM have great potential in understanding and informing recreation management. There are almost endless applications that could be tested in both the social and ecological sciences. From an applied perspective, ABMs would be very powerful for testing the unintended consequences of management decisions. ABMs could also be used in park and protected area planning processes to test the outcomes of different management alternatives. Once the human behavioral component of ABMs has been refined, there are opportunities to combine the social and behavioral data with other environmental layers. For example, visitor behavior patterns could be combined with data from GPS-tracked wildlife to examine how wildlife might respond to visitor use. From a social science perspective, ABMs could be used to examine crowding at recreation destinations and agents could be assigned “crowding standards.” Displacement could also be studied using ABMs by having the agents in model to be triggered to move to another recreation site when their standards have been violated.

Suggestions for developing both species-level susceptibility mapping and ABMs of recreation use have been around since the early 1990s (Deadman and Gimblett, 1994; Liddle, 1997). However, both of these advances in the field of recreation ecology have been hindered by a lack of appropriate data. Now with technological advances, accurate and robust geospatial data of both the social and ecological aspects of recreation use are readily available. The methodologies and approaches for how best to use this data are still in development. Using these data in a way that represents parks and protected areas as social-ecological systems is going to be the most effective way of proving managers with the information needed to manage public lands sustainably.

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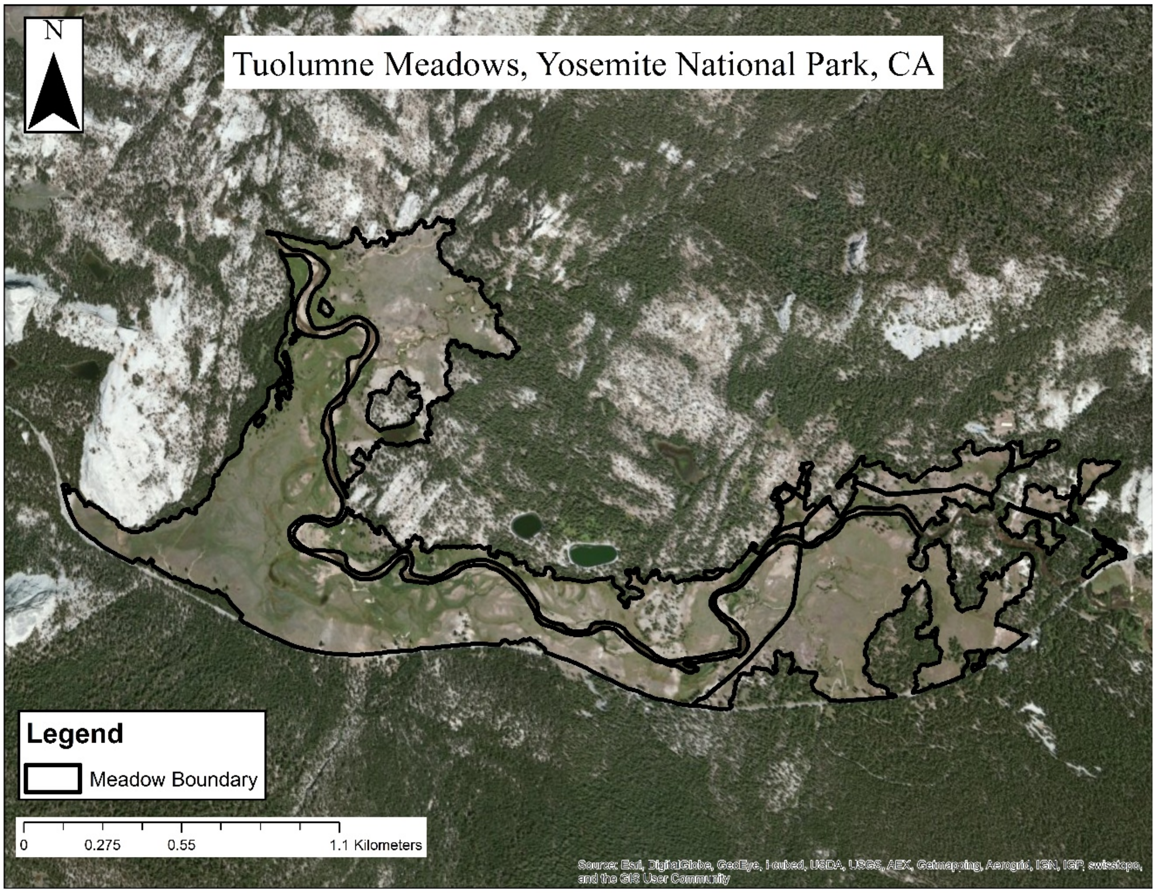
APPENDICES

APPENDIX A:

ADDITIONAL FIGURES FOR CHAPTER 2



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.1. Tuolumne Meadows management boundary in Yosemite National Park, CA.

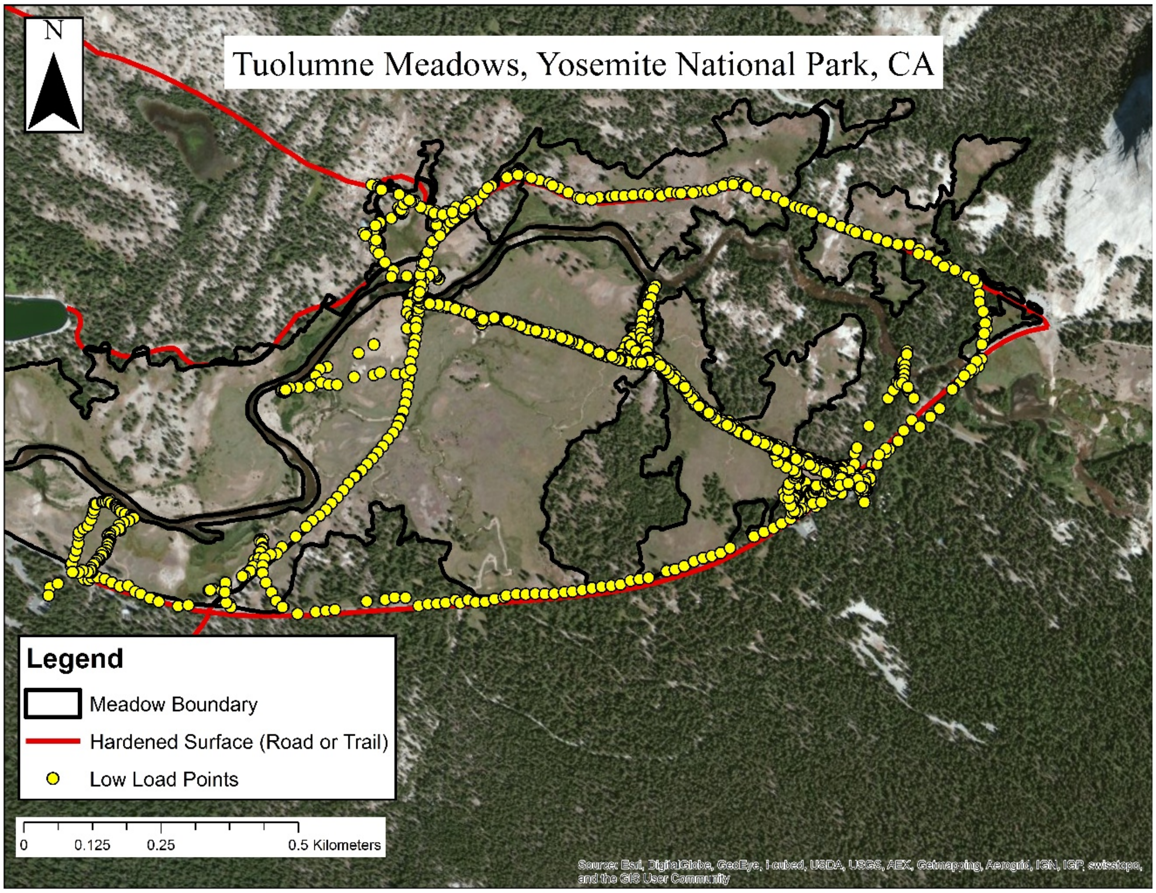


Fig. A.2. GPS tracks of visitor behavior collected during periods of low visitor use in Tuolumne Meadows in Yosemite National Park, CA.

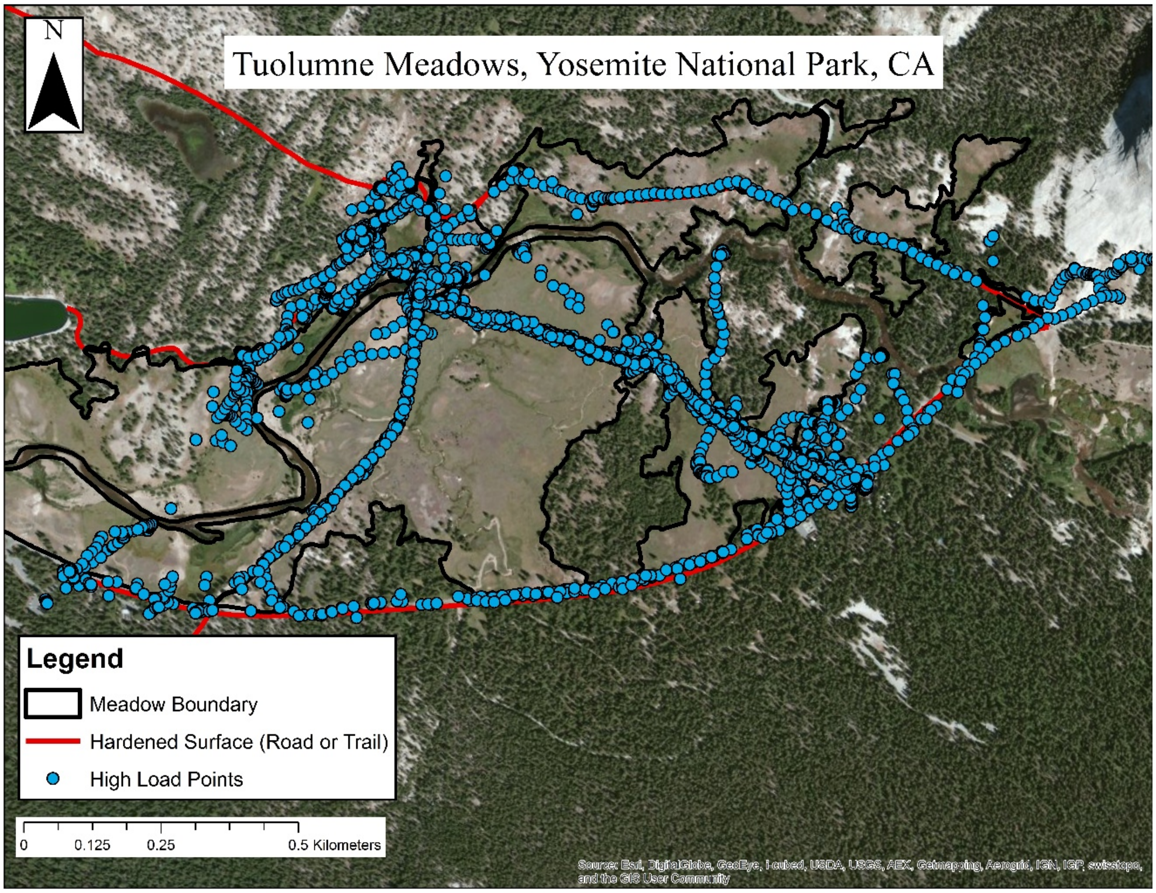
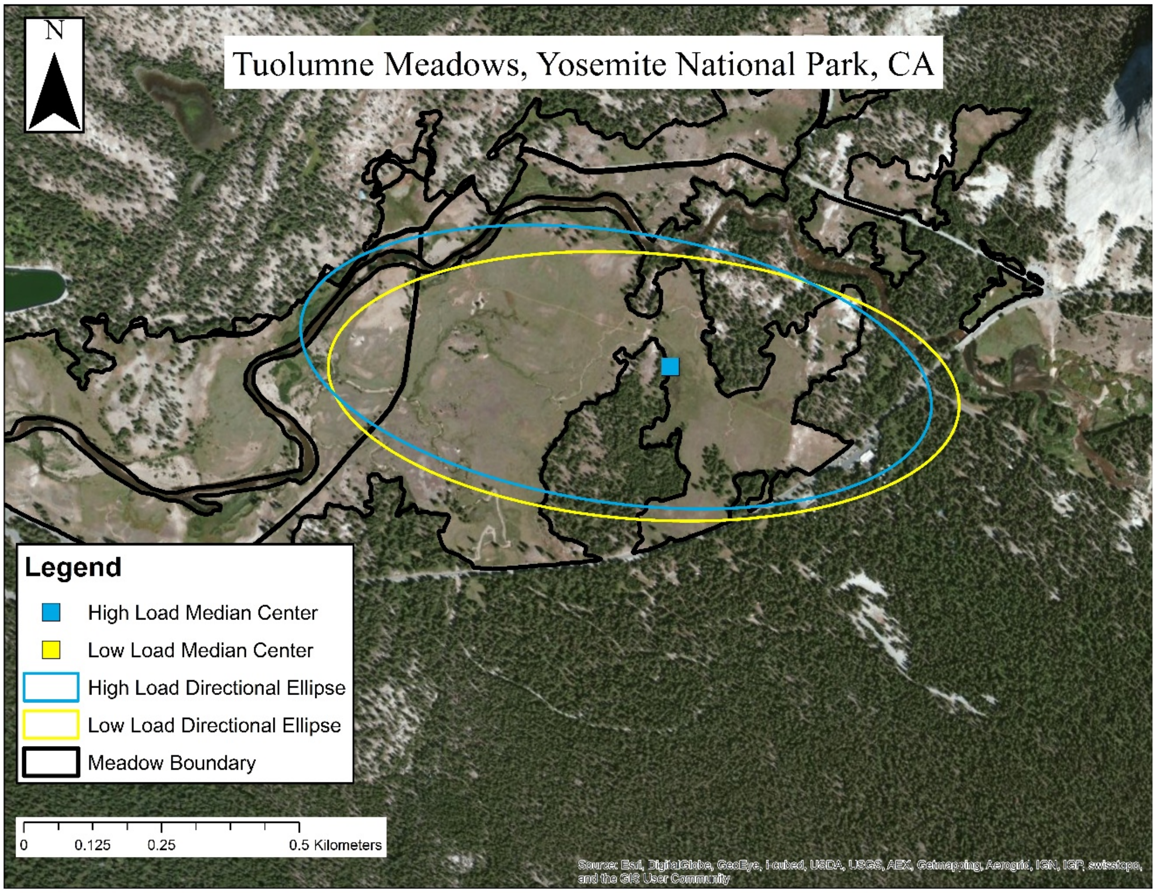
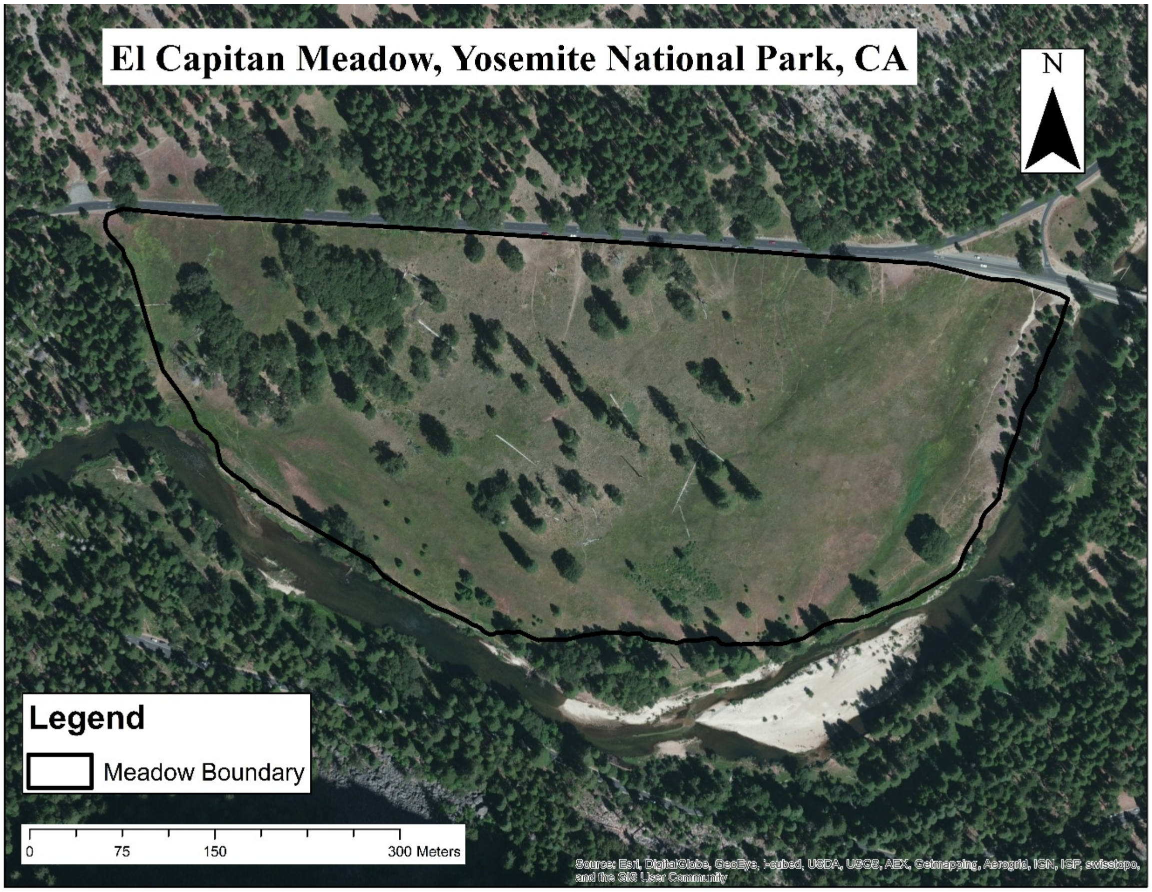


Fig. A.3. GPS tracks of visitor behavior collected during periods of high visitor use in Tuolumne Meadows in Yosemite National Park, CA.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.4. Descriptive metrics of overall visitor dispersion at Tuolumne Meadow.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.5. El Capitan Meadow management boundary in Yosemite National Park, CA.

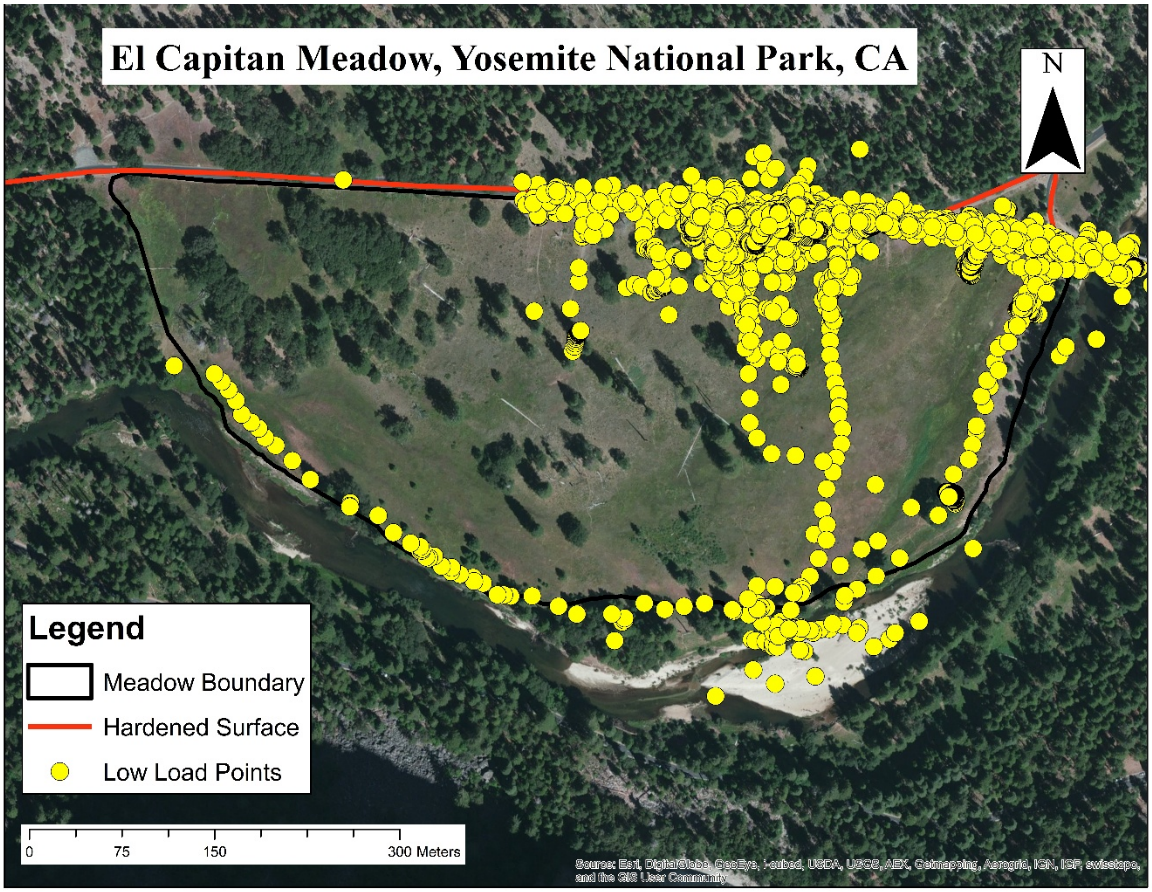
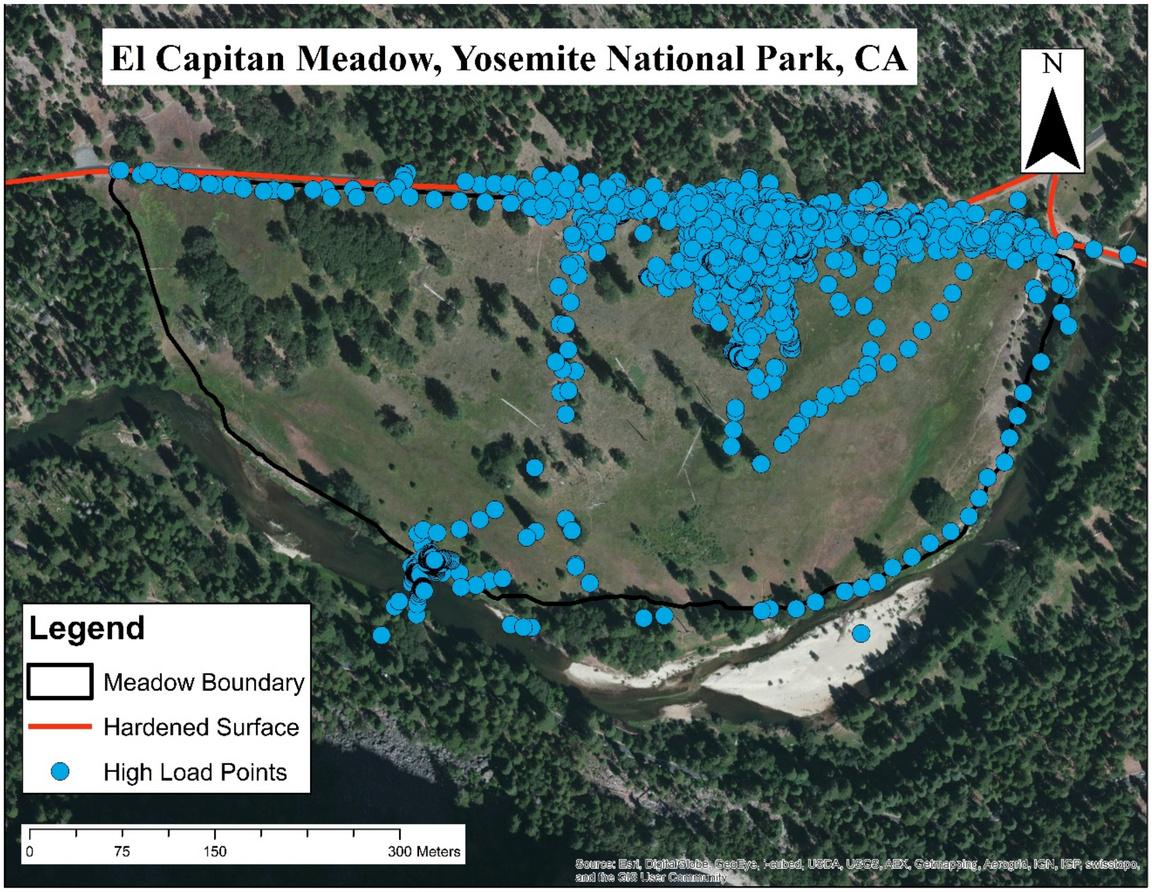


Fig. A.6. GPS tracks of visitor behavior collected during periods of low visitor use in El Capitan in Yosemite National Park, CA.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.7. GPS tracks of visitor behavior collected during periods of high visitor use in Tuolumne Meadows in Yosemite National Park, CA.

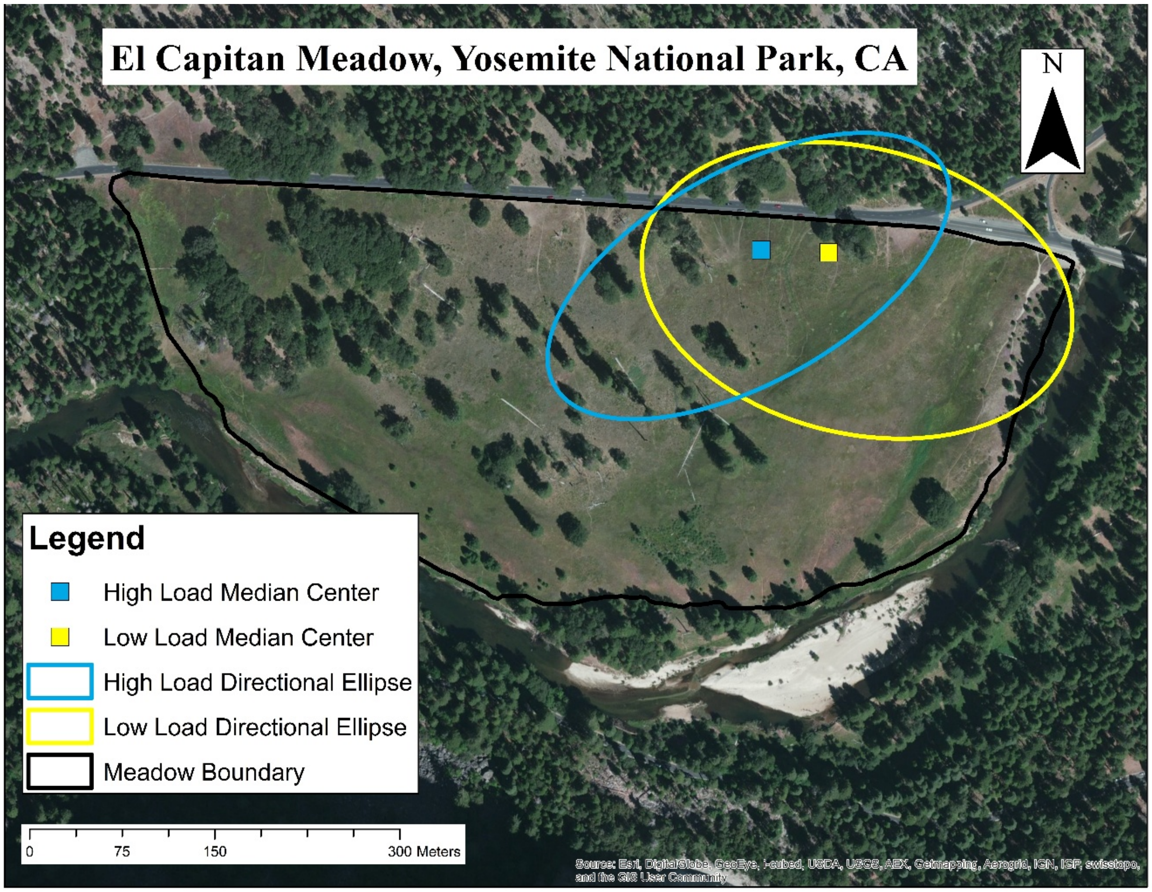
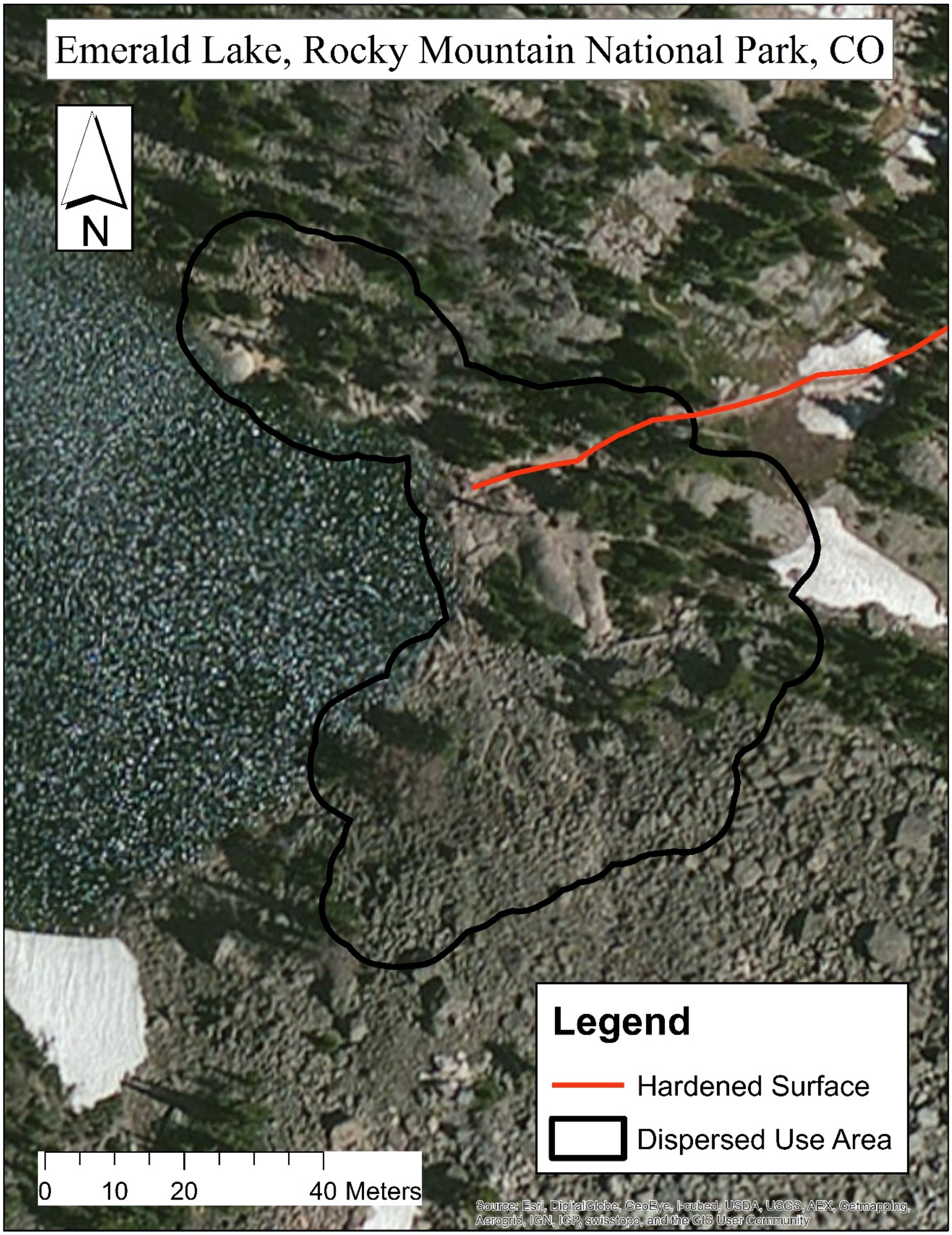


Fig. A.8. Descriptive metrics of overall visitor dispersion at El Capitan Meadow.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.9. Dispersed use area at Emerald Lake in Rocky Mountain National Park, CO.

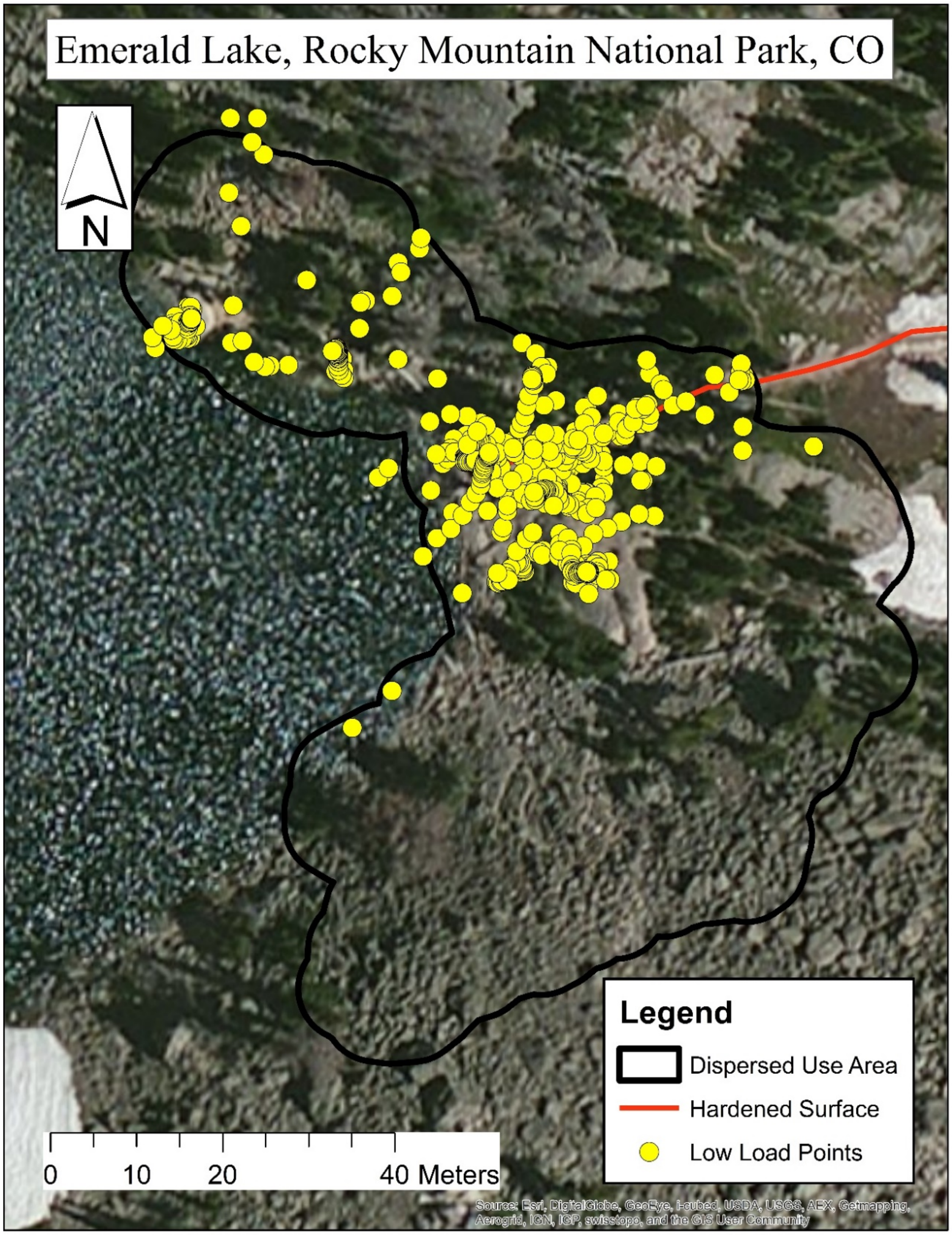


Fig. A.10. GPS tracks of visitor behavior collected during periods of low visitor use at Emerald Lake in Rocky Mountain National Park, CO

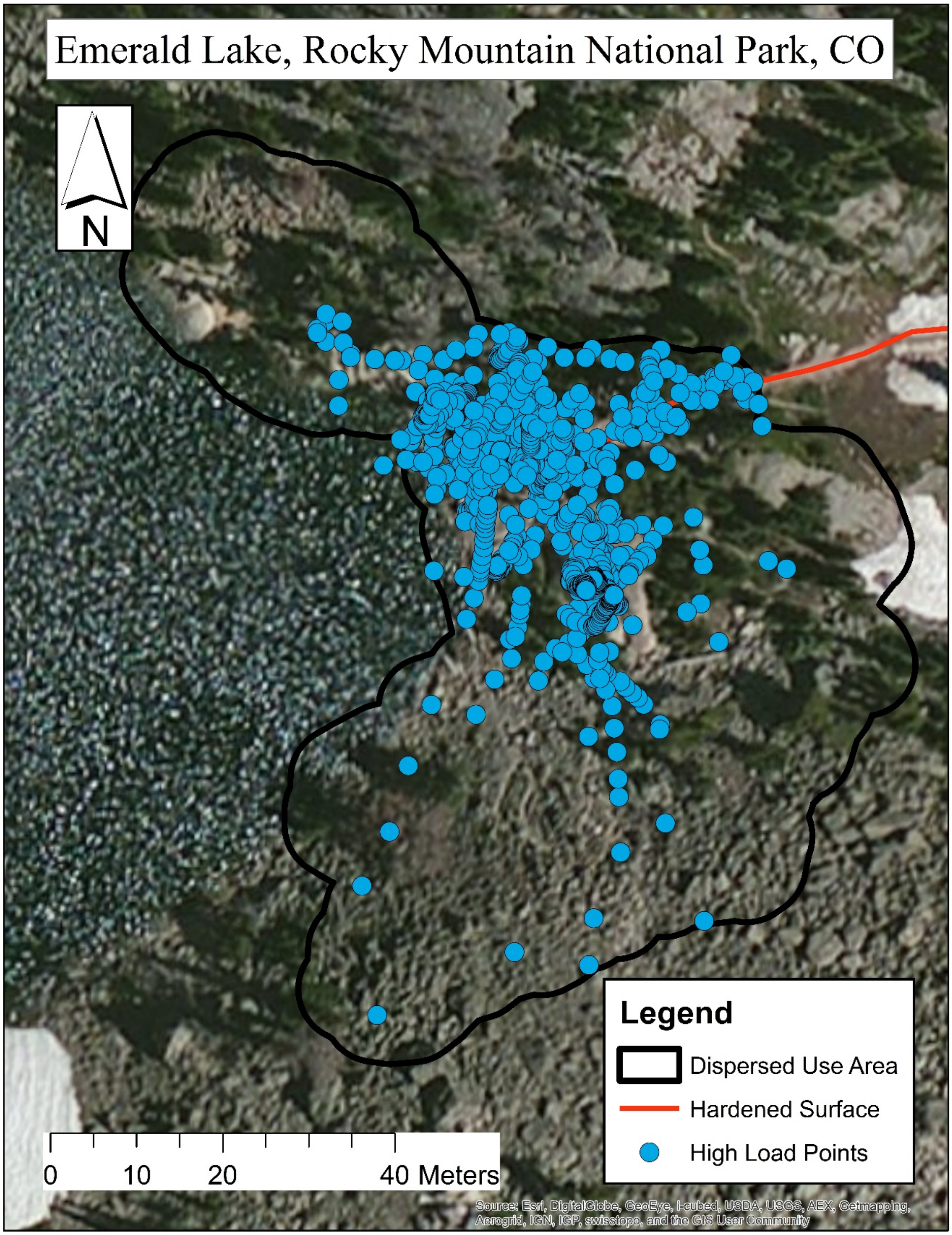
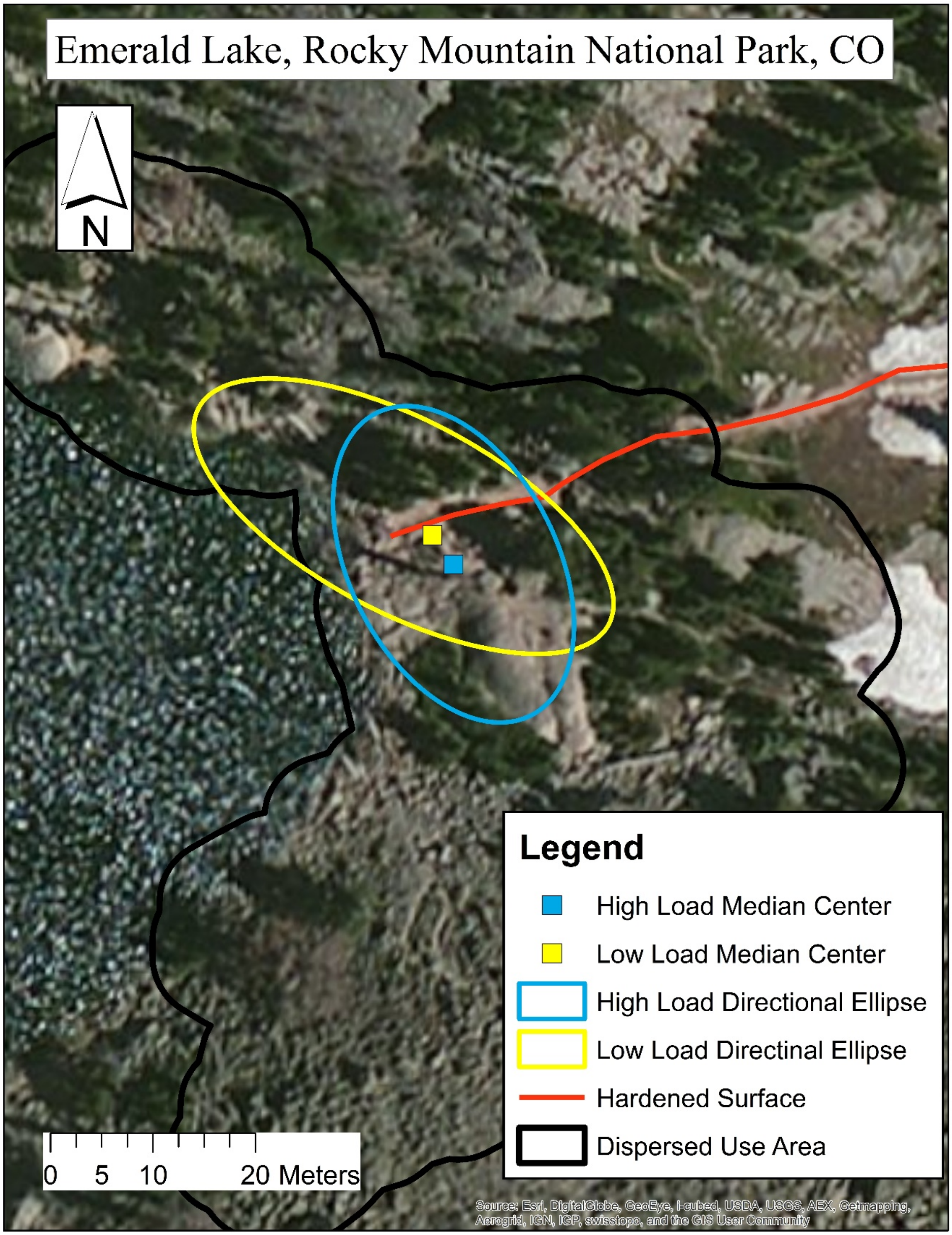


Fig. A.11. GPS tracks of visitor behavior collected during periods of high visitor use at Emerald Lake in Rocky Mountain National Park, CO.



Emerald Lake, Rocky Mountain National Park, CO

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.12. Descriptive metrics of overall visitor dispersion at Emerald Lake.

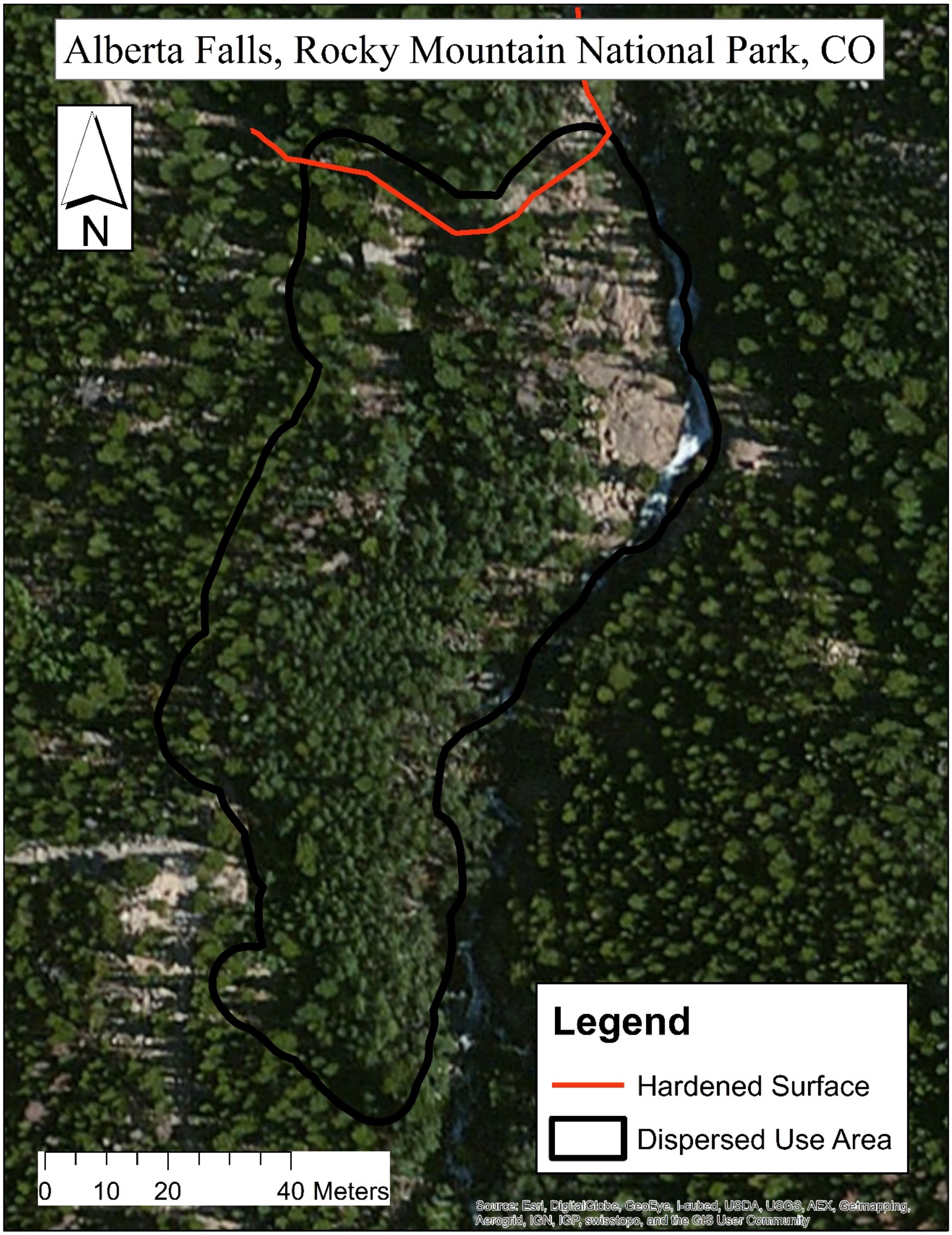


Fig. A.13. Dispersed use area at Alberta Falls in Rocky Mountain National Park, CO.

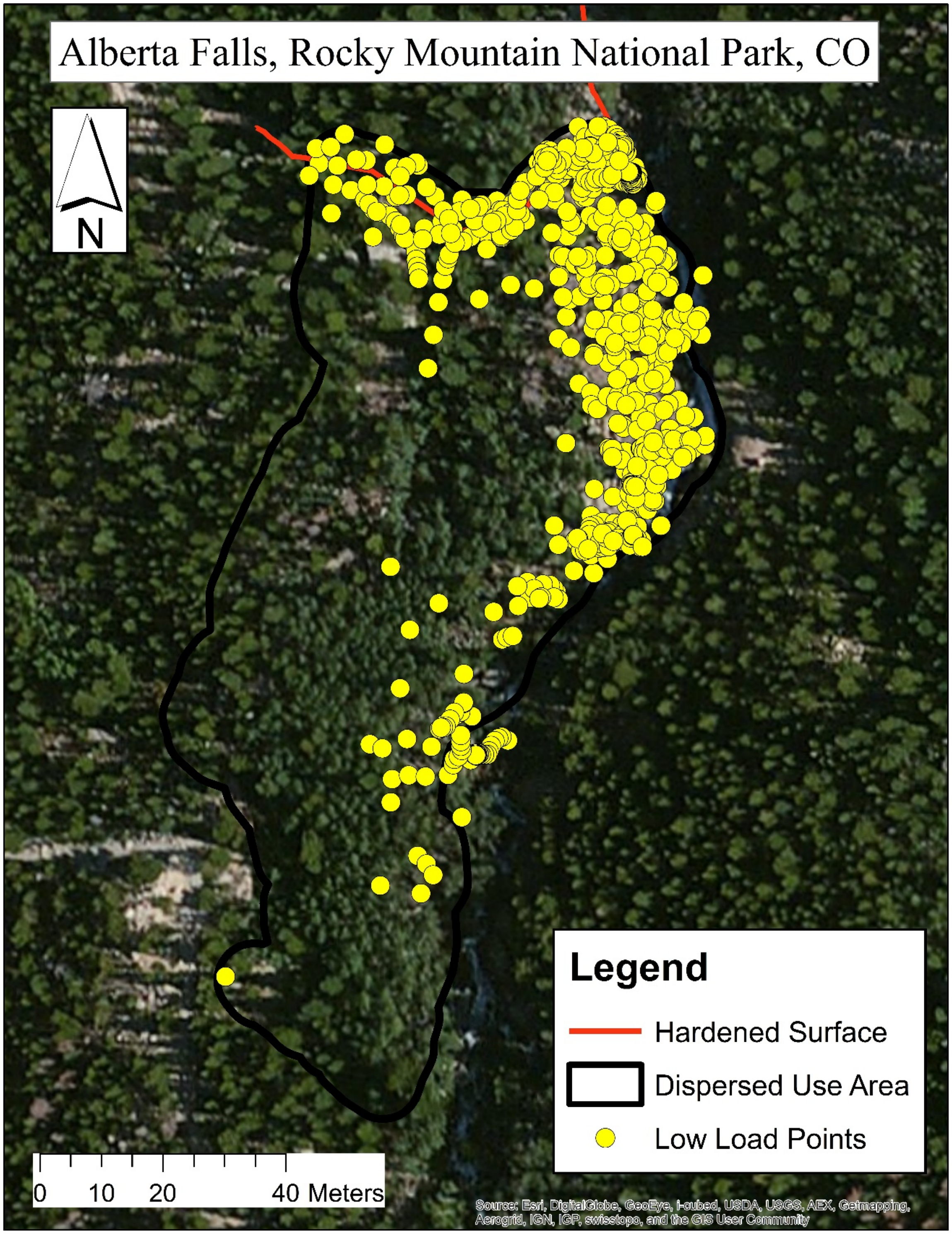


Fig. A.14. GPS tracks of visitor behavior collected during periods of low visitor use at Alberta Falls in Rocky Mountain National Park, CO.

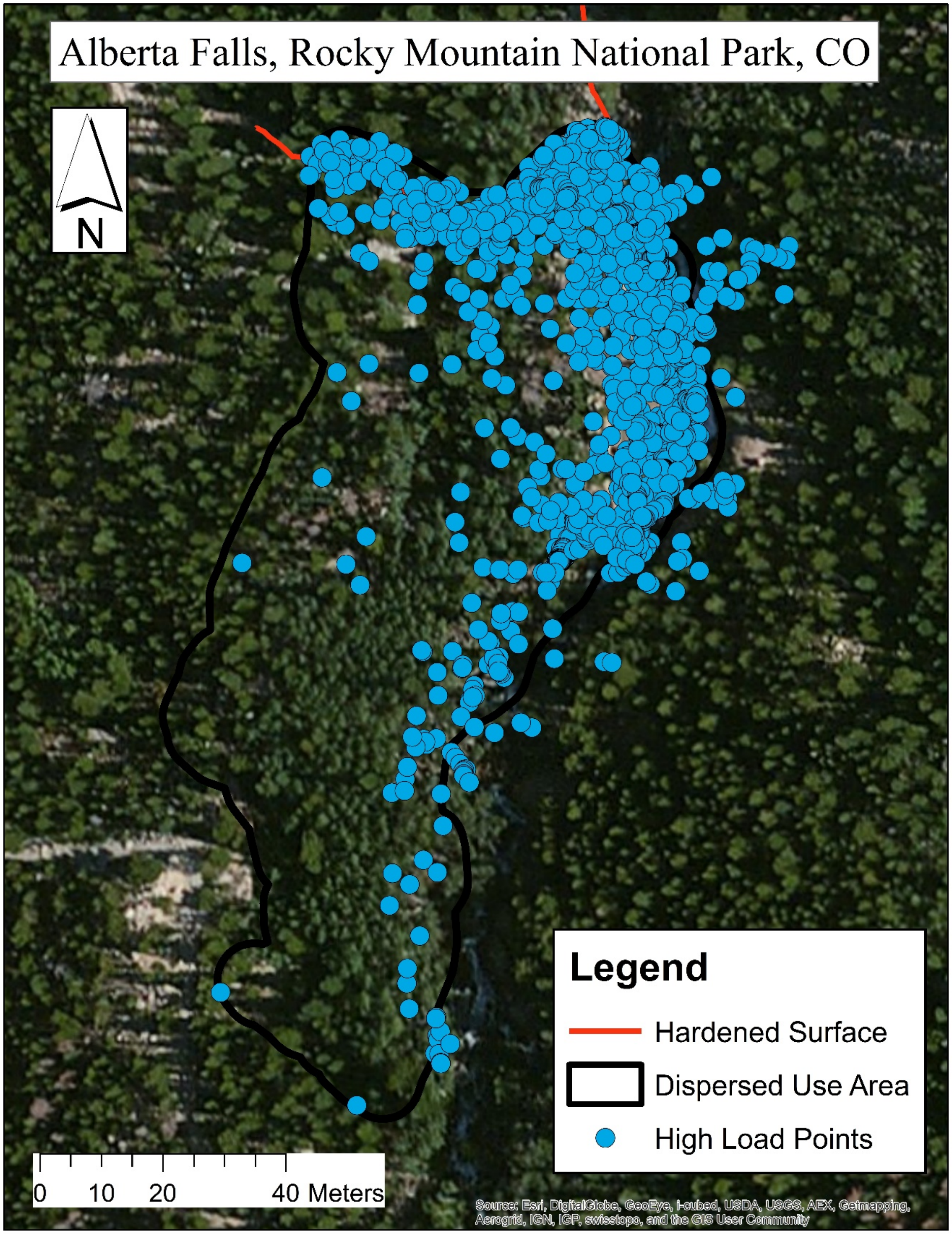


Fig. A.15. GPS tracks of visitor behavior collected during periods of high visitor use at Alberta Falls in Rocky Mountain National Park, CO.

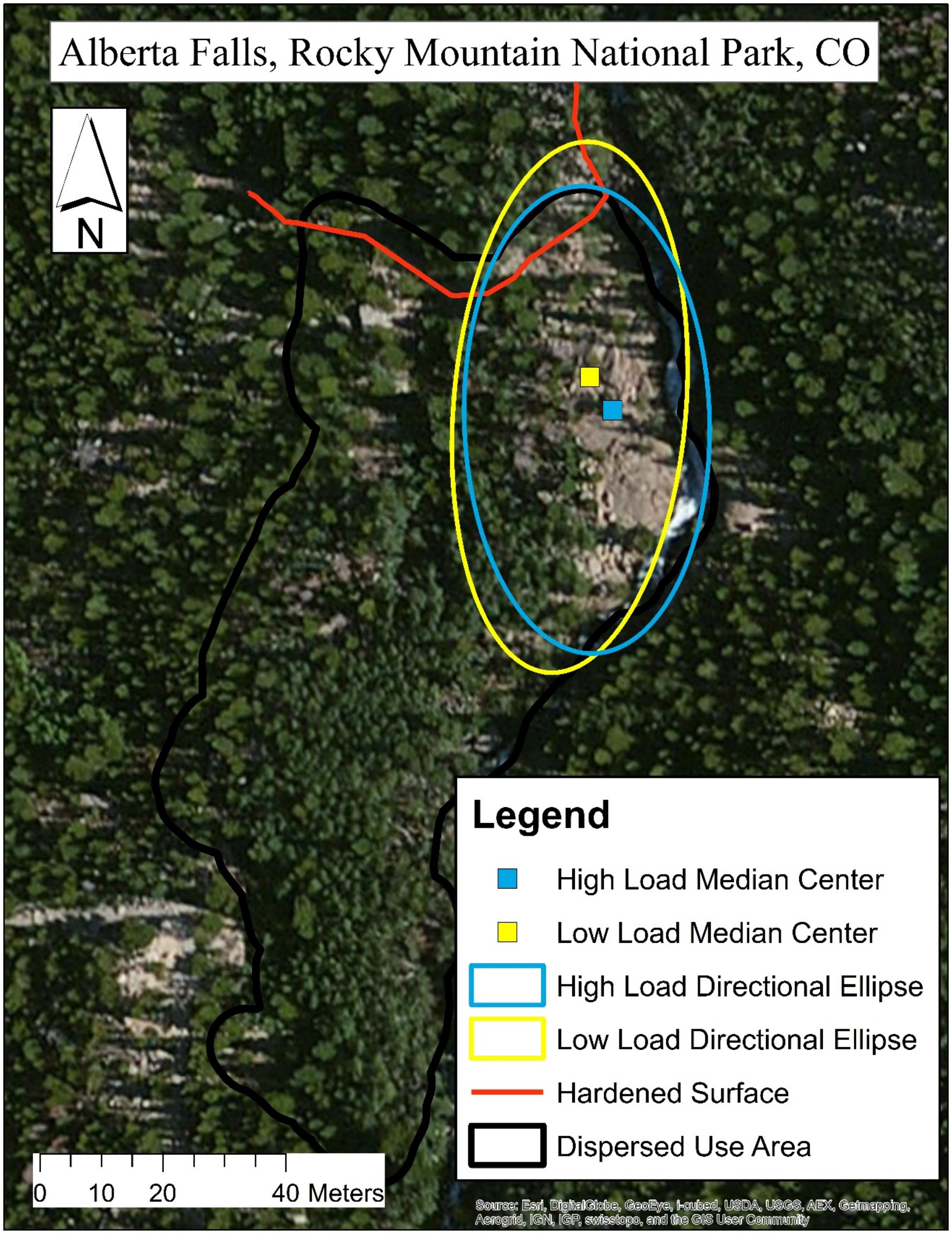


Fig. A.16. Descriptive metrics of overall visitor dispersion at Alberta Falls.

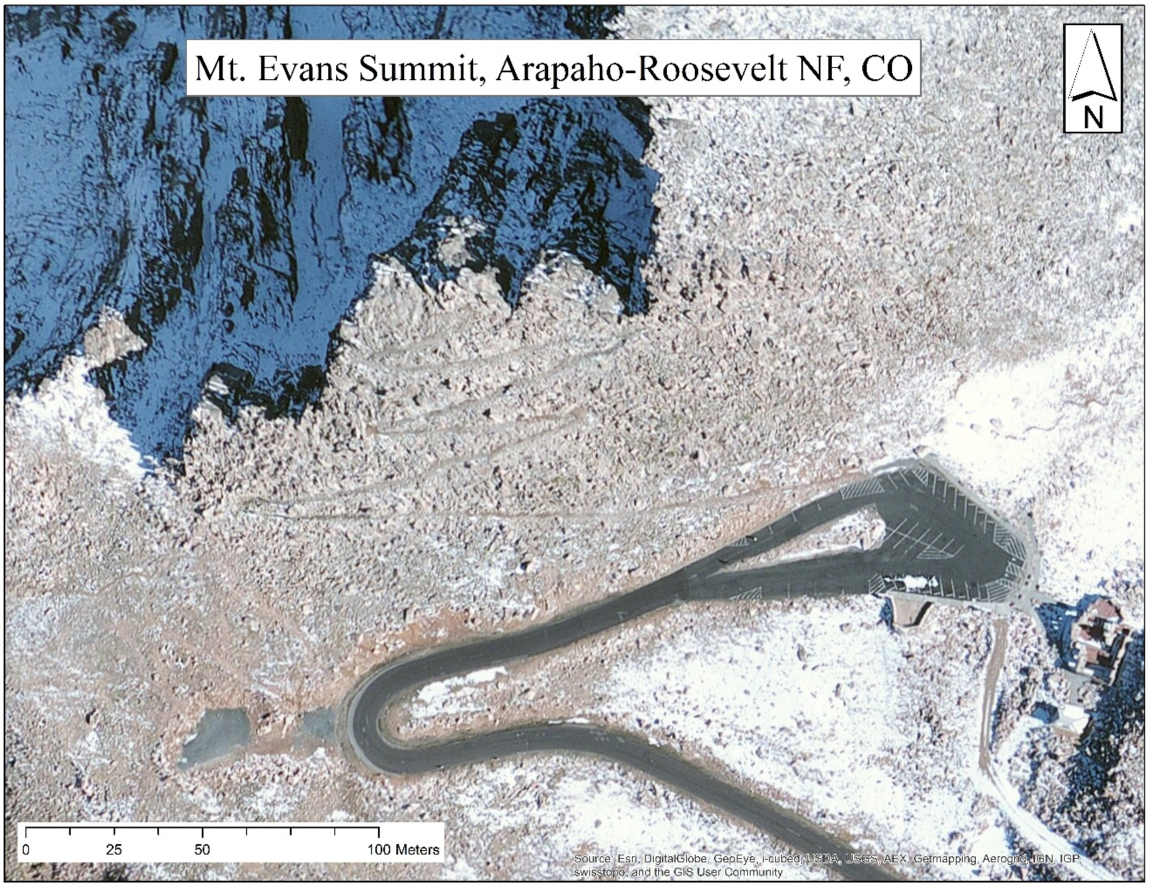


Fig. A.17. Summit of Mt. Evans in Arapaho-Roosevelt National Forest, CO.

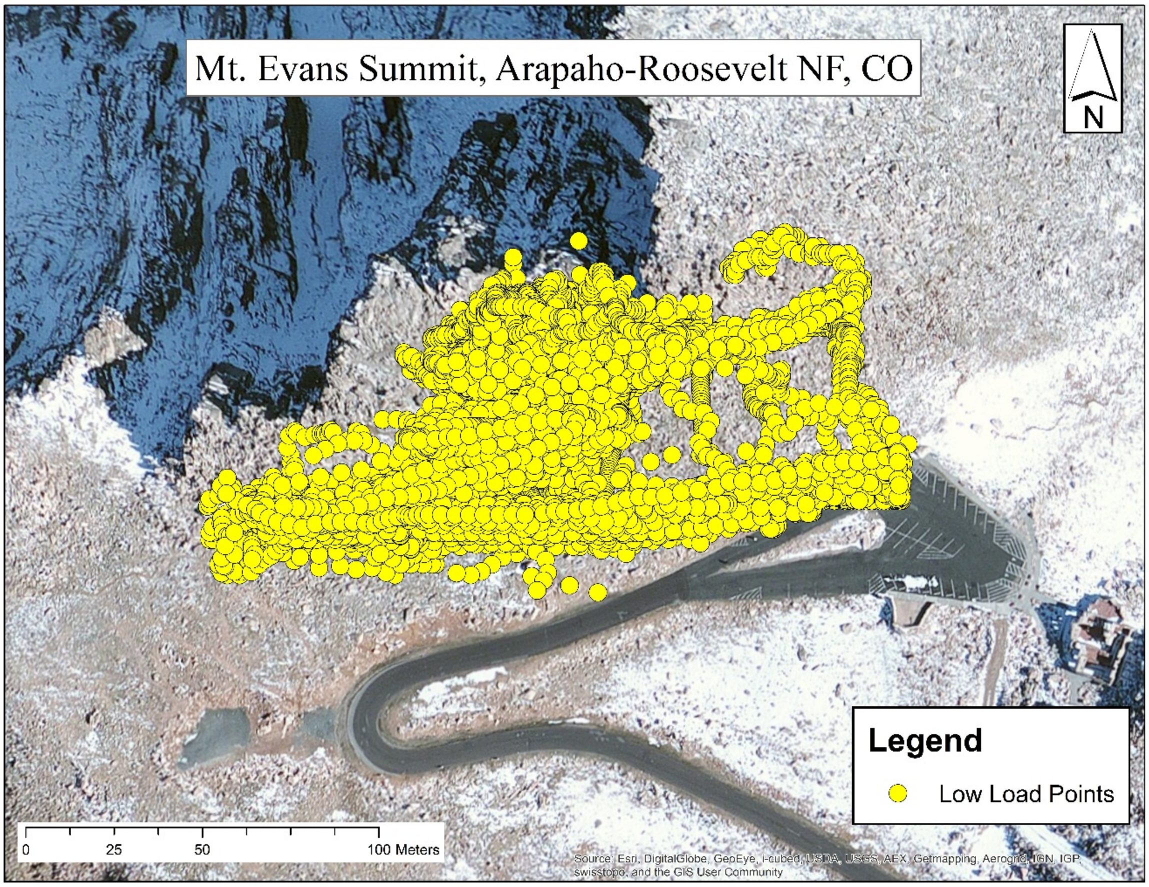
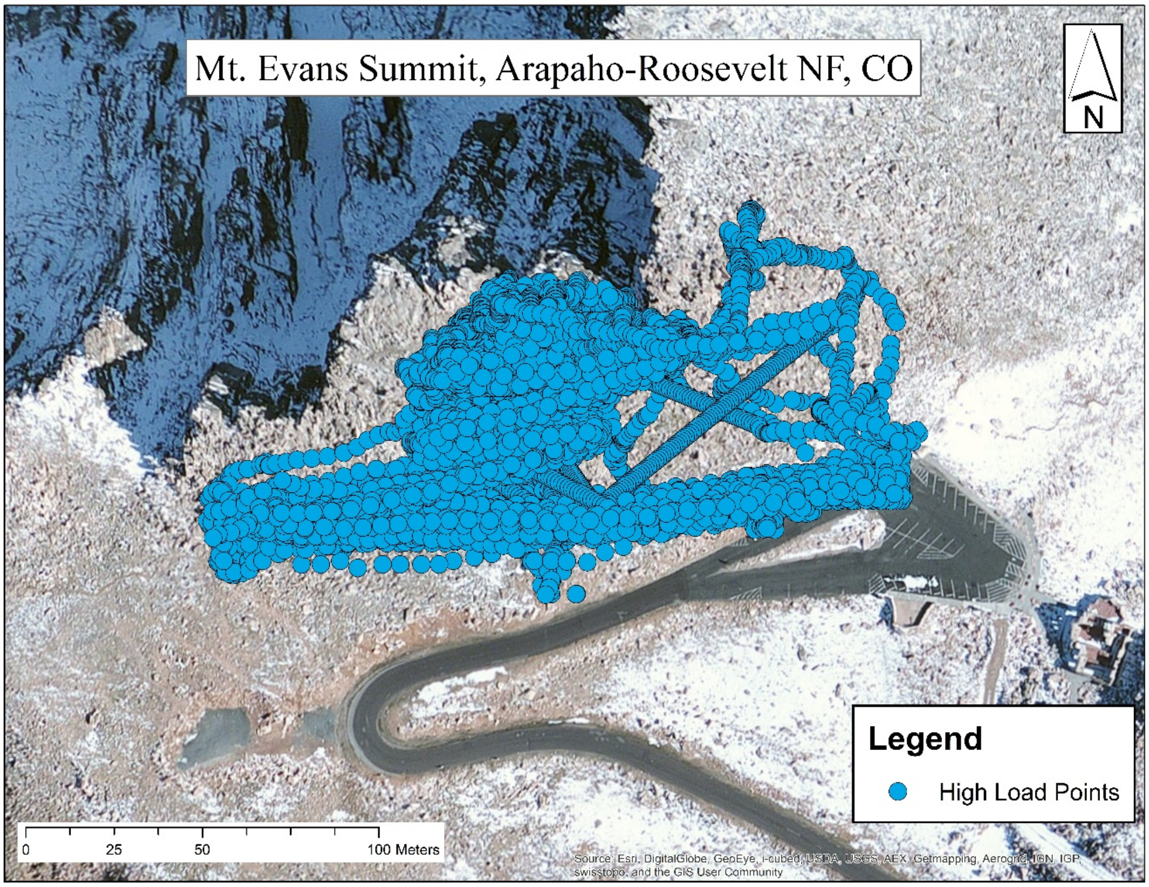
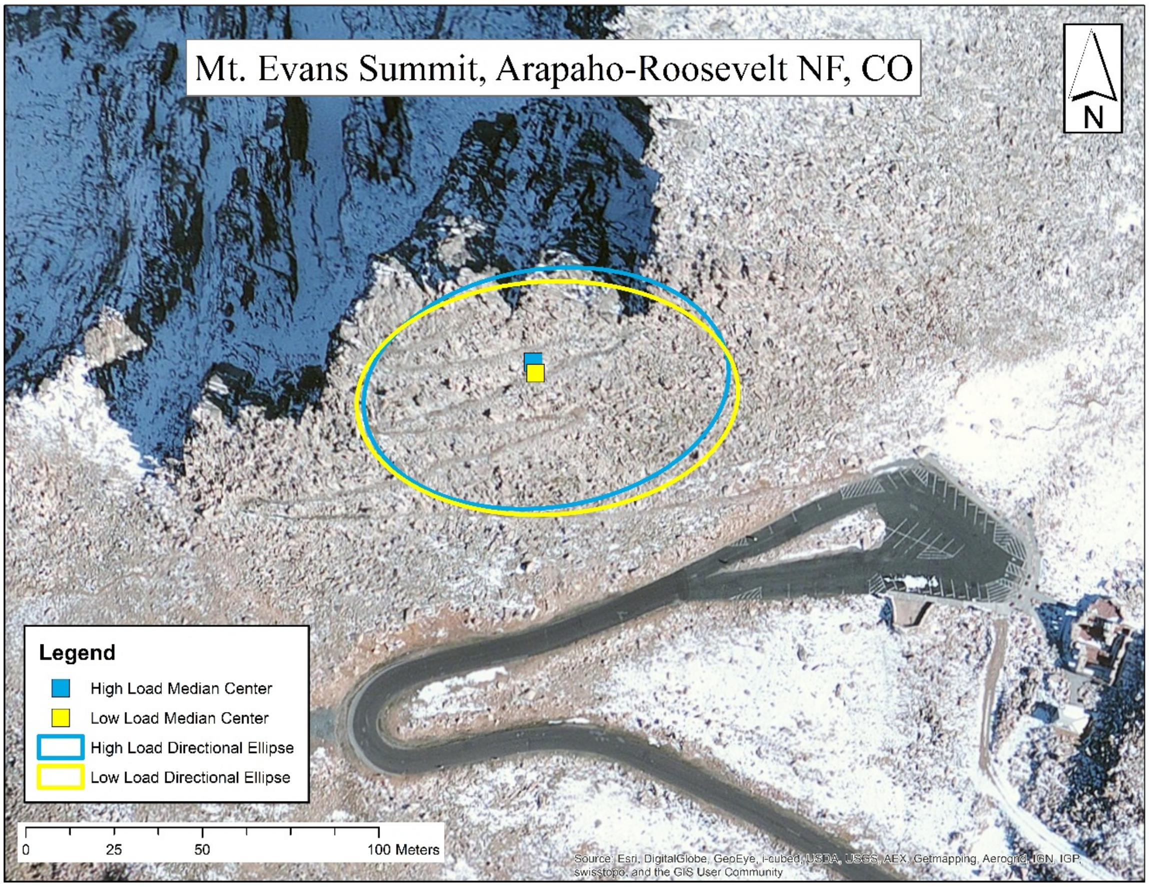


Fig. A.18. GPS tracks of visitor behavior collected during periods of low visitor use at the summit of Mt. Evans in Arapaho-Roosevelt National Forest, CO.



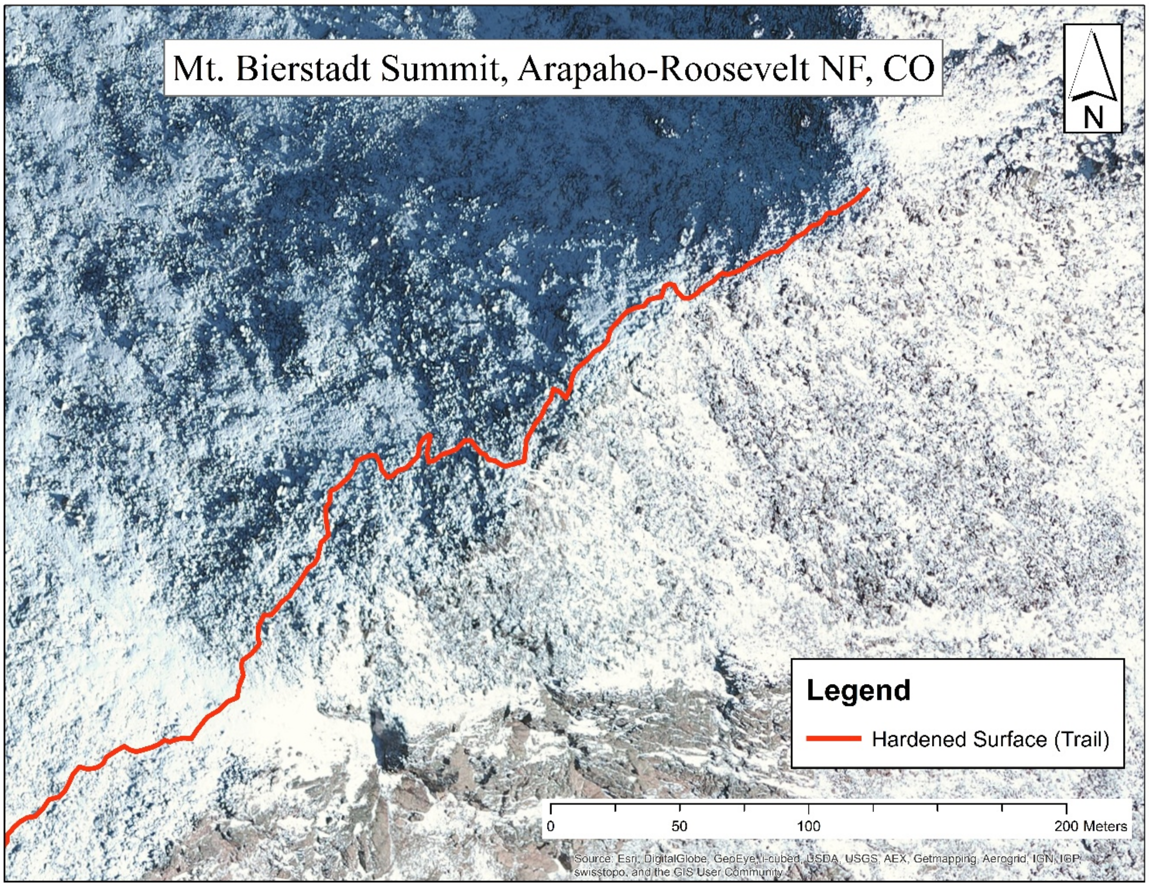
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.19. GPS tracks of visitor behavior collected during periods of high visitor use at the summit of Mt. Evans in Arapaho-Roosevelt National Forest, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.20. Descriptive metrics of overall visitor dispersion at the summit of Mt. Evans.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.21. The last approach to the summit of Mt. Bierstadt in Arapaho-Roosevelt National Forest, CO.

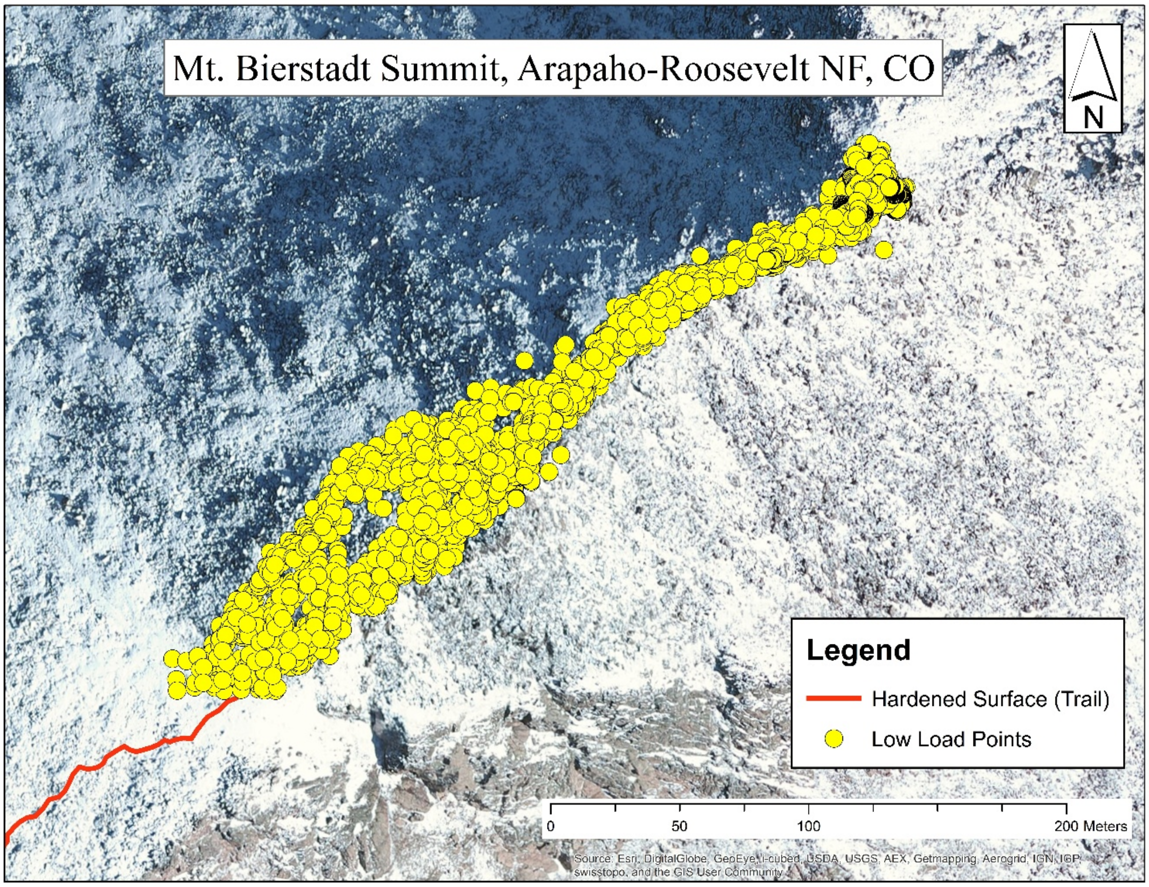
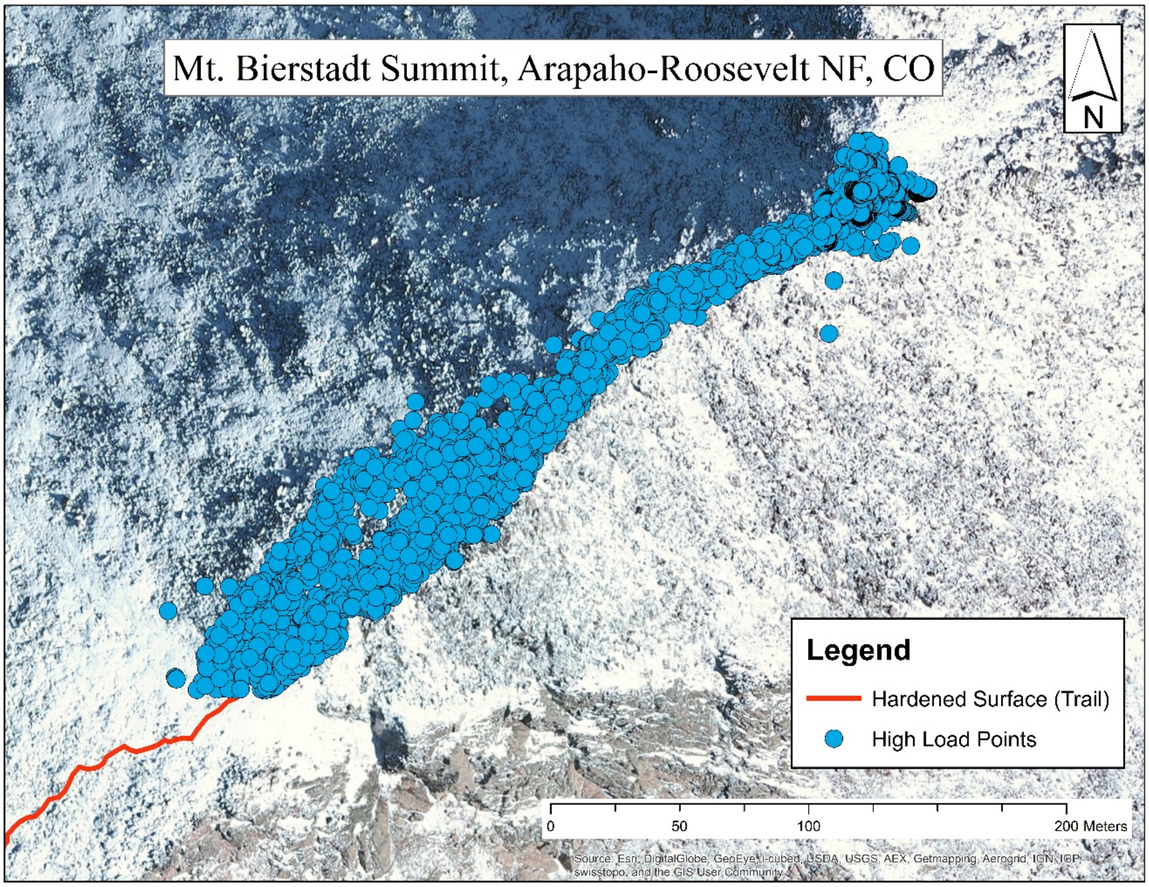


Fig. A.22. GPS tracks of visitor behavior collected during periods of low visitor use at the summit approach of Mt. Bierstadt in Arapaho-Roosevelt National Forest, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.23. GPS tracks of visitor behavior collected during periods of high visitor use at the summit approach of Mt. Bierstadt in Arapaho-Roosevelt National Forest, CO.

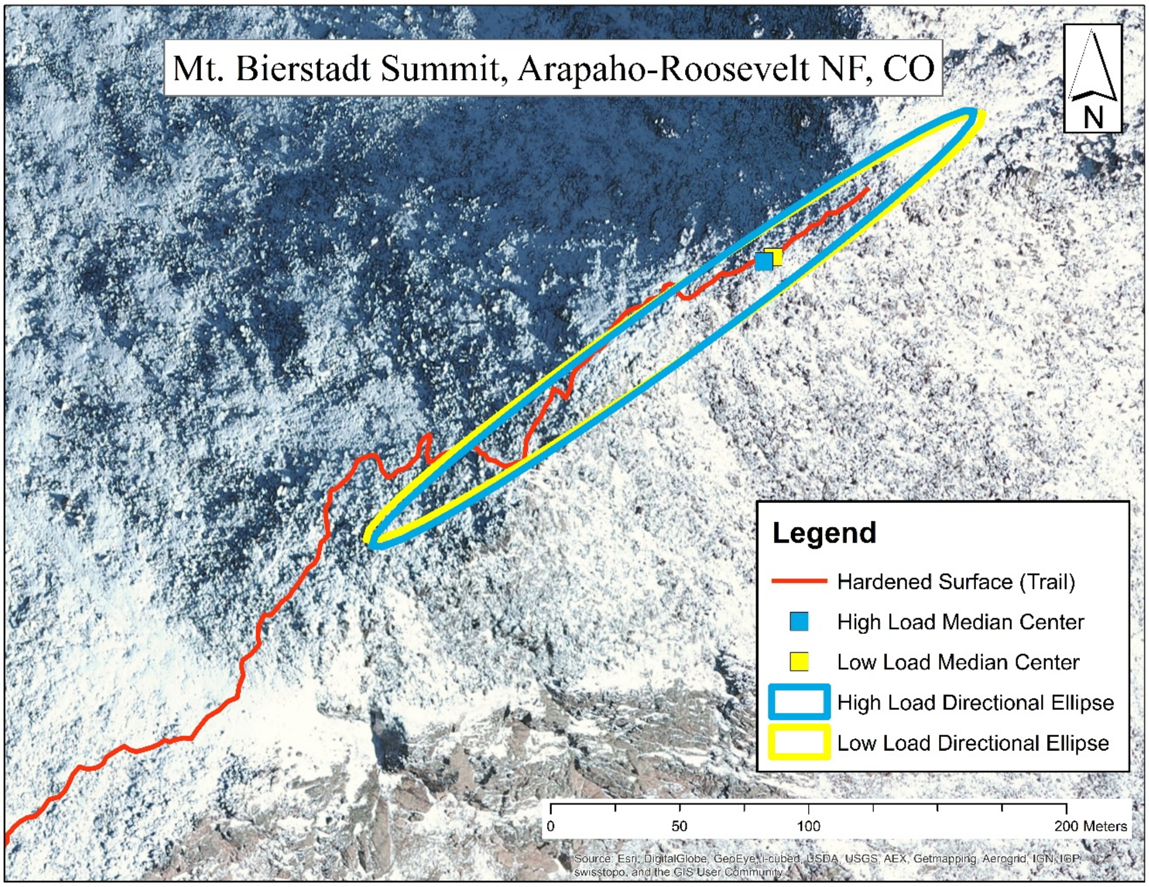


Fig. A.24. Descriptive metrics of overall visitor dispersion at the summit approach to Mt. Bierstadt.

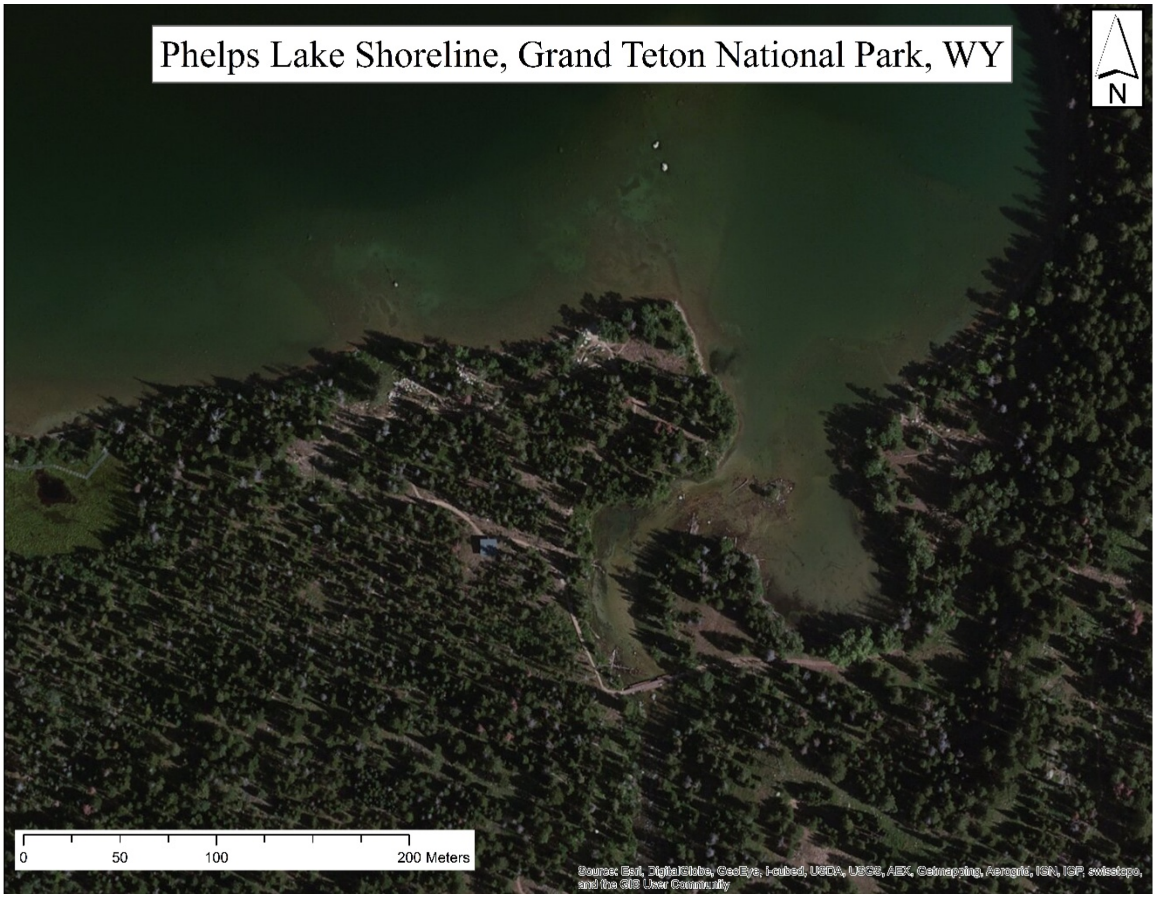


Fig. A.25. Shoreline of Phelps Lake in Grand Teton National Park, WY.

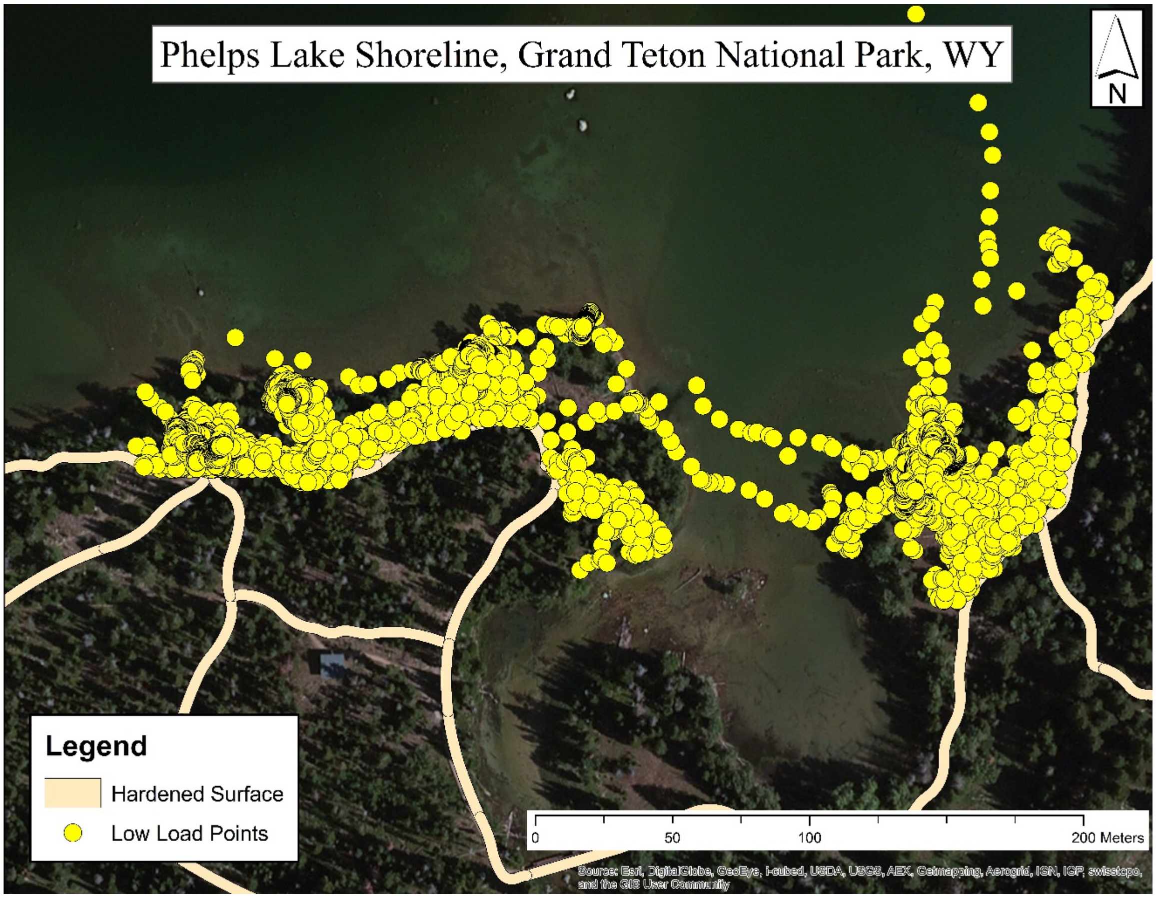
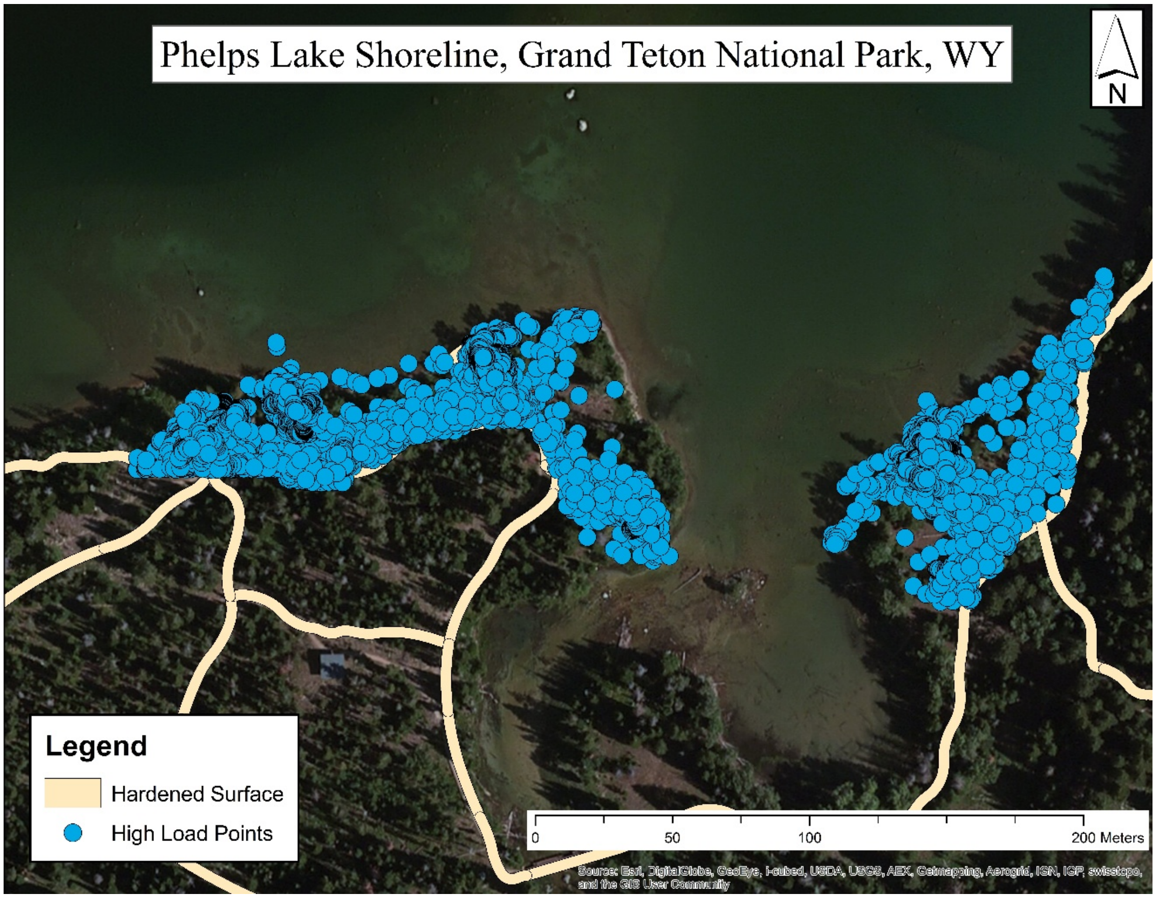


Fig. A.26. GPS tracks of visitor behavior collected during periods of low visitor use at the shoreline of Phelps Lake in Grand Teton National Park, WY.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. A.27. GPS tracks of visitor behavior collected during periods of high visitor use at the shoreline of Phelps Lake in Grand Teton National Park, WY.

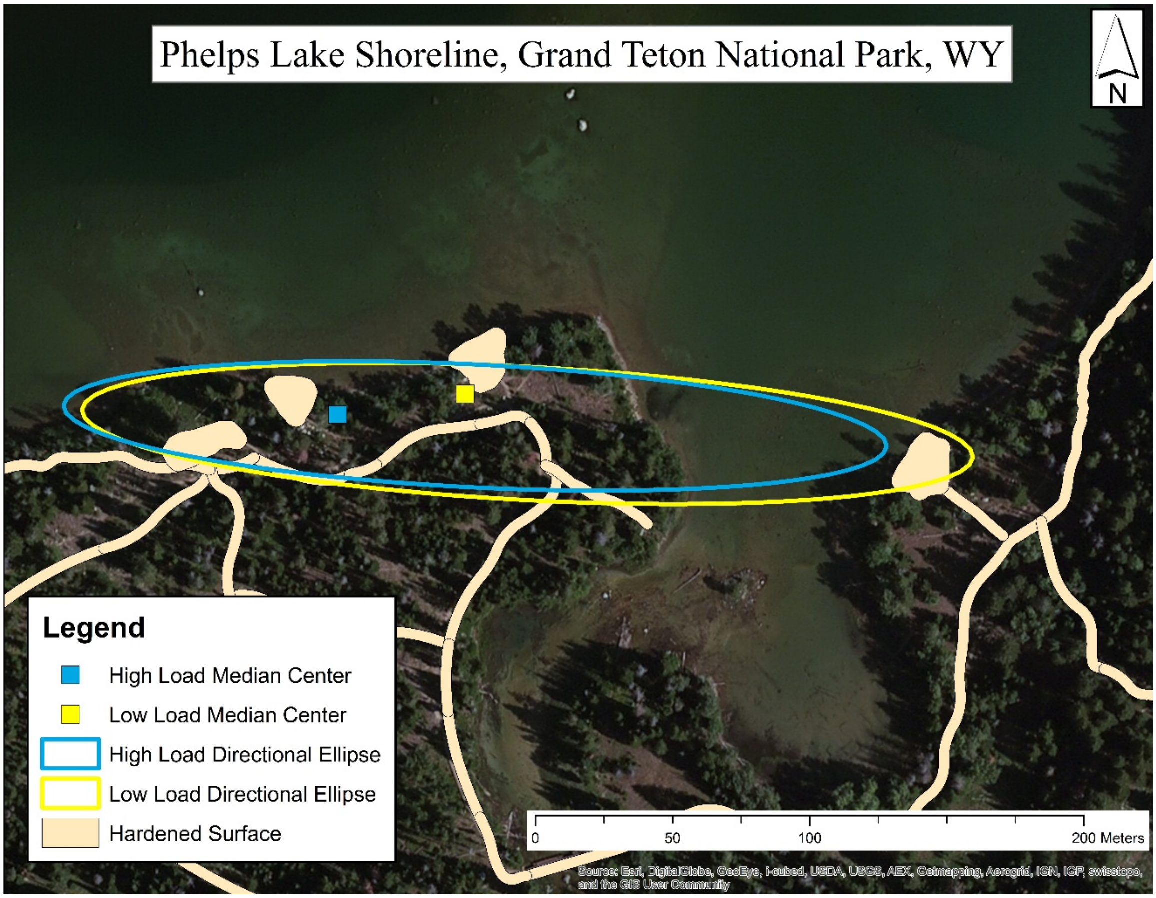


Fig. A.28. Descriptive metrics of overall visitor dispersion at the shoreline of Phelps Lake.

APPENDIX B:

ADDITIONAL FIGURES FOR CHAPTER 3

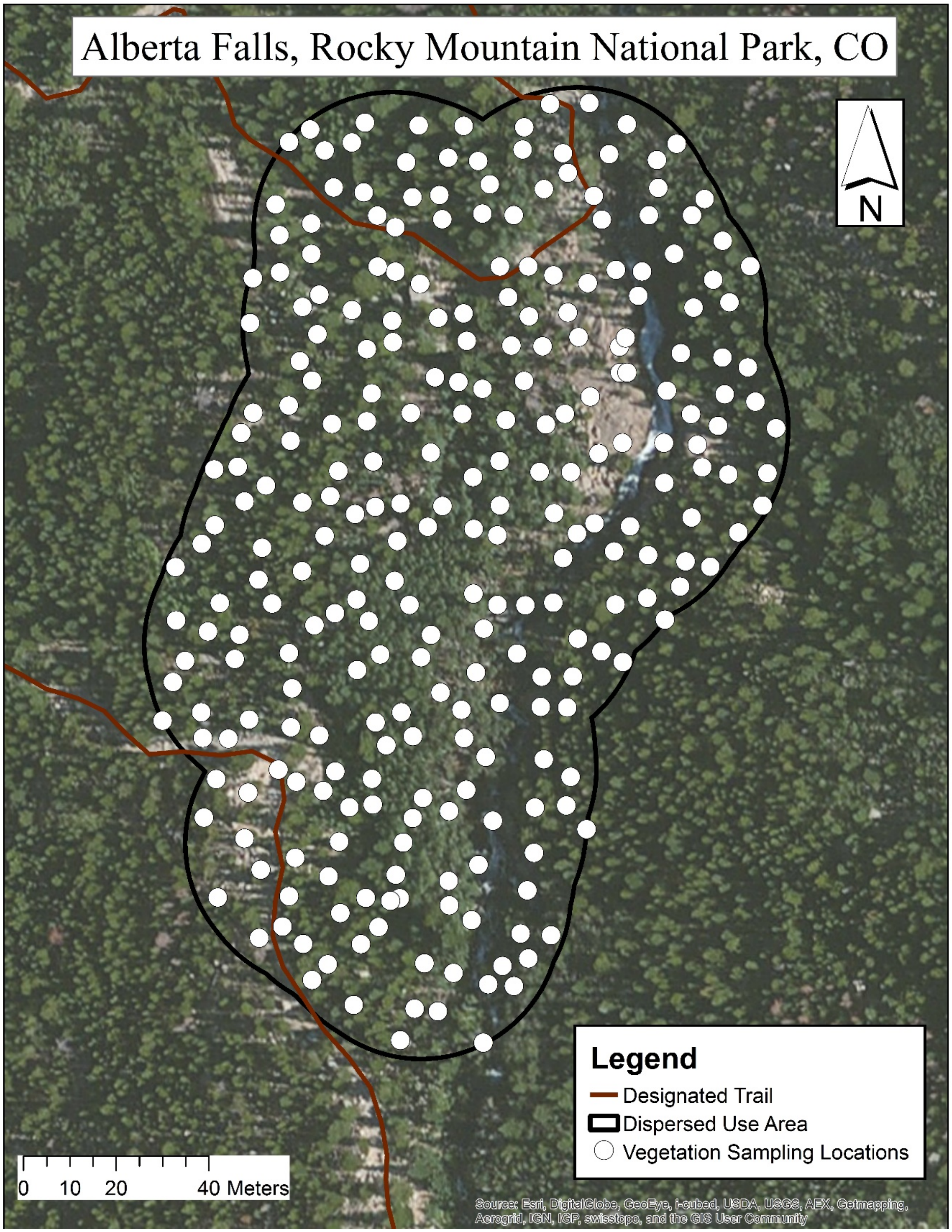


Fig. B.1. Sampling grid for 1-meter quadrats in the area of dispersed visitor use at Alberta Falls, Rocky Mountain National Park, CO.

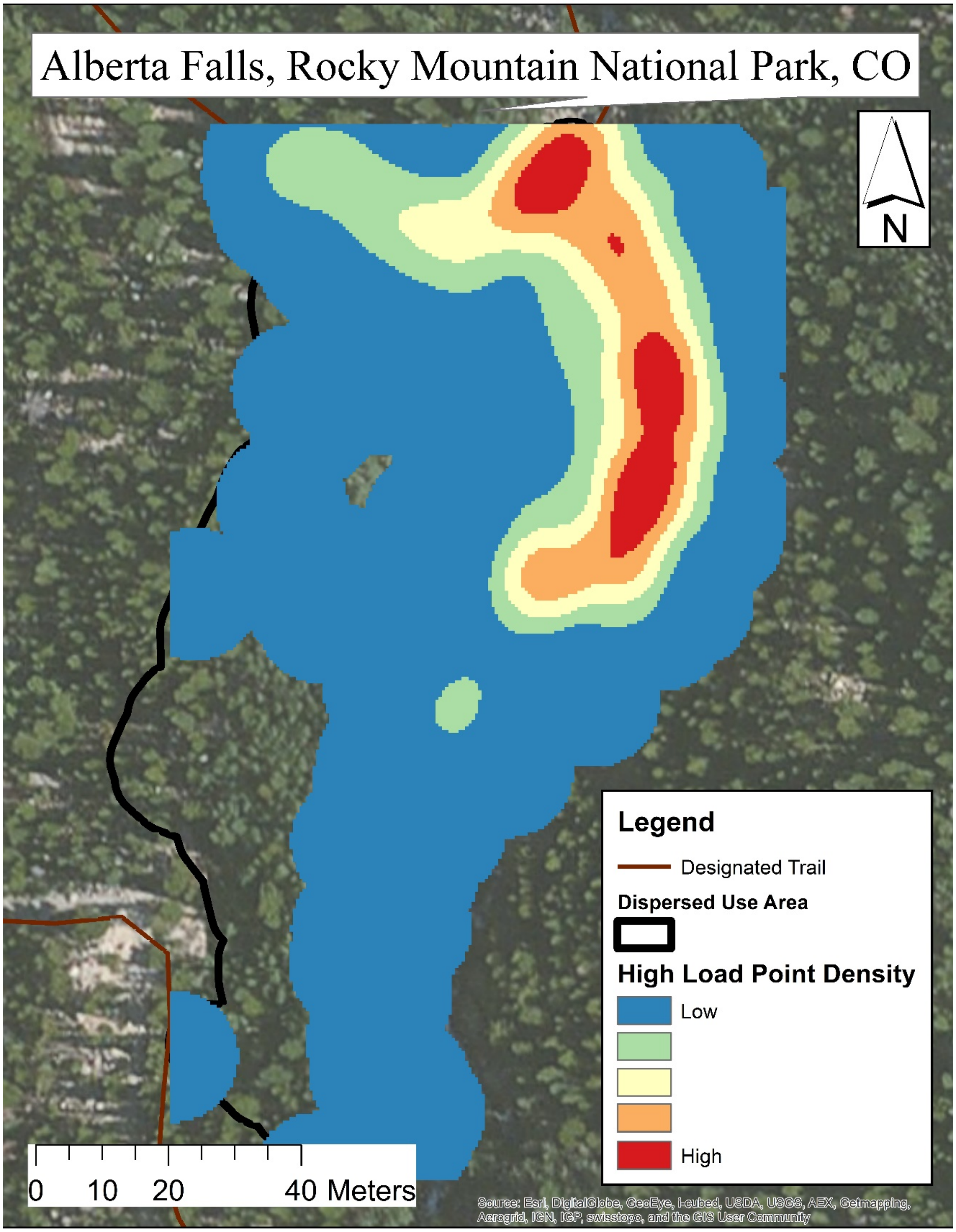


Fig. B.2. Density of visitor tracking points during periods of High Loads of visitor use at Alberta Falls, Rocky Mountain National Park, CO.

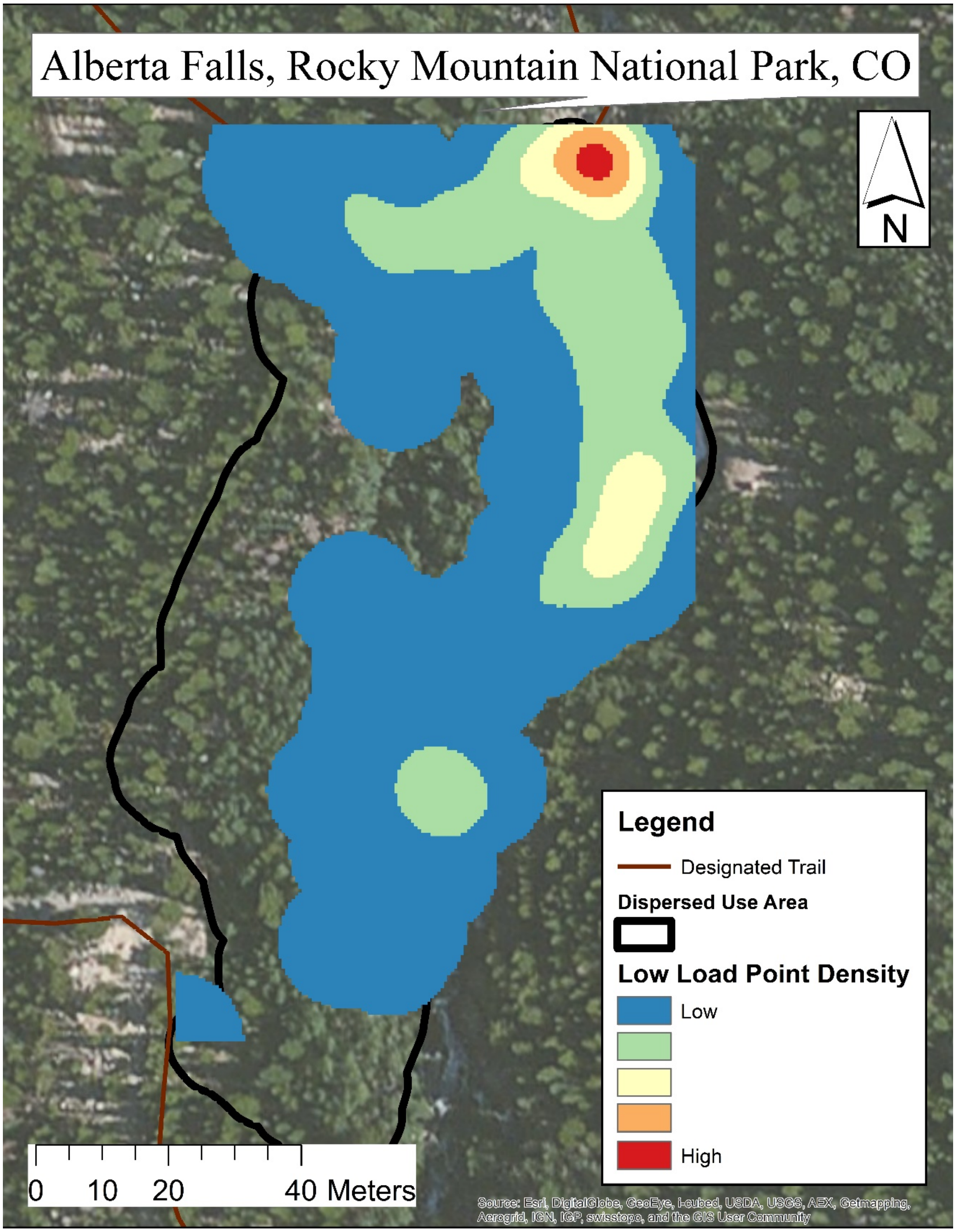


Fig. B.3. Density of visitor tracking points during periods of Low Loads of visitor use at Alberta Falls, Rocky Mountain National Park, CO.

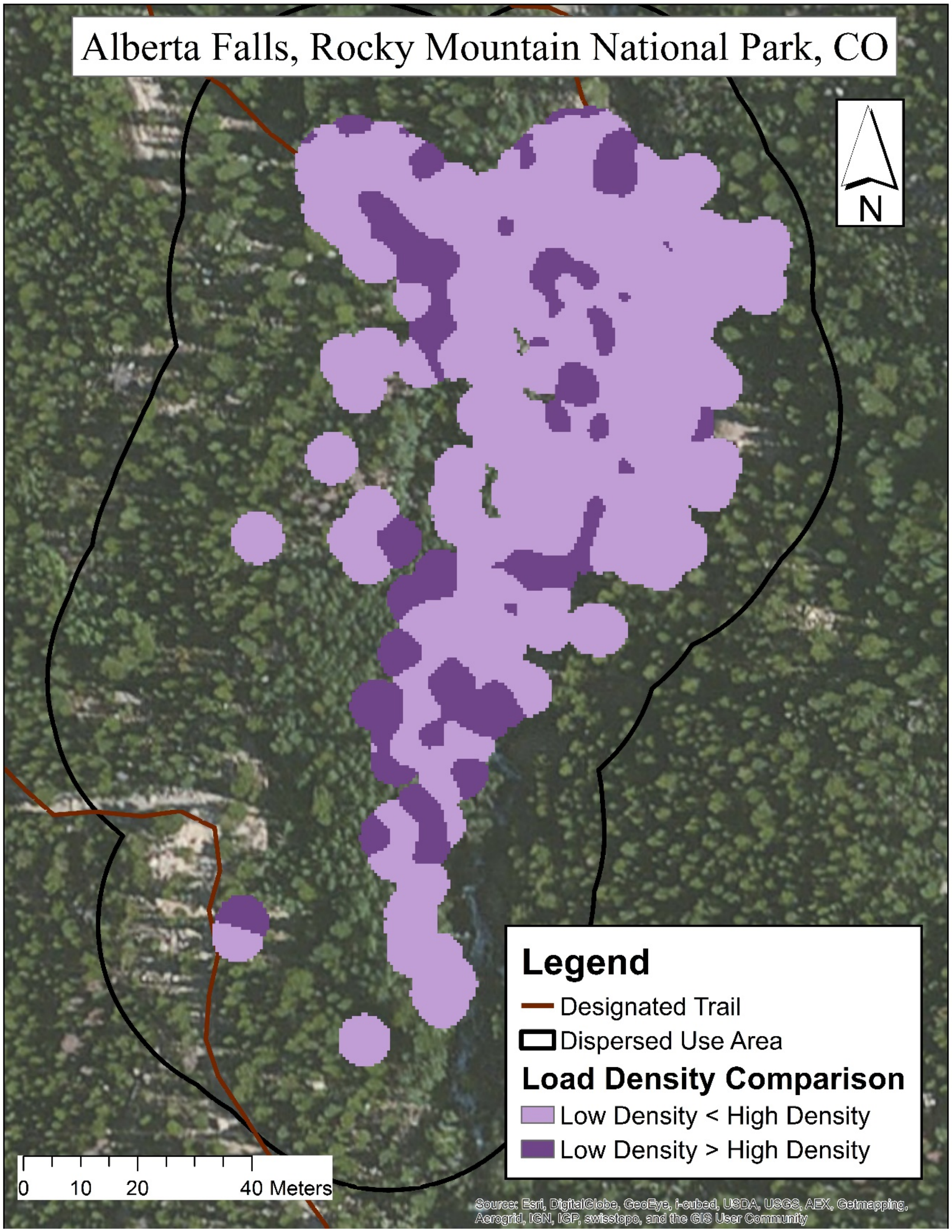
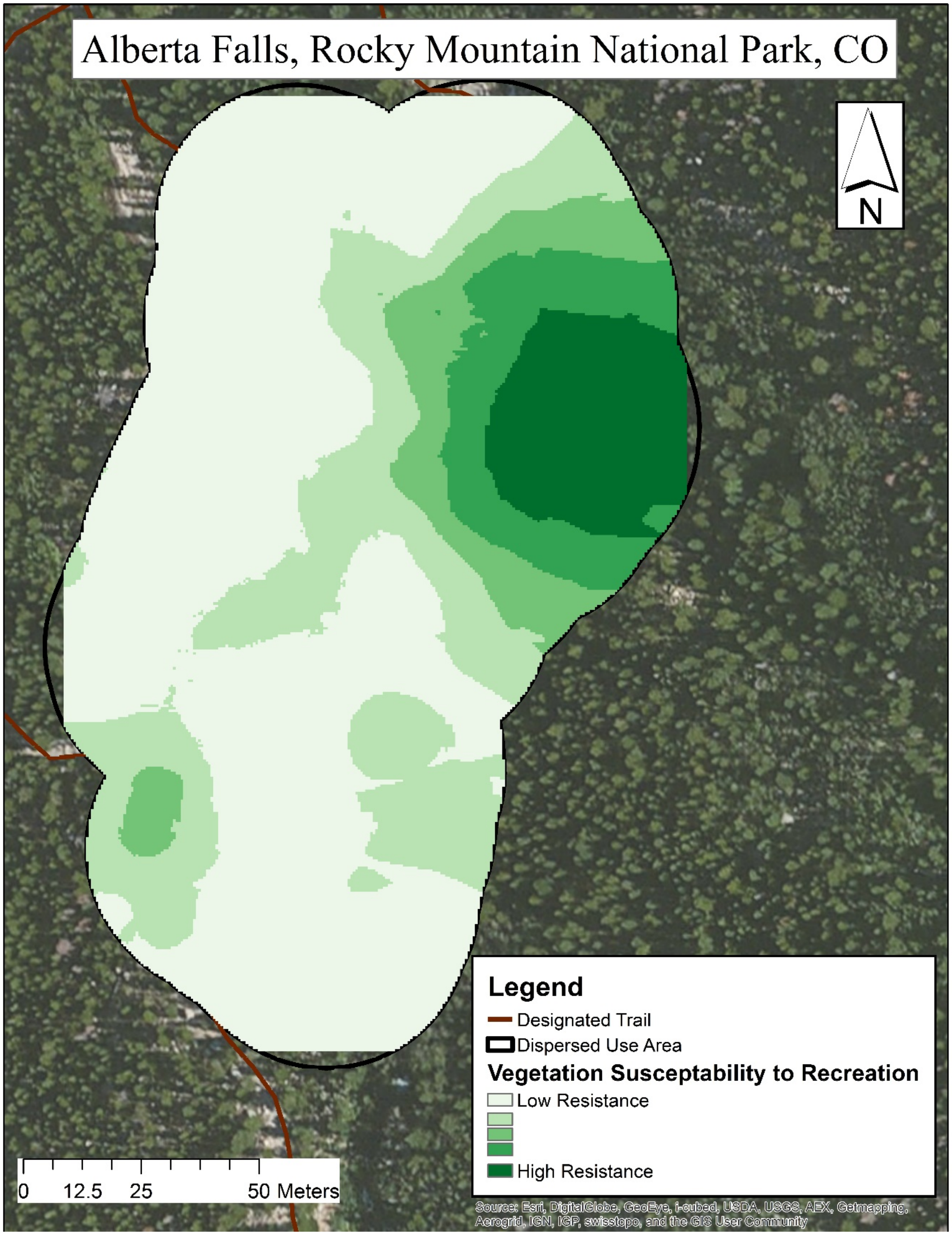


Fig. B.4. Comparison of density of visitor tracking points at Alberta Falls, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.5. Vegetation susceptibility to trampling disturbance in the area of dispersed use at Alberta Falls, Rocky Mountain National Park, CO.

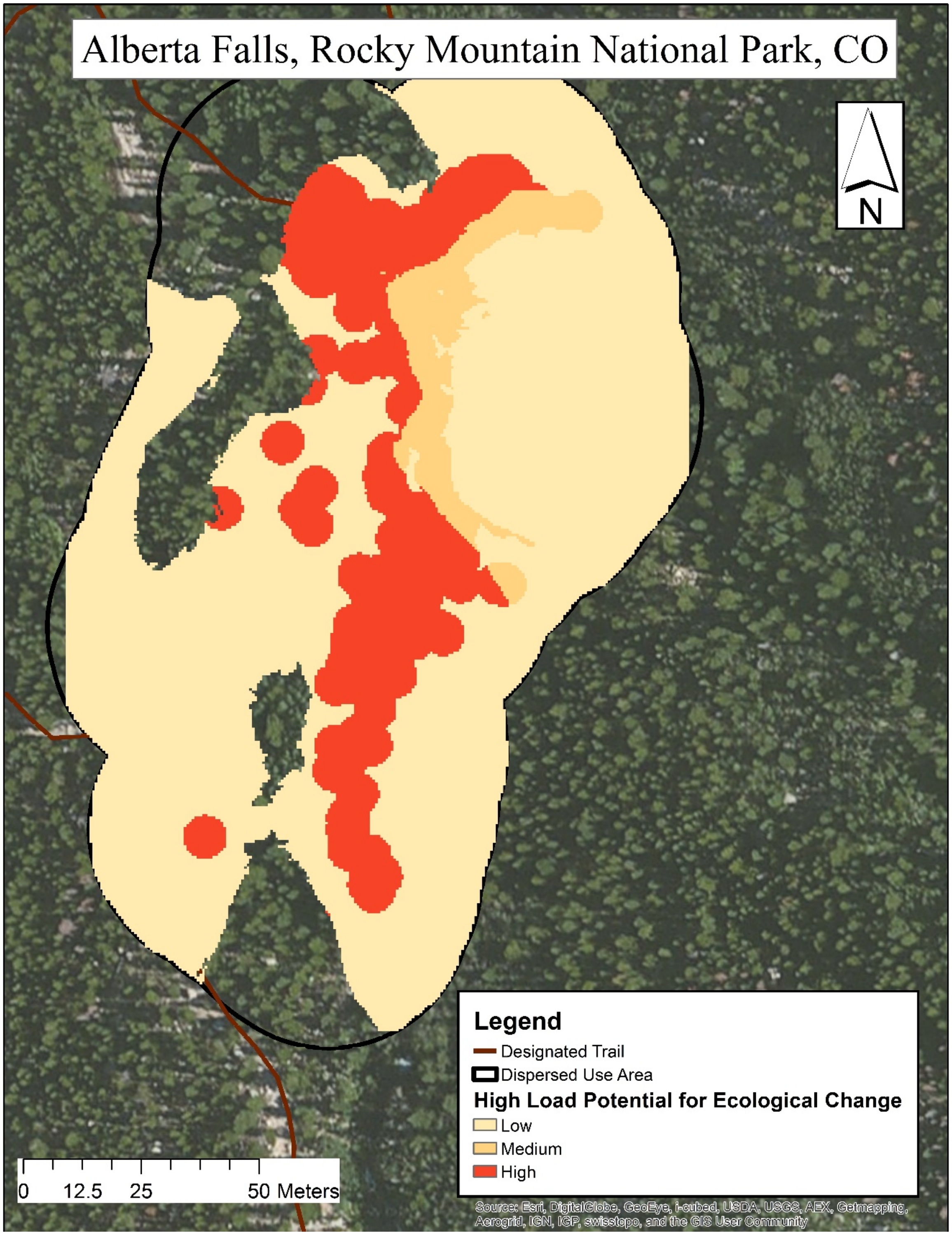
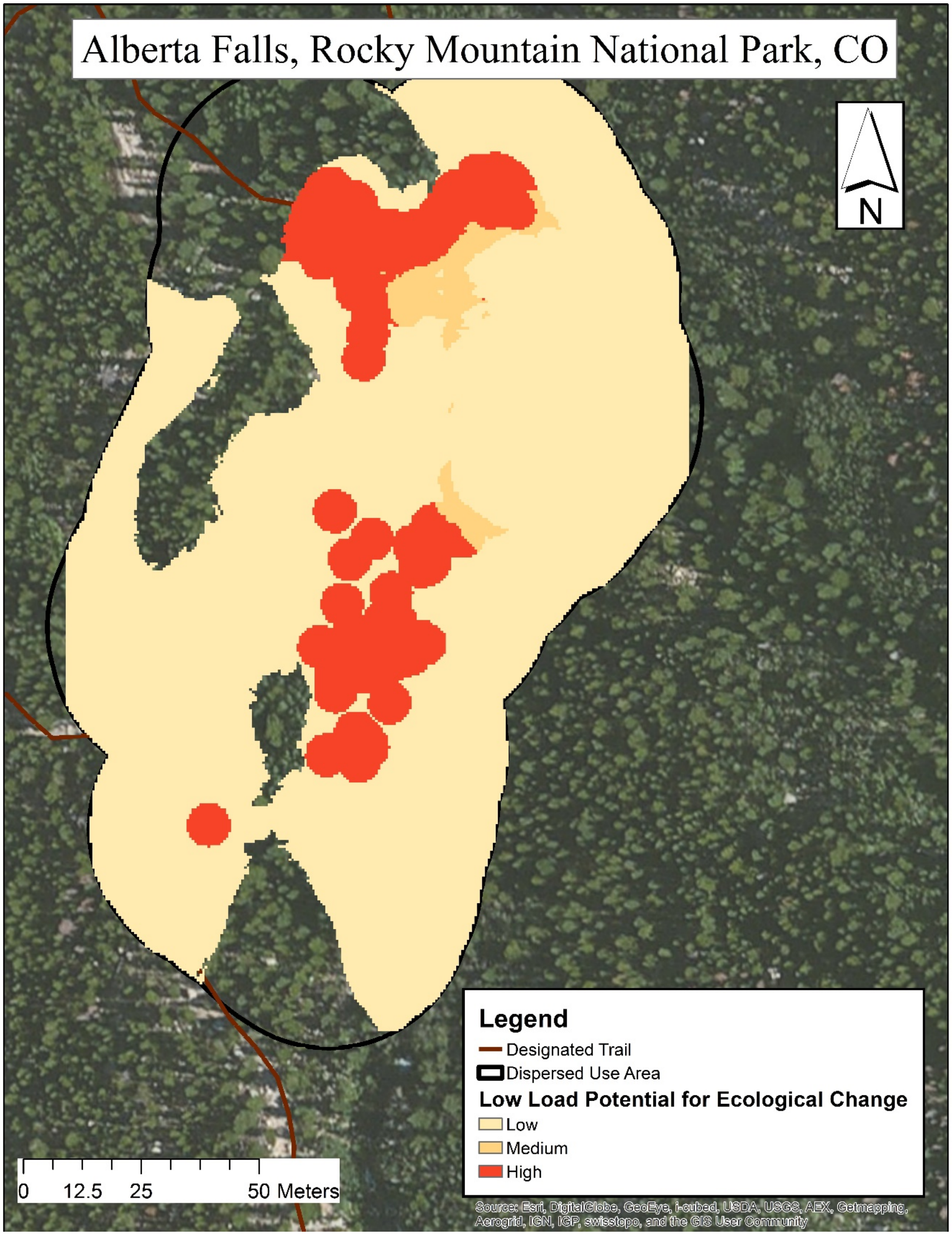
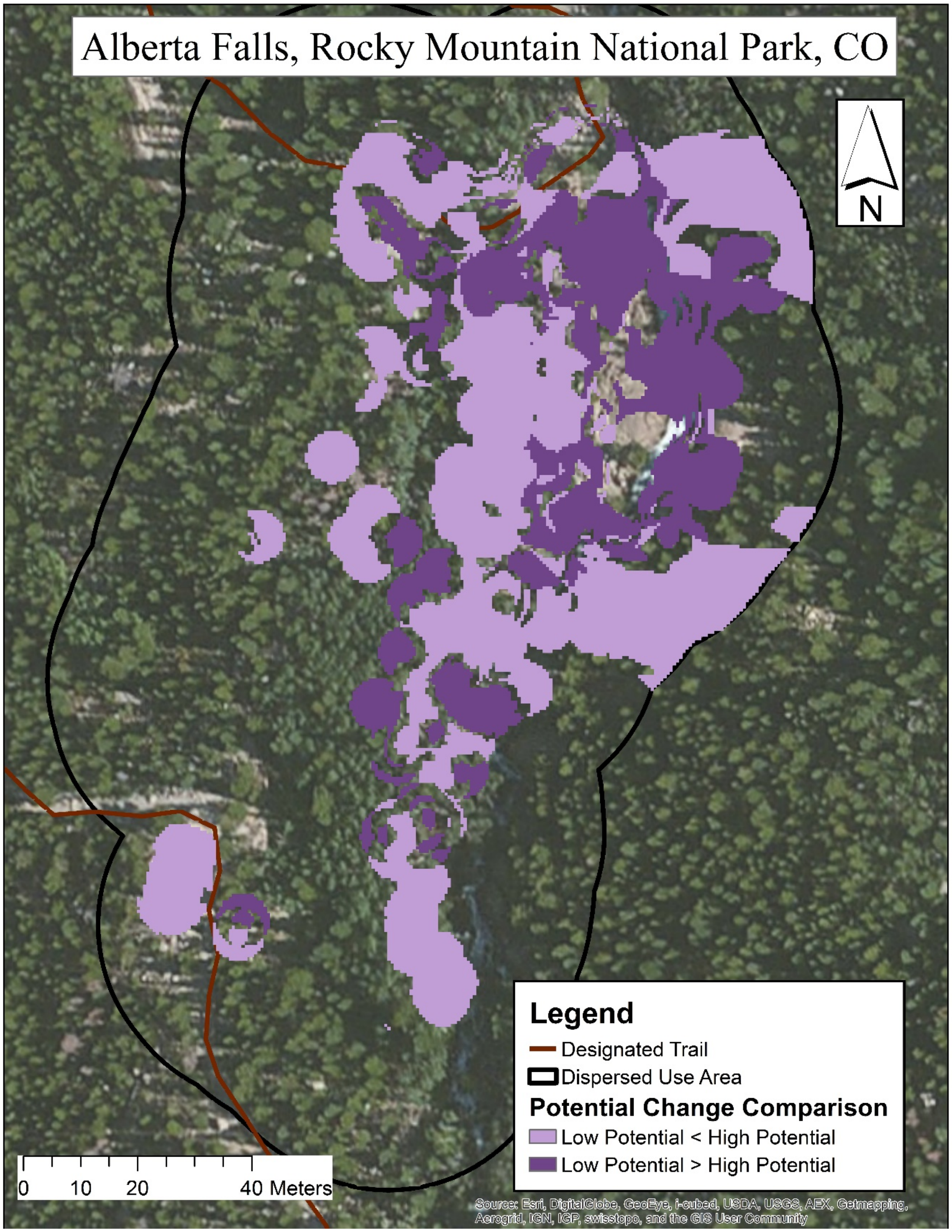


Fig. B.6. Potential for ecological change as a result of High Loads of visitor use at Alberta Falls, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.7. Potential for ecological change as a result of Low Loads of visitor use at Alberta Falls, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.8. Comparison of potential for ecological change as a result of visitor use at Alberta Falls, Rocky Mountain National Park, CO.

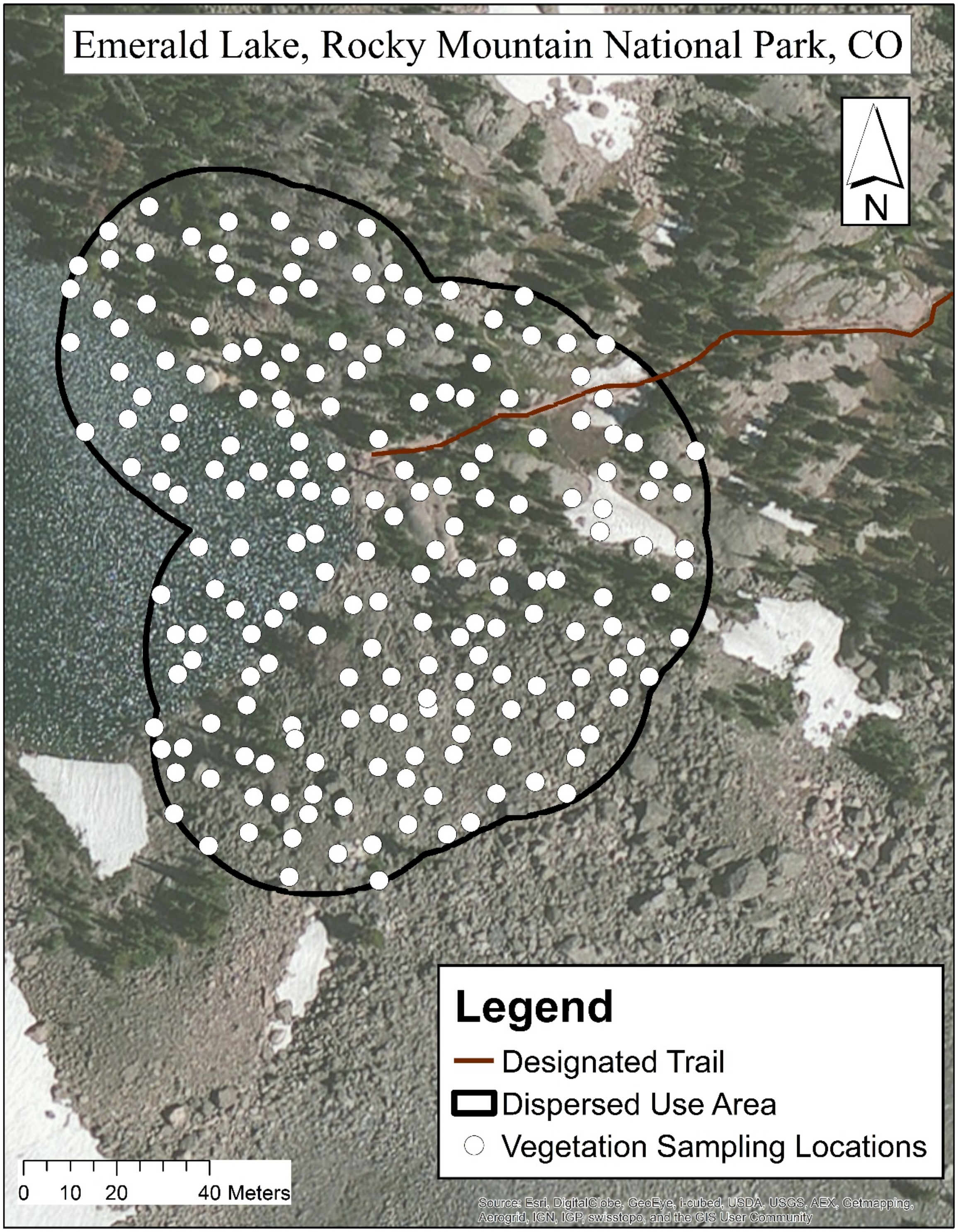


Fig. B.9. Sampling grid for 1-meter quadrats in the area of dispersed visitor use at Emerald Lake, Rocky Mountain National Park, CO.

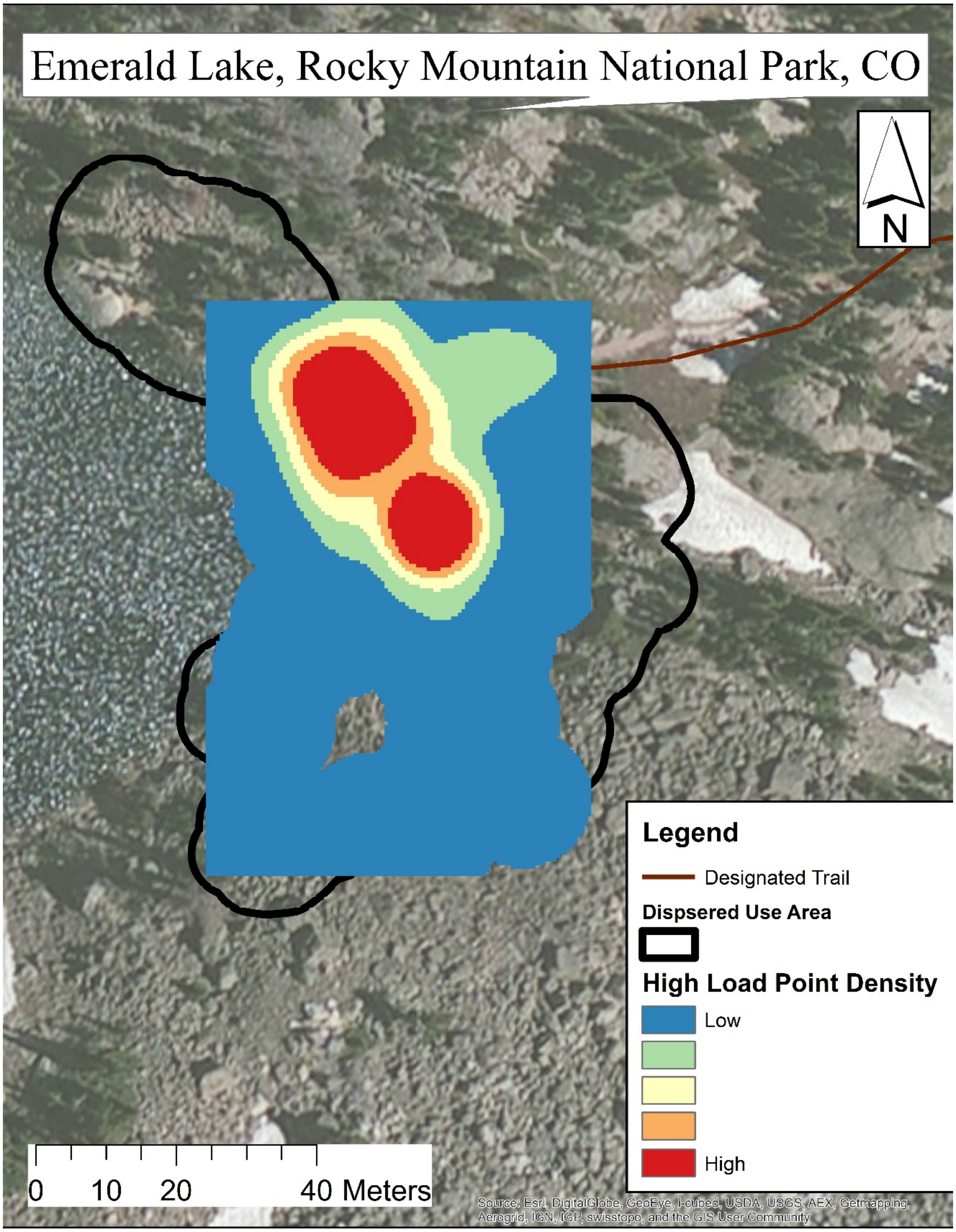


Fig. B.10. Density of visitor tracking points during periods of High Loads of visitor use at Emerald Lake, Rocky Mountain National Park, CO.

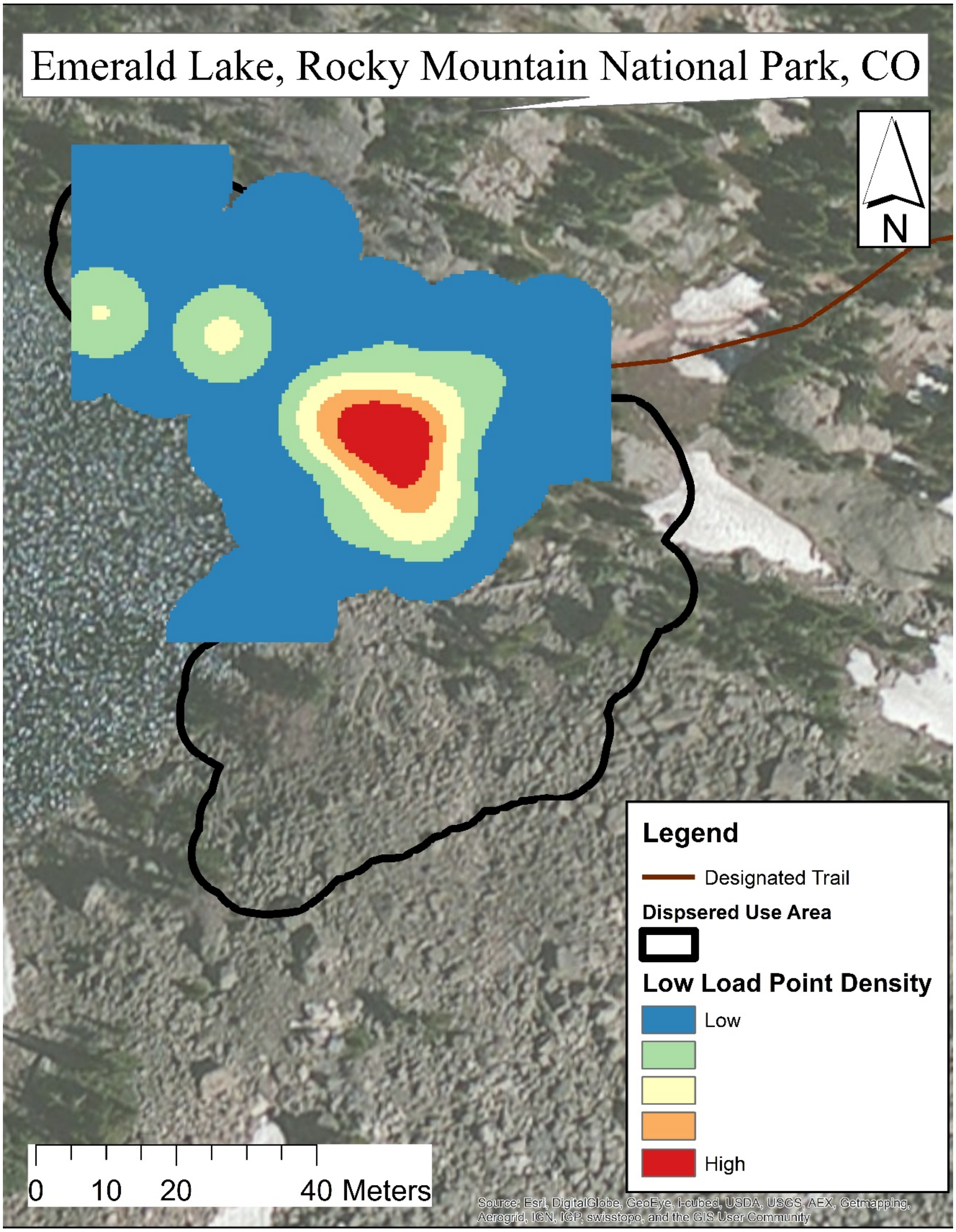
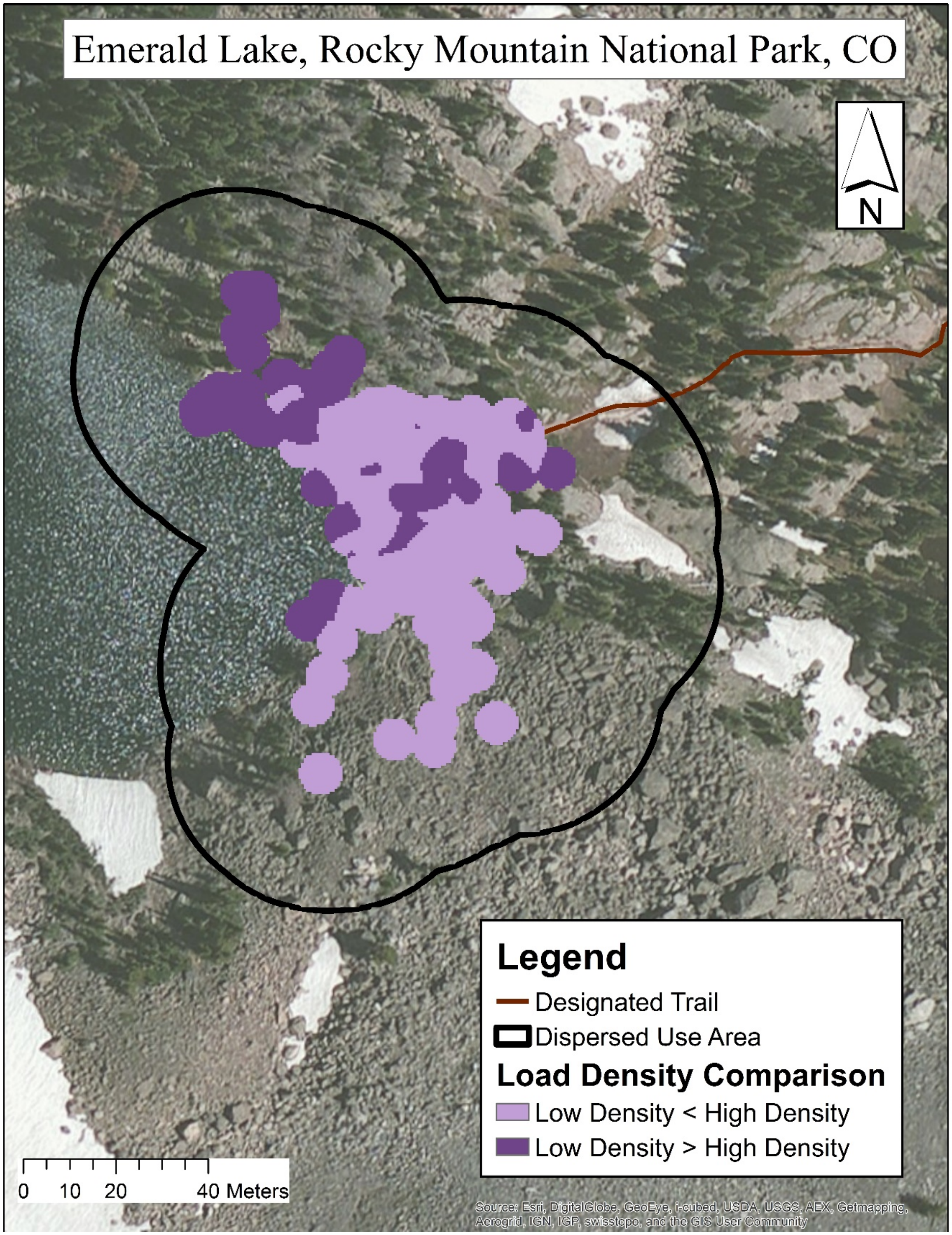
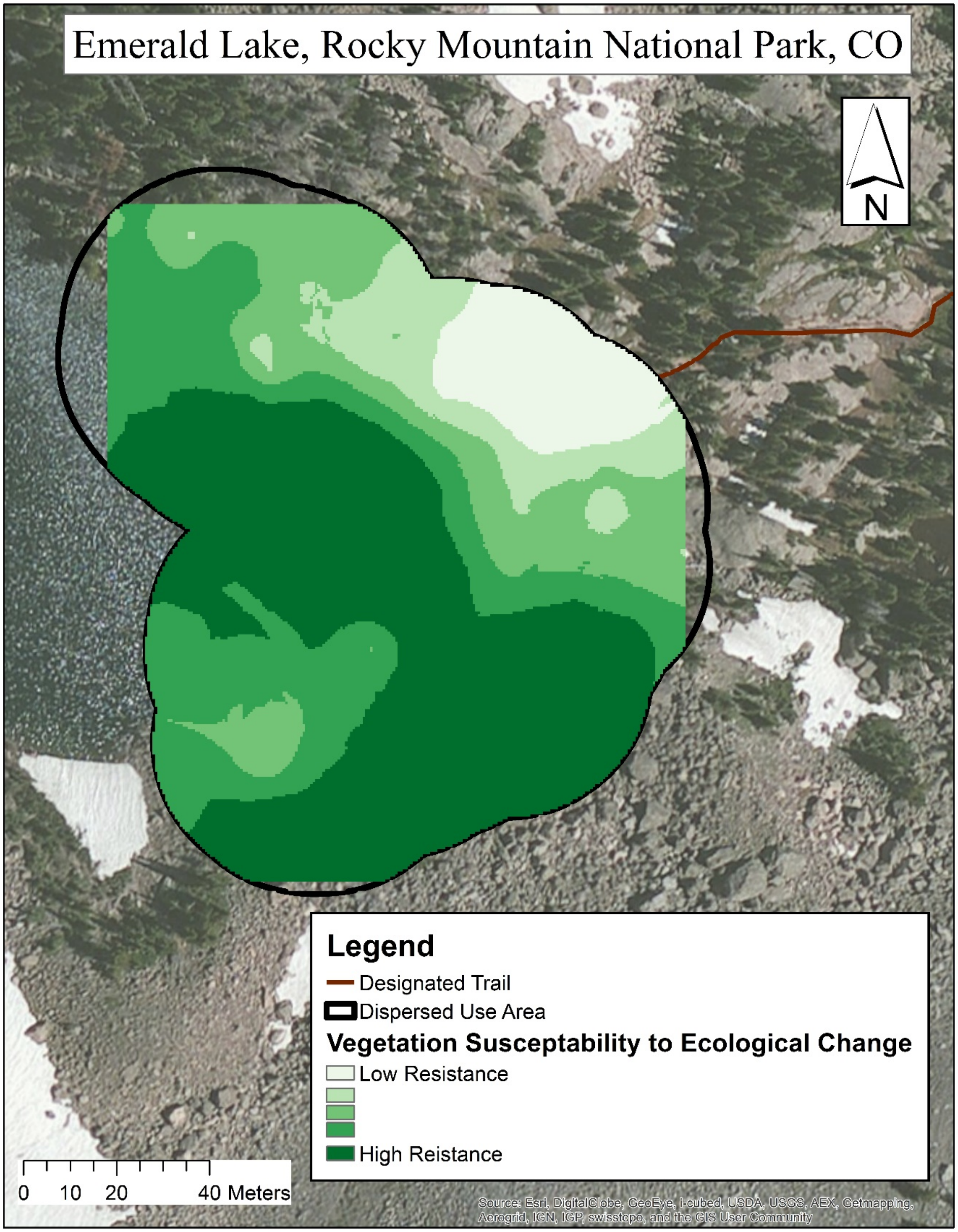


Fig. B.11. Density of visitor tracking points during periods of Low Loads of visitor use at Emerald Lake, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.12. Comparison of density of visitor tracking points at Emerald Lake, Rocky Mountain National Park, CO.



Emerald Lake, Rocky Mountain National Park, CO

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.13. Vegetation susceptibility to trampling disturbance in the area of dispersed use at Emerald Lake, Rocky Mountain National Park, CO.

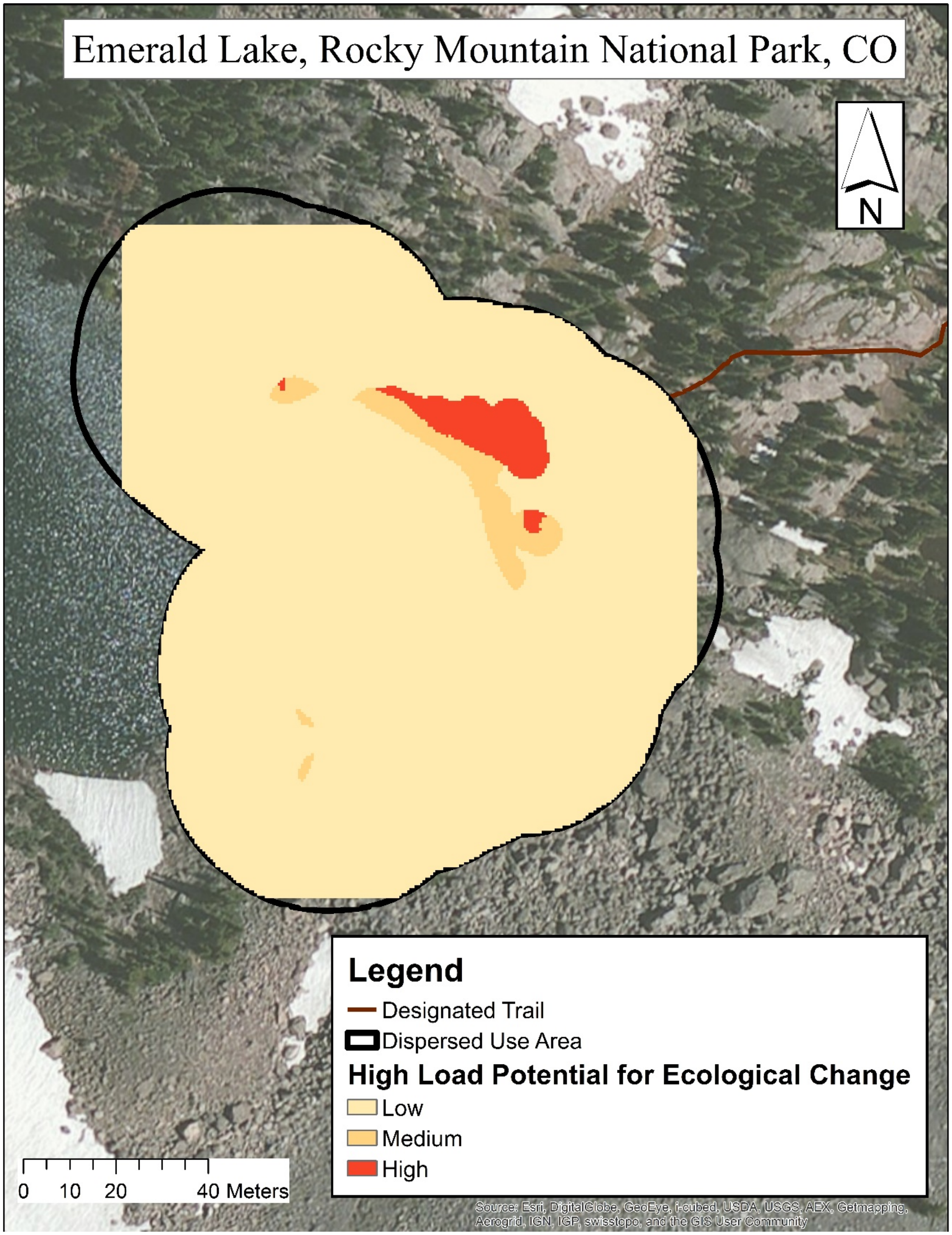
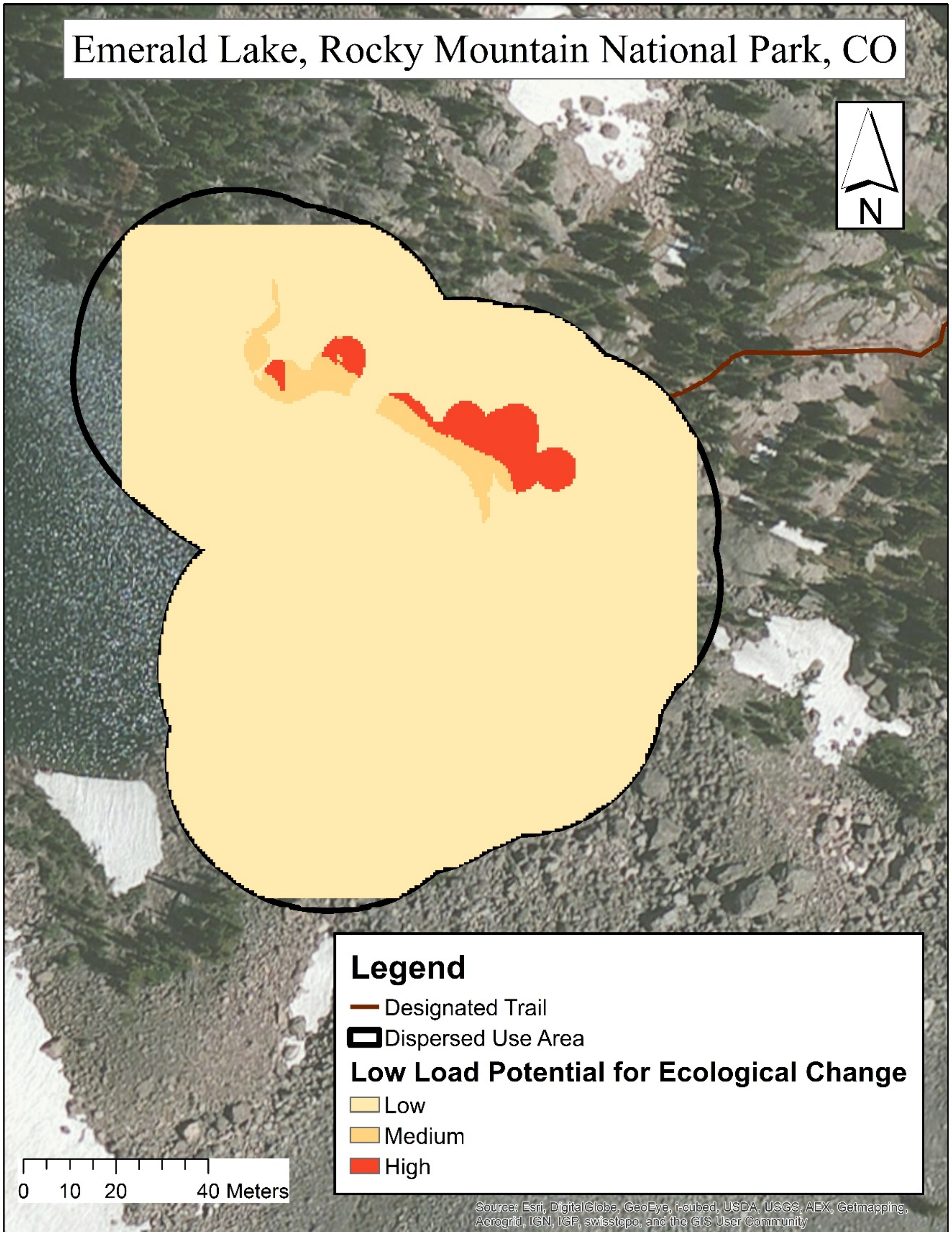
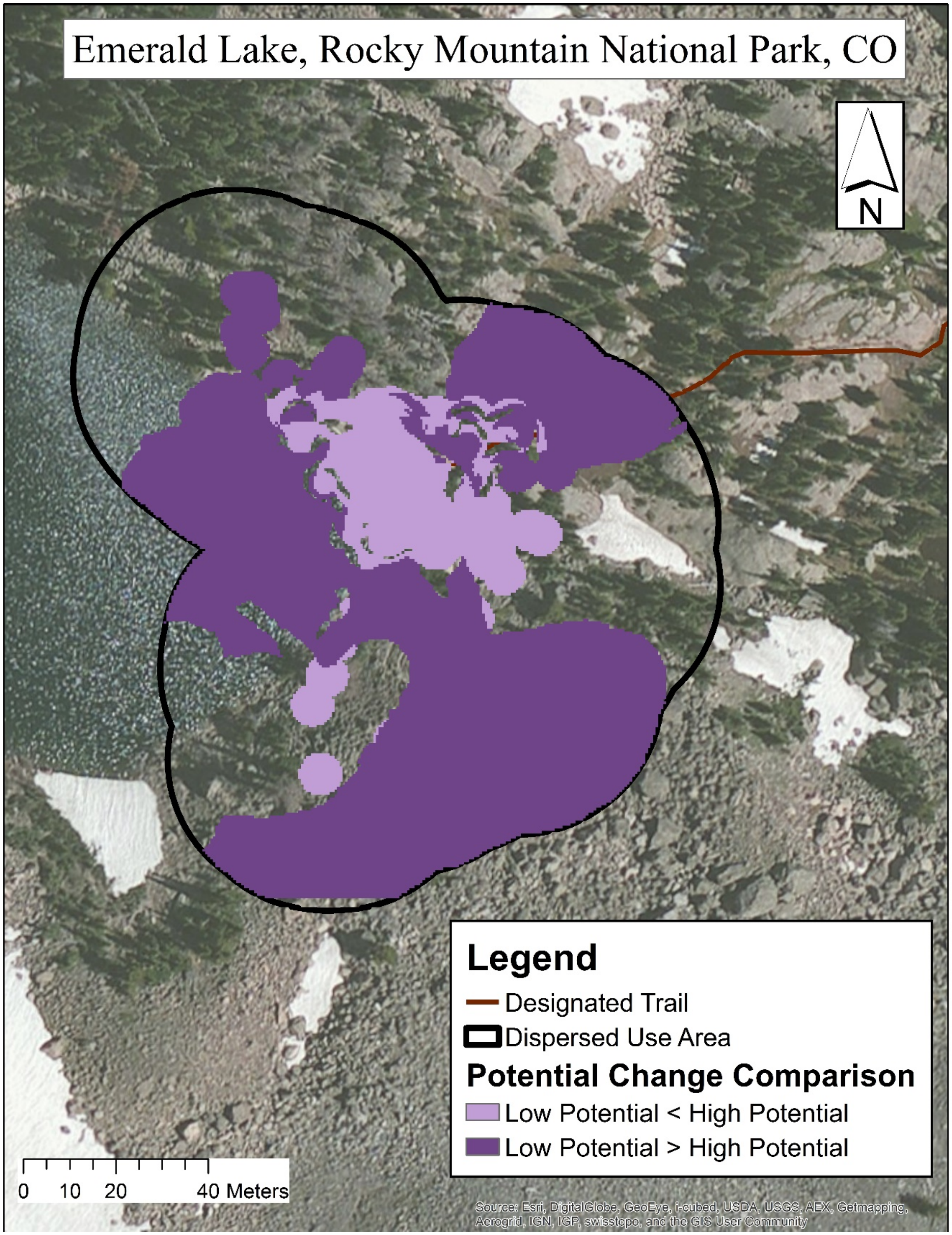


Fig. B.14. Potential for ecological change as a result of High Loads of visitor use at Emerald Lake, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.15. Potential for ecological change as a result of Low Loads of visitor use at Emerald Lake, Rocky Mountain National Park, CO.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.16. Comparison of potential for ecological change as a result of visitor use at Emerald Lake, Rocky Mountain National Park, CO.

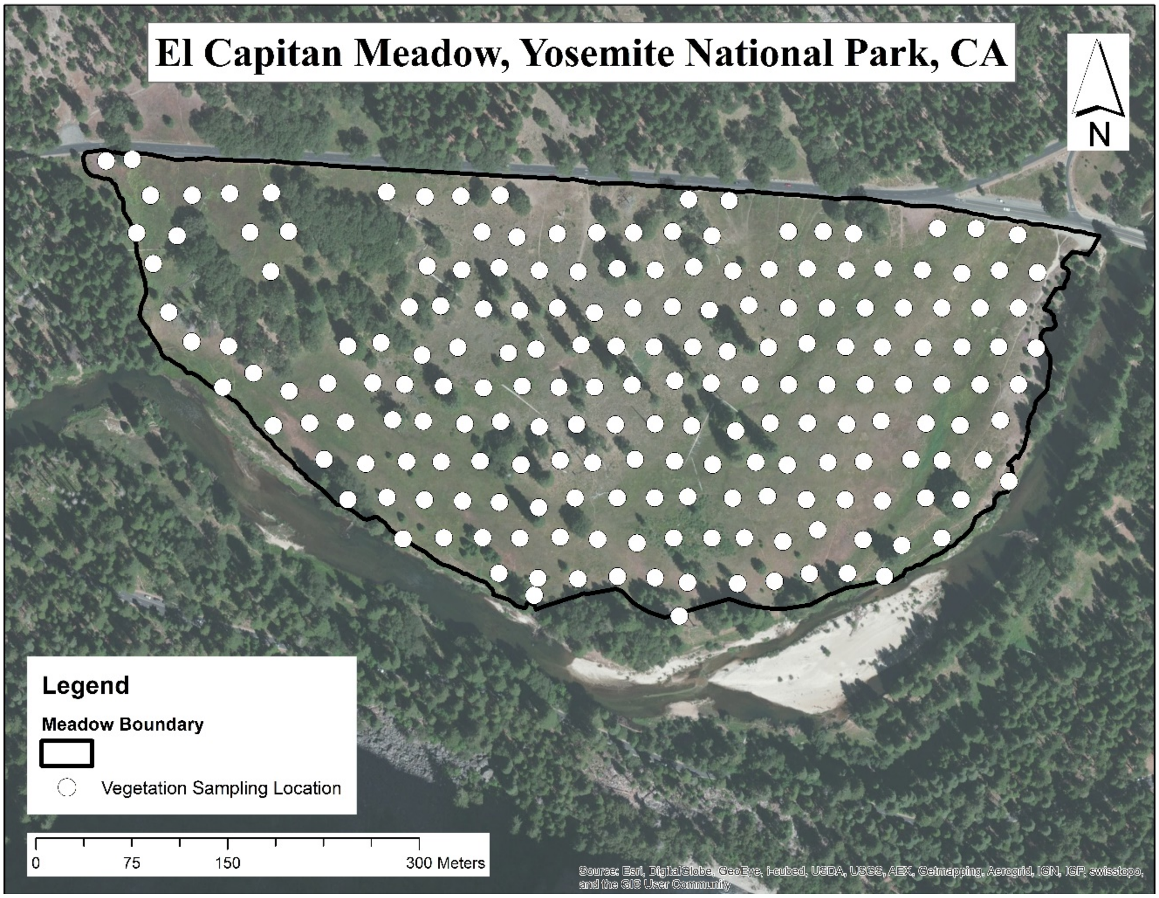


Fig. B.17. Sampling grid for 1-meter quadrats in the area of dispersed visitor use at El Capitan Meadow, Yosemite National Park, CA.

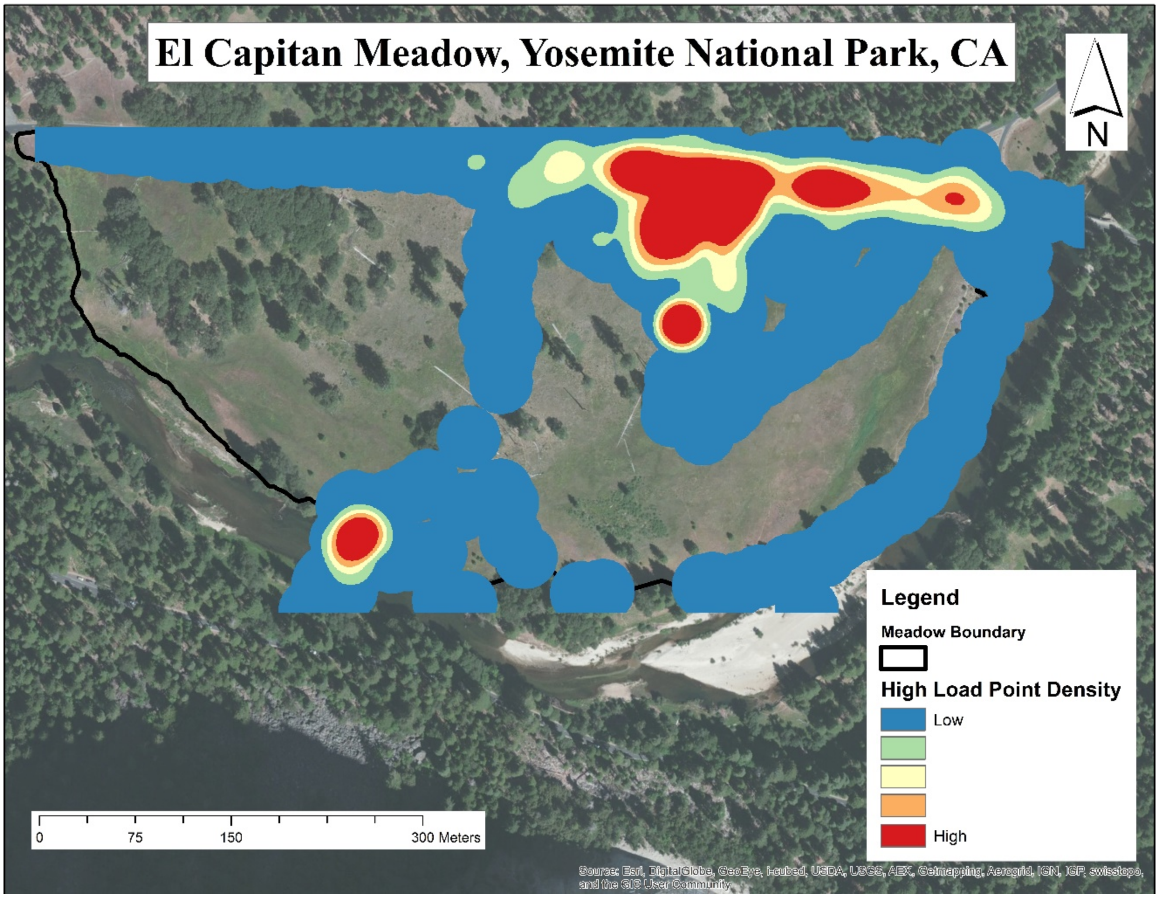


Fig. B.18. Density of visitor tracking points during periods of High Loads of visitor use at El Capitan Meadow, Yosemite National Park, CA.

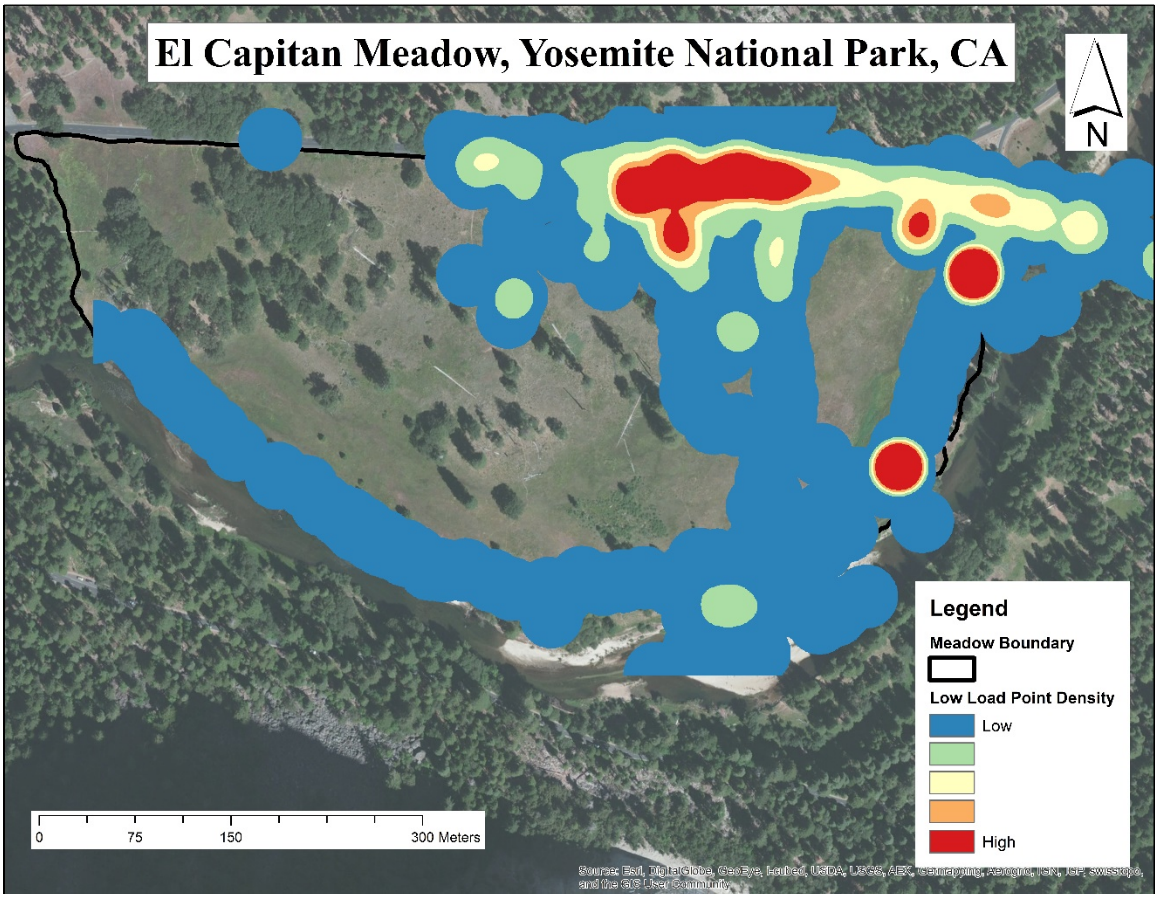


Fig. B.19. Density of visitor tracking points during periods of Low Loads of visitor use at El Capitan Meadow, Yosemite National Park, CA.

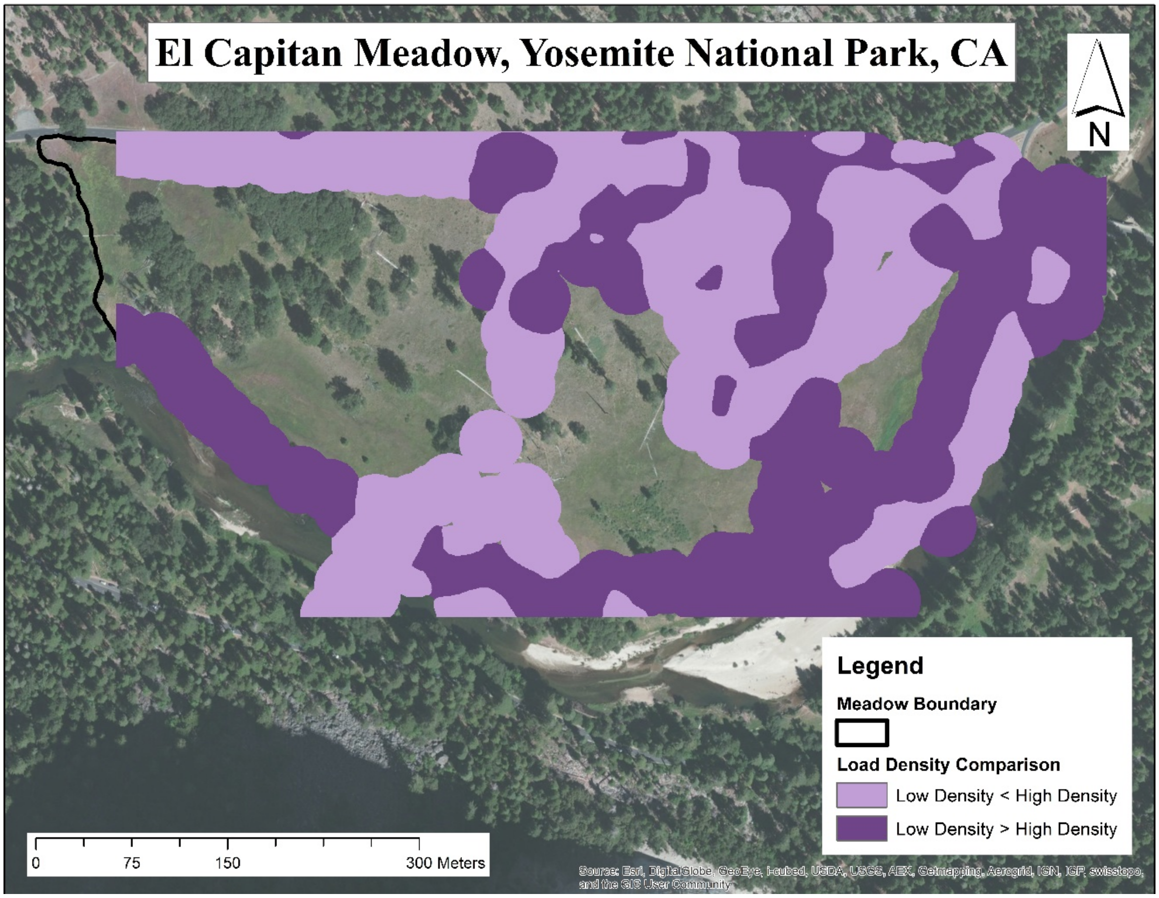
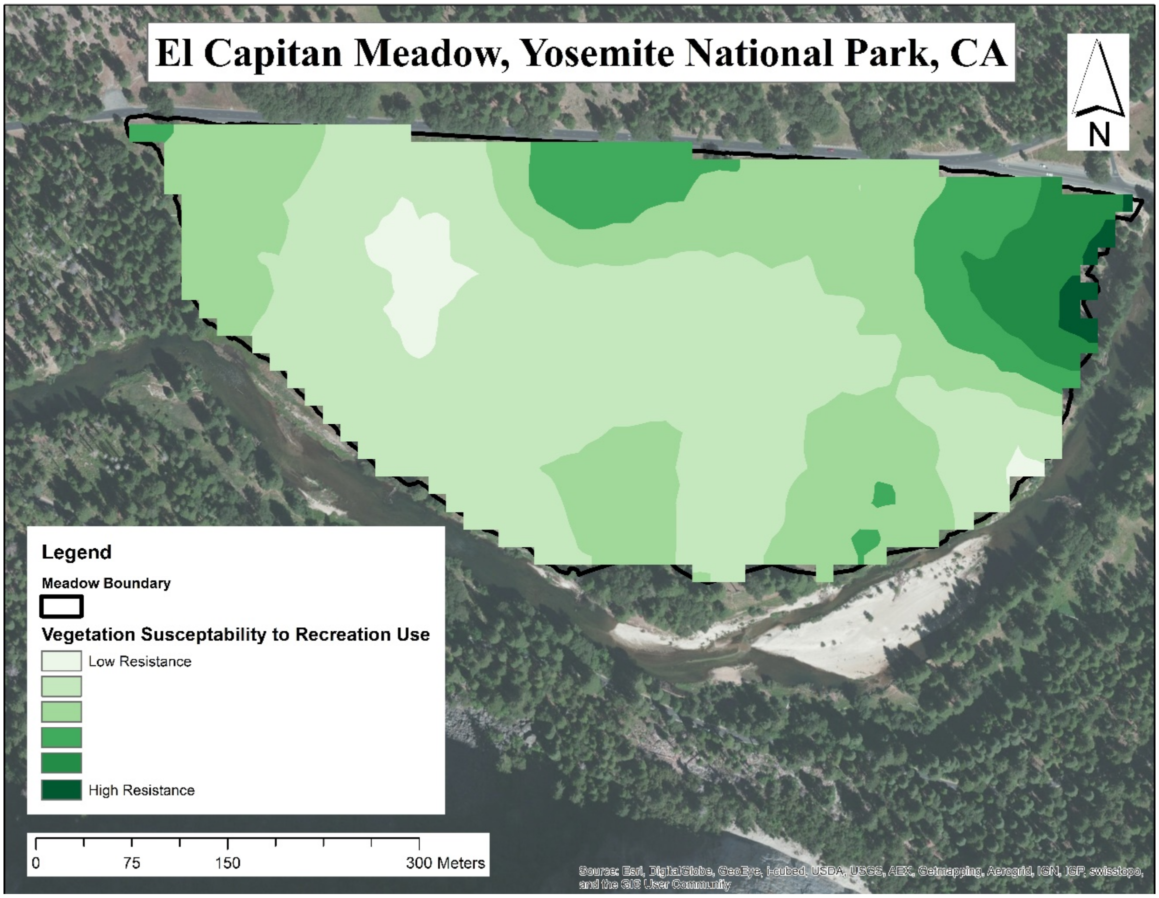


Fig. B.20. Comparison of density of visitor tracking points at El Capitan, Yosemite National Park, CA.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.21. Vegetation susceptibility to trampling disturbance in the area of dispersed use at El Capitan Meadow, Yosemite National Park, CA.

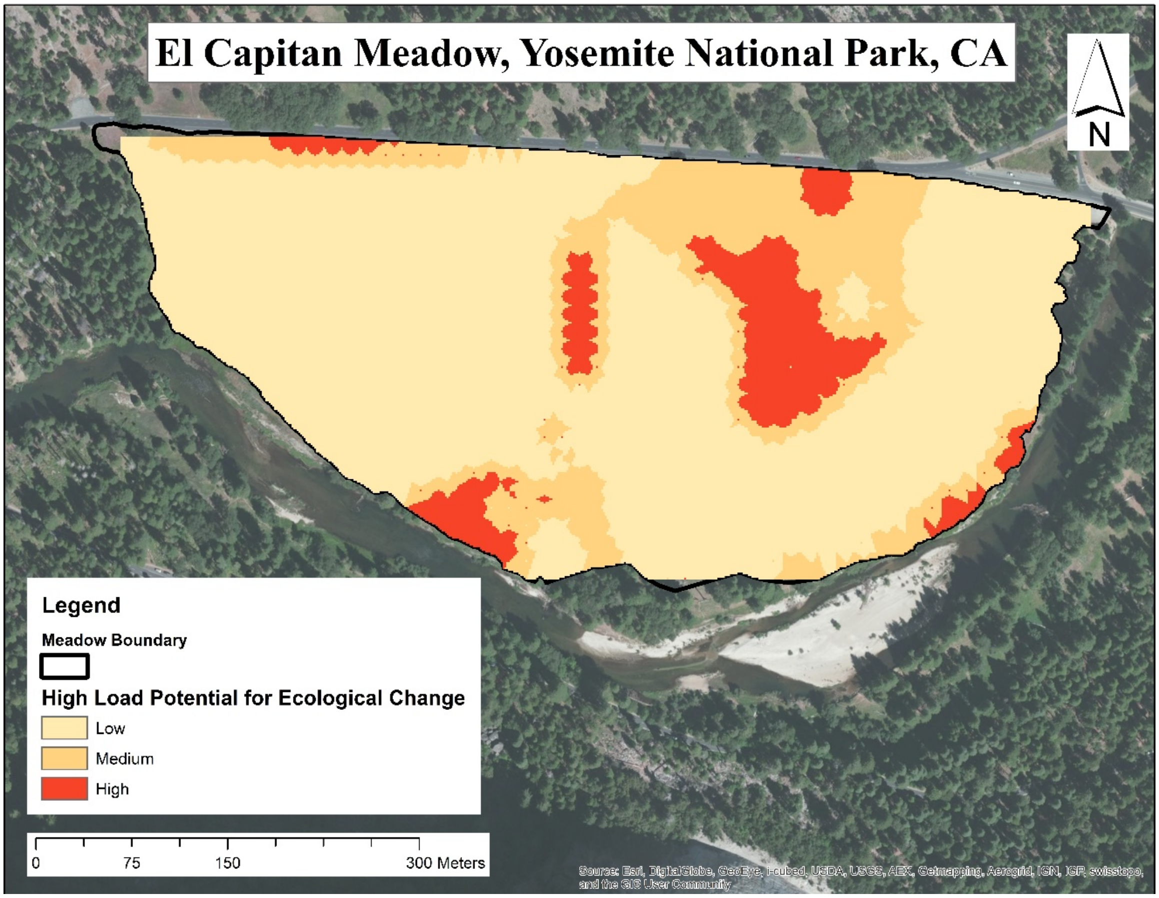
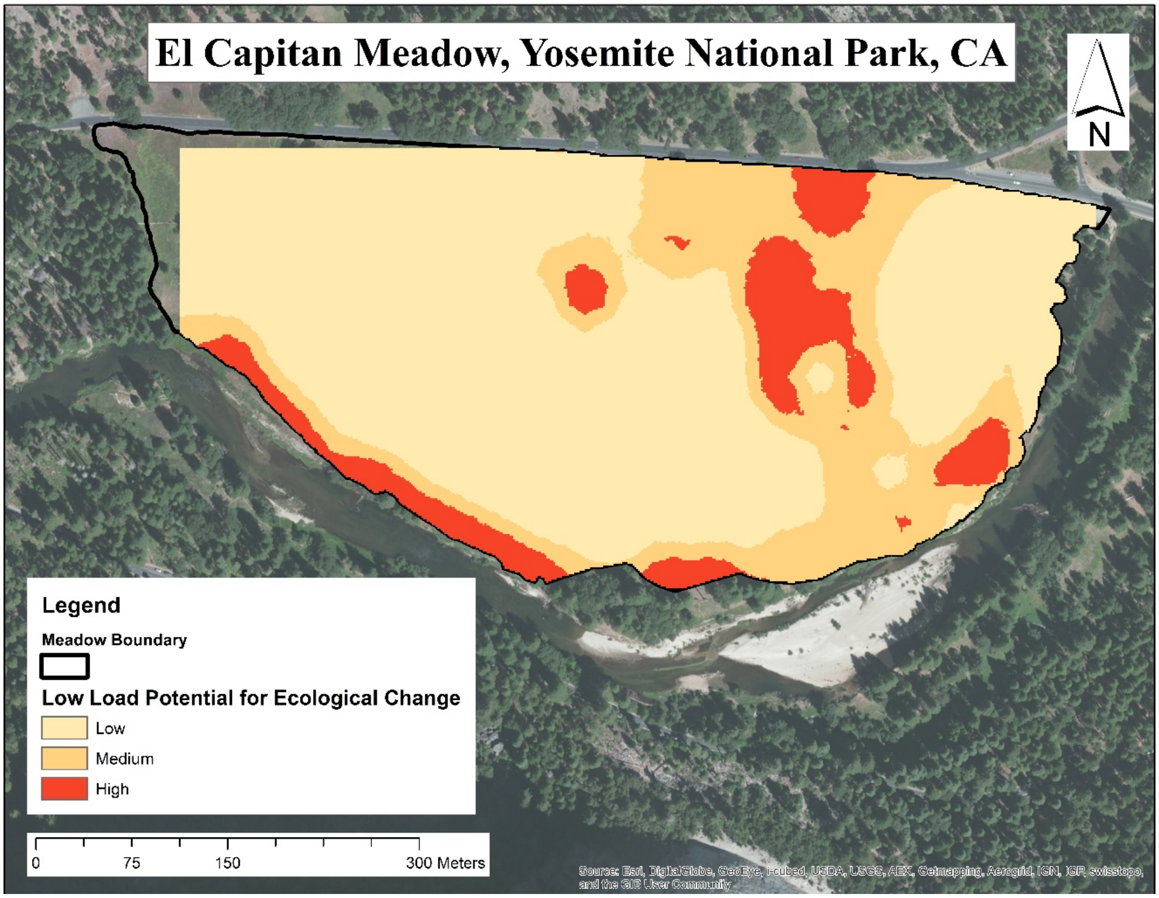
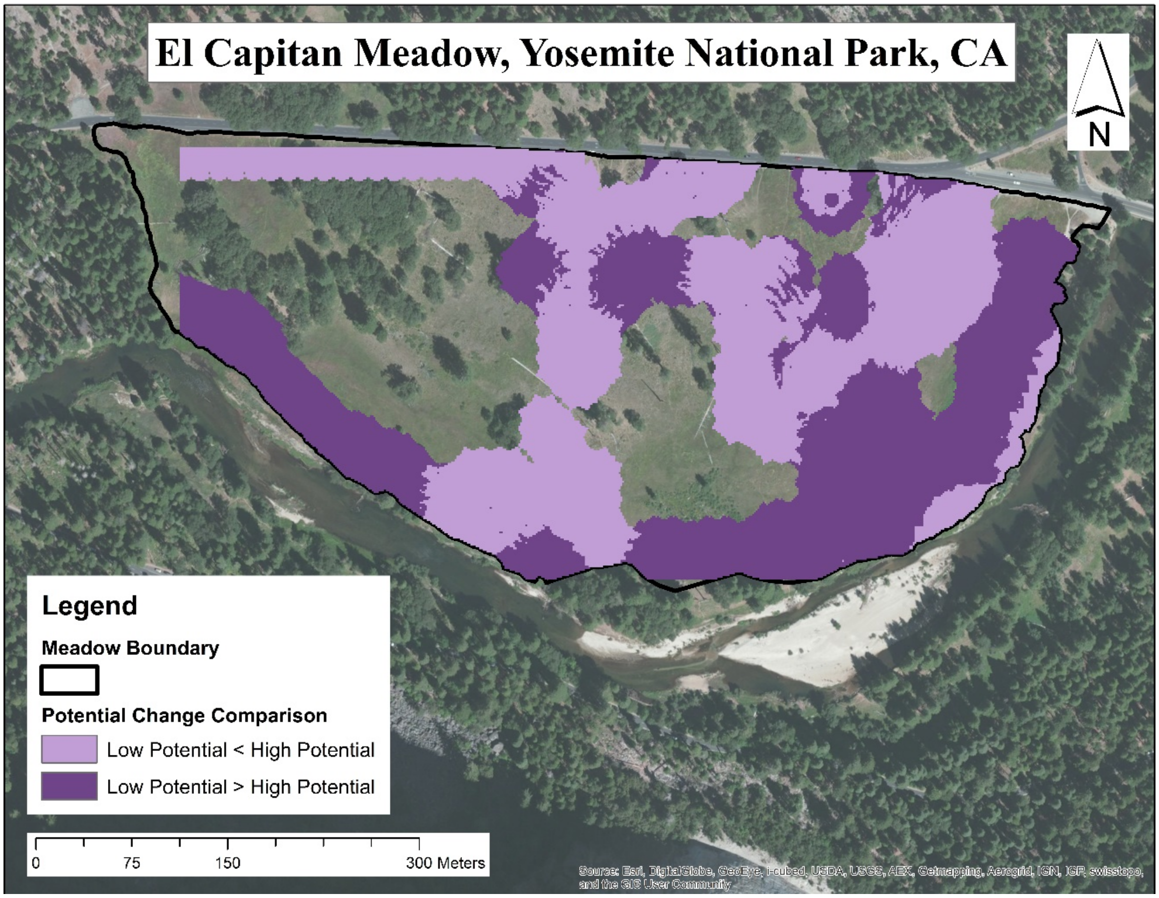


Fig. B.22. Potential for ecological change as a result of High Loads of visitor use at El Capitan Meadow, Yosemite National Park, CA.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.23. Potential for ecological change as a result of Low Loads of visitor use at El Capitan Meadow, Yosemite National Park, CA.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. B.24. Comparison of potential for ecological change as a result of visitor use at El Capitan Meadow, Yosemite National Park, CA.

APPENDIX C:

DATABASE OF RESISTANCE INDICES

Table C.1.
List of species found in areas of disperse use in Rocky Mountain National Park including the resistance indice (RI) assigned to that species, what level the RI was assigned, and where the RI was located in the experimental trampling literature.

Genus	Species	Morphological Group	RI	Level	Source	Species Source	Comments
Aquilegia	coerulea	Forb	75	G	Cole 1993	Aquilegia coerulea	Relative ranking (l)
Arnica	spp.	Forb	75	G	Cole 1993	Arnica mollis	Relative ranking (l)
Chamerion	danielsii	Forb	85	MG	Hill & Pickering 2010		
Juniperus	communis	Woody	199	MG	Hill & Pickering 2009		
Mahonia	spp.	Shrub	199	MG	Hill & Pickering 2009		
Mertensia	ciliata	Forb	85	MG	Hill & Pickering 2009		
Metrensia	spp.	Forb	85	MG	Hill & Pickering 2010		
Penstemon	whippleanus	Forb	85	MG	Hill & Pickering 2009		
Potentilla	spp.	Forb	75	G	Cole 1993; Cole 1995a	Potentilla flabellifolia, Potentilla simplex	Average of two species
Rubus	idaeus	Forb	75	G	Cole 1993	Rubus pubescens	Graph
Thermopsis	divaricarpa	Forb	25	SPP	Cole 1993	Themopsis divaricarpa	Graph
Vaccinium	caespitosum	Shrub	75	SPP	Cole 1987	Vaccinium caespitosum	Table 2
Vaccinium	scoparium	Shrub	200	SPP	Cole and Bayfield 1993, Cole 1993	Vaccinium scoparium	Graph
Vaccinium	spp.	Shrub	150	G	Cole and Bayfield 1993, Cole 1993	Vaccinium scoparium, Vaccinium membranaceum	Average between two species
Viola	spp.	Forb	75	G	Cole 1993	Viola glabella, Viola papillonacea	Relative ranking (l)
N/A	N/A	Mosses	300	MG	Cole 1993		Relative Ranking (m-h)
N/A	N/A	Lichens	100	MG	Cole 1993		Relative Ranking (l-m)
N/A	N/A	Bare Ground	3000	MG	Hill & Pickering 2009		2x the highest RI observed in

							the literature
N/A	N/A	Rock	3000	MG	Hill & Pickering 2010		2x the highest RI observed in the literature
N/A	N/A	Secant	235	MG	Hill & Pickering 2012		
N/A	N/A	Other	235	MG	Hill & Pickering 2011		Average for subalpine ecosystems

Table C.2.

List of species found in El Capitan Meadow including the resistance indice (RI) assigned to that species, what level the RI was assigned, and where the RI was located in the experimental trampling literature.

Genus	Species	Morphological Group	RI	Level	Source	Species Source	Comments
Achillea	millefolium	Grass	100	G	Cole 1993	Achillea lanulosa	
Achnatherum	spp.	Grass	497	MG	Hill & Pickering 2009		
Apocynum	cannabinum	Forb	85	MG	Hill & Pickering 2009		
Artemisia	douglasiana	Forb	180	G	Monz et al. 2000	Artemisia tridentata	
Artemisia	dracunculus	Forb	180	G	Monz et al. 2000	Artemisia tridentata	
Artemisia	spp.	Forb	180	G	Monz et al. 2000	Artemisia tridentata	
Bromus	carinatus	Grass	497	MG	Hill & Pickering 2009		
Bromus	hordeaceus	Grass	497	MG	Hill & Pickering 2009		
Bromus	jap	Grass	497	MG	Hill & Pickering 2009		
Bromus	tectorum	Grass	497	MG	Hill & Pickering 2009		
Calamagrostis	canada	Grass	497	MG	Hill & Pickering 2009		
Carex	angustata	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	douglasii	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	

Carex	feta	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	hoodii	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	integra	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	lanuginosa	Sedge	180	SPP	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	lenticularis	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	praegracilis	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	senta	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Carex	spp.	Sedge	180	G	YOSE Trampling Study 2011	Carex lanuginsa	
Elymus	glaucus	Grass	110	SPP	YOSE Trampling Study 2011	Elymus glaucus	
Festuca	idahoensis	Grass	400	SPP	Cole 1987	Festuca scabrella, Festuca idahoensis	Festuca grassland, dominated by two Festuca sp.
Festuca	occidentalis	Grass	400	G	Cole 1988	Festuca scabrella, Festuca idahoensis	Festuca grassland, dominated by two Festuca sp.
Iris	missouriensis	Forb	85	MG	Hill & Pickering 2009		
Juncus	balticus	Forb	85	MG	Hill & Pickering 2009		
Juncus	mertensianus	Forb	85	MG	Hill & Pickering 2008		
Lessingia	leptoclada	Forb	85	MG	Hill & Pickering 2009		
Leymus	triticoides	Grass	497	MG	Hill & Pickering 2009		

Lotus	oblongifolius	Forb	85	MG	Hill & Pickering 2009		
Lotus	purshianus	Forb	85	MG	Hill & Pickering 2009		
Muhlenbergia	rigens	Grass	497	MG	Hill & Pickering 2009		
Panicium	acuminatum	Grass	497	MG	Hill & Pickering 2009		
Penstemin	rydbergii oreo	Forb	85	MG	Hill & Pickering 2009		
Phleum	pratense	Grass	497	MG	Hill & Pickering 2009		
Pinus	ponderosa	Woody	199	MG	Hill & Pickering 2009		
Poa	pratensis	Grass	497	MG	Hill & Pickering 2009		Cole 1993 (RI = 200)
Potentilla	gland	Forb	75	G	Cole 1993; Cole 1995a	Potentilla flabellifolia, Potentilla simplex	Average of two species
Pteridium	aquilinum	Forb	20	SPP	Littlemore & Barker 2001	Pteridium aqualinum	
Rhododendron	occident	Woody	199	MG	Hill & Pickering 2009		
Rudbeckia	hirta	Forb	85	MG	Hill & Pickering 2009		
Rumex	acetosella	Forb	85	MG	Hill & Pickering 2009		
Smilacina	stellata	Forb	85	MG	Hill & Pickering 2009		
Solidago	canadensis	Forb	85	MG	Hill & Pickering 2009		
Solidago	californica	Forb	85	MG	Hill & Pickering 2009		
Stachys	albens	Forb	50	SPP	YOSE Trampling Study 2011	Stachys abens	
Trifolium	microcephalum	Forb	250	G	Cole 1993	Trifolium parryi, Trifolium dasyphyllum	Average of two species
Trifolium	monanthum	Forb	250	G	Cole 1993	Trifolium parryi, Trifolium dasyphyllum	Average of two species

Vulpia	microstachys	Forb	85	MG	Hill & Pickering 2009		
N/A	N/A	Bare Ground	3000	MG	Hill & Pickering 2009		2x the highest RI observed in the literature
N/A	N/A	Rock	3000	MG	Hill & Pickering 2010		See above comment

VITA

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EDUCATION

Utah State University, Logan, UT. Ph.D. in Human Dimensions of Ecosystem Science and Management. Anticipated completion date 2015.

Utah State University, Logan, UT. M.S. in Human Dimensions of Ecosystem Science and Management. December 2010.

The Pennsylvania State University, University Park, PA. B.S. in Biology (Ecology Concentration). May 2006.

RESEARCH EXPERIENCE

Utah State University, Logan, UT

Rocky Mountain National Park, Research Assistant 2015 – Present

- Building predictive GIS model of informal trail proliferation
- Mapping locations and conditions of bouldering-related ecological impacts

Grand Teton National Park, Research Assistant 2012 – Present

- Designed and implemented GPS-tracking study of vehicles and pedestrians
- Mapped locations and conditions of parking-related impacts along popular road corridor

Arapahoe-Roosevelt National Forest, Research Assistant 2012 – 2013

- Mapped locations and conditions of resource-related impacts at popular hiking destinations
- Collaborated with managers on GIS-analysis of feasible placement for new trail alignments

Joshua Tree National Park, Principle Investigator 2011 – 2013

- Designed study and survey instrument to examine visitor perceptions of resource impacts
- Administered survey and analyzed results to compare hiker and climber perceptions

Yosemite National Park, Research Assistant 2011 - 2013

- Designed and implemented GPS-tracking study to examine dispersed visitor use in meadows

- Designed and executed experimental trampling study to investigate vegetation susceptibility

Swaner Nature Preserve, Co-Principle Investigator 2010 - 2011

- Designed and implemented study to evaluate current trail conditions at urban nature preserve
- Designed and administered visitor use survey to evaluate visitor demographics and motivations

Rocky Mountain National Park, Research Assistant 2008 - 2010

- Examined visitor use patterns and off-trail impacts using GPS and GIS analysis in day use area
- Designed, administered, and analyzed survey evaluating visitor perceptions of resource impacts

TEACHING EXPERIENCE

Utah State University, Logan, UT

Instructor

Courses: Human Dimensions of Natural Resource Management (ENVS 4000) 2012
Human Behavior in Wildlands (ENVS 4500) 2013

Teaching Assistant

Courses: Wildland Recreation Behavior (ENVS 4500) 2009 – 2011, 2014
Natural Resources Interpretation (ENVS 4600) 2014

The Academy, Appleton, WI

High School Science Teacher 2006 – 2008

Courses: Cambridge International Curriculum for IGCES Chemistry and AS/A Biology

Middle School Science Teacher 2007 – 2008

Courses: Cambridge Checkpoint Curriculum for chemistry, biology, and physics

Physical Education Teacher 2007 – 2008

Courses: General physical education to elementary and middle school students

The Pennsylvania State University, Biology Department

Teaching Assistant 2005 – 2006

Courses: Biology: Basic Concepts and Biodiversity (BIOL 110)
Populations and Communities (BIOL 220)

PUBLICATIONS

PEER REVIEWED JOURNAL ARTICLES

- Kidd, A., Monz, C., D'Antonio, A.*, Manning, R.E., Reigner, N., Goonan, K., Jacobi, C. (2015). The effects of minimum impact education on visitor behavior: An experimental investigation using GPS-based tracking. *Journal of Environmental Management*. *In Press.*

- D'Antonio, A., Monz, C., Lawson, S., Newman, P., Taff, D. (2013). Enhancing the utility of visitor impact assessment in parks and protected areas: A combined social-ecological approach. *Journal of Environmental Management,* 124, 72-81.

- D'Antonio, A., Monz, C, Lawson, S., Newman, P., Taff, D. (2012). The effects of local ecological knowledge, minimum-impact knowledge, and prior experience on visitor perceptions of the ecological impacts of backcountry recreation. *Environmental Management*, 50 (4), 542-554.

- D'Antonio, A., Monz, C, Lawson, S., Newman, P., Pettebone, D., Courtemanch, A., (2010). GPS-based measurements of backcountry visitors in parks and protected areas: examples of methods and applications from three case studies. *Journal of Parks and Recreation Administration*, 28, 42-60.

BOOK CHAPTERS

- D'Antonio, A., Monz, C., Lawson, S., Newman, P., Taff, D. (2014). Resource Conditions in Park Locations Served by Alternative Transportation Systems at Rocky Mountain National Park. In: R. Manning, S. Lawson, P. Newman, J. Hallo, C. Monz (Eds). *Sustainable Transportation in National Parks: From Acadia to Zion.* University Press of New England.

TECHNICAL REPORTS

- Monz, C., D'Antonio, A.*, Heaslip, K. (2014) *Moose-Wilson Corridor Use Levels, Types, Patterns, and Impacts in Grand Teton National Park: Technical Report – Winter 2014.* Logan, Utah.

- Monz, C., D’Antonio, A.*, Heaslip, K. (2014) *Moose-Wilson Corridor Use Levels, Types, Patterns, and Impacts in Grand Teton National Park: Technical Report – Summer/Fall 2013.* Logan, Utah.

- D'Antonio, A. (2013). Understanding Visitor Perceptions of Recreation Resource Impacts: A Comparison of Climber and Hiker Perceptions. *Technical Report to Joshua Tree National Park*. Logan, Utah.

- Monz. C, D'Antonio, A.* (2012). Yosemite National Park Meadow Environments Visitor Tracking Study. *Technical Report*. Logan, Utah.

- D’Antonio, A., Monz, C. (2011) *Trail and Visitor Use Assessment: Swaner EcoCenter Study.* Logan, Utah.

SEMINAR AND WORKSHOP LEADERSHIP

- *Facilitator.* Arapaho-Roosevelt National Forest Recreation Transportation System Planning Study – Scopes of Work Workshop, Fort Collins, CO. September 2010.

SCHOLARLY PRESENTIONS

- D’Antonio, A., Monz, C., Newburger, T. “Dispersed recreation in Yosemite National Park, CA: Understanding visitor use patterns and the implications for management.” Lightning Presentation. The 2015 George Wright Society Conference on Parks, Protected Areas and Cultural Sites. March 29 – April 3, Oakland, CA.

- D’Antonio, A., Monz, C., Newburger, T. “Dispersed recreation in Yosemite National Park, CA: Understanding visitor use patterns and the implications for management.” The 2015 Science for Parks, Parks for Science: The Next Century Summit. March 25 – 27, Berkeley, CA.

- D’Antonio, A., Monz, C., Newburger, T. “Dispersed recreation in Yosemite National Park, CA: Understanding visitor use patterns and the implications for management.” The 2014 North American Congress for Conservation Biology. July 13 – 15, Missoula, MT.

- D’Antonio, A., Monz, C. “Understanding Visitor Perceptions of Recreation Resource Impacts: Comparing Climbers and Hiker Perceptions in Joshua Tree National Park, California”, The 2013 George Wright Society Conference on Parks, Protected Areas and Cultural Sites. March 11 - 15, Denver, CO.

- D’Antonio, A., Monz, C. “Using Traditional Recreation Management Techniques in an Urban-Proximate Natural Area: A Case Study from the Swaner Preserve.” Land Trust Alliance Rally. October 1-2, 2012. Salt Lake City, Utah.

- D'Antonio, A., Monz, C. "Understanding the Visitor Experience in Rocky Mountain National Park." Intermountain Graduate Research Symposium. March 30-31, 2011. Logan, Utah.
- D'Antonio, A., Monz, C., Lawson, S., Newman, P., Taff, D. "An Assessment of Visitor Perceptions of Recreation Resource Impacts In The Bear Lake Corridor Of Rocky Mountain National Park." 16th International Symposium on Society & Resource Management. June 6-10, 2010, Corpus Christi, Texas.

- D'Antonio, A., Monz, C., Lawson, S., Newman, P., Taff, D. "An Assessment of Visitor Perceptions of Recreation Resource Impacts In The Bear Lake Corridor Of Rocky Mountain National Park." 2010 Research Conference Rocky Mountain National Park. March 30-31, 2010. Estes Park, Colorado.

- D'Antonio, A., Monz, C., Lawson, S., Hockett, K., Logan, P., Newman, P., Hallo, J. "Utilizing GPS-based measurements of visitor behavior in parks and protected areas: Limitations and opportunities." Rethinking Protected Areas in a Changing World, The 2009 George Wright Society Conference on Parks, Protected Areas and Cultural Sites. March 2-6 2009, Portland, OR.

RESEARCH GRANTS

- 2014. Utah State University Dissertation Enhancement Award, $4,177
- 2011-2013. Robert Lee Graduate Student Research Grants at Joshua Tree National Park, $2,690.

SERVICE

ACADEMIC SERVICE

Robins Award, Utah State University 2015
Selection Committee

Ecology Center Seminar Series, Utah State University
Speaker Selection and Hosting Committee 2012 - 2015

College of Natural Resources Graduate Student Council, Utah State University
Environment and Society Department Representative 2012 - 2014
Council Head Chairperson 2010 - 2012
Council Member 2008 - 2010

PROFESSIONAL SERVICE

Department Head Search Committee, Utah State University
Graduate Student Representative
2013 - 2014

Reviewer
Journal of Environmental Management (2) 2012 – 2013

COMMUNITY SERVICE

The Valentine Chocolate Festival Fundraiser, Logan, Utah
Community Volunteer 2009– Present

Bridgerland Science and Engineering Fair, Logan, Utah
Volunteer Judge, High School Level 2013

Stokes Nature Center, Logan, Utah
Community Volunteer Educator 2009 – 2012

PROFESSIONAL AFFLIATIONS

Society for Conservation Biology (2014 to date)
George Wright Society (2009 to date)
International Association for Society and Natural Resources (2010 to date)

CERTIFICATIONS AND TRAINING

Utah State University Teaching Assistant Workshop (2010)
Wilderness First Aid

AWARDS & RECOGNITION

- *Recipient,* Quinney College of Natural Resources Graduate Teacher of the Year, 2013-2014
- *Recipient,* S.J. & Jessie E. Quinney Graduate Fellowship – Masters Degree, 2008-2010