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Monitoring Vegetation Change by Using Remote Sensing: An Examination of Visitor-Induced Impact at Cadillac Mountain, Acadia National Park

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MONITORING VEGETATION CHANGE BY USING REMOTE SENSING:

AN EXAMINATION OF VISITOR-INDUCED IMPACT

AT CADILLAC MOUNTAIN, ACADIA NATIONAL PARK

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DISSERTATION

ACCEPTANCE STATEMENT

On behalf of the Graduate Committee for Min Kook Kim, I affirm that this manuscript is the final and accepted thesis. Signatures of all committee members are on file with the Graduate School at the University of Maine, 42 Stodder Hall, Orono, Maine.

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MONITORING VEGETATION CHANGE BY USING REMOTE SENSING: AN EXAMINATION OF VISITOR-INDUCED IMPACT AT CADILLAC MOUNTAIN, ACADIA NATIONAL PARK

By Min Kook Kim

Advisor: Dr. John Daigle

An Abstract of the Thesis Presented
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Cadillac Mountain, the highest peak along the eastern seaboard in the United States, is a major visitor destination at Acadia National Park. Managing vegetation impact on the summit of Cadillac Mountain is extremely challenging given the number of users and dispersed nature of visitor use at this fragile environmental setting. Since 2000, more intensive management strategies based on placing physical barriers to protect threatened vegetation and leave no trace signs have been employed to reduce vegetation impact and enhance vegetation recovery in the vicinity of the summit loop trail. A number of different change detection techniques and high resolution remote sensing datasets were utilized to identify vegetation impact and recovery from 1979 to 2007. The detection of spatial pattern of vegetation impact and recovery was at a much larger scale than typical recreation ecology studies. Study results showed detailed measurable vegetation regrowth and reduction at distances up to 90 meters from the summit loop trail, indicating overall positive effects in enhancing vegetation recovery in the vicinity of the

summit loop trail compared to a nearby control site with similar environmental conditions but no visitor use. As expected, the vegetation recovery was higher as one moved away from the trail itself, and recovery was observed at a higher rate in the intermediate zone where visitor disturbance and ability for sites to regenerate would be higher than more natural variation of regrowth in the outer buffer zone with less visitor activity. It should be noted that overall minimal gains in vegetation regrowth was observed from 2001 to 2007, but compared with the time period of 1979 to 2001 there was more regrowth and less observed vegetation loss but total vegetation has not recovered to 1979 levels. The results also showed that, although with much less resolution than typical recreation ecology studies, vegetation diversity was lower at the experimental site at the level of plant family, suggesting limited success with enhancing vegetation diversity during the analysis time frame. Vegetation change detection using high resolution remote sensing datasets offers an approach for monitoring vegetation change dynamics and to some degree plant diversity, especially for a recreation setting in a sub-alpine environment with limited overstory vegetation such as the case at the summit of Cadillac Mountain. Remote sensing analysis could provide valuable baseline information for future visitor-induced impact monitoring programs and especially for dispersed recreation sites such as Cadillac Mountain.

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"So do not fear, for I am with you; do not be dismayed, for I am your God. I will strengthen you and help you; I will uphold you with righteous right hand."

(ISAIAH 2:10)

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CHAPTER 1

INTRODUCTION

"… to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Organic Act, the legislated mission of the National Park Service, 1916

Problem Statement

The dual mission of the National Park Service (NPS), often referred to as "contradictory," poses some significant challenges in the field of park management (Cole, 2006a; Cole & McCool, 2000; Daigle & Zimmerman, 2004; Growcock, 2005; Leung & Marion, 2000; Marion, 1998; Marion & Reid, 2007; McCool & Stankey, 2003; Monz & Leung, 2006; Way, 2003)[1]. As a result of the dual mandate, national park managers often struggle with the decision of how to balance the conservation of park resources with enjoyment of the park by the public, and it has been recognized that resource impact is an inherent and inevitable outcome of the interaction between the two objectives (Hammit & Cole, 1998; Leung & Marion, 2000). For example, vegetation loss and soil erosion caused by concentrated and accumulated trampling are some common signs of visitor-induced resource impact in national parks, and these can be especially pronounced over a period of time at popular "must see" destinations (Figure 1.1).

[1] The dual mission of NPS has been recognized as a major source of problems associated with management issues in national parks. However, there is also an interesting viewpoint about the dual mission. Particularly, Winks (1996) and Galvin (2007a, 2007b) indicated that there is no fundamental contradiction in the dual mandate: the first priority of NPS should be preservation of natural resources, and at the same time, guarantee the enjoyment for future generations. However, as Winks (1996) notes, there is a potential source of contradiction caused by ambiguity in the language of the Organic Act.

1960s **2000s**

Figure 1.1. Bubble Rock in Acadia National Park. Certain locations such as scenic viewpoints and special features attract people many visitors. These two photos illustrate a loss of ground vegetation cover sometime between 1960 and 2000 (Sources: Images courtesy of Acadia National Park).

One of the significant characteristics of resource impact by recreational use is its highly concentrated nature because recreationists consistently tend to use the same places. Therefore, recreational resource impact does not occur randomly in space, but exhibits spatially explicit and predictable patterns (Hammitt & Cole, 1998). Manning (1979) defined this spatial phenomenon as a “node” (destination areas) and “linkage” (trails) system (Leung, 1998; Leung & Marion, 1998). In other words, considering the entire coverage of national parks and other recreation land areas, resource impact occurs in a very small portion of areas (localized in destination areas and trails) (Cole, 1981b; Wagar, 1975). However, such a spatially predictable impact pattern is a management concern, since the characteristics of localized impact can be severe and long-lasting (Cole, 1981a, 2004b; Growcock, 2005; Hammitt & Cole, 1998; Pickering & Hill, 2007). Visitor-induced resource impact shows an asymptotic rather than linear relationship overtime, that is, vegetation disturbance and soil erosion occur rapidly even with relatively low use during the first couple of years after a site is established (Cole, 1986; Hammitt & Cole, 1998). The severity of resource impact may also increase the potential conflict of use and visitor displacement that ultimately affect the quality of the visitor experience (Farrell & Marion, 2002a; Leung & Marion, 1996; Leung & Monz, 2006).

Moreover, resource impact on vegetation and soil, while localized at the site level, can gradually expand or creep with time as visitor use shifts across the larger landscape (Cole, 2004a; Cole & Hall, 1992; Hammitt & Cole, 1998). This is a legitimate management concern recognized by many national park managers and recreation ecologists because unintended proliferation and expansion of the site tends to have more ecological impact than intensive impact in already-established sites (Hammitt & Cole, 1998; Leung & Marion, 1998; Leung & Monz, 2006; Marion et al., 1993; McEwen et al., 1996). Consequently, this spatio-temporal pattern of resource impact has led management efforts to concentrate visitor use on trails and other durable surfaces (Cole, 2001; Cole et al., 2008; Marion, 1998; Whinam & Chilcott, 2003).

A number of site and visitor management strategies have been developed to cope with the problem associated with vegetation loss and other resource impacts. It is not easy to distinguish site management from visitor management actions because site manipulation could be a potential means of managing the amount and distribution of visitor use. As Manning (1999) indicated, a continuum between the two management actions clearly exists. However, it should be mentioned that visitor management seeks a balance between visitor satisfaction and resource protection components; whereas, site management focuses more on the development of site protection techniques to minimize impact. For example, site management strategies include permanent or temporary site closures, site manipulation for controlling spatial distribution of use (e.g., establishing an official/durable trail system and installing barriers/fence), and site hardening and shielding using gravel and wood chips (Hammitt & Cole, 1998). Also, visitor management strategies include, among others, use limit, length of stay limit, dispersal of use, concentration of use, restrictions on type of use, group size limits, seasonal limitation on use, and low-impact educational messages (Hammitt & Cole, 1998). Within a spatial context, the site and visitor management strategies could be re-categorized as spatial segregation (site closures), spatial dispersal (dispersal of use), spatial containment (concentration of use), and spatial configuration (site manipulation) (Cole, 1982; Cole & Landres, 1996; Hammitt & Cole, 1998; Leonard et al., 1981; Leung, 1998; Lloyd & Fischer, 1972).

Many of the above site and visitor management strategies have been further classified, reflecting a direct and indirect influence on visitor behavior (Gilbert, 1972; Lucas, 1982; Manning, 1999). Direct management action emphasizes regulating visitors' behavior; whereas, indirect management action emphasizes modifying visitors' behavior by managing factors and situations that influence visitor behavior rather than directly controlling visitors (Hendee & Dawson, 2002; Hendee et al., 1990). It is commonly agreed that the indirect approach is preferable and more effective than the direct approach, and it should be tried first (Clark & Stankey, 1979; Gunderson et al., 2000; Hendee et al., 1990; Lucas, 1982; McCool & Christensen, 1996; Peterson & Lime, 1979). However, there is also evidence showing the effectiveness of the direct approach in certain recreational settings (Dustin & McAvoy, 1984; Frost & McCool, 1988; Johnson & Kamp, 1996; Marion & Reid, 2007; Shindler & Shelby, 1993; Swearingen & Johnson, 1995). In particular, Cole (1995d) asserted that indirect methods such as visitor education and information programs have little supporting scientific evidence for controlling recreational use and environmental impact. Cole (2001) further suggested the need for the direct approach because the indirect approach is ineffective in solving specific resource impact problems, and the education and information programs need a relatively long period of time until they are adopted by visitors.

Which management approach is more effective under given circumstances has been widely discussed (Manning, 1999). On the basis of arguments for using either indirect or direct approaches, some researchers suggest that using both management approaches simultaneously is more applicable depending on the context of the problem or issue (Alder, 1996; Gramann & Vander Stoep, 1987). Although it is not easy to pursue a balanced approach, the mixed use of both management approaches will be persuasive because there are complementary relationships between the two management approaches (Alder, 1996; Cole et al., 1997). However, a question still remains regarding how we can effectively evaluate the outcome of site and visitor management strategies employed to reduce resource impact.

Contemporary Park Management Framework: Monitoring

Contemporary park management frameworks such as Visitor Experience and Resource Protection (VERP) and Limits of Acceptable Change (LAC) heavily rely on a fundamental role of visitor-induced impact monitoring (Bennetts et al., 2007; Cole, 1993, 2006a, 2006b; Cole et al., 2008; Hadwen et al., 2007; Hammitt & Cole, 1998; Hendee & Dawson, 2002; Leung & Farrell, 2002; Leung & Marion, 2000; Leung & Monz, 2006; Manning, 1999; Marion, 1998; Monz & Leung, 2006; Newman et al., 2006; Way, 2003). First, visitor-induced impact monitoring will help to establish a desirable management objective through an initial resource inventorying process. In other words, investigation on current resource conditions and use trends will be beneficial to select a level of VERP or LAC and to establish a potential indicator of quality (Hammitt & Cole, 1998; Marion et al., 2006; Newman et al., 2006). Second, monitoring will help to estimate the effectiveness of management strategies already employed to reduce resource impact by capturing early warning of abnormal conditions of resources (Bennetts et al., 2007; Hammitt & Cole, 1998). By regularly evaluating effectiveness of management strategies, managers can choose an optimal way between current management (when effective) and other alternative management strategies (when not effective).

Diverse monitoring techniques have been utilized that include 1) on-site observation (visitor behavior and use), 2) on-site measurement and experiment (resource condition), and 3) survey and interview (visitor or park staff) (Hammitt & Cole, 1998). These monitoring techniques could be further categorized as biophysical and social science approaches (Ingle et al., 2003; Leung & Marion, 2000) (Table 1.1). While there have been substantial variations in terms of levels of accuracy, precision, and time and cost, more advanced methods have been developed by adapting GIS/GPS technologies and by selecting detailed monitoring protocols for both biophysical and social science approaches (Cole, 2004a; Manning et al., 2006).

Table 1.1. Visitor-Induced impact monitoring techniques.

Biophysical Science Approach	
Condition Class Assessment	(Cole, 1989b; Marion & Farrell, 1996; Williams & Marion, 1995)
Multiple Parameter Rating System	(Cole, 1983; Hammitt & Cole, 1998; Leung & Marion, 2002; Marion & Farrell, 2002)
Experimental Design (often using cross-sectional, longitudinal, or permanent plot design)	(Andrés-Abellán et al., 2006; Bakker et al., 1996; Bayfield, 1979; Cole, 1993, 1995a, 1995b, 1995c; Cole & Bayfield, 1993; Cole & Monz, 2002; Cole & Spildie, 1998; Cole & Trull, 1992; Lemauviel & Roze, 2003; Monz et al., 2000; Turner, 1990; Whinam & Chilcott, 1999, 2003)
Ground Photographs (photopoint, quadrat photographs, and panoramic landscape photographs)	(Brewer & Berrier, 1984; Coleman, 1977; Nassauer, 1990; Skovlin, 2001)
Water Quality Estimation	(Hammitt & Cole, 1998)
GIS/GPS	(Beck & Gottschalk, 2004; Cole et al., 1997; Gajda et al., 2000; Ingle et al., 2003; Leung, 1998; Marion et al., 2006; Newman et al., 2006)
Social Science Approach	
Observation (Visitor Behavior and Use)	(Haas & Jacobi, 2002; Jacobi, 2001a, 2003; McCool & Cole, 2000; Turner, 2001)
Qualitative Study	(Bullock & Lawson, 2007; Farrell & Marion, 2002b)
Quantitative Study	(Bullock & Lawson, 2008; Cahill et al., 2007; Christensen & Cole, 2000)
Photographs (Crowding/Social Norm)	(Manning et al., 2006; Manning et al., 1996; Manning et al., 2002)
GIS/Computer-based Simulation Modeling (Visitor Use Density and Flow)	(Bishop & Gimblett, 2000; Cole, 2005; Gimblett et al., 2001; Itami et al., 2003; Lawson et al., 2004; Manning et al., 2006; Murdock, 2004; O' Connor et al., 2005; Wang & Manning, 1999; Wing & Shelby, 1999)

Leung and Monz (2006) cited challenges that exist in developing monitoring techniques in cost-effective and adaptive ways that can be implemented in perpetuity, providing useful and comparable data as visitor use and managerial situations change. For example, such existing methods, including on-site measurements and experiments, often require substantial field work and significant consideration in selecting size, number, and the location of the quadrats to be investigated. Consequently, they may not be well-suited to monitoring changes in resource conditions, especially for a long-term period. As they all involve “wait and see” procedures (Marion, 1998), a certain amount of time should be considered after the first measurement, as well as a methodological consistency which is often subjective or biased. These limitations may help explain why most visitor impact monitoring studies, so far, have been short-term assessments or one-time studies. It should be mentioned that it is often impossible to evaluate the true effect of the employed management strategies, if the temporal scales of studies are too short. There are also drawbacks to the social science approaches. Visitor opinions about resource conditions are merely guesses (i.e., tend not to be highly perceptive), so they may not be helpful in identifying the degree of impact (Manning, 1999; Noe, 1992; Williams et al., 1992). Cole (2006b) further point out that attitudes and beliefs of managers may also hinder the development of visitor-induced impact monitoring programs, especially if there is a need to prioritize the collection of scientific information.

The main problem in the monitoring process is how to obtain uniformly reliable datasets for evaluating the current condition and effect of management actions employed, at the same time, minimizing potential errors and bias, and saving time and labor. Hammitt and Cole (1998) specifically indicated that there are seldom available datasets for monitoring resource impact and evaluating the efficacy of management strategies utilized. Therefore, managers are often forced to make a decision without enough information associated with visitor use and resource impact, often leading to incremental decision-making (Cole, 2006b; Monz & Leung, 2006). Clearly, a more fundamental and scientific approach is needed to apply monitoring results effectively to inform management decision-making (Cole, 2004b; Cole & Wright, 2004). This may in-turn promote the value of developing and maintaining a visitor impact monitoring program.

Remote Sensing Technology for Monitoring

Remote sensing refers to the detection and recording of values of emitted or reflected electromagnetic radiation with sensors in aircrafts or satellites (Ingle et al., 2003). While remote sensing datasets, such as satellite imageries and aerial photographs, would be a useful tool for monitoring purposes, the value of remote sensing has not been well-recognized in visitor-induced impact monitoring (Hammitt & Cole, 1998). This is, as mentioned, because recreation impact tends to occur in a very small portion of areas (localized). Subsequently, it was not easy to apply a remote sensing dataset having a broad or medium scale ground resolution to directly detect those localized small scale changes. It was also impossible to detect any significant vegetation changes if there is a dense canopy cover or a multiple vegetation layer in a study site. Second, it was difficult to capture an available dataset on time. Sometimes, utilizing high-quality remote sensing datasets for analyses are very limited given the spatial and temporal scales of datasets. However, in spite of these problems, recent advances in image resolution and popularity, coupled with highly sophisticated image processing techniques, are becoming useful and helpful to minimize the proposed problems, to monitor visitor-induced resource impacts and to evaluate the effect of management strategies.

From the perspective of recreational resource management, research regarding imagery and remote sensing has been explored since the early development of the technology to aid in monitoring. Generally, there have been four main research trends: 1) supporting general management using vegetation mapping and classification, 2) inventorying recreational resources, 3) monitoring impact and change in recreational resources, and 4) addressing the usefulness of remote sensing in park and recreation management (Table 1.2).

Table 1.2. Research trends using remote sensing in recreational resource management.

Research Trends*	***Sources***
Supporting general management (mapping & classification)	(Baker et al., 1995; Hathout, 1980; Kindscher et al., 1997; Mehner et al., 2004; Ramsey et al., 2002; Taylor et al., 2000)
Inventorying recreational resources	(Burnett & Conklin, 1979; Dill, 1963; Jusoff & Hassan, 1997; Kearsley, 1994; Lindsay, 1969; MacConnell & Stoll, 1968; Miller & Carter, 1979; Silva & Pfeifer, 1989; Welch et al., 1999)
Monitoring impact and change in recreational resources	(Allan, 1983; Coleman, 1977; Grizzle et al., 2002; Hockings & Twyford, 1997; Lee et al., 1999; Leung et al., 2002; Li et al., 2006; Marion et al., 2006; Narumalani et al., 2004; Parmenter et al., 2003; Pauchard et al., 2000; Price, 1983; Witztum & Stow, 2004)
Addressing the usefulness and importance of remote sensing in park and outdoor recreation management	(Aldrich et al., 1979; Booth & Tueller, 2003; Butler & Wright, 1983; Dahdouh-Guebas, 2002; Draeger & Pettinger, 1981; Green, 1979; Gross et al., 2006; Hammitt & Cole, 1998; Ingle et al., 2003; Moran & Ostrom, 2005; Rochefort & Swinney, 2000; Taylor et al., 2000)

* Some of the studies included human impact monitoring analyses in broad disciplines of natural resource management. It is somewhat difficult to distinguish remote sensing analyses in visitor impact monitoring from those in general natural resource management because visitor-induced impact monitoring could be one major part of the natural resource management.

As recreation ecologists, Monz and Leung (2006) clarified that a digital photo analysis would be useful in identifying vegetation change, soil erosion, social trail identification, unofficial site identification, and shoreline disturbance. Ingle and others (2003) also indicated the importance and usefulness of remote sensing techniques for identifying extent and severity of visitor-induced impact as a major biophysical approach. They clearly stated that applications including GIS and remote sensing will enhance the overall quality of a monitoring dataset.

A primary advantage of remote sensing datasets is that a relatively “big picture” can be easily captured in collecting datasets. In other words, quick experiment and measurement is available in identifying changes in resource conditions between dates without direct contacts, compared to the on-site measurement and experiment process that usually takes a much longer amount of time. During this process, a potential likelihood of inconsistency in gathering required information for monitoring resource conditions could be significantly reduced by excluding observers' biases, as well as saving time and labor. This will enhance a visitor-induced impact monitoring program by identifying impact quickly enough to implement alternative management strategies, and by offering information associated with hot spots or heavily impacted areas (Witztum & Stow, 2004). Also, in many cases, archived imagery is available that may further enhance development of a visitor-induced impact monitoring program.

The difficulties in evaluating an actual outcome of management strategies have been discussed due to the complexity of an ecosystem subject to change spatial and temporal (Agee & Johnson, 1988; Bennetts et al., 2007; Johnson & Agee, 1988; Wallace et al., 1996). In order to overcome this complexity, Agee and Johnson (1988) indicate that high-quality information is necessary to identify trends and to respond to resource impacts intelligently and deliberately. Cole (2004b) also asserts that scientific knowledge provides powerful tools for monitoring recreational impact and for identifying efficacy of the employed management strategies. Therefore, remote sensing technology that offers more credible and accurate products in terms of quality and ground resolution will be continuously amplified in recreational resource management and analysis due to the technological advances in both software and hardware.

Study Site

Acadia National Park (ANP) spans 47,000 acres, and being part of the National Park System, it has a dual mission to conserve biological and cultural resources as well as provide for the enjoyment of people (Daigle & Zimmerman, 2004). Geographically, ANP is the only national park in the Northeastern U.S. (Figure 2). The mean annual temperature ranges from 41 to 46 degrees; the rain average is about 49 inches (123cm), and the snow average is about 5 feet (1.5m) annually (Lubinski et al., 2003; McMahon, 1990; Wherry, 1929).

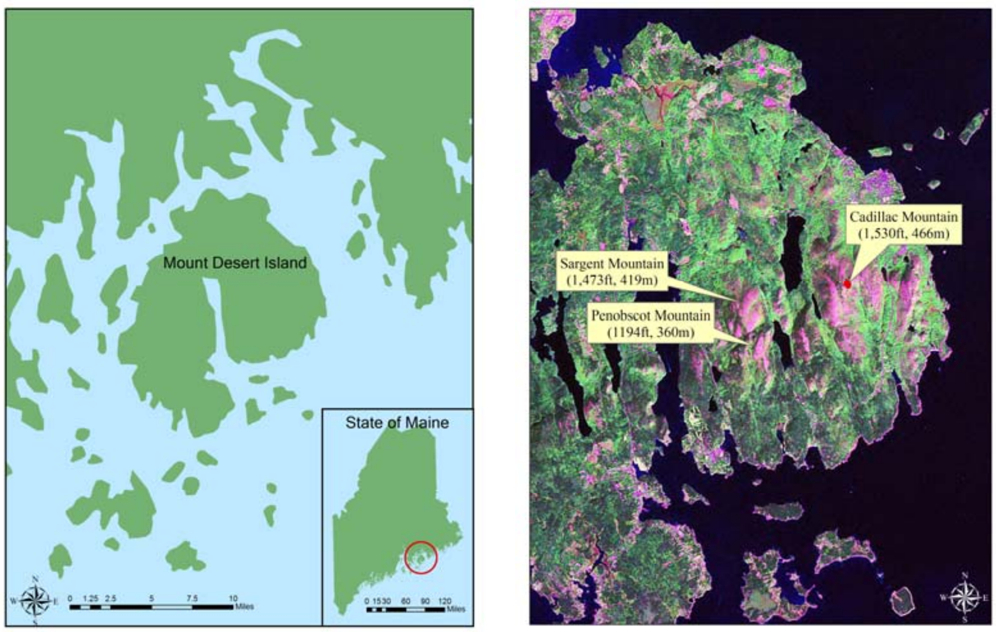

Figure 1.2. Acadia National Park: Mount Desert Island has three major mountains: Cadillac, Sargent, and Penobscot. The Cadillac summit is the highest point on the Eastern Seaboard of the U.S. (1,530 feet).

The park was established in 1919, and has become one of the most intensively used national parks in the United States (Jacobi, 2001b; Manning et al., 2006; Wang & Manning, 1999). Visitation rate is similar to many other national parks in that it has been relatively stable over the past two decades. For example, ANP received an estimated 2.2

million visitors in 2007 and 2.3 million in 1990 (Figure 1.3). However, given the acreage of the park and visitation rate, ANP is the most densely populated of the major national parks in the U.S. (Figure 1.4).

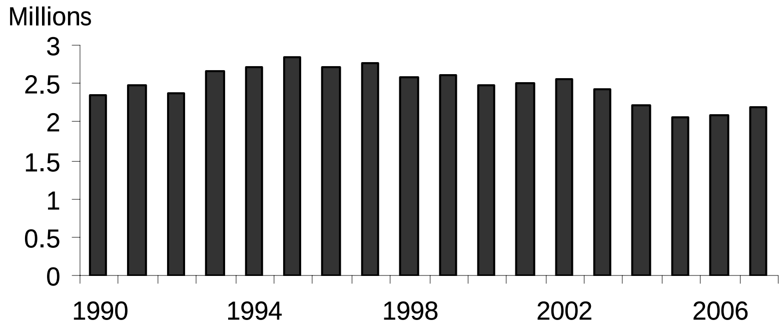

Figure 1.3. Visitation level in ANP from 1990 to 2007 (Sources: National Park Service Public Use Statistics Office, http://www.nature.nps.gov/stats/).

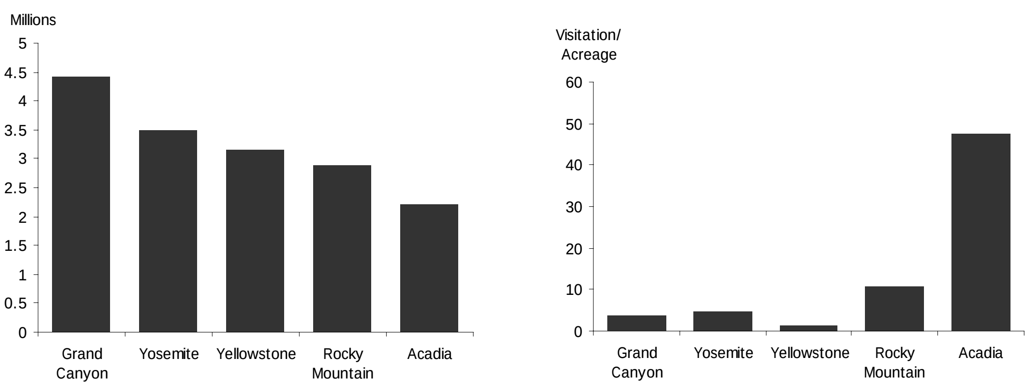

Figure 1.4. Visitation levels at five major national parks in 2007 (left), and visitation level in 2007 divided by acreage (right), showing ANP as the most densely populated park (Sources: National Park Service Public Use Statistics Office, http://www.nature.nps.gov/stats/).

Cadillac Mountain, the study site, is one of 26 peaks in ANP. At 1,530 ft elevation, Cadillac Summit is the highest point on the Eastern Seaboard of the U.S. The summit of Cadillac Mountain is a major destination for ANP visitors because it is the only mountain in Acadia with an auto road (Jacobi, 2001a, 2003). There are three hiking trails to the summit of Cadillac, as well as the auto road and the summit loop trail that is 0.3 miles long. A visitor survey completed by the National Park Service in 1998 shows that approximately 76% of total visitors to the park visited the summit of Cadillac Mountain (Littlejohn, 1999).

Historic photos and archived materials show that the site became a popular visitor destination between the 1860s and 1870s, even before being designated as a national park in 1919 (Figure 1.5). The unique scenic beauty attracted people to build three hotels at the actual summit area (near the current summit loop trail) around 1890. The automobile road was built between 1929 and 1932, and the summit loop trail was initially paved in 1933 with crushed rocks (re-paved often afterwards).

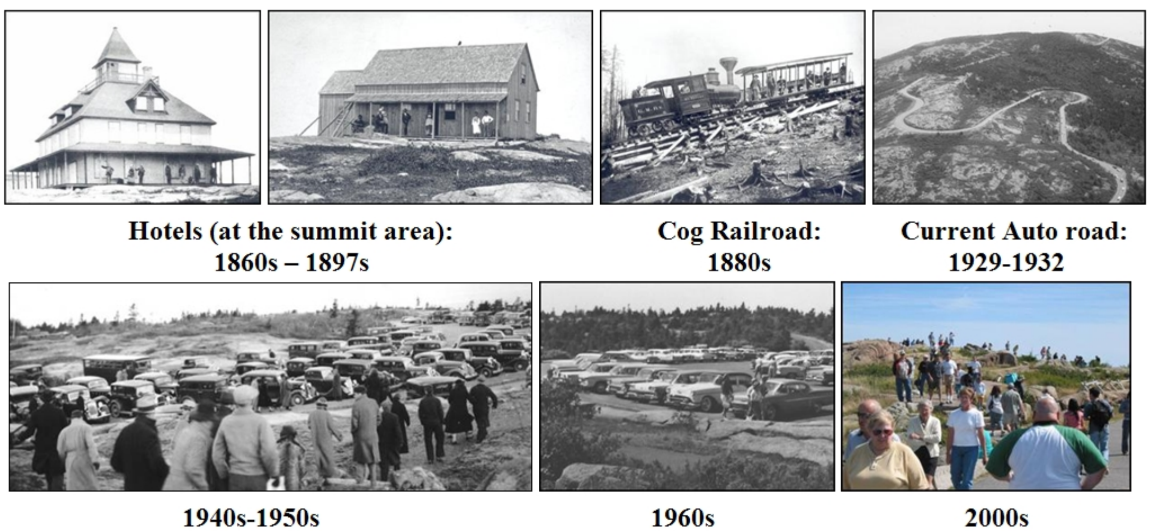

Figure 1.5. Historic photos in the vicinity of the summit loop trail
(Sources: Images courtesy of Acadia National Park).

Although visitation levels have stabilized over the past few years, the summit receives an estimated 0.5 ~ 0.8 million visitors during the summer (June – August) each year (Jacobi, 2001a, 2003). The earlier observational study, completed by Turner (2001), found that the bulk of these visits come during the 100 days from Memorial Day to Labor Day. This high visitation rate is partly explained by the auto road that provides convenient access to the top of the summit and beautiful scenic vistas of the Maine coast.

However, the short growing season coupled with severe weather conditions make Cadillac Summit a difficult place for plants to grow. Many of the plants on the Mountain are slow to recover from damage because of the weather and soil conditions (Jacobi, 2003; Turner, 2001). The sensitive sub-alpine nature of the site and the convenient accessibility via the auto road has created a scenario where vegetation degradation and soil erosion are both at a high risk. This site represents a management challenge to balance the desire of the public for visiting a popular destination while at the same time maintaining the natural conditions of the area for current and future generations.

Efforts to induce concentration of visitor uses and limit impact to vegetation on the summit were initiated in 1933 by installing the paved summit loop trail (no official management records, interview with the ANP resource management staff, 2007). This durable surface trail was made to blend with the exposed granite surfaces intermixed with vegetation on the summit. Interpretive platforms and wayside exhibits were also placed along the summit loop trail many years ago. However, given the volume of visitors and general open nature of landscape, low vegetation and shallow soils, the summit was still experiencing trampling and soil erosion that prevented regeneration of vegetation. In 2000, a shift towards more intensive management was put in place to minimize visitor-induced vegetation impact (Figures 1.6 & 1.7). A combination of site and visitor management strategies using physical barriers and low impact education messages, respectively, were deployed in strategic locations to address vegetation loss on Cadillac

Summit. The current resource management chief and staff in ANP had constantly observed a significant vegetation loss over the area, so all of these site and visitor management strategies were used as a management tool, not as a research mechanism (Turner, 2001; interview with the ANP resource management staff, 2007). Until now, several studies based on social science approaches have attempted to verify the effect of the deployed management strategies coupled with visitors' perceptions and experiences (Bullock & Lawson, 2007, 2008; Cahill et al., 2007; Park et al., 2008; Turner, 2001), but there has been little direct study examining the effect of the management strategies focusing on one of the most important biophysical factors — vegetation.

Figure 1.6. Indirect management (left, leave no trace signage) and direct management (right, physical barriers): ANP has been using both management approaches since 2000 along the summit loop trail of Cadillac Mountain in order to reduce vegetation impact by trampling or visitor use.

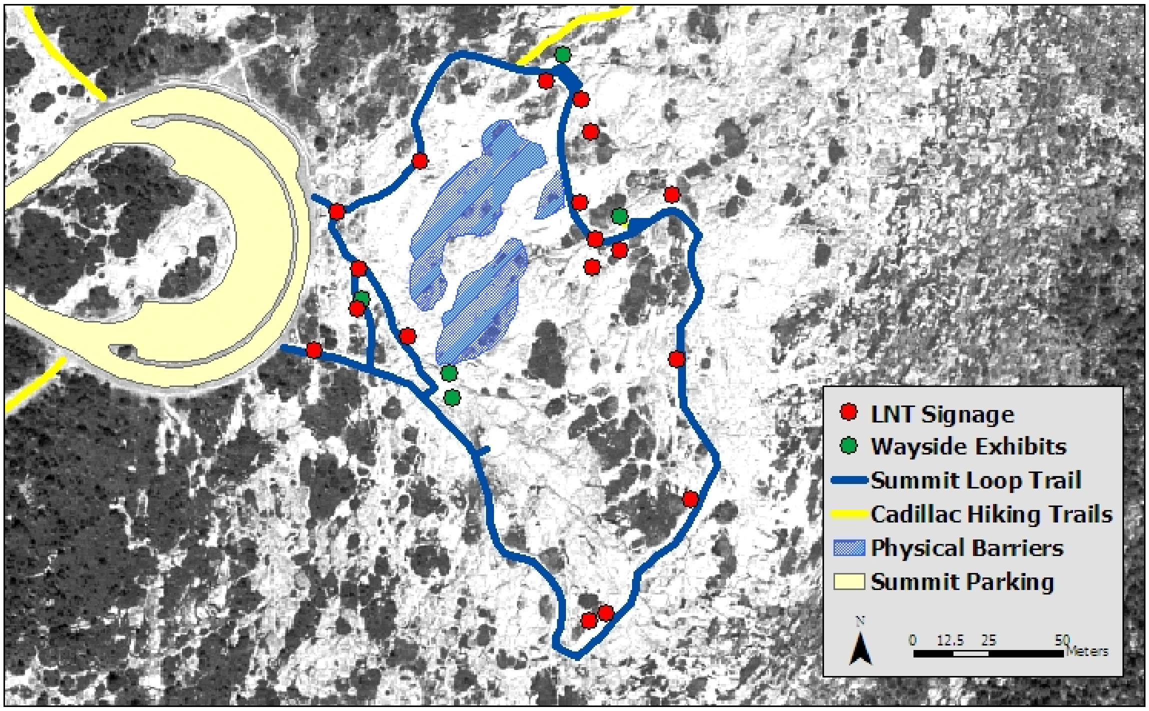

Figure 1.7. Locations of physical barriers (light blue) and LNT signage (red), captured by GPS (Trimble GeoXT) and exported as ESRI shapefile format.

Considering the sensitivity of the site and the ecological pressure caused by high levels of visitation, the primary objective of this study was to examine the effect of the two site and visitor management strategies to reduce vegetation impact in the vicinity of the summit loop trail. Remote sensing and GIS technologies were utilized to investigate pre- and post-conditions of vegetation. Additionally, this study set out to identify the utility and feasibility of remote sensing/GIS technologies to examine micro-scale vegetation changes at the high-use destination area.

Specific research objectives were to:

1) Detect fractional vegetation cover changes associated with off-trail hiking and trampling on Cadillac Mountain, using multi-spectral medium resolution remote sensing datasets: 2001 and 2006;

2) Examine effect of the site and visitor management strategies to reduce vegetation impact in the vicinity of the summit loop trail on Cadillac Mountain, using NDVI change detection analysis based on multi-spectral high resolution remote sensing datasets: 2001 and 2007;

3) Evaluate effect of the site and visitor management strategies to reduce vegetation impact in the vicinity of the summit loop trail on Cadillac Mountain, using post-classification change detection analysis based on multi-spectral high resolution remote sensing datasets: 2001 and 2007;

4) Assess effect of the site and visitor management strategies to reduce vegetation impact in the vicinity of the summit loop trail, using pre-classification change detection analysis based on multi-temporal remote sensing datasets: 1979, 2001 and 2007.

Holistic Approach

This study was mainly motivated by recreation ecology, which is a relatively new field beginning in the 1970s (Liddle, 1997). Recreational ecology refers to the scientific study examining recreational impact on the environment: vegetation, soil, water, and wildlife (Leung & Marion, 2000; Leung et al., 2001). More specifically, recreation ecology could be defined as the field of study that examines, assesses and monitors visitor-induced impact in a national park or protected area, and their relationships to influential factors (Hammitt & Cole, 1998; Liddle, 1997; Marion, 1998). Recent research trends in the discipline include development of impact monitoring protocols, management strategies, and low-impact educational messages (Cole, 1981a, 1989a, 2004a; Hampton & Cole, 1988; Marion, 1995, 1998). The main purpose of the discipline is to help managers identify and evaluate the level of resource impact, allow understanding factors that cause impact, and suggest appropriate management actions to minimize impact under given conditions (Leung & Marion, 2000). Although the discipline has developed effectively by adapting various experimental study designs (cross-sectional and longitudinal) and by developing detailed monitoring protocols (Cole, 2004a), one of the major challenges that recreation ecology currently faces is to identify "how much impact (change) should be allowed under the dual mission of NPS?"

Indeed, various management frameworks such as VERP and LAC, on the basis of the concept of "carrying capacity," were developed to answer the question. Indicators in many management frameworks, however, have little or no ecological background as well as difficulties in providing desirable ecological or biophysical indicators for monitoring impact (Buckley, 2003). Studies have shown that there are often complexities and lack of definitions related to selecting indicators and standards of quality for monitoring protocols (Alldredge, 1973; Becker et al., 1984; Cole, 2004a; Graefe et al., 1984; Manning, 1999). If indicators and standards of quality related to management objectives set relatively low carrying capacities, ultimately the areas may require direct regulations like use limits. Otherwise, if indicators and standards of quality related to management objectives set relatively high carrying capacities, the areas may be significantly impacted at the first phase of recreational use (Burch, 1984; Stankey et al., 1984; Washburne, 1982).

A series of studies recently showed the importance of a holistic approach for solving the resource impact problem in protected areas (Blockstein, 1999; Chan et al., 2007; Clark & Stankey, 2006; Clark et al., 1999; Endter-Wada et al., 1998; McConnell & Moran, 2000; Parsons, 2004; Wallace et al., 1996). What they commonly emphasized is that more holistic approaches will be required to effectively conserve natural resources by integrating social and biological concerns. When considering the situation of Cadillac Mountain in terms of research approaches, it is easily found that many studies based on social science were completed since 2000 (Table 1.3.). Although their main objectives were slightly different, they generally attempted to identify visitors' perceptions and experiences associated with the current site and visitor management strategies.

Table 1.3. Impact monitoring studies at Cadillac Mountain.

Studies based on Social Science	***Studies based on Biophysical Science***
1. Littlejohn (1999): Visitor survey 2. Jacobi (2001a): Visitor # counting & observation 3. Turner (2001): Visitor behavior observation 4. Jacobi (2003): Visitor # counting & observation 5. Bullock & Lawson (2007): Visitor interview 6. Bullock & Lawson (2008): Visitor survey 7. Park & Others (2008): Visitor behavior observation	1. Lubinski, Hop, & Gawler (2003): Vegetation mapping project by USGS-NPS

Some of the major findings based on human dimension issues can be summarized: 1) several studies identified the visitation and major recreational activities in the vicinity of the summit loop trail in order to offer baseline information (Jacobi, 2001a, 2003; Littlejohn, 1999), 2) visitors' experience at the summit do not appear to be diminished by the exclosures and signs (Turner, 2001), 3) visitors consider resource protection as an important matter and they are willing to accept on-site regulation, reinforced with the use of moderately to highly intensive management structures, but generally do not support use limits (Bullock & Lawson, 2008), 4) current site and visitor management strategies (barriers, trail hardening, and indirect methods) appeared to be of little consequence to visitors' experiences, but if fencing and regulatory messages were installed along the trail, it could be a negative factor to visitors' experiences (Bullock & Lawson, 2007).

Overall, studies based on social science identified that the current management strategies will not degrade visitors' experiences, even if the use level is extremely high during the summer. Now, it could be assumed that one major issue of the dual mandate (visitors' enjoyment) was solved to a degree in the vicinity of the summit loop trail. The next step, for a holistic approach, is to identify the degree of resource impact by directly examining the effect of site and visitor management strategies that were intended to reduce vegetation impact.

As aforementioned, there are two potential benefits of visitor-induced impact monitoring: 1) help to prove the effectiveness of site and visitor management strategies; and 2) help to establish a site objective by the inventorying process. Therefore, the expected benefits of this study include the detection of significantly impacted areas at the destination over a relatively long time period, and evaluation of effectiveness of the management techniques that have been employed to minimize vegetation loss and impact. These results would provide insight for managers to select an optimal management technique in a sub-alpine natural environment, especially in densely populated areas. Moreover, the study results would contribute to establishing a specific site objective in terms of maintaining biological conservation, which is one of the dual missions of NPS, by adapting and utilizing a "vegetation component" as the ecological indicator.

Study Design

Chapter 2: Since the study was designed to use several different vegetation change detection techniques on the basis of the same vegetation comparison mechanism and study boundary, some of the important/common methodological considerations in vegetation change detection analysis were discussed in Chapter 2.

Chapter 3: Fractional vegetation cover changes associated with the hiking trail network at Cadillac Mountain were analyzed using Landsat TM between 2001 and 2006. Three major vegetation indices, Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Transformed Vegetation Index (TVI), were applied to detect major vegetation cover changes over the trail network on Cadillac Mountain. According to proximity to the trail network, Cadillac Mountain was divided into two zones. Then, the rates of increased and decreased vegetation areas along with the trail network were identified and compared between the two zones by using statistical analysis based on a systematic sampling approach. In addition, spatial interaction between the trail network and the decreased vegetation areas was tested using Cross K-function, in order to identify the spatial interaction of impact along the trail network.

Chapter 4: Vegetation cover changes in the vicinity of the summit loop trail were analyzed using multi-spectral high resolution remote sensing datasets between 2001 and 2007. In order to better understand the effect of the employed management strategies in the experimental site (the summit loop trail) representing “vegetation impact by visitors” and “management actions,” a control site was selected on the basis of landscape analysis, natural factors (temperature, precipitation, elevation, vegetation species homogeneity), human disturbance factors (existing trails and automobile roads), and natural disturbance factors (fires, wind, and storm). NDVI, one of the pre-classification change detection analysis techniques, was used to detect fractional vegetation cover changes in the experimental site as well as in the selected control site. Then, the rates of increased and decreased vegetation areas between the two sites were statistically compared to identify the effect of the deployed management strategies.

Chapter 5: Vegetation cover change between the experimental and control sites were analyzed using the same high resolution datasets discussed in the previous chapter. However, post-classification change detection analysis based on supervised classification was used to detect vegetation cover changes. Based on a training dataset gathered in the field investigation during the summer of 2007, two supervised classifications for 2001 and 2007 imageries were completed at the levels of plant family and binary mode (vegetation vs. non-vegetation). Then, the rates of vegetation cover changes between the two sites were statistically compared to identify the effect of the deployed management strategies. In addition, vegetation diversity considering evenness and richness was calculated using Shannon Wiener Index (*alpha* diversity metrics) and Euclidian Distance (*beta* diversity metric), in order to measure the effect of the employed management strategies in terms of maintaining and enhancing vegetation diversity.

Chapter 6: Vegetation cover changes in the vicinity of the summit loop trail were analyzed using single-spectral high resolution remote sensing datasets in 1979, 2001, and 2007. Pre-classification change detection analysis was applied to detect significant vegetation cover changes in both the experimental and the selected control sites. Unlike the studies in Chapters 4 and 5, this study included vegetation cover change analysis before 2000, when no active management actions were applied. Again, the rates of vegetation cover changes were statistically compared to identify the effect of management actions.

Chapter 7: Recommendations based on the study findings were made for future management and study. In addition, study limitations such as temporal and spatial scales of analyses were discussed.

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CHAPTER 2

VEGETATION COVER CHANGE DETECTION ANALYSIS: METHODOLOGICAL CONSIDERATIONS

The study was designed to use several different vegetation change detection techniques on the basis of the same vegetation comparison mechanism and study boundary. Therefore, some of the important methodological backgrounds and common considerations are discussed in this Chapter.

Previous Vegetation Studies at Cadillac Mountain

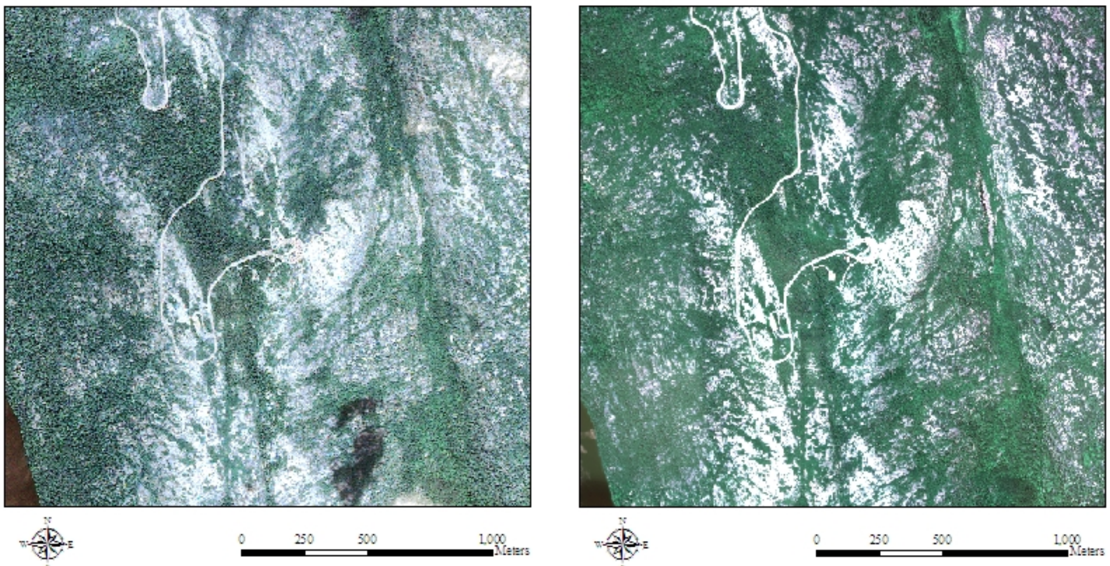
Many vegetation studies have been done in ANP, which reflects the importance of the resource as the only national park in the northeastern U.S. Some of the early vegetation studies were completed by Rand and Redfield (1894), Hill (1919, 1923), Moore and Taylor (1927), and Johnson and Skutch (1928a, 1928b). The feature of those early vegetation studies focused more on plant identification and classification. However, the trend of vegetation studies was changed to fit particular interests, focusing on spatial distribution and analysis. Kuchler (1956) mapped dominant species in the southeastern portion of Mount Desert Island including the burned areas of the 1947 fire, and Davis (1966) investigated spatial distribution of spruce-fir forests based on a field sampling method in the coast of Maine covering ANP. Waggoner (1981) used a color-infrared aerial photograph taken in August 1979 in the first attempt to map the vegetation distribution and classification of Mount Desert Island using remote sensing analysis. Demers (1991) combined GIS applications to present vegetation richness and habitat preference of Mount Desert Island by integrating a vegetation classification map based on the result of Kuchler's work (1956). Calhoun (1994) inventoried and mapped the wetland areas, using the U.S. Fish and Wildlife Service wetland definition and classification methodology. Other notable studies in ANP mainly include an inventory of natural resources: 1) Mittelhauser (1996): investigated forest composition as a part of an ecological baseline information inventory, 2) Greene and others (1999): inventoried aquatic plants and their distribution, 3) Schauffler and others (2007): classified five different vegetation cover types over the two upper watersheds using aerial photographs, 4) Wiersma (2007): investigated spatial distributions of two forest vegetation types (deciduous and coniferous forests) in two watersheds, 5) Lubinski and others (2003): conducted vegetation classification research for supporting resource assessment and park management under the cooperative effort by USGS and NPS. Until now, there has been little direct study examining vegetation impact caused by recreational activities on Cadillac Mountain, especially off-trail hiking and trampling using remote sensing technology.

High Resolution Remote Sensing Dataset

It is generally accepted that the emergence of the IKONOS satellite has created a new phase for remote sensing analysis since it offers an advanced spatial ground resolution (Enclona et al., 2004; Sawaya et al., 2003). Many studies show the usefulness of IKONOS satellite imagery for monitoring vegetation loss and change (Colombo et al., 2003; Goetz et al., 2003; Hirose et al., 2004; Jain & Jain, 2006; Katoh, 2004; Khorram et al., 2003; Stow et al., 2004; Turner et al., 2003; Wallace & Marsh, 2005; Wulder et al., 2004). It has been shown that land cover and land use change information from medium spatial resolution sensors such as Landsat and SPOT may be difficult to apply directly to ecosystem analysis in a local scale due to a coarse spatial resolution (Wulder et al., 2004). Therefore, major advantages of high resolution remote sensing datasets including IKONOS are to reduce a mixed pixel problem that is often pronounced in medium or coarse spatial resolution, and to provide a higher probability to obtain more detailed information related to land cover and change (Hirose et al., 2004; Jollineau & Howarth, 2002; Lu & Weng, 2007; Sawaya et al., 2003). Given recent advances and its increased availability in platforms and sensors, the utilization of high resolution datasets offer improved opportunity for analyzing detailed vegetation changes (Gross et al., 2006; Hirose et al., 2004; Loveland et al., 2002).

In national parks and protected areas, high resolution aerial photographs and IKONOS from the 1940s to 1990s were used for mapping and quantifying land use, land cover changes, and ecological impact of such changes at the Effigy Mounds National Monument, Iowa (Narumalani et al., 2004). Mehner and others (2004) utilized a pre-classification change detection analysis based on IKONOS imagery for mapping upland vegetation classification in Northumberland National Park, UK. They showed that IKONOS imagery is a useful tool for mapping vegetation at a finer spatial scale, providing accuracy comparable to a traditional on-site mapping method of ground survey. Gross and others (2006) introduced diverse uses of high resolution remote sensing datasets for landscape dynamics evaluation, conservation biodiversity, and ecosystem management. Their research detailed possible applications of remote sensing technology, especially focusing on the management of U.S. national parks.

In Chapters 4 and 5, two multi-spectral remote sensing datasets, IKONOS 2001 and Airborne 2007, holding an advanced spatial resolution, were used to detect vegetation changes between 2001 and 2007. The IKONOS 2001 was obtained from Acadia National Park (ANP) and the airborne 2007 was obtained from the John Deere AGRI Service (Figure 2.1).



IKONO 2001 (August 18, 2001)
Projection: UTM, Zone 19
Spheroid: GRS 1980
Datum: NAD 83
Resolution: 1.0*m* (PAN), 4.0*m* (Multi)
Binary Digit: 11bit (0-2047)

Airborne 2007 (June 24, 2007)
Projection: UTM, Zone 19
Spheroid: GRS 1980
Datum: NAD 83
Resolution: 0.96*m* (B, G, R, NIR)
Binary Digit: 8bit (0-255)

Figure 2.1. Description of remote sensing datasets used (natural color composite).

Identifying the Study Boundary

Remote sensing technology has been recognized as useful way to collect spatial information, and has played an important role in investigating vegetation diversity and structural composition across multiple scales (Innes & Koch, 1998; Linke et al., 2007). Also, by integrating with GIS and other spatial statistic applications, the technology has been more useful to understand the human dimensions of land use and cover change (Green et al., 2005). However, both spatial and temporal scales of remote sensing datasets that will be utilized in this analysis should be examined in order to produce an observed and measured change pattern more effectively and meaningfully.

Studies for considering the importance in both spatial and temporal scales have been mainly addressed from the perspective of landscape ecology and analysis (Levin, 1992; Turner, 1989, 1990; Wiens, 1989). Levin (1992) proposed the problem of observer bias and filtering process associated with simplification and aggregation in investigating ecological change and analysis. Levin's main point is that the recognition of a natural system would be inevitably biased because we look at a natural system and function with our own filter at a certain position. Alternative ways, therefore, should be developed to quantify spatial patterns under the variability of space and time in order to understand how patterns change with different scales (Levin, 1992). In the same context, Wiens (1989) indicated that our measurement or observation at a certain spatial and temporal scale influences measured or observed results. Therefore, it is extremely important to establish appropriate the spatial and temporal scales of research (Green et al., 2005).

As a practical application for controlling the spatial scale issue, two distinctive concepts have been suggested[2] (Moran & Ostrom, 2005; Turner, 1990; Turner et al., 2001; Wiens, 1989). The first is "grain" that refers to a finest spatial resolution or measurement, and the second is "extent" that refers to a total area sampled within a given dataset (Gergel & Turner, 2002). From the remote sensing perspective, grain and extent are generally related to resolution (pixel size) and area of coverage, respectively (Lillesand et al., 2004). The problem associated with grain and extent is simple. If we control and change the size of grain or extent, detailed or important sources for an analysis would also be changed together (Figures 2.2 and 2.3).

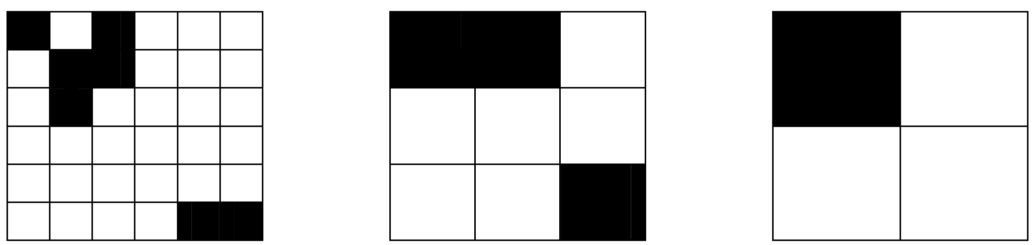


Figure 2.2. Increasing grain size: depending on the size of grain, observed spatial pattern would be different (Turner, 1990).

[2] There are relatively fewer methods in terms of coping with a temporal scale issue because we have a limited number of remote sensing datasets for analysis. However, two main factors are often recommended to be considered (Wiens, 1989). The first is selecting an optimum seasonal time to ensure leave-on and dry vegetation and dry soil in a study area. Furthermore, a selected remote sensing dataset must have no haze and clouds that may cause a false interpretation. The second is monitoring a frequency of natural disturbance (e.g., fire or drought). In other words, any natural disturbance that may influence vegetation structure and composition during an intended time frame should be identified and considered to better understand changes.

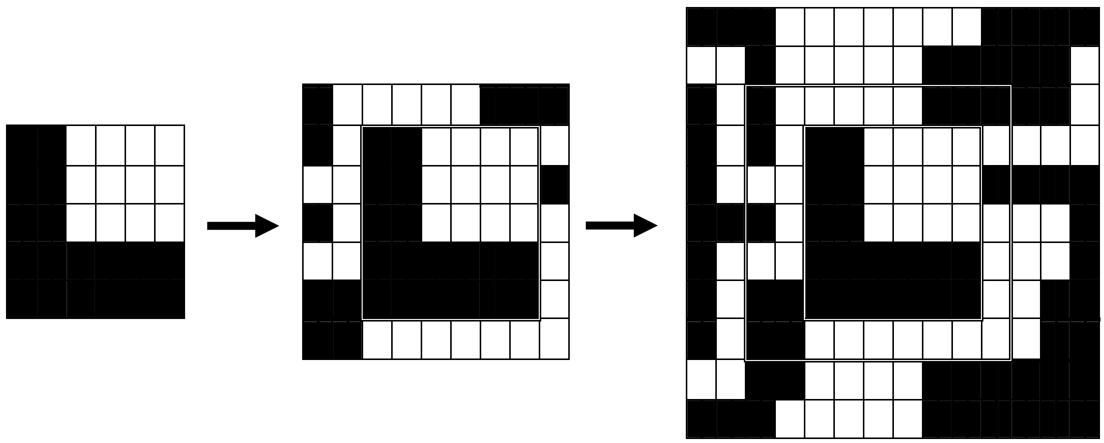


Figure 2.3. Increasing extent size: by increasing extent of study areas, different spatial pattern and results would be observed (Turner, 1990).

Although there is no single correct scale for an analysis, it is commonly agreed that more appropriate extent and grain would be discovered by considering given study assumptions (Gergel, 2007). In that regard, multi-spatial scale studies have been introduced by altering the size of extent and grain or by applying a statistical technique and modeling (Carroll & Pearson, 2000; Galzin, 1987; Turner, 1990; Turner et al., 2001; Wiens, 1989). Wiens (1989) mentioned two techniques in order to control spatial variance and heterogeneity: 1) increasing the size of grain while holding the size of extent constant, and 2) increasing the size of extent while holding the size of grain constant.

Pauchard and others (2000) controlled the grain sizes from broad to fine by different standards and tried to integrate them in a multiscale method for assessing vegetation distribution. Kalkhan and Stohlgren (2000) applied two different spatial sampling approaches using $1m^2$ and $1{,}000m^2$ to identify the spatial pattern of plant species richness. Tasser and Tappeiner (2002) adopted two different grain sizes of $25m^2$ and $250m^2$ for their vegetation sampling research. Graham and Knight (2004) used three different multi-scale sampling plots to identify plant diversity in cliff environments: 1m^2, 20m^2, and 30m^2. Underwood and others (2007) utilized two different spatial resolution scales (4m^2 and 30m^2) in detecting three invasive plants in California's coastal ecosystem using Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and spatially degraded AVIRIS. In addition, in the field of recreation ecology, two different sampling strategies at both 1m^2 and 4m^2 were used to identify vegetation trampling effect on a forest understory community (Taylor et al., 1993).

On the other hand, Kendall and others (2003) employed two different extents (100*m* and 500*m*) to evaluate spatial distribution of a certain family of fish for discovering the pattern of settlement. Madrigal and others (2008) also used two different spatial extents (micro and regional scales) to identify factors influencing a herbaceous community in the Mediterranean. In addition, more than three different spatial extents were adopted to cope with the spatial scaling issue in two studies (Senft et al., 1987; Wiens et al., 1986). In the field of recreation ecology, Cole and Monz (2004) utilized three different spatial extents to monitor campsite vegetation impact in two sub-alpine communities: core (3m^2), intermediate (5m^2), and periphery (7m^2). Although there is a slightly different aspect in understanding the concept of extent between landscape ecology that tries to cope with the inherent spatial problem of analysis and recreation ecology that mainly attempts to verify a localized impact and regular radial pattern of vegetation impact, it is remarkable that they reported the magnitude, variability, and spatial pattern of vegetation impact were varied with the spatial scale of analysis.

Since the two remote sensing datasets which were used in our study have their own spatial resolutions around 1m, the vegetation change analysis using those datasets was fixed within 1m grain size by a supplementary resampling process. Establishing a appropriate grain size for an intended spatial analysis will be naturally settled by the fixed cell size of grid maps. Also, in a spatial sampling process, the size of grain for calculating the rates of vegetation changes (the size of sampling plot) was controlled to obtain a minimum sampled plot (e.g., $N \geq 10$) on the basis of a systematic sampling approach over the study region. However, there still is a spatial issue associated with extent.

It is important to establish a reasonable extent of the study site because a core idea to identify the effectiveness of the site/visitor management strategies has a close relationship with how much area in the vicinity of the summit loop trail will be impacted by visitors. For our analysis, three different spatial extents were adopted to identify vegetation changes in the vicinity of the summit loop trail: small (30*m* buffering width from the summit loop trail), medium (60*m* buffering width), and large (90*m* buffering width). Although the adopted method was guided by the landscape ecology literature, the physical delimitations of three extents were decided on the basis of an assumption that there will be limited visitor dispersion and associated impact beyond 100m from the summit loop trail. This assumption is linked to a visitor observation study at the Cadillac Summit Loop Trail (Turner, 2001) which found that visitor impact on vegetation and soil was not limited to a few meters from the trailside of the summit loop trail. Impact was occurring far beyond the summit loop trail, as well as the area surrounded by the trail, that could be easily taken up to 50-90*m* from the trail on the basis of Turner's sampling plots for vegetation trampling and observational locations for visitor behaviors. The important point was not the fact that we specifically assigned three different figures for designing the buffering widths, but that we used three different spatial extents for investigating vegetation changes and trends. Each result in the three spatial extents was then compared to ensure a consistency in detecting vegetation changes.

Selecting the Control Site

A method to estimate vegetation changes in the field of recreation ecology is mainly divided into two parts: 1) estimating amount of vegetation cover, 2) estimating vegetation composition and diversity (Hammitt & Cole, 1998). The first is the most common and classic approach that calculates total or mean of vegetation cover, while the second is relatively less used in studies (Hammitt & Cole, 1998). These methods could be further classified by spatial sampling strategies (e.g., random, stratified random, systematic, and cluster sampling) and the size of quadrat (e.g., $1m^2$ vs. $5m^2$). In traditional recreation ecology studies, commonly used methods include a $1m^2$ quadrat based on a systematic sampling approach, and a line transect method for estimating the mean cover of vegetation (Cole, 1982; Hammitt & Cole, 1998; Marion, 1991).

Vegetation changes could be indentified also by comparing vegetation cover on a target area with cover on adjacent undisturbed/pristine areas (Cole, 1995). In this case, the most essential factor is that selected undisturbed sites (control sites) must have environmentally similar characteristics with the experimental site (original study site). This vegetation comparison mechanism was used in our vegetation change analysis to maximize the advantage of remote sensing datasets that allows us to capture areas having low or little accessibility. Since our experimental site represents an “intensively used area” having both a constant vegetation impact by visitors and site/visitor management actions to reduce vegetation impact, the control site must have different characteristics in terms of visitor use patterns and management actions, while their environment characteristics should be similar. The similar environmental characteristics and boundaries can be explained as the same levels of climatological parameters such as temperature and precipitation aspect (Butler et al., 2003; Lloyd & Graumlich, 1997; Motta & Nola, 2001).

In order to spatially identify areas that maintain a similar climatological parameter at Cadillac Mountain, the Maine Office of GIS (http://megis.maine.gov/) was investigated to check atmospheric, climatological, and meteorological GIS datasets, but no relevant datasets were discovered. As an alternative, the National Digital Forecast Dataset (NDFD) (http://ndfd.weather.gov/), administrated by NOAA, was used to check climatological datasets covering the experimental site. The NDFD is a grid-based weather forecast system that includes wind speed, wind direction, moisture level, precipitation, dew point, temperature, etc. Basically, the NDFD is a forecast system projecting from every 3 to 120 hours, but what was necessary to investigate were the minimum spatial boundaries of those climatological parameters at Cadillac Mountain. Therefore, all related GIS datasets were downloaded, selected by location to contain one polygon covering the summit of Cadillac Mountain, and intersected to identify an overlay area (Figure 2.4). The intersected area in Figure 2.4 included a relatively large area of Cadillac Mountain, so it was not useful to narrow down a target area where the control site could be potentially selected. However, the spatial boundary of the intersected area was useful in discovering the fact that two other major summits, Sargent Mountain (1,473 ft) and Penobscot Mountain (1,194 ft) considered as strong candidates for the control site within Mount Desert Island, may have a different climatological regime (Figure 2.5).

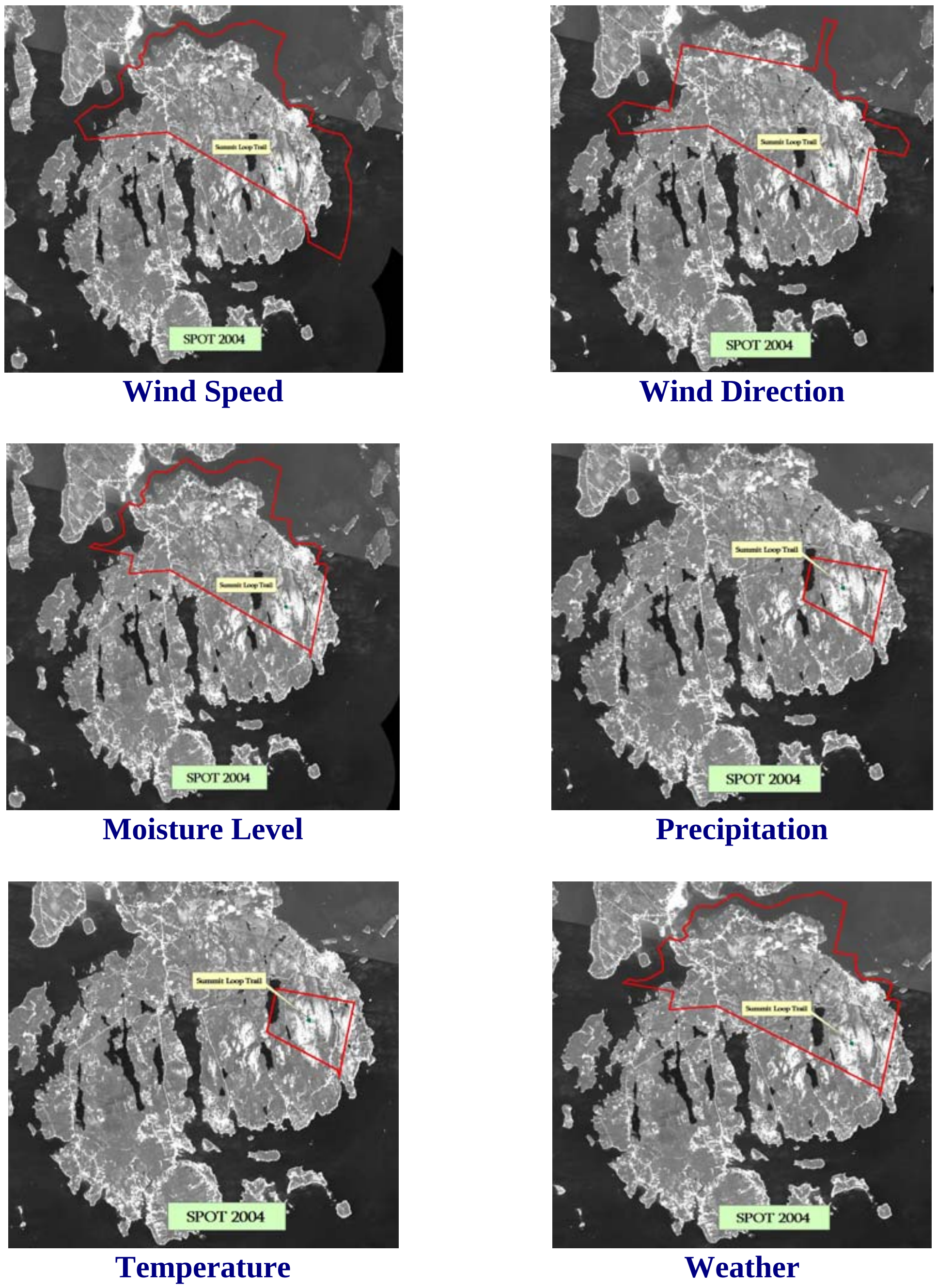


Figure 2.4. Spatial boundaries of climatological parameters by NDFD (Background Image: SPOT 2004).

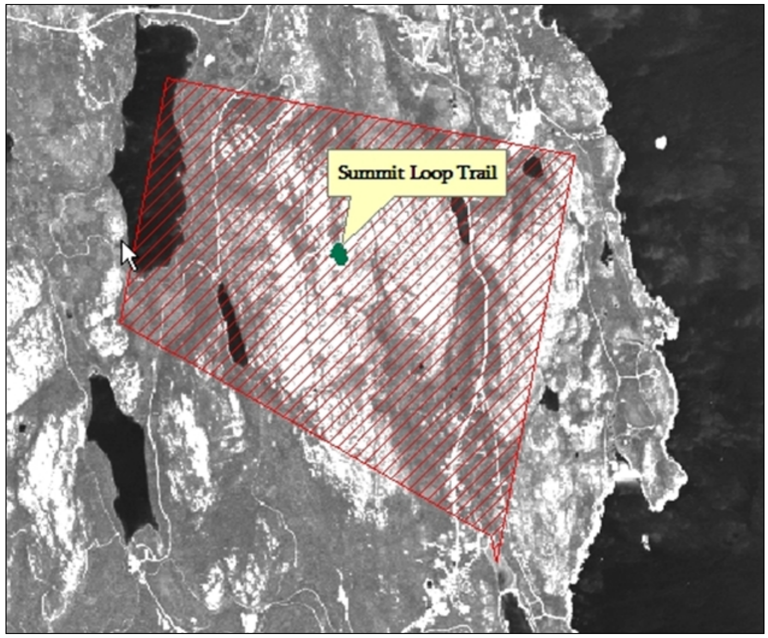


Figure 2.5. Intersected area by 6 climatological parameters (Background Image: SPOT 2004).

More fundamentally, many studies discuss "elevation" as the most important single factor for shaping a homogeneous vegetation community, suggesting a shorter growing season, especially in alpine or sub-alpine environments (Barnes et al., 1998; Boughton et al., 2006; Kimball & Weihrauch, 2000). In addition, recommendations associated with elevation in selecting the control site were suggested in the 5th Northeastern Alpine Stewardship Gathering at the Schoodic Education and Research Center, ANP, from June 8-9, 2007. There was an attempt by participants to define "geographic area" of the summit loop trail area. Among various ideas, using the 1,450 ft contour was commonly suggested because it would capture all areas of interest and the area already impacted (Jacobi, 2007).

Elevation as a baseline boundary was applied in selecting the control site. Initially, 1,450 ft in elevation was considered, but it included only a small portion of the vicinity of the summit loop trail as mainly impacted areas. Consequently, it was expanded to 1,300 ft to capture more undisturbed/pristine areas (Figure 2.6). This minimum elevation included our large spatial scale boundary (90m buffering width from the summit loop trail) in the intended multi-scale analysis.

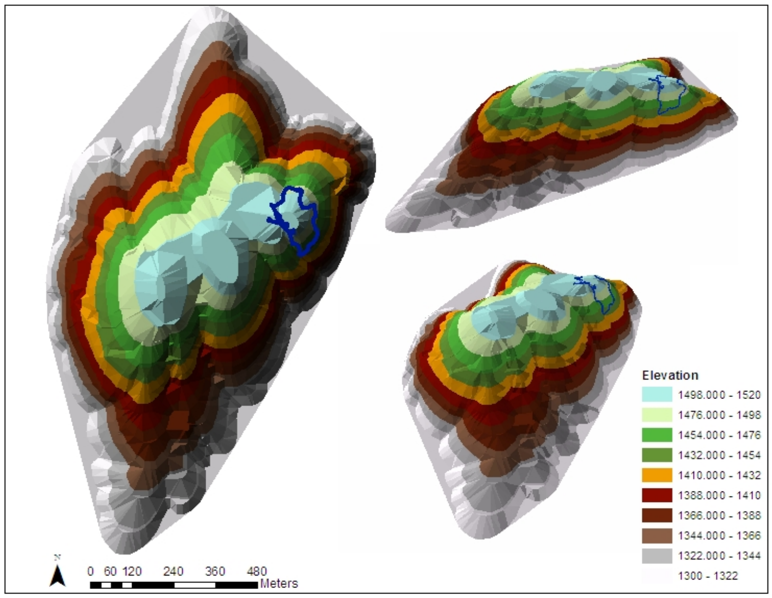


Figure 2.6. Elevations at the summit of Cadillac Mountain: baseline boundary to select the control site (1,300 feet).

On the basis of the selected boundary of 1,300 ft in elevation, a disturbance factor was additionally considered as empirical studies showed that disturbance is a key mechanism in maintaining species diversity by preventing dominance (Roberts & Gilliam, 1995; Turner, 1989). Disturbance is defined as a relatively discrete event that disrupts structure and process of ecosystems, communities, or populations and changes resource availability or physical environment (Barnes et al., 1998; Begon et al., 1996; Pickett & White, 1985). It can be generally divided into two categories: natural and human-induced disturbances (Randolph et al., 2005). Natural disturbance is a biological and physical mechanism including insect damage, disease, hurricane, windstorm, flood, snow, ice damage, fire, earthquake, landslide, and volcanic eruptions. Human disturbances include timber harvesting, clearing, mining, and agriculture.

Major natural disturbances were investigated since the establishment of ANP in 1919 using archived materials and interviews with park staff. A notable event was the disastrous fire in 1947 (Figure 2.7). The fire burned most of the eastern side of Mount Desert Island, including the vicinity of the summit loop trail (Patterson et al., 1983). It is agreed that fire is the most important natural disturbance agent causing change of stand structure in sub-alpine forests (Rebertus et al., 1992; Veblen et al., 1994). Therefore, it was suggested that the control site must be within the same burned areas.

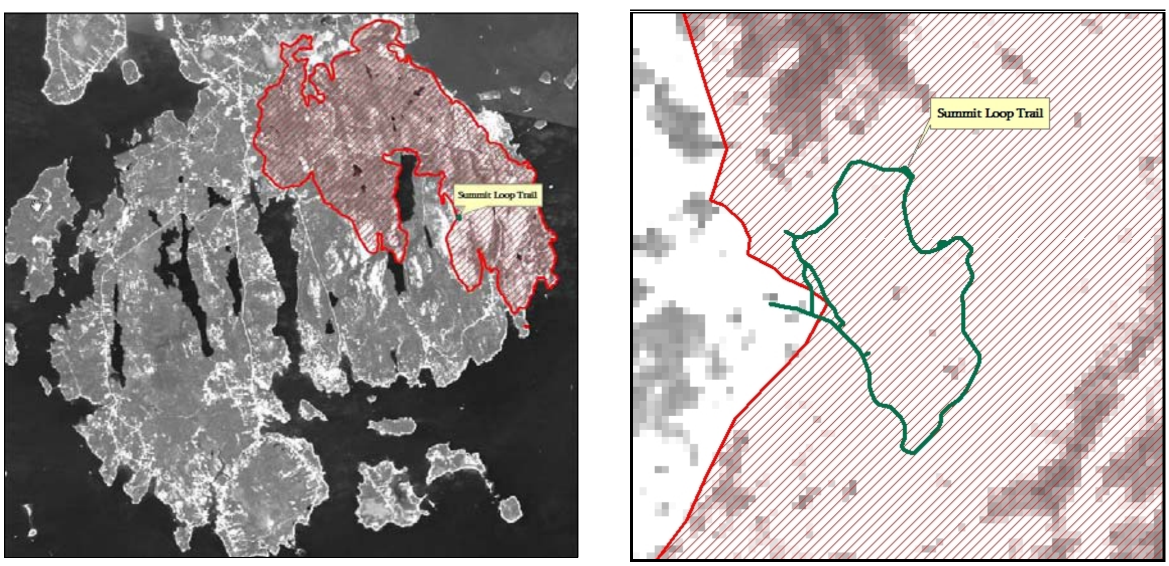


Figure 2.7. Burned area in the vicinity of the summit loop trail (right) and Mount Desert Island (left) by the Fire in 1947.

Next, the human disturbance factor was considered. From the perspective of forestry, the human disturbance factors have been investigated and observed by a relatively large scale land use and land cover change over a long time period in order to discover direct human impact, such as timber harvesting and clear cutting (Heckenberger et al., 2007; Hessburg et al., 1999; Sader et al., 2004; van Gemerden et al., 2003; White & Oates, 1999). However, it was assumed that there was no clear cutting and timber harvesting activities because ANP has been protected as a federal land since its establishment in 1919. Instead of those direct human disturbance factors, two concepts were utilized to exclude potentially human accessible areas under the assumption that accumulated trampling effect is the most serious human disturbance factor in the vicinity of the summit loop trail: riparian buffering and wildlife conservation buffering distances. As mentioned, the two distance concepts were used as an alternative way in establishing undisturbed and potentially disturbed areas by visitors or recreationists.

Establishing riparian buffer zone is a widely accepted tool for improving and protecting stream resources (Dosskey et al., 2005; Reid & Hilton, 1998). It provides an ecologically important buffering function to alleviate direct impact of land use activities, mainly agricultural purposes (Dwire & Lowrance, 2006). An appropriate buffering zone will be varied by topographic information such as slope and soil condition (Dosskey et al., 2005), but related studies typically suggest distances ranging from 7m to 120m from stream shoreline (Buffler et al., 2005; Chase et al., 1997; Johnson & Buffler, 2008; Yeakley et al., 2006). There is also the alert (or flush) distance concept as one of wildlife conservation buffering distances, indicating minimum approaching area to avoid a stressful situation to wildlife (Fernández-Juricic et al., 2002). This alert distance is extremely varied among species, with large species being less tolerant of human disturbance than small ones (Fernández-Juricic et al., 2002). Again, associated studies normally suggest the distances ranging from 12m to 200m from wildlife (Buckley & Buckley, 1976; Erwin, 1989; Fernández-Juricic et al., 2002; Rodgers & Schwikert, 2002;

Rodgers & Smith, 1997; Taylor & Knight, 2003). There is another clue to derive an appropriate human disturbance distance. Urban (2000) used more than 100*m* from a road network for undisruptive sampling areas for GIS landscape analysis and impact assessment, even though this study is neither about riparian buffering nor alert distance concepts.

Accordingly, in order to exclude potentially human accessible areas, 150m was applied from the existing structures including parking lots, auto roads, concession and restroom areas, and the hiking trail network (Figure 2.8). Originally, 200m was considered, but relatively huge portions of our baseline boundary of 1,300 ft in elevation were masked-out, so it was impossible to obtain potential pristine areas. The targeted area for the control site was additionally reduced by eliminating cloud cover areas in IKONOS 2001 to avoid later classification confusion.

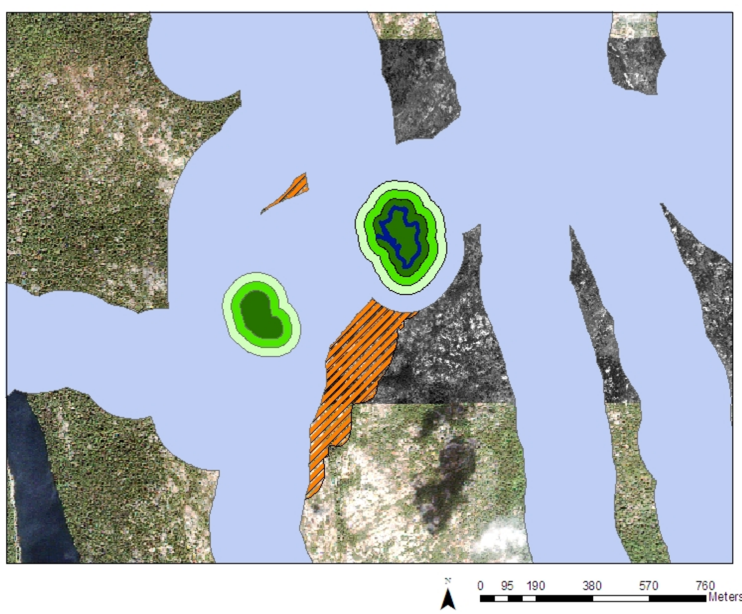
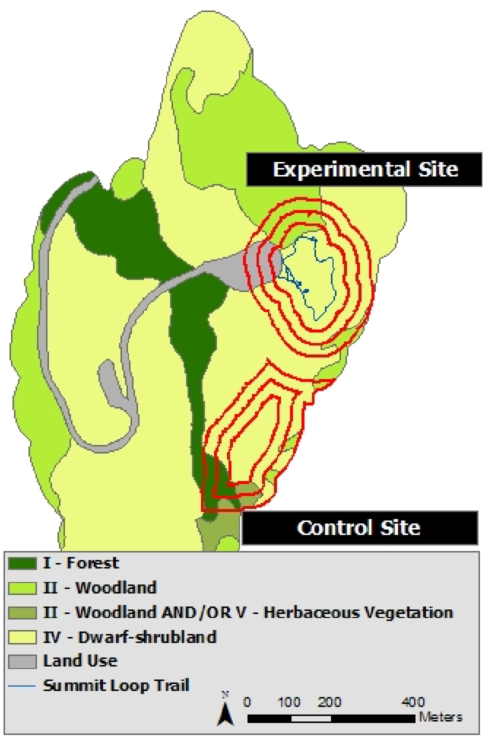


Figure 2.8. Buffering from the existing structures to exclude human impact area (sky blue: 150m buffering distances, ocher: 1,300 ft in elevation at the summit).

Figure 2.9 shows the selected control and experimental sites. The control site was delineated by excluding the fire impacted and the potentially human accessible areas on the basis of the 1,300 feet in elevation contour. The minimum distance between the experimental and control site at the large spatial scale was 60m, indicating a geographically adjacent area. Both sites have a relatively similar south-east facing aspect, while the control site was slightly steeper than the experimental site, when comparing topographic factors.



	Experimental Site *Visitor Impact, Management*	
	Area (m^2)	Vegetation Cover*
Small (30*m*)	33,497	Dwarf-shrubland: 93%
Medium (60*m*)	57,612	Dwarf-shrubland: 86%
Large (90*m*)	87,136	Dwarf-shrubland: 81%
	Control Site *No/limited Visitor Impact, No/little Management*	
	Area (m^2)	Vegetation Cover*
Small (30*m*)	13,524	Dwarf-shrubland: 99%
Medium (60*m*)	33,460	Dwarf-shrubland: 86%
Large (90*m*)	61,551	Dwarf-shrubland: 76%

Figure 2.9. Selected control site showing the three different spatial scales (red lines).

Tests were made to investigate the similarity and difference between the two sites in terms of a vegetation composition and a level of impact. The first test was done during our field vegetation investigation on July 20, 2007. Undisturbed/pristine areas (about 10m^2) for comparing trampling impact in the vicinity of the summit loop trail were investigated by Dr. John Daigle (University of Maine), Dr. Jeff Marion (Virginia Tech), and Charlie Jacobi (ANP). The objective of the field investigation was to spatially discover undisturbed/pristine areas representing no site/visitor management and no visitor use, so that the selected points dataset could be potentially used for future trampling research. Criteria used included minimum bare rock portion, no soil exposure scars, and relatively abundant vegetation covers. Consequently, 22 sites were identified as undisturbed/pristine areas. The location of each site was recorded by a Trimble GeoXT (a submeter GPS unit) with a bypass and external antenna and exported as ESRI shape file format (Figure 2.10). Due to the accessibility issue, it was impossible to investigate intensively the entire vicinity, but the effort was made to visit many sites. Overall, undisturbed/pristine sites were identified more at the core area of the control site. The result showed six pristine sites were included in the selected control site, even though four sites were included over the medium scale of the experimental site. In addition, the northern area of the summit loop trail included five potential sites in woodlands which are less accessible. It was not possible to locate a potential site within the small spatial scale of the experimental site due to the significantly impacted level.

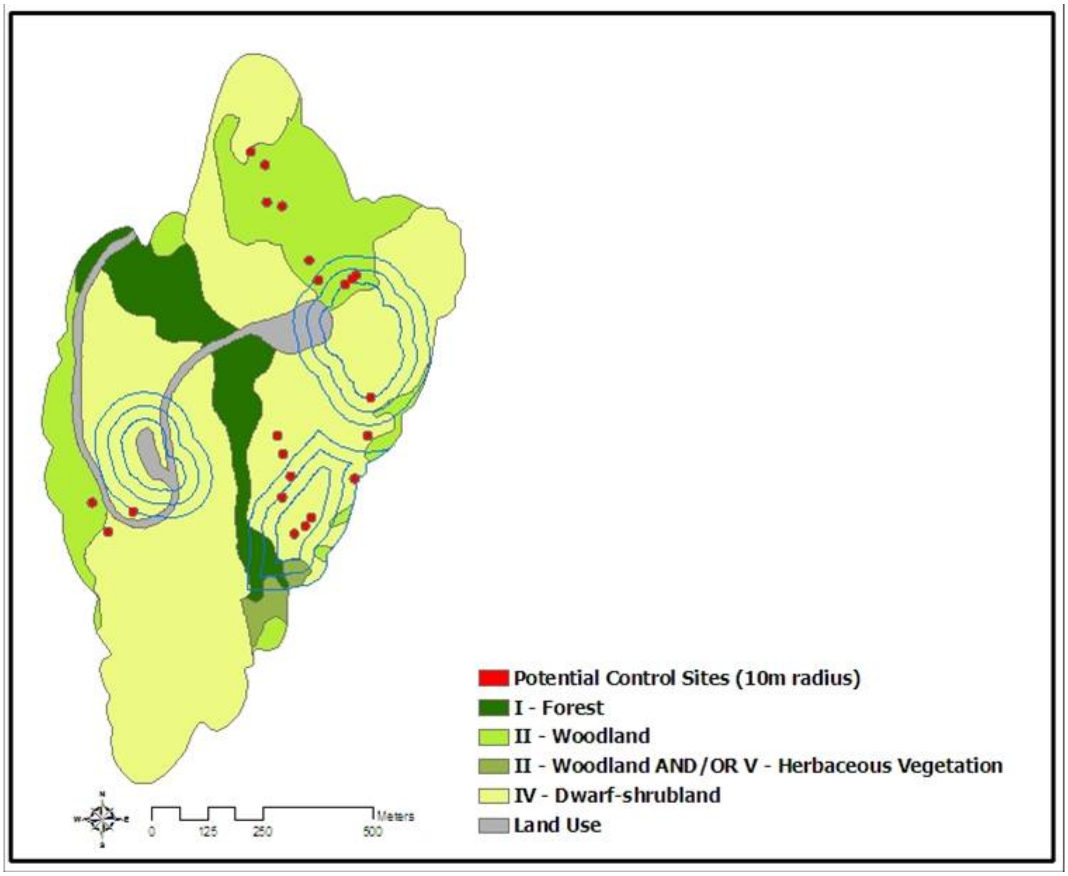


Figure 2.10. Potential control sites: 22 red points (background classes by VMP)

Additionally, vegetation composition in the selected control site was investigated using the result of the Vegetation Mapping Project (VMP) completed in Acadia (Lubinski et al., 2003) (Figure 2.9 & 2.10). Under the cooperative effort by USGS and NPS, vegetation classification research in ANP was done for supporting resource management in 2003. The project utilized 1,216 aerial photos in conjunction with 216 community based vegetation sampling plots. For the classification scheme, 50 different map classes were developed for ANP on the basis of the National Vegetation Classification System (NVCS) developed by The Nature Conservancy (Anderson et al., 1998; Grossman, 1998) and endorsed by the Federal Geographic Data Committee (FGDC), to maintain classification consistency across regions. Overall accuracy of the classification result was about 80% via 668 accuracy assessment points. When comparing vegetation cover at the level of plant class, it was found that vegetation covers between the experimental and the control sites were almost similar to Dwarf-shrubland in the small and medium scales, while the vegetation cover in the control site is a slightly more dynamic in the large spatial scale. However, there was no outstanding difference in terms of vegetation composition at the level of plant class in the VMP.

Pre-Classification Change Detection Analysis

Classification is the process of sorting dataset pixels into a number of classes on the basis of their spectral values (Singh, 1989). The common pixel-based classification methods are unsupervised and supervised classifications (Jensen, 2005). One of the advantages of unsupervised classification is that it requires minimum input from the analyst. Therefore, when the analyst does not have enough knowledge and information about a study site, this method may be more useful for classification. However, the signatures (training dataset) in unsupervised classification are automatically generated, so the classification results may have less discerning ability compared to the supervised classification. Unlike the unsupervised classification, supervised classification requires knowledge about a study area. This background information (signature, training data, or *priori* knowledge) could be collected through a field survey and interpretation from other ancillary datasets (e.g., aerial photographs and vegetation maps). The advantage of supervised classification is that the analyst can define a required classification scheme for organizing classification results. However, the process of collecting the training data could be a drawback compared to unsupervised classification.

More importantly, there is a need to discuss change detection analysis techniques based on the classification algorithms. Change detection is a process of identifying differences by observing land cover types at different times (Lu et al., 2004; Singh, 1989). Until now, two main techniques associated with change detection have been widely accepted in remote sensing analysis: pre-classification and post-classification change detection analyses (Lunetta et al., 2006; Rogan & Chen, 2004; Rymasheuskaya, 2007; Serra et al., 2003; Singh, 1989). Both methods have pros and cons in terms of analyzing datasets and obtaining results (Table 2.1). Therefore, change detection methods should be carefully selected among various analysis techniques under the given circumstance and detailed study objective.

Table 2.1. Advantage and disadvantage of vegetation change detection methods (Lunetta et al., 2006; Rogan & Chen, 2004; Rymasheuskaya, 2007; Serra et al., 2003; Singh, 1989).

	Advantage	***Disadvantage***
Pre-classification Change Detection	1. Easy to manipulate by transforming band ratio 2. Partly compensating the problem of different illumination condition, surface slope, and aspect 3. No need to have a training data (time saving)	1. Must have a radiometric co-registration process between imageries 2. Non-detailed classification scheme (e.g., change vs. non-change)
Post-classification Change Detection	1. More detailed and flexible classification scheme by land cover types or user-defined classes (e.g., species, genus, and family) 2. No radiometric co-registration process required between two images	1. Relatively complicated process compared to pre-classification change detection technique 2. Problem with result accuracy level (e.g., 80% accuracy × 80% accuracy = 64% accuracy) 3. Time component

Although it is commonly agreed that high resolution remote sensing datasets including IKONOS are useful for vegetation change analysis, several factors should be considered before designing the vegetation change analysis using multi-spectral and high-resolution remote sensing datasets captured by different sensors and platforms. The measured spectral value of each band in remote sensing datasets is easily affected by external factors, such as changes in scene illumination, atmospheric conditions, seasonality, viewing geometry, and sensor response characteristics (Lillesand et al., 2004; Moran & Ostrom, 2005). These factors could cause potential problems in identifying vegetation species, in assigning proper classification schemes and in detecting vegetation changes. Even though the post-classification approach has been considered as a promising way for detecting changes and identifying detailed vegetation types, it requires extensive field work to obtain a training sample dataset often accompanying time and cost components, significant consideration in selecting classification schemes, consistency in imagery processing, and accuracy assessment regarding post-classification results (Singh, 1989; Weismiller et al., 1977). Moreover, the reliability of the post-classification change detection analysis result will be decreased considerably when two images have a relatively low level of accuracy (Coppin et al., 2004; Lambin & Strahler, 1994; Petit & Lambin, 2001; Singh, 1989). Many pre-classification change detection methods have been developed by ratio transformation between each band in order to partly cope with the problems related to the distortion of measured spectral values and the post-classification approach (Jensen, 2005; Lunetta et al., 2006) (Table 2.2).

Table 2.2. Applicable vegetation indices for IKONOS satellite imagery (Crist, 1985; Huete, 1988; Jensen, 2005; Katoh, 2004; Senseman et al., 1996; Tucker, 1979). There are numerous vegetation indices depending on study objectives and available remote sensing datasets. Five major vegetation indices that could be applied for IKONOS are briefly summarized here (* In SAVI, 0.5 is generally used as L).

Vegetation Index	***Equation***
Simple Ratio (SR) or Biband	Band4 – Band3
Brightness	$(\mathrm{Band3}^2 + \mathrm{Band4}^2)^{0.5}$
Normalized Difference Vegetation Index (NDVI)	(Band4 − Band3)/ (Band4+Band3)
Soil Adjusted Vegetation Index (SAVI)	(1+L*) (Band4-Band3)/ (Band4+Band3+L*)
Transformed Vegetation Index (TVI)	$(\mathrm{NDVI}+0.5)^{0.5}$

One of the most commonly used ratio transformations is Normalized Difference Vegetation Index (NDVI) (Crist, 1985; Jensen, 2005; Michener & Houhoulis, 1997; Song et al., 2001; Xavier & Vettorazzi, 2004). NDVI is a simple formula using two different reflective bands (red and near infrared) of multi-spectral remote sensing dataset for estimating vegetation cover, representing vegetation photosynthetic activity, vegetation biomass and vegetation canopy closure (Huete & Jackson, 1987; Rouse et al., 1973; Sader & Winne, 1992). Particularly, NDVIs extracted from high resolution datasets have been used for supporting many diverse purposes: 1) for mapping rapidly growing impervious covers in urban areas (Sawaya et al., 2003), 2) for classifying vegetation covers (Katoh, 2004; Mehner et al., 2004), 3) for estimating a leaf area index (Soudani et al., 2006), and 4) baseline information for habitat classification (Wallace & Marsh, 2005). The advantage of the NDVI compared to a post-classification change detection analysis can be summarized (Avery & Berlin, 1992; Chen et al., 2005; Gertner et al., 2006; Katoh, 2004; Lillesand et al., 2004; Wulder, 1998a, 1998b): 1) relatively stable results of the spectral values could be obtained compensating for illumination problems by differences in the angle and intensity of sunlight, and 2) uncertainties in the process of classification could be minimized by adopting the automated vegetation detection algorithm between bands.

Post-Classification Change Detection Analysis

It is considered that post-classification change detection analysis is a more common approach in that analysts generally can create a required land cover classification scheme (Fuller et al., 2003; Lu et al., 2004). Particularly, when comparing two imageries from different sensors and platforms, performing a radiometric co-registration could be a challenging process to analysts (Du et al., 2002; Lillesand et al., 2004). Therefore, the primary advantage of the post-classification change detection process is that the radiometric correction process is not an essential factor in an image processing step. In other words, in the post-classification change detection analysis, two imageries could be separately classified and compared to each other to identify major changes between dates, minimizing the radiometric co-registration problem (Chen et al., 2005; Coppin et al., 2004).

However, there are still potential problems associated with a pixel-based classification using high resolution remote sensing datasets. First, a radiometric variability of high resolution dataset often shows a wide range of distribution, even within homogenous vegetation species (Carleer & Wolff, 2006; Lu & Weng, 2007). Consequently, it decreases class separability, adding a complexity for determining an appropriate boundary to differentiate a specific vegetation type from others (Aplin et al., 1997; Carleer & Wolff, 2006; Lu & Weng, 2007; Thomas et al., 2003; Woodcock &

Strahler, 1987). In addition, a relatively poor spectral resolution compared to other hyperspectral datasets should be mentioned (Carleer & Wolff, 2006). Due to the lack of a spectral band, classification results less pertinent to characteristics of actual ground information may be produced despite the very high resolution and the visual improvement. Also, a traditional pixel-based classification method generally produces a "salt-and-pepper" effect which can be displayed as noise in the classified image (Herold et al., 2003; Hirose et al., 2004; Lu & Weng, 2007). This could be a potential problem in interpreting the classified image.

Widely adopted methods to solve the aforementioned problems related to a classification of high resolution remote sensing datasets include: 1) image smoothing in a pre-processing step, and 2) majority filtering in a post-processing step. The first is to remove local (high or low) variability by applying a mathematical transformation to the original dataset. It has been reported that class separability and classification accuracy can be improved by eliminating low or high frequencies in the pre-processing process (Carleer & Wolff, 2006; Cushnie, 1987; Hsieh & Landgrebe, 1998; Jacobsen, 2005; Katoh, 2004; Marceau et al., 1990; Quackenbush et al., 2000; Wulder et al., 2000). The second is to remove the salt-and pepper effect for better interpretation of results in the post-processing step. It is often recommended to perform this function to eliminate scattered and isolated pixels (Lu & Weng, 2007; Macleod & Congalton, 1998). Therefore, in our post-classification change detection analysis, a low pass filtering method in the pre-process and a spatial neighbor majority filtering method in the post-process were applied, respectively, to cope with the potential problems associated with a pixel-based classification using the high resolution remote sensing datasets.

Classification Scheme for Post-Classification Change Detection Analysis: Field Surveys

The most important element in post-classification change detection analysis is to select an appropriate classification scheme (Jensen, 2005). From the perspective of a high resolution remote sensing dataset, this matter has a close relationship in deciding how detailed classification will be possible using a given dataset. Although the two high resolution datasets have an advanced ground resolution at this point, it is essential to consider an appropriate classification scheme because they have a relatively small number of bands (four band compositions: blue, green, red, and near-infrared).

A number of different classification schemes have been developed for the purpose of interpreting remotely sensed datasets: U.S. Fish and Wildlife Service Wetland Classification System, N.O.A.A. Coast Watch Land Cover Classification System, and U.S. Geological Survey Land Use/Land Cover Classification System (Jensen, 2005, 2007). One of the representative classification schemes is the U.S. Geological Survey Land, Use/Land Cover Classification System (Anderson et al., 1976; USGS, 1992). This classification scheme focuses more on resource (land cover) interpretation and offers a standard for four different levels of classification depending on the spatial resolution of the remote sensing dataset (Joy et al., 2003; Khorram et al., 2003; Narumalani et al., 2004; Peterson et al., 2004). Another representative classification scheme is the NVCS which was developed by The Nature Conservancy (Anderson et al., 1998; Grossman, 1998). This method offers more detailed vegetation classification results considering physiognomic and floristic characteristics over the study regions.

Using the modified NVCS method, the vegetation classification and mapping research was jointly done in 2003 for ANP by USGS and NPS (Lubinski et al., 2003). However, the vegetation classification scheme developed and used in the research for ANP could not be directly applied to our pixel-based classification study because the suggested classification scheme covers relatively a large number of plant species, genera, and families in one scheme on the basis of a cluster sampling approach and a manual polygon delineation for the classification. Therefore, in order to produce a more relevant vegetation classification scheme for our analysis, a recent vegetation classification research trend using high resolution remotely sensed datasets was intensively reviewed (Table 2.3).

Table 2.3. Classification scheme using IKONOS

Authors	***Objective***	***Dataset***	***Scheme***	***Accuracy***
Olmanson *et al.* (2002)	Aquatic Plants Detection and Classification	IKONOS	**7 Classes**: 3 emergent aquatic vegetation and 4 submerged aquatic vegetation	-
Jollineau and Howarth (2002)	Wetland Mapping and Monitoring	IKONOS	Study 1: **10 classes** including Lake Erie, Wetland (each species), Woodland, Dry Materials (sand) Study 2: **10 classes** including woodland, wetland, grassland, cropland, and roads/building	Over 95%
Goetz *et al.* (2003)	Land Cover Classification	IKONOS	**2 Classes** (for per pixel classification): forest vs. non-forest	83-86%
Sawaya *et al.* (2003)	Study 3: Aquatic Vegetation Mapping	IKONOS	**9 Classes**: 5 different classes (cattail, sedge, brush, water lily, and mud flat with dead sedge or cattail) in emergent vegetation, 4 different classes in submerged aquatic vegetation	79.5%
Khorram *et al.* (2003)	Land Use and Land Cover Mapping for Stream Riparian Zones	IKONOS	**8 Classes**: 1) Impervious Surfaces, 2) Water, 3) Agriculture, 4) Grass/Open space, 5) Deciduous Forest, 6) Coniferous Forest, 7) Mixed Forest, 8) Bare/Disturbed Soil	63-64%

Table 2.3. Continued

Authors	***Objective***	***Dataset***	***Scheme***	***Accuracy***
Hirose *et al.* (2004)	Vegetation Cover Mapping	IKONOS	**13 Classes**: 1) Water plant, 2) Grass, 3) Deciduous tree, 4) Coniferous tree, 5) Bamboo, 6) Bush, 7) Bare land, 8) Orchard, 9) Vegetable Field, 10) Rice Filed (difficult to distinguish from other agricultural field), 11) Manmade structure, 12) Residential area, 13) Water)	-
Blasco *et al.* (2004)	Ground Truth Purpose	IKONOS, Orthophotos	**12 Classes**: 1) fine forest, 2) mixed forest, 3) broad-leaved forest, 4) broad-leaved forest under smoke, 5) Phrygana, 6) Phrygana under smoke, 7) fire scars, 8) Crops, 9) Bare cultivated soils, 10) Roads, 11) settlements/plants, 12) water	88%
Katoh (2004)	Vegetation Classification at Species and Genus levels	IKONOS	**21 Classes**: 2 Conifers and 19 Broadleaved trees (at the level of species)	58-62%
Narumalani *et al*. (2004)	Land Use and Land Cover Change Detection	IKONOS	**23 Classes** based on Anderson et al. (1976)	-
Mehner *et al.* (2004)	Land Cover Classification	IKONOS	**15 Classes**: some species, genus, family, forest (broadleaved vs. coniferous), rivers, lakes, and shadow, etc.	80.28% (summer) 61.67% (winter)
Serra *et al.* (2003)	Land Cover Classification	IKONOS	**9 to 15 classes** in two research sites	Over 85%
Mathieu and Aryal (2005)	Management Support for Vegetated Areas in Urban	IKONOS	**9 Classes**: amenity grass, garden, tree group, plantation, forest, exotic, mixed, native, rough grass, pasture grass	92%
Jain and Jain (2006)	Land Cover Classification for Urban Area	IKONOS	**3 Classes**: hard surface, soft surface, and green cover	88%
Huggins (2006)	Monitoring Cedar Populations and Distribution	IKONOS, ASTER	Family level (cedar) identification	-

Our review found that there was no fixed rule for assigning a potential vegetation classification scheme. The research trend showed that the classification schemes were changed and controlled by analysts in order to attain given study purposes. It was common that the classification accuracies were lower if analysts achieved more detailed vegetation classification at the level of species and genus. On the other hand, the accuracies were relatively higher in a broad spectrum of classification schemes including non-vegetation such as urban areas and impervious surfaces. More importantly, one major recommendation was commonly suggested throughout the recent studies using IKONOS associated with a pixel-based supervised classification: the recommendation was to use a field survey.

The field survey is an essential process to collect ground information before a classification. From the viewpoint of an analyst, a field survey enables obtaining outlined ground information of a study area. Moreover, the collected ground information could be utilized for a spectral difference analysis, eventually for choosing a desirable vegetation classification scheme to maximize classification accuracy. In terms of collecting field datasets, many studies showed the importance of training site selections (Jensen, 2005; Mausel et al., 1990). It was generally recommended to select many smaller training sites rather than fewer and larger training sites (Khorram et al., 2003). In addition, selecting a sufficient number of training sites for each potential class was highly recommended in order to discover spectral characteristics (Chen & Stow, 2002; Hubert-Moy et al., 2001; Landgrebe, 2003; Lu & Weng, 2007; Mather, 2004).

During the summer of 2007, 129 ground surface points covering 25 different plant genera, soil, bare rock, and human-made surfaces were collected in the vicinity of the Cadillac summit (Figure 2.11). The main purpose of the field survey was to identify how detailed or accurate vegetation classification will be within a desirable accuracy level. Specifically, the field survey was completed to 1) develop a draft list for a vegetation classification scheme in the vicinity of the summit loop trail, 2) collect spatial information of dominant plant species in order to analyze spectral characteristics of the plant species (eventually to be used as a training site for the supervised classification process), and 3) additionally collect randomly generated 300 ground surface points that were encoded into GPS unit for accuracy assessment purpose of the classified result maps.

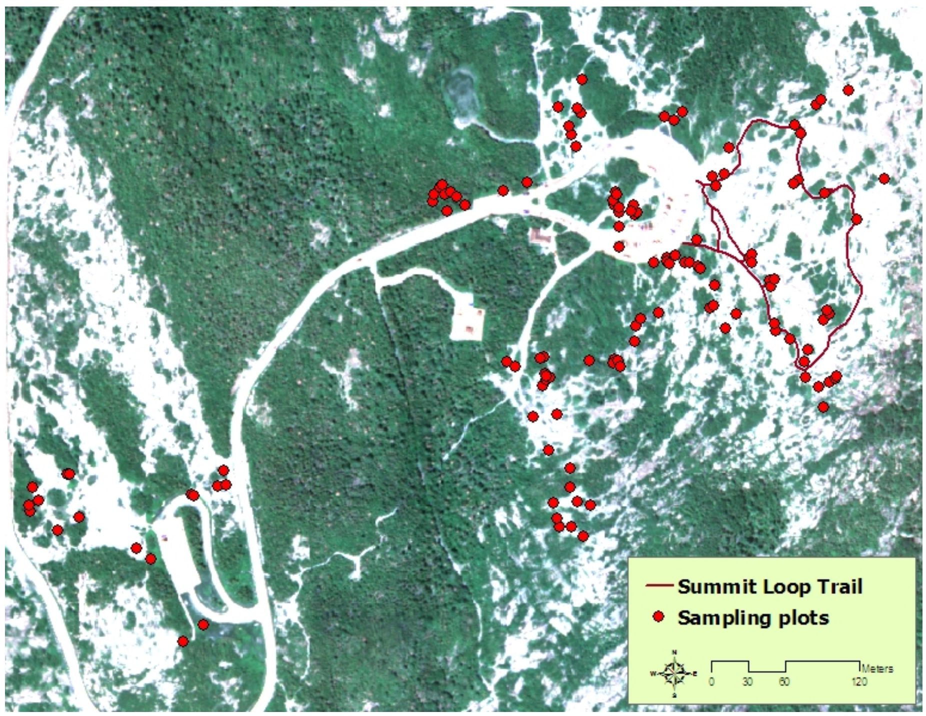


Figure 2.11. Sampling plots for training sites at post-classification.

A sub-meter accuracy GPS unit (Trimble GeoXT) was used to collect spatial information at sampled plots, and then post-processed at a base station located at the University of Maine. In order to cope with a potential GPS measurement error and maintain consistent spectral values of species within the study region, more than 5m^2 homogenous vegetation surfaces were considered to be plotted considering physiognomic modifiers (e.g., coverage density, coverage pattern, and height). However, it was a challenging process to discover more than $5m^2$ homogenous vegetation surfaces over the study region, so a modification to include $3m^2$ and $4m^2$ homogenous vegetation surfaces was made in the field. Homogeneous vegetation surfaces were sampled more than three times, which was suggested by other vegetation classification field surveys to investigate spectral values of different plant species.

Table 2.4. Field survey summary.

Date	August 15-31, 2007
Place	Summit of Cadillac Mountain
Weather	Mostly Sunny
Number collected	129 points covering 25 different genera
Plot type	Vegetation: 101 (82%) vs. Non-vegetation plots: 25 (19%)
Plot location	Open field: 94 (93%) vs. Under close canopy 7 (7%)
Plot structure	Homogeneous: 73 (72%) vs. Heterogeneous: 28 (28%)
Cover size	3^2m, 4^2m, 5^2m
Coverage density	closed canopy, open canopy, sparse canopy
Coverage pattern	even, clumped
Others	height, stem diameter

Due to an accessibility issue over the study region, a random sampling approach was used to focus more on the experimental site. Over 35 independent plant species were identified, but our field survey could not include all investigated plant species because most of them did not meet our cover size requirement (i.e., less than 3^2m), even if attempts to discover them were made throughout the study area using a modified transect method. For a potential vegetation classification scheme, a scientific plant classification system that hierarchically categorizes genera was constructed using plant taxonomy in order to include all investigated and sampled points (Figure 2.12).

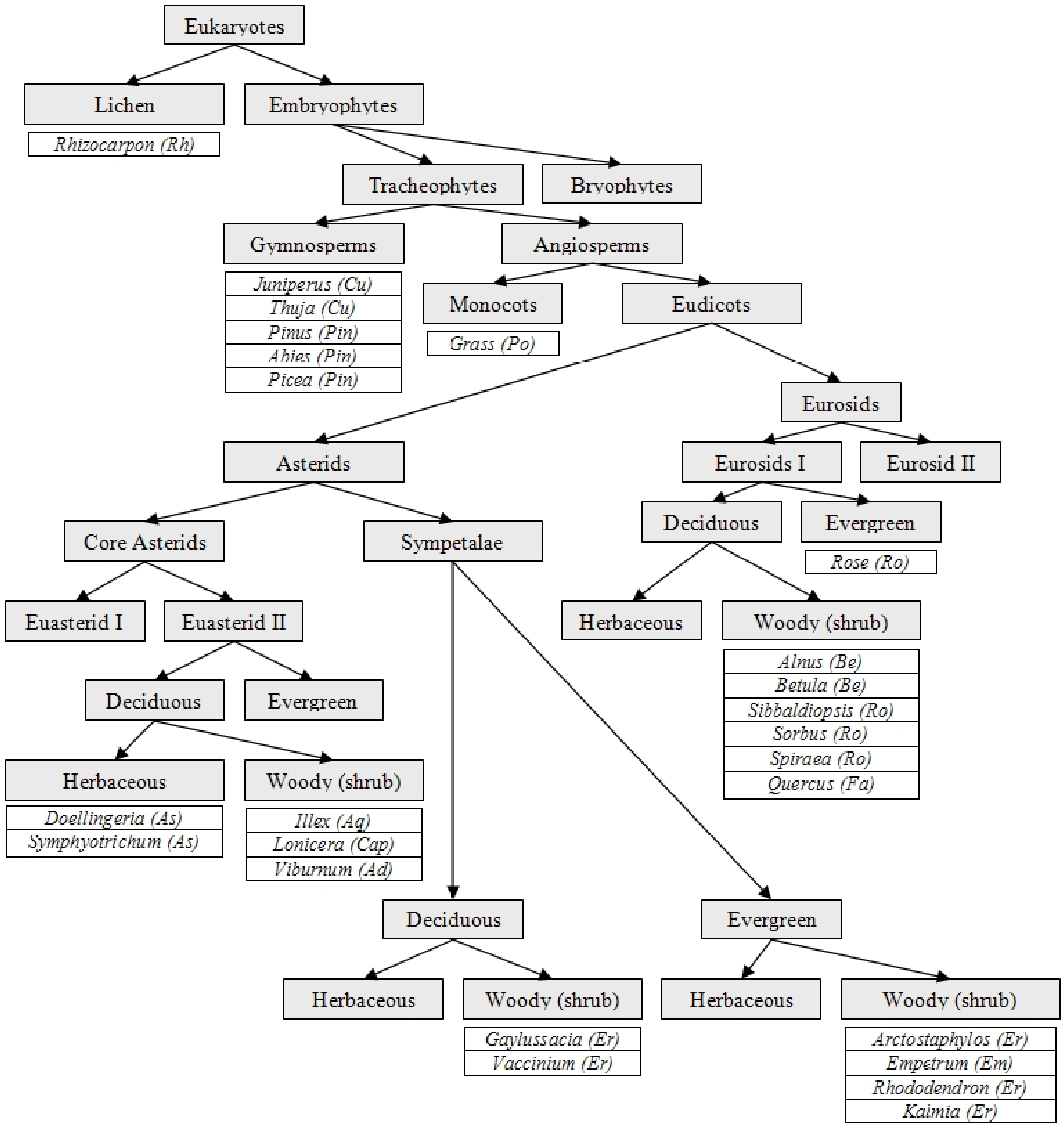


Figure 2.12. Hierarchic plant classification system covering all investigated and sampled points (Judd *et al*. 2002).

Then, a vegetation classification scheme at the genus level was organized for detailed vegetation change analysis. However, in each reflective band at both 2001 and 2007 datasets, it was found that there were too many spectral mixtures among the plant genera through a statistical analysis, even though a GPS measurement error was considered by eliminating potential outliers (very high or low spectral value points) in each plant genus. In addition, there were plant genera sampled fewer than three times (*Lonicera, Viburnum, and Empetrum*), which was eventually impossible to use as an independent vegetation classification scheme. Accordingly, the vegetation classification scheme was controlled by up-scaling from genus to family levels, in order to include those fewer-sampled genera and prevent statistical confusions among genera. Furthermore, two aspects were taken into consideration in non-vegetated surfaces: 1) bare rock and soil were merged since there was no significant difference in terms of the spectral values at the level of plant family in both datasets; and 2) *Rhizocarpaceae* (lichen family) was significantly different from bare rock in the 2007 dataset, but not in the 2001 dataset. Therefore, for a consistency in analysis, *Rhizocarpaceae* was merged to bare rock/soil in both datasets. Table 2.5 shows the modified plant family level classification scheme using the spectral analysis of the collected points and the hierarchic plant classification system.

Table 2.5. Classification scheme for post-classification change detection analysis.

	Family Level	***n***	***Anderson 4 level***	***Binary Mode***
1	*Aquifoliaceae*	5	Deciduous Forest	Vegetation
2	*Asteraceae*	5	Deciduous Forest	Vegetation
3	*Betulaceae*	6	Deciduous Forest	Vegetation
4	*Cupressaceae*	14	Evergreen Forest	Vegetation
5	*Ericaceae*	13	Mixed Forest	Vegetation
6	*Fagaceae*	4	Deciduous Forest	Vegetation
7	*Pinaceae*	17	Evergreen Forest	Vegetation
8	*Poaceae*	7	Deciduous Forest	Vegetation
9	*Rosaceae*	7	Deciduous Forest	Vegetation
10	Mixed Forest	19	Mixed Forest	Vegetation
11	Bare Rock & Soil	15	Non-Forest	Non-Vegetated

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CHAPTER 3

VEGETATION COVER CHANGE DETECTION BY LANDSAT SATELLITE: DOES IT HAVE POTENTIAL FOR CADILLAC MOUNTAIN HIKING TRAIL MANAGEMENT AT ACADIA NATIONAL PARK?

Abstract

Vegetation impact by trampling is often concentrated along travel corridors and at destination areas; consequently it tends to add up to only a small fraction of total park areas. This spatially explicit pattern has been identified as a "node and linkage" system in the field of park and recreation management. Knowing the spatial pattern of vegetation impact by recreational use, the objective of this study was to detect fractional vegetation cover changes associated with off-trail hiking and trampling by using medium resolution remote sensing datasets. Additionally, this study was established to examine whether remote sensing technology could be utilized as a method of identifying the node and linkage system. Three major vegetation indices were applied to measure fractional vegetation cover changes on Cadillac Mountain between 2001 and 2006. For spatial sampling purpose, the study area was divided into two zones on the basis of proximity to the trail network in order to compare the rates of increased and decreased vegetation covers between the two zones, expecting much higher impact and lower recovery in closer proximity to the trail network. Spatial interactions between the trail network and the decreased vegetation areas were tested using Cross K-functions to assess whether or not the existing trail network is attracting and inducing more vegetation impact in a spatial context. The statistical results showed no significant differences between the two

zones in terms of the rates of increased and decreased vegetation covers (all $p > 0.05$), indicating that the magnitudes of impact and recovery were similar regardless of the proximity to the trail. Nonetheless, the applied methods based on zoning and spatial interaction analyses were useful for identifying spatially explicit patterns of vegetation impact related to the hiking trail network.

Key words: trampling, remote sensing, vegetation cover changes, NDVI, SAVI, TVI, spatial interaction

Introduction

Vegetation in a national park is greatly impacted by anthropogenic activities, particularly as a result of visitor use such as trampling and off-trail hiking (Hammitt & Cole, 1998). From the aerial perspective, vegetation impact is often concentrated along travel corridors and at destination areas, thus it tends to add up to only a small fraction of total park area (Hammitt & Cole, 1998). Manning (1979) defined this spatially explicit phenomenon as a "node" (destination areas) and "linkage" (trails) system to explain a recreational resource impact pattern. Leung (1998) also identified a spatial pattern of recreational resource impact as linear feature (line), nodes (points), and areas (attractions) within the same context.

A number of techniques for monitoring visitor-induced impact have been developed to identify and assess the spatial pattern of vegetation impact by recreational use in a national park or protected area. Although there have been substantial variations in sampling techniques and variables to be measured (Manning, 1999), dominant on-site monitoring techniques include 1) condition class assessment (Cole, 1989; Marion &

Farrell, 1996; Williams & Marion, 1995) and 2) multiple parameter rating system (Cole, 1983; Leung & Marion, 2002; Marion & Farrell, 2002).

While such exiting techniques have been useful for identifying a visitor-induced resource impact at a micro scale, it is ineffective to apply the techniques in observing the overall impact trend and pattern, often referred to as the node and linkage system, particularly when a study region covers relatively large areas. In addition, widely accepted sampling strategies such as clustering and line transect methods that often require intervals (distance) between sampled points may cause too much simplification for synthesizing the results of the impact pattern spatially. Consequently, a more effective and simple approach is needed to verify the overall spatial pattern of vegetation impact by recreational use in a national park or protected area, and we suggest the utilization of remote sensing technology for visitor impact monitoring, especially for verifying the node and linkage system at the large spatial scale.

Remote sensing refers to the detection and recording of values of emitted or reflected electromagnetic radiation with sensors in aircrafts or satellites (Ingle et al., 2003). Particularly, from the perspective of recreation ecology, Monz and Leung (2006) showed that a digital photo analysis could be useful in identifying vegetation change, soil erosion, social trail identification, unofficial site identification, and shoreline disturbance. Ingle and others (2003) also indicated the importance and usefulness of remote sensing techniques for identifying the extent and severity of visitor-induced impact as a major biophysical approach.

The advantages of remote sensing technology for detecting vegetation cover changes could be more specifically summarized as follows (Underwood et al., 2007):

1) the entire study region could be mapped simultaneously including inaccessible areas, 2) the time and cost could potentially be saved over a field based data collection process, 3) the collected dataset could be easily archived, manipulated, and integrated with other GIS datasets, and 4) the dataset record presenting the current site condition could serve as baseline information for future analysis.

Study Area

Acadia National Park (ANP) is part of the U.S. National Park System, which has its dual mission to conserve biological and cultural resources as well as to provide enjoyment to people (Daigle & Zimmerman, 2004). The park was established in 1919, and has become one of the most intensively used national parks in the United States (Manning et al., 2006). Visitation rate is similar to many other national parks in that it has been relatively stable over the past two decades. For example, ANP received an estimated 2.2 million visitors in 2007 and 2.3 million in 1990. Cadillac Mountain, the study area, is one of 26 peaks in ANP. At 1,530 ft, Cadillac is the highest point on the Eastern Seaboard. Because it is the only mountain in Acadia with an auto road, Cadillac Mountain is a major destination for ANP visitors. According to a National Park Service (NPS) study, approximately 76% of the total visitors to the park visit the summit of Cadillac Mountain (Littlejohn, 1999). The most common activities in ANP are scenic driving (86%), hiking on the trails (72%), and walking on the Carriage roads (40%) (Littlejohn, 1999).

Table 3.1. Vegetation cover change studies in ANP.

Sources	Contents
Rand and Redfield (1894), Hill (1919, 1923), Moore and Taylor (1927), Johnson and Skutch (1928a, 1928b)	plant identifications and classification
Kuchler (1956)	mapped dominant vegetation species including the burned areas of the 1947 fire
Davis (1966)	investigated spatial distribution of spruce-fir forests
Waggoner (1981)	applied color-infrared aerial photographs taken in August 1979 (first attempt to map the vegetation distribution and classification using remote sensing technology)
Demers (1991)	combined GIS application to present vegetation richness and habitat preference by integrating vegetation-map classification based on Kuchler's work (1956)
Calhoun (1994)	mapped and inventoried the wetland areas, using the U.S. Fish and Wildlife Service wetland definition and classification methodology
Mittelhauser (1996)	investigated forest composition as a part of an ecological baseline information inventory
Greene and others (1999)	inventoried aquatic plants and their distribution
Lubinski and others (2003)	USGS-NPS vegetation mapping program for Acadia National Park
Schauffler and others (2007)	Classified five different vegetation covers over the two upper watersheds using aerial photographs
Eckhoff (2007)	investigated spatial distribution of two forest vegetation stands (deciduous and coniferous forests)

Several vegetation studies have been completed in ANP reflecting the importance of the resource as the only national park in the northeastern U.S. (Table 3.1). However, until now, there has been little direct study examining vegetation impact caused by recreational activities on Cadillac Mountain, especially off-trail hiking or trampling, using remote sensing technology. This research trend in park management or recreation ecology primarily originated from three main reasons: 1) multi-spectral remote sensing datasets for analysis were limited to utilize given the spatial and temporal scales of datasets 2) localized impact by recreational use was not detectable using remote sensing datasets having broad or medium scale ground resolutions (Hammitt & Cole, 1998), and 3) techniques to estimate direct vegetation impact by off-trail hiking or trampling were not well-established using remote sensing datasets.

Understanding the major obstacles, the objective of this study was to detect fractional vegetation cover changes associated with off-trail hiking or trampling by using medium resolution sensing datasets. More importantly, this study was proposed to explore whether or not remote sensing could be used as a method of testing or identifying the effect of the node and linkage system. We applied a simple zoning method based on the proximity of a trail network using a Landsat TM which is the most commonly used and widespread remote sensing dataset. The study was designed to measure potential impact of off-trail hiking or trampling by analyzing and comparing the rates of increased and decreased vegetation covers between the two zones. We hypothesized that there would be much higher impact and less recovery in closer proximity to the trail network.

Methods

The Cadillac Mountain Trail Network dataset, ESRI shapefile format, was obtained from ANP (Figure 3.1). The dataset was originally composed of 65 different polylines, and the total length of the trail network was 32.267*km* (about 20 miles). Based on the trail network shapefile, the extent of the study area was defined (12km^2). In addition, two different Landsat TM imageries covering the defined study area were obtained from the Maine Image Analysis Laboratory (MIAL), University of Maine (captured on October 2, 2001 and September 19, 2006).

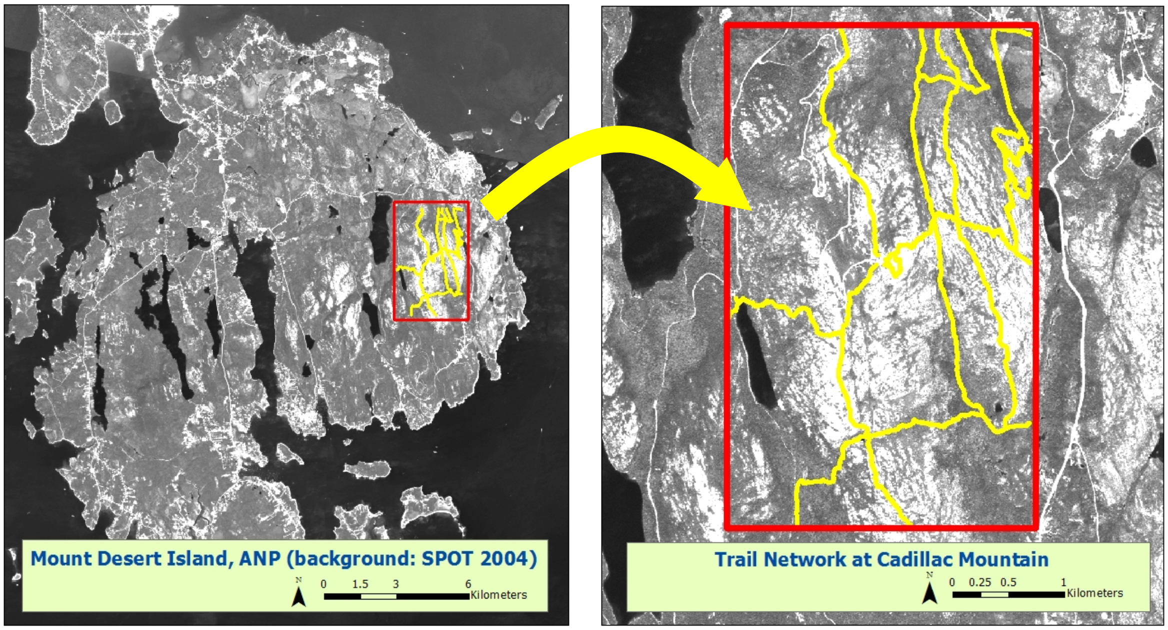


Figure 3.1. Mount Desert Island (left) and trail network at Cadillac Mountain (right).

Most of the functions to detect fractional vegetation cover changes were completed under ERDAS IMAGINE 9.1. Although the two remote sensing datasets were already geo-referenced and ready to have image analysis, a geometric correction between the two imageries (2001 and 2006) was completed again (reference: 2001 imagery, input: 2001 imagery, a first order polynomial method, 5 GCP used, RMSE=0.5). Additionally, an image subset was carried out to focus on the trail network (ULX: 560327, ULY: 4913503, LRX: 563207, LRY: 4908853). Then, as a part of the radiometric correction process, haze reduction in each imagery and histogram matching between two imageries (master: 2006, slave: 2001) were applied, respectively.

As a pre-classification change detection analysis method, Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Transformed Vegetation Index (TVI) were separately used and extracted from the two imageries using a spatial modeler function (Table 3.2). Also, in order to avoid confusion and false interpretation in the extracted index comparison between the two imageries, image mask function was applied by creating the mask layer of Bubble Pond on Cadillac Mountain.

Table 3.2. Pre-classification change detection analysis methods used.

Vegetation Index	***Equation***
Normalized Difference Vegetation Index (NDVI)	(Band4 − Band3)/ (Band4+Band3)
Soil Adjusted Vegetation Index (SAVI)	(1+L*) (Band4-Band3)/ (Band4+Band3+L*)
Transformed Vegetation Index (TVI)	$(NDVI+0.5)^{0.5}$

Sources: Jensen, 2007; Katoh, 2004 (* In SAVI, 0.5 was used as L.)

Multi-temporal RGB image analysis was utilized to identify fractional vegetation cover changes between 2001 and 2006 (Sader et al., 2003; Sader & Winne, 1992). The analysis technique used was a simple and logical method to visualize vegetation cover changes by combining three dates of NDVI imagery concurrently and applying the interpretation concepts of color additive theory (Sader & Winne, 1992). Our application was re-designed to produce two distinctive colors in identifying vegetation cover changes because only two different dates were used: blue (increased vegetation areas) and yellow (decreased vegetation areas).

Cross K-function (expected number of points of type ***j*** within a given distance of a point of type ***i***) was applied to identify spatial point interactions between the trail network and the decreased vegetation areas (Baddeley & Turner, 2005), to better understand whether or not the existing trail network is attracting and inducing more vegetation impact in a spatial context. The results of the function represent one among three possible relationships between two types of point patterns: Repulsion, Attraction, and

Completely Spatial Randomness (CSR). For the analysis, the decreased vegetation areas in all indices were converted into point datasets having X/Y coordinates information as well as the trail network at the 100*m* interval (total 306 points). As a data processing software for the Cross K-functions, R (statistical software package) was used for computations and simulations.

Depending on the proximity to the trail network, the study area was divided into two different zones in order to verify the node and linkage system of vegetation impact (*Zone 1*: within 100*m* from the trail network and *Zone 2*: 100 to 400*m* from the trail network). The distances used were decided to include a certain numbers of pixels in the remote sensing datasets for calculating the rates of increased and decreased vegetation areas. Additionally, areas within 100*m* from major automobile roads, Bubble Pond and other hiking trails outside the study boundary were excluded from the pre-defined *zone 2*. Based on a systematic sampling approach, 100m^2 plots were created within each zone (number of plots: 126 in *zone 1* and 96 in *zone 2*) (Figure 3.2). This simple zoning method enabled us to test the following hypotheses in the study area:
1) the rate of increased vegetation area will be higher in *zone 2* due to the direct impact of the off-trail hiking and trampling in *zone 1*, and 2) the rate of decreased vegetation area will be higher in *zone 1* due to the direct impact of off-trail hiking and trampling in *zone 1*. To test our hypotheses, we computed the rates of increased and decreased vegetation areas in each plot by an equation: *increased (or decreased) vegetation area / total vegetation area* × *100*. Between the two zones, T-tests were used to compare the means of the increases and decreases at the $p = 0.05$ level.

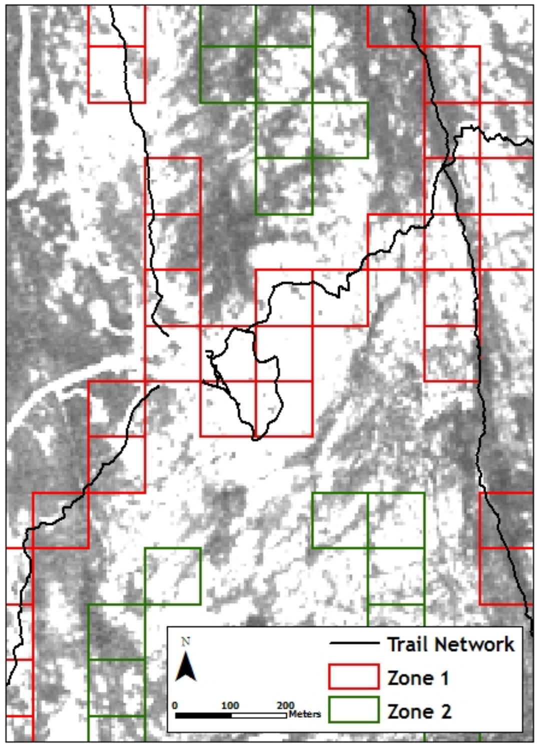
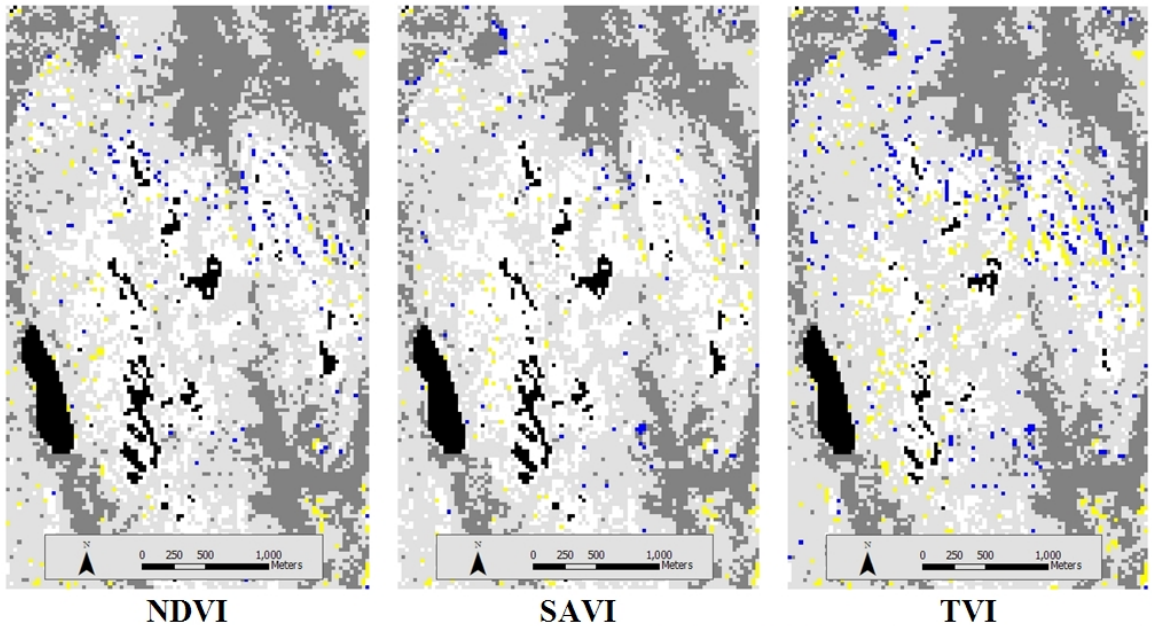


Figure 3.2. Applied systematic sampling approach based on zoning (the vicinity of the summit loop trail at Cadillac Mountain).

Results

The three vegetation cover change detection results showed very similar spatial patterns, suggesting more dynamic changes along Cadillac North Ridge, Cadillac South Ridge, and Schiff Path within the trail network (Figure 3.3). In addition, the results showed similar patterns in measuring the total increased and decreased vegetation areas, indicating more impacted and less recovered vegetation areas in the three results (Figure 3.3). The TVI was the most sensitive in terms of identifying vegetation cover changes, though the same boundary threshold was used to distinguish changed pixels from non-changed pixels in all three indices. The increased vegetation area was 8,580m^2 and the decreased vegetation area was 9,420m^2 in the TVI analysis, while showing 2,700m^2

increases and 4,080m^2 decreases in the SAVI analysis, as the least sensitive index in detecting fractional vegetation cover changes.



	Vegetation Increased (m^2)	Vegetation Decreased (m^2)	No Change, Non-Vegetation (m^2)	No Change, No/Low Biomass (m^2)	No Change, Medium Biomass (m^2)	No Change, High Biomass (m^2)
NDVI	**3,660**	**4,410**	17,940	91,350	223,020	106,020
SAVI	**2,700**	**4,080**	17,580	108,030	226,920	87,090
TVI	**8,580**	**9,420**	11,760	65,460	250,320	100,860

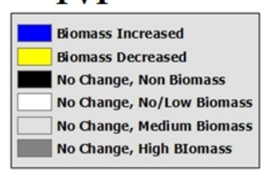


Figure 3.3. Results of fractional vegetation cover changes based on vegetation indices.

Spatial interaction tests between the trail network and the decreased vegetation cover points suggested CSR, showing no clear spatial relationships, in all vegetation indices (Figure 3.4). In the NDVI and the SAVI, the theoretical CSR Cross K-function lines (red) were initially plotted over the border corrected Cross K-function lines (black), suggesting repulsive relationships between the two types of events. On the other hand, in the TVI, the border corrected Cross K-function line (black) was plotted over the theoretical CSR Cross K-function line (red), suggesting an attractive relationship between the two types of events. However, when a hypothesis of independence between the two types of events was tested using the envelope with 99 simulations (maximum: green, minimum: blue) in each vegetation index, it was verified that the border corrected Cross K-function lines fell within the envelope, indicating failure to reject the null hypothesis that two point patterns are spatially independent.

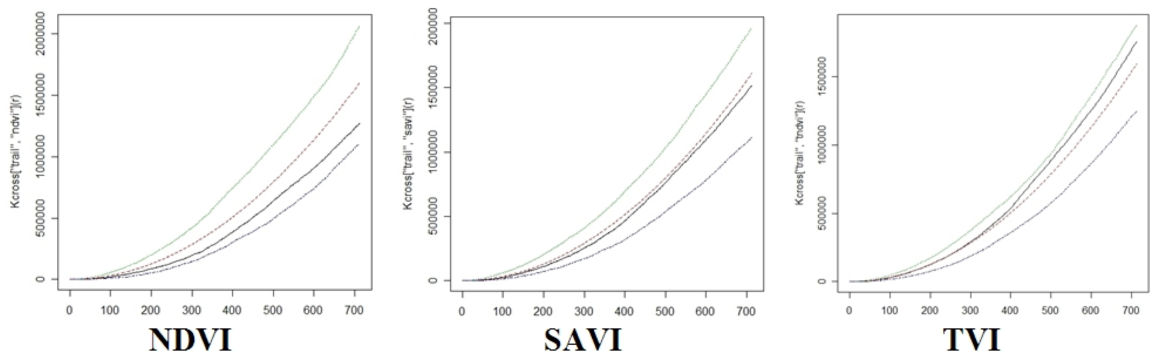


Figure 3.4. Hypothesis tests of spatial interaction between decreased vegetation cover points and the trail network (green: maximum envelope, blue: minimum envelope, black: border corrected Cross K-function, red: theoretical CSR Cross K-function, x: distance, y: K-cross).

Overall, the three analysis results showed the same patterns in identifying the rates of increased and decreased vegetation areas on the basis of 100m^2 plots and systematic sampling, indicating more impacted and less recovered vegetation areas in *zone 1* (Table 3.3). In the TVI analysis, the mean rate of decreased vegetation area based on 126 plots in *zone 1* was 2.97%, while the mean rate based on 96 plots in *zone 2* was 1.48%. The mean rate of increased vegetation area was 4.12% in *zone 1* and 4.31% in *zone 2*. In the SAVI analysis, the mean rate of decreased area was 0.58% in *zone 1* and 0.13% in *zone 2*, and the mean rate of increased area was 0.80% in *zone 1* and 2.41% in *zone 2*. However, the results of T-tests showed no significant differences in terms of the mean rates of the increased and decreased vegetation areas between the two zones in all vegetation indices (all $p > 0.05$). These results suggest that the impact and recovery magnitudes between the two zones were similar regardless of the proximity to the hiking trail network in each index at the p = 0.05 level.

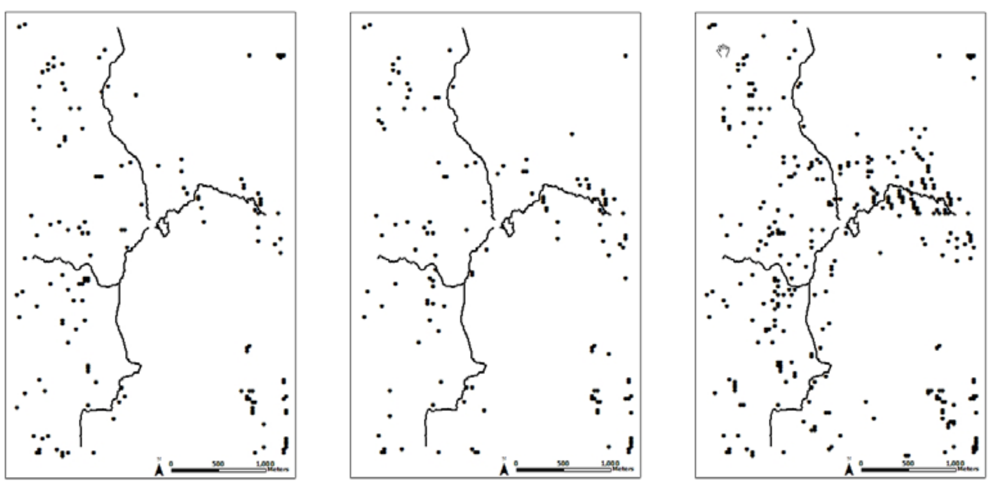
Table 3.3. T-test summary for comparison between the two zones: The rates of increased and decreased vegetation covers based on 100m^2 plots (n: # of plots, M: mean of percent change).

Spatial Scale (Variables)		***Zone 1** (n: 126)* ***M***	***Zone 2** (n: 96)* ***M***	***T***	***P***
NDVI	Impact	0.51	0.20	-1.2156	0.2255
	Recovery	1.15	1.49	-0.6391	0.5235
SAVI	Impact	0.58	0.13	-1.4109	0.1601
	Recovery	0.80	2.41	1.607	0.1108
TVI	Impact	2.97	1.48	-1.5894	0.1136
	Recovery	4.12	4.31	0.1205	0.9042

Discussion

More extensive vegetation change detection analysis covering the entire trail network at Cadillac was completed by alleviating significant considerations in selecting size, number, and the location of the quadrats to be investigated, that could be spatial constraints in traditional recreation ecology methods such as on-site measurement and experiment. Statistically, we failed to verify the effect of the node and linkage system, which is the concentrated vegetation impact along the trail network based on the designed zoning and sampling methods. This result, conversely, may suggest that the hiking trail network is relatively well-managed at Cadillac, indicating no significantly impacted areas surrounding the trail network at the medium ground resolution analysis. However, our analysis results suggest some considerations associated with the overall trend of fractional vegetation cover changes. Although the concentrated vegetation impact by the node and linkage system at Cadillac Mountain was not verified at the medium ground resolution analysis, it should be noted that more impact and less recovery rates in the closer proximity to the trail network were verified in all three vegetation indices.

Spatially explicit patterns of vegetation cover changes derived from our analysis show more considerations for managing the hiking trail network at Cadillac Mountain. The analysis results directly indicate which trails in the trail network could attract or repulse vegetation impact spatially. Figure 3.5 showed that the decreased vegetation areas calculated by the three vegetation indices were spatially clustered along six specific trails (Cadillac North Ridge, Cadillac South Ridge, Cadillac West Face Trail, Gorge Path, Cadillac-Dorr Connector, and Schiff Path) within the study region. Particularly, the re-simulated results of the Cross K-function with the only six specific trails suggested an attractive relationship with the decreased vegetation cover points based on the TVI analysis result, by rejecting the null hypothesis of spatial independence between the two types of events. Therefore, management priority might be given for those six trails and adjacent areas in the hiking trail network at Cadillac Mountain.



NDVI **SAVI** **TVI**

Figure 3.5. Six trails with decreased vegetation cover points.

One of the most popular destinations on Cadillac Mountain associated with visitor use is the summit loop trail. The summit receives an estimated 0.5 ~ 0.8 million visitors during the summer (June – August) each year (Jacobi, 2001, 2003). This high visitation rate is partly explained by an auto road that provides convenient access to the summit and offers beautiful scenic vistas of the Maine coast. Unlike the entire trail network of Cadillac Mountain, two distinctive site/visitor management practices using physical barriers and signposts based on the "Leave No Trace" principle have been implemented in the summit loop trail since 2000. In our analysis, using medium-spatial resolution satellite imageries, the vicinity of the summit loop trail was mainly classified as "non-vegetation" or "low/no vegetation biomass area" in all vegetation indices. In addition, it was impossible to detect significant vegetation cover changes in the vicinity of the summit loop trail. In that regard, it should be noted that there is a growing demand for monitoring land cover changes with finer spatial resolution (Gross et al., 2006; Hirose et al., 2004; Loveland et al., 2002). More advanced satellites such as IKONOS and QuickBird, therefore, could be considered to identify micro-scale vegetation changes associated with trampling and the employed management practices.

It should be noted that various spatial scales in our analysis were applied under the given assumptions: 1) the hiking trail network at Cadillac Mountain for identifying the study boundary ($12km^2$ in Mount Desert Island), 2) $100m$ buffering width from the trail for defining *zone 1* and $100\text{-}400m$ buffering width for *zone 2*, and 3) $100m^2$ plots for calculating the rates of vegetation cover changes. From the perspective of landscape ecology, it is obvious that there is no single correct spatial scale for analysis (Levin, 1992; Turner et al., 2001). Therefore, changes such as downsizing the *zone 1* and extending the study area would be required to capture potentially different scenarios of vegetation impact along the trail network. Additionally, though no significant natural disturbances were reported during the analysis time-frame, there is a potential phenological issue from the temporal gap between the two imageries acquisitions. Therefore, there might be a different moisture level and canopy structure that may cause a false interpretation of the classified vegetation index results.

Conclusion

Obtaining objective and reliable results in measuring the amount of vegetation cover change in a protected area is becoming important for monitoring resource impact in recreation ecology (Hammitt & Cole, 1998). Although remote sensing approach has been recognized as a novel and less-profound method in the field, the applied remote sensing analysis could offer a potential approach for assessing the different rates of increased and decreased vegetation areas associated with off-trail hiking or trampling activities. Measurable changes of growth and reduction could be baseline data for detecting a vegetation change trend over time within the trail network. Particularly, given that Landsat TM is continuously updated and archived, the change detection analysis results will be applicable for monitoring further changes over a longer period of time on Cadillac Mountain.

While the trail network and decreased vegetation cover point datasets were spatially independent, providing information such as a spatial pattern of impact and a magnitude of impact would be a valuable source to resource managers for a decision-making process. Based on the results of the vegetation cover change detection analysis, other landscape factors including soil type, vegetation type, aspect, slope, elevation, and proximity from a trail, water resources, and a road could be combined as a modeling approach that explains major factors of spatial impact pattern by off-trail hiking and trampling. This will be particularly useful for prioritizing trails that need more intensive management.

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CHAPTER 4

MONITORING VEGETATION IMPACT BY TRAMPLING ON THE SUMMIT OF CADILLAC MOUNTAIN THROUGH HIGH RESOLUTION REMOTE SENSING DATASETS: 2001 AND 2007

Abstract

Cadillac Mountain at Acadia National Park, Maine, the highest peak on the eastern seaboard in the United States, is a popular destination that receives more than 1 million visits each year. A scenic driving road makes the summit easily accessible to visitors, and managing vegetation impact by off-trail hiking and trampling is extremely challenging given the sparse low-growing shrubs and vegetation and vast granite rocky outcrops attractive for visitors to disperse from parking areas and along trails. Since 2000, a number of management strategies including physical barriers and "Leave No Trace" signage have been implemented to reduce vegetation loss and soil erosion in this sensitive sub-alpine natural environment. The primary purpose of this study was to evaluate the effect of the management strategies to reduce vegetation impact by detecting vegetation cover changes between 2001 and 2007 using multi-spectral high resolution remote sensing datasets. Pre-classification change detection analysis based on Normalized Difference Vegetation Index (NDVI) was applied to identify the rates of increased and decreased vegetation areas at three pre-defined spatial zones (0-30*m*, 30-60*m*, 60-90*m*) emanating from the edge of the summit loop trail and at similar spatial scales at a nearby control site with no visitor use. There was no significant difference in the mean rate of decreased vegetation area among the three pre-defined spatial zones (F =

1.6099, $p = 0.2019$). However, a similar spatial pattern of vegetation recovery, that is, increasing vegetation recovery relationship from the central portion to the outer edge of the site, was observed at this recreation site as noted in other recreation ecology studies. A significant difference in the mean rate of increased vegetation area was observed for the outer spatial zone (60-90*m*) as compared to the intermediate spatial zone (30-60*m*) located in closer proximity to the summit loop trail ($F = 3.7199$, $p = 0.02556$). Given the visitor behavior of off-trail use on durable rock surfaces and interspersed patches of vegetation, it appears recovery did not follow a predicted pattern of recovery at all spatial zones (more recovery in the 0-30*m* than 30-60*m*). Our study results suggest that this recovered portion of vegetation in the closest proximity to the summit loop trail could be a direct positive effect of the combination of the management practices. No significant differences were detected between the mean rates of increased and decreased vegetation areas for the experimental as compared to a nearby control site at the small spatial scale comparison, but the mean percentage increase in vegetation growth and decrease in vegetation reduction at all spatial scales at the experimental site versus the control site suggests a trend in the desired direction for management strategies to reduce vegetation impact and to enhance vegetation recovery. While the applied NDVI analysis offers an approach for assessing the fractional vegetation cover changes at a large spatial scale, alternative change detection methods for identifying recovered and impacted vegetation characteristics should be considered at this study site in the future. We also discuss strengths and limitations of remote sensing as a tool for monitoring recreation impact at larger spatial scales than typical campsite and trail systems at a recreation setting.

Key words: vegetation, trampling, site management, visitor management, remote sensing, NDVI

Introduction

Vegetation is one of the main natural resource components that can be profoundly impacted by recreational activities, particularly as a result of trampling (Cole, 2004a; Hammitt & Cole, 1998; Liddle, 1997). The ultimate effect of trampling is a reduction in the amount of vegetation, often resulting in a complete loss of vegetation cover (Marion, 1998). The severity of vegetation impact eventually affects the quality of the visitor experience as well as resource degradation. Vegetation impact in national parks does not occur randomly in space, but exhibits spatially explicit and predictable patterns because recreationists consistently tend to use trail and road networks and other visitor-related infrastructure such as campsites, scenic overlooks, and popular attractions. Manning (1979) defined this spatial impact pattern as a "node" (destination area) and "linkage" (road or trail) system. While the localized vegetation impact in the node and linkage system is very often severe and long lasting (Cole, 1981a, 1981b; Hammitt & Cole, 1998; Pickering & Hill, 2007; Wagar, 1975), the impact can gradually expand or creep with time as visitor use shifts across the larger landscape (Cole, 2004a; Cole & Hall, 1992; Hammitt & Cole, 1998).

A number of on-site management strategies including site and visitor management practices have been developed to cope with the spatial and temporal problems associated with vegetation impact, especially in high-use destinations. For example, site management practices include, among others, site manipulation for controlling spatial distribution of use (e.g., establishing an official durable trail system, installing barriers/fence or focus use around natural barriers such as a rock face that limits possible expansion of the site), and site hardening/shielding using gravel or wood chips (Hammitt & Cole, 1998). Also visitor management practices such as signage (educational and Leave No Trace (LNT) or penalty/fine for behaviors such as picking flowers or going off-trail) are used as well as limits to the length of stay or restrictions on type of use or size of group (Hammitt & Cole, 1998). Many of these practices have been further classified as to whether they represent a direct or indirect influence on visitor behavior, and a continuum exists within and among site and visitor management practices (Manning, 1999). All these management practices focus on tactics and actual management tools applied by managers to accomplish specific management objectives (Manning, 1999). Yet, a question still remains regarding how we can prove or evaluate the effectiveness of the site and visitor management strategies which have been employed to reduce vegetation impact.

As a classic approach to estimate the effectiveness of these management practices, several methods have been utilized that include on-site observations (visitor behavior and use), on-site measurement and experiment (resource condition), and survey and interview (visitors and park staff) (Hammitt & Cole, 1998). These assessment techniques could be further categorized as biophysical and social science approaches by the applicability to specific questions to be asked (Ingle et al., 2003). While there have been substantial variations in terms of levels of accuracy, precision, and time and cost, more advanced methods have been developed by adapting GIS/GPS technologies and by selecting detailed monitoring protocols for both biophysical and social science approaches (Cole, 2004a; Manning et al., 2006). However, the main problem in the monitoring process is how to obtain a uniformly reliable dataset for evaluating the current condition and efficacy of management actions employed, at the same time, minimizing potential errors and bias, and saving time and labor. Hammitt and Cole (1998) indicate that there are seldom available datasets for monitoring resource impact and evaluating the efficacy of management strategies utilized. Therefore, managers are often forced to make a decision without enough information associated with visitor use and resource impact, often leading to incremental decision-making (Cole, 2006; Monz & Leung, 2006). Clearly, a more fundamental and scientific approach is needed to apply monitoring results effectively to inform management decision-making (Cole, 2004b; Cole & Wright, 2004). This process may, in turn, promote the value of developing and maintaining a visitor impact monitoring program.

Spatial Pattern of Vegetation Impact and Recovery

A significant contribution by scientists conducting recreation ecology research has been the identification of the spatial and temporal patterns of vegetation changes in a recreational setting (Cole & Monz, 2004; Frissell, 1978; Hammitt & Cole, 1998; Leung, 1998; Manning, 1979; McEwen & Tocher, 1976; Merriam & Smith, 1974). McEwen and Tocher (1976) identified the spatial pattern of impact and recovery by applying a three distinctive zoning concept at a cluster of campsites: *impact zone* (most severely impacted areas, that never recover as long as use continues), *intersite zone* (partially impacted areas with informal trails and satellite sites, but recovery will be higher than in impact zone because the capacity of vegetation to regenerate is not severely compromised), and *buffer* *zone* (transitional zones between the developed and the natural areas). The logic behind this zoning method is to specifically design management and monitoring practices suitable for each zone. For example, objectives of management in the impact zones are to keep them as spatially small and as attractive as possible. An objective for the intersite zone is that the capacity of vegetation to regenerate is not severely compromised. Some placing of logs and rocks may be necessary both to minimize use of intersite zones and to provide protected regeneration sites. Finally, an objective for the buffer zone is to avoid encroachment from the expanding intersite zone. Recognition of these zones and spatial patterns is an important first step in devising management strategies for controlling impact (Hammitt & Cole, 1998). Therefore, essential to this system are field measurements that define the boundaries of each zone for management and monitoring activities.

The magnitudes of vegetation impact and recovery are varied by 1) environmental condition (e.g., amount of rainfall and length of growing season), 2) site durability (e.g., different resilience and resistance characteristics of vegetation species, and topographic factors such as slope and aspect), and 3) recreational use level and type (e.g., party size, type of user, user behavior, and mode of travel) (Cole, 1988; Hammitt & Cole, 1998; Liddle, 1997). However, a general recovery pattern of vegetation can be similar to a normal curve on the basis of the zoning concept of McEwen and Tocher (1976) (Figure 4.1). The recovery will be greater in the intersite zone than the impact zone because the capacity of vegetation for regenerating is not severely impacted in the intersite zone (Hammitt & Cole, 1998; McEwen & Tocher, 1976). At a certain point, the rates of recovery will be decreased in the buffer zone, since there is a positive relationship between the amount of use (disturbance) and the amount of recovery (Cole & Monz, 2004), and vegetation in the buffer zone will follow more natural variation of vegetation condition given there is no severe human disturbance factor.

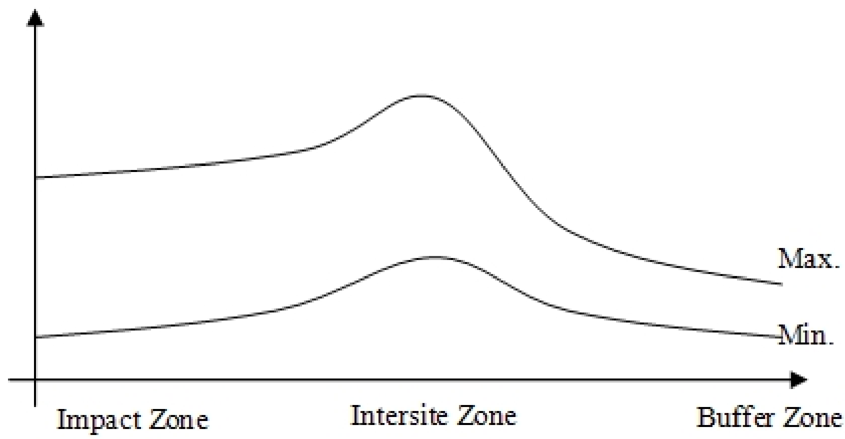


Figure 4.1. Spatial pattern of recovery.
X: proximity, Y: rate of recovery (percent change), Maximum recovery line (top): areas having plentiful rainfall and long growing season, high resilience vegetation characteristics, and low visitor use level, Minimum recovery line (bottom): areas having low rainfall and short growing season, low resilience vegetation characteristics, and high levels of visitor use (Cole, 1988; Hammitt & Cole, 1998; Liddle, 1997).

On the impact zone, the degrees of vegetation impact and recovery tend to fit a predictable pattern based on a regular radial system, which is, most vegetation impact at the central portion of a site and increasing vegetation recovery potential at the outer edge of a site (Cole & Monz, 2004; Frissell, 1978; Hammitt & Cole, 1998). Cole and Monz (2004) verified magnitude, variability, and spatial pattern of vegetation impact using a different spatial zone of analysis with core ($3m^2$), intermediate ($5m^2$), and periphery ($7m^2$) in two sub-alpine vegetation communities. Consequently, they reported decreasing vegetation impacts with the distance from the center of the campsites. While the studies have been focused on the conceptualization of spatial pattern of vegetation changes by estimating current size and areal extent of impact, it is not easy to identify the spatial pattern of vegetation changes associated with visitor use if a site boundary is relatively large for on-site measurements, and if a site boundary grows or retreats as use level and density are changed. Especially, in sub-alpine mountain summits where bare-rock is dominant with sparse low-lying shrubs and grasses, visitor use coupled with prevalent off-trail hiking activities could be widespread by ambiguous site boundaries. Therefore, more spatially extensive investigations are required to identify the pattern of vegetation changes as well as the effect of the management practices designed to induce concentrated visitor use. Remote sensing technology may offer a useful approach to monitoring long-term and large spatial scale changes to park resources caused by visitor use.

Remote Sensing Technology

Remote sensing refers to the detection and recording of values of emitted or reflected electromagnetic radiation with sensors in aircrafts or satellites (Ingle et al., 2003). A primary advantage of remote sensing datasets is that a relatively "big picture" can be captured easily in collecting datasets. In other words, quick experiment and measurement are available in identifying changes in resource conditions between dates without direct contact, compared to the on-site measurement or experiment process that usually takes a longer amount of time. Witztum and Stow (2004) found remote sensing data enhanced their visitor impact monitoring program by identifying impact quickly enough to implement alternative management strategies and assisted in identifying hot spots or heavily impacted areas. Also, in many cases, archived imagery is available that may further enhance development of a monitoring program. From the perspective of recreational resource management, research regarding imagery and remote sensing has been explored since the early development of technology to aid in monitoring. Generally, there have been three main research trends: 1) inventorying recreational resources, 2) monitoring impact and change in recreational resources, and 3) addressing the importance of remote sensing in park and recreation management (Table 4.1).

Table 4.1. Uses of remote sensing in recreational resource management including recreation ecology.

Main Research Trends	Sources
Inventorying recreational resources	Burnett & Conklin (1979), Dill (1963), Green (1979), Jusoff & Hassan (1997), Kearsley (1994), Lindsay (1969), MacConnell & Stoll (1968), Miller & Carter (1979), Welch et al. (1999)
Monitoring impact and change in recreational resources	Allan (1983), Coleman (1977), Grizzle et al. (2002), Hockings & Twyford (1997), Lee et al. (1999), Leung et al. (2002), Li et al. (2006), Marion et al. (2006), Price (1983), Witztum & Stow (2004)
Addressing the usefulness and importance of remote sensing	Butler & Wright (1983), Draeger & Pettinger (1981), Gross et al. (2006), Hammitt & Cole (1998), Ingle et al. (2003), Monz & Leung (2006), Rochefort & Swinney (2000)

Key to new investigations of utilizing remote sensing technology is knowing past limitations found in applying remote sensing to recreation problems and in particular to vegetation impact studies. A frequently identified problem utilizing remote sensing was the difficulty in assessing vegetation impact caused by recreation under a tree canopy where trails or campsites are located for shade or other reasons (Hammitt and Cole 1998). Another issue has been that localized impact was undetectable in a broad or medium spatial scale resolution remote sensing dataset (e.g., 30m^2 pixel resolutions). However, recent advances of spatial resolution in datasets has helped to reduce a mixed pixel problem that is often pronounced in medium or coarse spatial resolution, and now provides a better opportunity to obtain more detailed information related to land cover and change (Lu & Weng, 2007). The use of remote sensing, therefore, will be continuously amplified in recreational resource management and analysis due to the technological advances in both software and hardware, eventually offering more credible and accurate products in terms of quality and ground resolution. More importantly, the value of high spatial resolution remote sensing datasets will be significantly increased for monitoring vegetation conditions in environments dominated by bare-rock with sparse low-lying shrubs and grasses, reducing the potential problems associated with the localized impact and multiple vegetation layers.

Methods

Study Site

Our application of remote sensing technologies was focused on the summit of Cadillac Mountain, one of the most popular visitor destinations in Acadia National Park (ANP). There are three hiking trails to the summit of Cadillac in addition to an auto road, and the 0.3 mile long summit loop trail (Figure 4.2). According to a National Park Service (NPS) study, approximately 76% of the total visitors to the park visit the summit of Cadillac Mountain (Littlejohn, 1999). Although visitation levels have stabilized over the past few years, the summit receives an estimated 0.5 ~ 0.8 million visitors during the summer (June – August) each year (Jacobi, 2001, 2003). The sensitive sub-alpine nature of the site and the convenient accessibility via the automobile road has created a scenario where vegetation degradation and soil erosion is at high risk. This site represents a management challenge to balance the public's desire for visiting a popular destination and at the same time to maintain the natural conditions of the area for current and future generations.

Archived visitor photos show that the scenic overlook site on Cadillac Mountain was accessed by trail as early as the 1860s and 1870s, even before being designated as a National Park in 1919. The automobile road was built between 1929 and 1932 and provided additional access opportunity for visitors to the summit. Soon after the road was built, a paved summit loop trail was constructed using crushed rocks and cement to blend with the exposed pink and gray granite surfaces intermixed with vegetation on the summit. Given the volume of visitors and general open nature with exposed granite, low vegetation and shallow soils, the summit was still experiencing trampling and soil erosion, leading management to implement of more intensive visitor and site management measures to prevent future vegetation loss (Park et al., 2008; Turner, 2001).

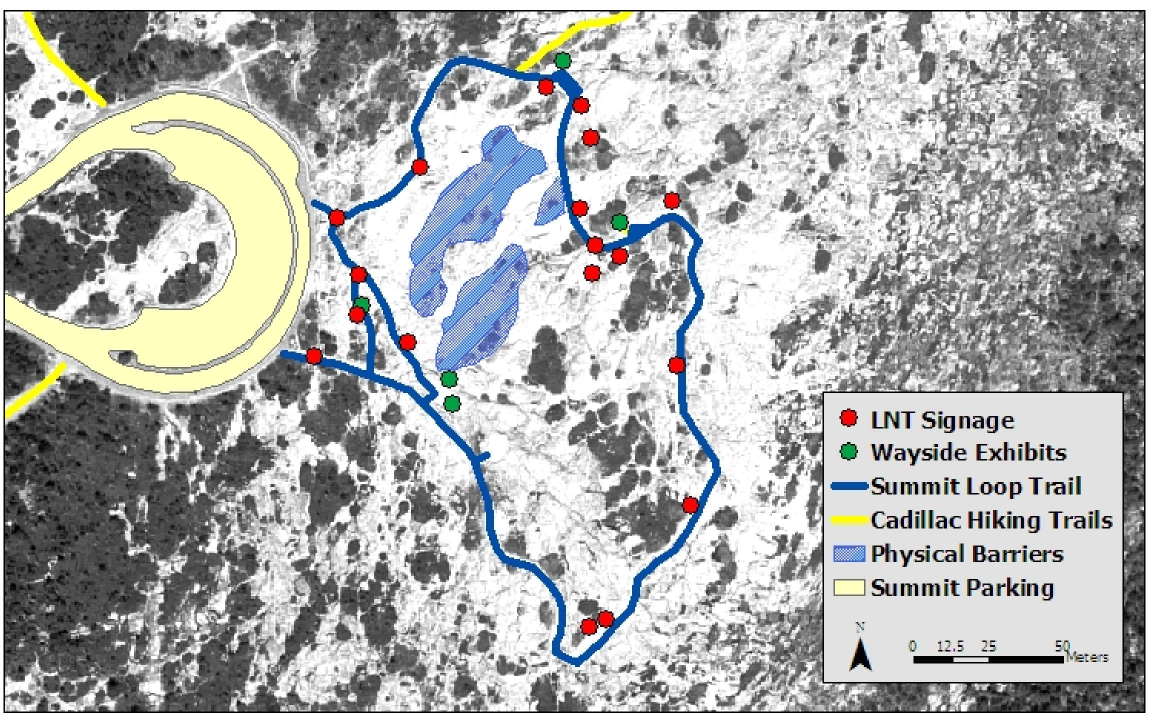


Figure 4.2. Locations of physical barriers (light blue) and LNT signage (red), captured by GPS (Trimble GeoXT) and exported as ESRI shapefile format.

Figure 4.3. Indirect management (left, LNT signage) and direct management (right, physical barriers): ANP has been using both management approaches since 2000 along the summit loop trail of Cadillac Mountain, in order to reduce the trampling effect, especially caused by off-trail hikers.

In 2000, a combination of site and visitor management strategies using physical barriers and low-impact educational messages, respectively, were deployed in strategic locations to address vegetation loss on Cadillac Summit (Figure 4.2 and 4.3). The strategies were initially used as a management tool, not as a research mechanism (Turner, 2001; interview with the ANP resource management staff, 2007). Until now, several studies based on social science approaches have attempted to verify the effectiveness of the deployed management strategies coupled with visitors' perceptions and experiences (Bullock & Lawson, 2007, 2008; Park et al., 2008; Turner, 2001), but there has been little direct study examining the effectiveness of the management strategies focusing on vegetation changes.

The objective of this study was to utilize remote sensing/GIS technologies to examine the effect of management strategies to reduce human-induced vegetation impact around the Cadillac Mountain summit loop trail. Two multi-spectral high spatial resolution remote sensing datasets and pre-classification change detection analysis were used to identify fractional vegetation cover changes between 2001 and 2007. Three important dimensions associated with the design of this remote sensing study were defined:

1) First we sought to verify the utility and applicability of using remote sensing/GIS technologies to measure the areal extent of vegetation cover changes around the summit loop trail as compared to a control site with no/little visitor use. We hypothesized that recovered and impacted vegetation areas would differ based on the human-induced activity such as off-trail use and trampling as compared to other areas with no or little visitor use. Multiple social trails were observed leading away from different locations along the summit loop trail, and incidentally these same locations were often places used for placing LNT signs. Also, previous research documented wide-spread summit off-trail use by visitors (e.g., it is not uncommon to observe visitors being off-trail 50 meters or more), and this suggested that remote sensing datasets may be helpful to detect changes in human-induced visitor impacts to vegetation.

2) After determining the areal extent of vegetation cover changes, we hypothesized that the vegetation cover changes at the experimental site would be reflective of the radial pattern and three-category zoning concept of McEwen and Tocher (1976). Specifically, that the spatial patterns of vegetation cover changes might be identified at the experimental site, for example, the intermediate (middle) zone would exhibit a higher increase in vegetation recovery than the other two zones.

3) The third dimension of this study was to reflect on the “magnitude of change” that one could detect using remote sensing and GIS technologies and as a tool to assess the relative efficacy of the employed management practices to reduce the dispersed-use occurring away from the parking and trail systems. We also discuss the strengths and limitations of using remote sensing as a tool for monitoring recreation impact at larger spatial scales than typical campsite and trail systems at a recreation setting.

Identifying the Site Boundary

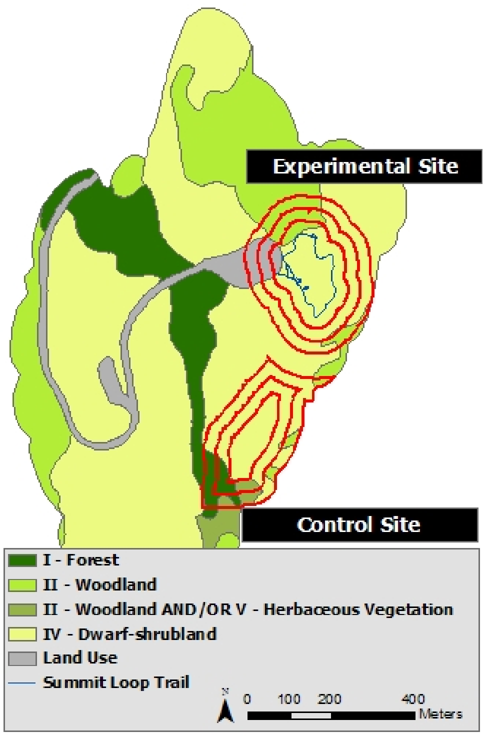
A previous visitor observation study at Cadillac Summit Loop Trail (Turner, 2001) found that visitor impact on vegetation and soil was not limited to just a few meters from the trailside of the summit loop trail, which is different from a typical recreational ecology study that attempted to identify localized impacts spatially in individual sites having a clearly defined site boundary. Instead, impacts were occurring far beyond the summit loop trail as well as the area surrounded by the trail, that could be easily taken up to 50-90*m* from the trail on the basis of Turner’s sampling plots for vegetation trampling and observational locations for visitor behaviors. Several reasons were offered by Turner (2001) to explain the off-trail hiking such as observation of visitor congestion on the trail as well as visitor’s traveling off-trail to do recreational activities such as photo-taking, berry-picking, cairn building and bird watching. Other reasons attributing to the spatial pattern of impact were: 1) The summit loop trail and vicinity has an entirely open landscape characteristic (a mixture of sparse low-lying shrubs and grasses with bare-rock dominant) that encourages one to go off and explore, guaranteeing relatively easy mobility; 2) Visitor density (6,000 visits in a single day) especially in summer (Jacobi, 2001), contributes to the spatial distribution of visitors and particularly noted on the northern and southern ends of the summit loop trail due to the flatness of ground as compared to other areas with steeper slopes; and 3) Several signs on the summit that indicate "*Step only on the paved trail or rocks*" that imply off-trail usage. Therefore, visitors are technically encouraged to do off-trail hiking on the summit albeit on durable surfaces.

A major issue associated with the assessment of the management practices that deter vegetation trampling has a close relationship with knowing the areal extent of the visitor-induced vegetation impact and area likely to be influenced by the deployed management actions. Therefore, it was deemed important to establish a desirable or reasonable "extent" of vegetation impact caused by visitors from the summit loop trail since this was the area of more intensive management. If this outer boundary is vague given the completely open landscape characteristic, we hypothesized the impact boundary to be fuzzy with off-trail use at this popular scenic overlook site, thus requiring consideration of a much larger extent of visitor-induced vegetation impact. In order to cope with the ambiguous site boundary problem that characterizes the summit loop trail and to verify the effect of the employed management strategies, we utilized three different buffering distances emanating from the summit loop trail for defining multiple extents of the study site. The buffering scales included: small (0-30*m* buffering distance from the summit loop trail), medium (0-60*m*), and large spatial scale (0-90*m*), guided in part by the visitor observation studies as well as landscape ecology studies (Kendall et al., 2003; Levin, 1992; Madrigal et al., 2008; Turner et al., 2001; Wiens, 1989). Within the experimental site, the spatial pattern of vegetation changes related to the zoning concept was analyzed by dividing the large spatial scale into the three different zones (core: 0-30*m*, intermediate: 30-60*m*, and periphery: 60-90*m*). More importantly, the multi-spatial scale analysis utilizing the different spatial extents for the study site was done to compare the rates of increased and decreased vegetation areas with a control site not influenced by visitor, as a way of examining the effect of the management practices at the experimental site.

Control Site Selection

One of the most essential factors in selecting a control site is for the undisturbed site to have environmentally similar characteristics as the experimental site (Hammitt & Cole, 1998). We adopted elevation and aspect as important factors that shape a vegetation community in alpine or sub-alpine environment (Barnes et al., 1998; Boughton et al., 2006; Kimball & Weihrauch, 2000). The 1,300ft elevation of Cadillac Mountain was employed as a minimum baseline to contain our pre-defined large spatial scale of the experimental site (90*m* buffering distance from the summit loop trail).

Major natural and human-induced disturbance factors were additionally considered as they are key mechanisms in maintaining species diversity (Roberts & Gilliam, 1995; Turner, 1989). As a natural disturbance factor, the disastrous 1947 fire that burned most of the eastern side of Mount Desert Island including the vicinity of the summit loop trail was considered to select the control site within the same burned areas (Patterson et al., 1983). The human-induced disturbance factor was considered to exclude potential human trampling and off-trail hiking areas using various distance concepts and undisruptive sampling techniques (Dosskey et al., 2005; Fernández-Juricic et al., 2002; Urban, 2000). Accordingly, a 150*m* buffer from the existing structures including parking lots, auto roads, concession and restroom areas, and the hiking trail network, was applied in order to exclude areas potentially accessible to humans.



	Experimental Site *Visitor Impact, Management*	
	Area (m^2)	Vegetation Cover*
Small (30m)	33,497	Dwarf-shrubland: 93%
Medium (60m)	57,612	Dwarf-shrubland: 86%
Large (90m)	87,136	Dwarf-shrubland: 81%
	Control Site *No/limited Visitor Impact, No/little Management*	
	Area (m^2)	Vegetation Cover*
Small (30m)	13,524	Dwarf-shrubland: 99%
Medium (60m)	33,460	Dwarf-shrubland: 86%
Large (90m)	61,551	Dwarf-shrubland: 76%

Figure 4.4. Selected control site: the experimental site represents visitor impact and management strategies. In contrast, the control site represents no/limited visitor impact and no management strategies. *Vegetation types based on the result of the Vegetation Mapping Project by USGS-NPS (Lubinski et al., 2003).

Figure 4.4 shows the selected control site and the experimental site. The distance between the outer edges of the experimental and control site was 60 meters. Both sites have a similar south-east facing aspect, while the control site was slightly steeper than the experimental site. Vegetation characteristics were similar with the dominant cover characterized as mostly “Dwarf-shrubland” using the vegetation mapping project completed by NPS-USGS (Lubinski et al., 2003).

Image Processing Steps

Two multi-spectral high spatial resolution remote sensing datasets were used to detect fractional vegetation cover changes between 2001 and 2007. IKONOS imagery (product level: PRO) from 2001 was purchased by ANP and airborne imagery collected in 2007 was obtained from the John Deere AGRI Service. The IKONOS imagery captured on August 18, 2001 has 5 separate bands including 4*m* ground resolution blue, green, red, near-infrared, and 1*m* panchromatic. The Airborne imagery captured on June 24, 2007 was already in a high ground resolution format (about 0.9m) and had 4 bands composed of blue, green, red, and near-infrared. A Trimble GeoXT (GPS) with an external antenna and bypass was used to identify the location of signpost messages (LNT) and physical barriers on the top of Cadillac Mountain. After post-processing to increase the level to sub-meter accuracy, the data were exported as ESRI shapefile format for GIS analysis.

ERDAS IMAGINE 9.1 was used for most of image processing steps for IKONOS and Airborne imagery. As a pre-processing, a high-pass filter pan-sharpening technique was conducted to enhance the IKONOS imagery for 1*m* high ground resolution format. Re-sampling of the Airborne imagery, using a nearest-neighbor method for preserving spectral values, was performed to have a consistency as 1*m* ground resolution dataset, while rescaling of the pan-sharpened IKONOS imagery was performed to make it 8 bit (0-255) imagery. A geometric correction between the two imageries was completed using 20 ground control points (GCPs) and a second order polynomial method. The IKONOS imagery was used as a reference and Airborne as an input image, targeting to have less than a half pixel accuracy registration (RMSE=0.5). In addition, an image subset was performed to focus on the summit loop trail area of Cadillac Mountain as well as the control site (ULX: 561244.5, ULY: 4911505.5, LRX: 562050.5 563207, LRY: 4910714.5). Finally, as a part of the radiometric correction process, histograms of the two imagery were matched using the Airborne as reference imagery, particularly for a high resolution dataset radiometric normalization (Hong & Zhang, 2005).

Normalized Difference Vegetation Index (NDVI) was used for detecting vegetation cover changes between the two imagery (Jensen, 2005, 2007). NDVI is a simple formula using two different reflective bands of a multi-spectral remote sensing dataset for estimating vegetation cover, representing vegetation photosynthetic activity, vegetation biomass, greenness and vegetation canopy closure (Huete & Jackson, 1987; Rouse et al., 1973; Sader & Winne, 1992). Additionally, in order to avoid confusion and false interpretation in the NDVIs comparison between the two imagery, an image mask function was used to exclude the summit parking area (10*m* buffering to include additional parking areas close to the summit loop trail), automobile road (15*m* wide), hiking trails (2*m* wide), viewing platforms (2*m* wide), durable summit loop trail (2*m* wide), cloud covered areas in the IKONOS 2001 (not included in the experiment and control site), and constructed buildings.

Multi-temporal RGB-NDVI image analysis was used to identify fractional vegetation cover changes between the 2001 and 2007 imageries (Sader et al., 2003; Sader & Winne, 1992). The analysis is a logical technique to visualize vegetation cover changes using NDVI and concepts of color additive theory (Sader and Winne, 1992). By simultaneously combining each date of NDVI through the red, green, and blue (RGB), major changes in NDVIs between dates appear in combinations of the primary (RGB) or complimentary (yellow, magenta, cyan) colors. Since our analysis was for two different dates, two distinctive colors were produced in the results image: blue (increased vegetation cover) and yellow (decreased vegetation c). In interpreting the NDVI results, a maximum variation between the two NDVIs was utilized by controlling a boundary threshold (Long Dai & Khorram, 1999; Lu et al., 2004), as a way of reducing phenological issues such as a different moisture level and a different canopy structure caused by the temporal gap of imagery acquisition.

A field investigation was completed in the summer of 2007 to help assess the accuracy of the classified NDVI result indicating vegetation and non-vegetation areas. A total of 300 reference ground points were randomly generated along with the classified results recoded in binary mode (vegetation vs. non-vegetation) by merging increased vegetation cover and no changed vegetation areas as "Vegetation," and decreased vegetation cover and non-vegetation areas as "Non-vegetation." A Trimble GeoXT with an external antenna was used to locate the 300 randomly generated reference points in order to verify the accuracy level of the classified NDVI result.

To test our hypothesized relationship of the areal extent of human-induced vegetation changes, we computed the rates of increased and decreased vegetation areas for $10m^2$ plots that were systematically sampled in the experimental and the control site at all three spatial zones. For each plot, the rates of increased and decreased vegetation areas were calculated by an equation: *increased (or decreased) vegetation area / total vegetation area* × *100*. On the basis of the multi-spatial scaling approach that uses different extents of the study site to maximize the applicability of remote sensing datasets, the mean rates of increased and decreased vegetation areas were calculated for small (0-

30*m*), medium (0-60*m*), and large (0-90*m*) spatial scales. T-test comparisons were used to compare the mean rates of vegetation cover changes in each spatial scale among the experimental and control sites at the $p = 0.05$ level.

To test our hypothesized relationship of spatial patterns of vegetation impact and recovery within the experimental site, similar computations were made calculating the rates of increased and decreased vegetation areas based on the $10m^2$ plots that were systematically sampled at the experimental site. Mean rates of increased and decreased vegetation areas were calculated for core (0-30*m*), intermediate (30-60*m*) and periphery (60-90*m*) and, one-way analysis of variance was used to compare the means of changes over the three spatial zones. Tukey post-hoc tests of pairwise differences in means were used to identify significant differences at the $p = 0.05$ level. It should be noted that the plots having no vegetation areas (complete bare rock or masked-out areas) in the change detection results were not considered as a sample in each statistical test, since the analyses were intended to identify the rates of increased and decreased vegetation areas.

Results

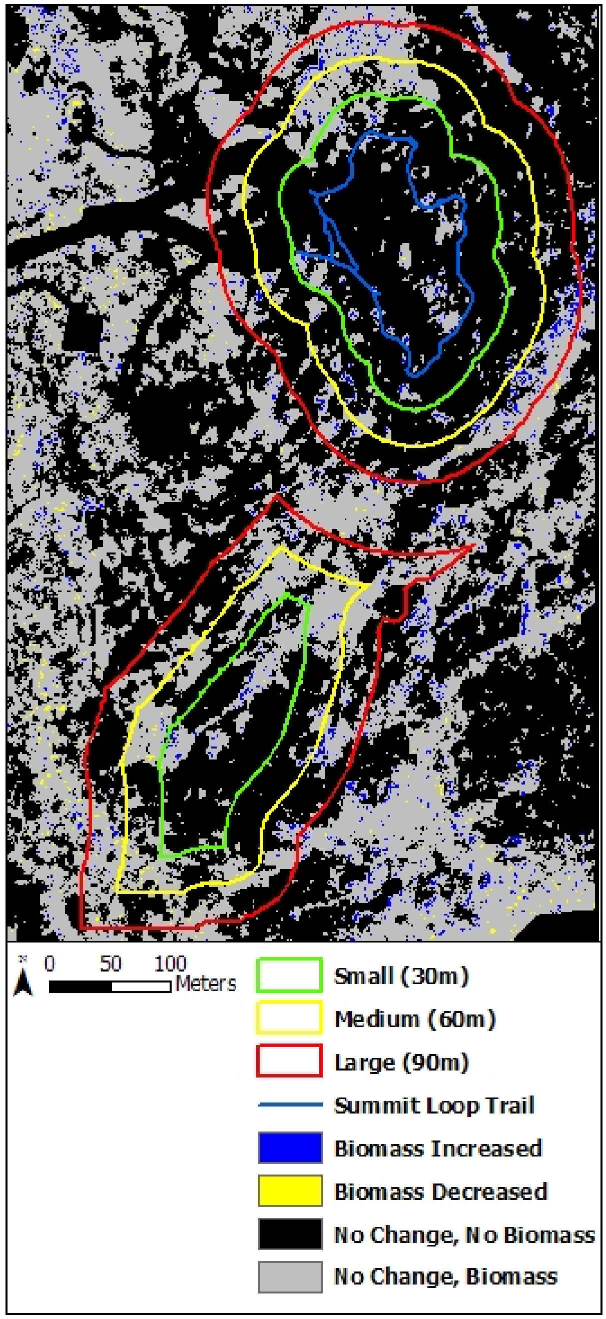


Figure 4.5. NDVI change detection analysis from 2001 to 2007 (Top: experimental site, Bottom: control site).

Figure 4.5 shows the vegetation cover change detection results from 2001 to 2007 on Cadillac Mountain. Overall accuracies estimated using the 300 randomly generated points over the study region were 76.19% (producer accuracy: 71.25%, user accuracy: 80.23%) at the level of binary mode. The increased vegetation areas at the experimental site were 299m^2 in the core (0-30m), 329m^2 in the intermediate (30-60m), and 1,040m^2 in the periphery zone (60-90m). The decreased vegetation areas at the experimental site were 4m^2 in the core (0-30m), 3m^2 in the intermediate (30-60m), and 16m^2 in the periphery zone (60-90m). The increased vegetation areas at the control site were 203m^2 in the core (0-30m), 145m^2 in the intermediate (30-60m), and 443m^2 in the periphery zone (60-90m). The decreased vegetation areas at the control site were 6m^2 in the core (0-30m), 94m^2 in the intermediate (30-60m), and 80m^2 in the periphery zone (60-90m). Though these changed vegetation areas were not the rates of vegetation cover changes that calculate the total vegetation areas as denominators in each pre-defined zone, there was a spatial relationship of increasing vegetation area from the core to the periphery zone at the experimental site. However, there was no spatial relationship of decreasing vegetation area at the experimental site, showing the highest decreased vegetation area in the periphery zone.

Verifying Areal Extents of Vegetation Changes

As hypothesized, the areal extent of human-induced vegetation changes at the experimental site differed from the control site (Table 4.2). Throughout the three different spatial scales, the means of rates of increased vegetation areas were higher at the experimental site than the control site. Also, in the medium and large spatial scales, the means of rates of decreased vegetation areas were lower at the experimental site than the control site, while showing the same percentage in the small spatial scale analysis.

Table 4.2. T-test summary for comparison between experimental and control sites: The rates of increased and decreased vegetation areas based on 10m^2 plots at the three different spatial scales (*M*: mean of percent change, *n*: # of plots).

Spatial Extent (Variables)		***Experimental Site***		***Control Site***		***T***	***P***
		M (%)	***n***	***M (%)***	***n***		
Small Scale	Impact	0.06	172	0.06	69	-0.0985	0.9217
(0-30*m*)	Recovery	4.91	172	3.68	69	-1.1276	0.2609
Medium Scale	Impact	0.04	327	0.67	222	4.0401	7.306e-05
(0-60*m*)	Recovery	4.36	327	2.06	222	-3.6138	0.0003299
Large Scale	Impact	0.12	545	0.64	456	4.4503	9.937e-06
(0-90*m*)	Recovery	5.56	545	2.36	456	-6.2044	8.272e-10

The results of the T-test showed that there were no significant differences in terms of the rates of the increased and decreased vegetation areas between the two sites in the small spatial scale (all $p > 0.05$). In the medium and large spatial scales, it was observed that the rates of increased and decreased vegetation areas at the experimental site were significantly different from those in the control site (all $p < 0.001$), showing more increased and less decreased vegetation areas in the experimental site. Therefore, within the three multi-spatial scales, the employed management strategies had a positive effect in terms of reducing vegetation impact and enhancing vegetation regeneration compared to the control site from 2001 to 2007, using the applied NDVI analysis and the vegetation comparison mechanism.

Spatial Patterns of Vegetation Changes

Table 4.3. One-way ANOVA summary for experimental site analysis: The rates of increased and decreased vegetation areas based on 10m^2 plots at the three different spatial zones (*n*: # of plots, *M*: mean of percent change)

Variables	***Core Zone M (%)***	***Intermediate Zone M (%)***	***Periphery Zone M (%)***	***n***	***F***	***P***
Impact	0.02	0.00	0.26	86	1.6099	0.2019
Recovery	5.06	4.81	8.62	86	3.7199	0.02556*

*Significance of differences: recovery at core = recovery at intermediate ($p = 0.9855799$), recovery at core = recovery at periphery ($p = 0.0609131$), recovery at intermediate < recovery at periphery ($p = 0.0406764$)

Table 4.3 contains the means rates of increased and decreased areas classified for each spatial zone within the experimental site. There were no significant differences among the three different spatial zones in terms of the rates of decreased vegetation areas ($F = 1.6099$, $p = 0.2019$). It was shown that there was no regular radial pattern or decreasing relationship of vegetation impact, which is typically reported by identifying a localized impact close to trails or campsites in recreation ecology studies, within the designed three spatial zones at the experimental site. However, there was a significant difference among the three different spatial zones in terms of the rates of increased vegetation areas ($F = 3.7199$, $p = 0.02556$). Specifically, Tukey post-hoc tests ($p < 0.05$ for all significant contrasts) for pairwise comparison indicated that there was a significant difference in the rate of increased vegetation area between the intermediate ($M = 4.81$) and periphery zone ($M = 8.62$), indicating that the mean rate of increased vegetation area was higher in the periphery zone (60-90*m* from the summit loop trail). This result suggests that there was a clear zone difference among the three zones, partially supporting the regular radial pattern or the increasing relationship of vegetation recovery at the experimental site.

Discussion

Unlike traditional recreation ecology studies that attempt to report how the size of the impact zone has been changed and to determine success of management focused within this zone, our study extended earlier works by adopting a multi-spatial scale approach and by enlarging the study region extensively with the aid of remote sensing datasets. The relationship of decreasing vegetation impact based on the proximity within a confined site boundary situation was not verified in our study site. This result suggests that vegetation impact may be fuzzier due to the completely open nature of terrain characteristics and prevalent off-trail use at the vicinity of the summit loop trail. The result may not be different from other sub-alpine environment summits with high levels of visitor use due to ambiguous site boundaries. However, some of our findings supported the spatial relationship of increasing vegetation recovery in the outer compared to the intermediate zone. Although the different landscape condition and visitor behavior should be added to explain more detailed spatial patterns of vegetation changes at Cadillac Summit, we believe that the spatial patterns based on the proximity and the zoning concept are still a powerful tool to explain vegetation change dynamics in a recreation site as well as to establish a site boundary.

Cole (2004a) indicates that the theory related to resource impact and recovery still remains poorly developed, even though data processing methods have become more sophisticated in the field of park and recreation management. In that regard, we attempted to define the site boundary using the recovered vegetation pattern that we observed in the vicinity of the summit loop trail. As briefly mentioned, the recovery pattern of McEwen and Tocher (1976) can be delineated as a similar pattern to a normal curve, suggesting the highest recovery rate in the middle of the intersite zone. On the other hand, Figure 4.6 shows the calculated vegetation recovery rates based on our study results, indicating initial decrease and change to increase at the 40*m* point from the summit loop trail. This observed line was used to presume the boundary between the impact and the intersite zones based on the increasing relationship of vegetation recovery between the two zones. Since the calculated vegetation recovery rates showed the maximum recovery between 70 and 80*m* from the summit loop trail, we suggest this distance could be used to identify a point in the middle of a reclassified intersite zone. This reclassification of the intersite zone would be more indicative of the higher recovery patterns expected with human-induced impact in this zone as compared to other zones. Consequently, this assumption associated with the reclassification suggests that the intersite zone encompass at least the 70-80*m* edge in order to maximize the spatial containment of human-induced vegetation impact, and that the buffer zone be more reflective of natural variation in vegetation increases and decreases. The next management process is to build more specific objectives for each zone at Cadillac Summit.

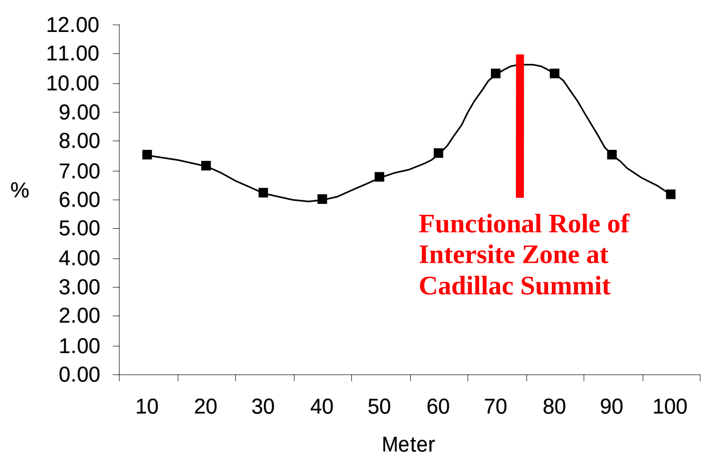


Figure 4.6. The rate of recovery in the vicinity of the summit loop trail from 0 to 100*m* based on the NDVI analysis (X: distance from the summit loop trail, Y: rate of recovery (percent change), the curve line showed the maximum recovery rate between 70 and 80m from the summit loop trail)

Additionally, we suggest that the more recovered vegetation from 0 to around 20*m* in distance compared to the distance from 30 to 40*m*, unlike the general recovery pattern, may be a direct effect of the management practices focusing on the closet proximity to the summit loop trail. Considering the given assumption of the increasing relationship in vegetation recovery as we go away from the central part of the site, the increased recovery rates from 0 to about 20*m* could be the portions that may be positively influenced by the management strategies. It is plausible that some visitors might be adhering to the signs and barriers focused close to the trail to stay off sensitive areas at points of contacts, but forgetting or not considering about the management actions in the less intensive management areas.

No significantly clustered areas in terms of negative vegetation impact were identified within the large spatial scale (0-90*m*) emanating from the summit loop trail by using the applied NDVI analysis. However, away from the summit loop trail, more decreases than increases in vegetation area were found from 2001 to 2007 at two specific locations: 1) near the gift shop and a nearby trail not associated with the summit loop trail, and 2) at a high ridge located on the west side of the parking lot. In these locations, there are fewer visible forms of intensive site/visitor management actions such as physical barriers and educational signs. It is possible that many visitors may be going to these locations before they walk the summit loop trail and they are unaware that they should remain on trails and other durable surfaces. The gift shop was renovated in 2004 with new interpretative exhibits, and the attached toilet facility was rebuilt in 1999 with eco-friendly technology. A high ridge located on the west side of the parking lot has been used for a bus tour stop associated with cruise ships during the summer. It is possible that the vegetation impact on these locations could be attributed to the increased visitor use associated with the updated facilities and bus tour stop. Therefore, more intensive management approaches in conjunction with the current management strategies in the loop trail are recommended in those areas.

Direct effect of the physical barriers to reduce vegetation impact at the summit loop trail was estimated by calculating the rates of increased and decreased vegetation areas. Currently, the three oval shaped physical barriers covering the total areas of 1,860m^2, mostly focusing on the northern part, were installed within the loop trail. The intrinsic objective of the physical barriers was to keep visitors out of specific areas where trampling and soil erosion were at high risk (Turner, 2001). The analysis results showed that the rate of increased vegetation area within the three exclosures between 2001 and 2007 was 3.51% (4m^2), while the rate of decreased vegetation area was 0% (0m^2), and no-changed vegetation was 95% (96.49m^2). The rate of increased vegetation area was not significantly high, but there was no direct negative impact during the analysis time frame. This suggests that no dynamic vegetation changes by trampling or off-trail hiking occurred within the three physical barriers. Considering the nature of sub-alpine environments that usually take a long time to recover after being damaged, the 3.51 percent of recovery and the 95 percent of no-change rates may reveal the positive effect of the direct approach to reduce further vegetation impact at Cadillac Summit. Interestingly, visitors' experiences at the summit were not diminished by the exclosures, and visitors preferred more intensive management such as physical barriers along the summit loop trail (Bullock & Lawson, 2008). Therefore, reinforcing and expanding the utilization of the exclosures coupled with broader landscape issues on the summit near the parking area identified above could be utilized at those potentially susceptible areas.

Our analysis results supported our hypothesized relationships related to examining the efficacy of management strategies using vegetation comparison mechanism between the experimental and the control site. The analysis results, also, showed that fewer decreased vegetation areas compared to the increased vegetation areas were identified across all the spatial scales. Given the fact that the study site was a popular visitor destination even before ANP was designated as a national park in 1919, this suggests that the most serious vegetation impact may have occurred at the beginning of the 20th century, based on the asymptotic relationship between vegetation impact and visitor use over time (Hammitt & Cole, 1998). It is plausible that the site has been transformed to a more resistant site permitting less vegetation impact, even under constant visitor use. While the applied NDVI change detection analysis was valuable to measure vegetation cover changes, more detailed analyses about vegetation characteristics would be helpful to fully assess vegetation change dynamics on the summit. Research has consistently shown that re-vegetated sites often consist of more resilient and resistant species, and overall less diversity than the previous impacted condition (Hammitt & Cole, 1998). In other words, vegetation diversity would be significantly lowered after being trampled, eventually leading vegetation changes in composition and structure (Cole, 1995; Green, 1998; Hammitt & Cole, 1998; Kobayashi et al., 1997; Kuss & Hall, 1991; Tasser & Tappeiner, 2002; Taylor et al., 1993). More specifically, Cole (1995) indicated that grass family becomes the most dominant and common species after being disturbed by trampling (Cole, 1995; Hammitt & Cole, 1998; Marion & Cole, 1996). Therefore, for verifying vegetation characteristics, the post-classification change detection methods in conjunction with field investigation could be considered as an alternative method.

To encourage more vegetation recovery some distance away from the summit loop trail consideration will probably need to be given to revising the content of the LNT message that technically encourages off-trail hiking activities: "*Step only on the paved trail or rocks*." Given the visitor density estimated at 6,000 in a single day during the summer and the narrow 0.3 mile long summit loop trail, it may be inevitable to compromise visitor uses on durable surfaces at Cadillac. However, it is recommended that the content of the message should be revised to reveal the high risk of vegetation at Cadillac Summit, understanding that sparse and low-lying vegetation are spatially distributed with bare rocks over the summit. Applying other visual forms of signs such as prompters and symbols rather than using text message contents could be a management alternative since they appear to be more effective in influencing visitor behavior (Bullock & Lawson, 2008). In addition, as an integrated method, these visual forms of signs could be strategically located at identified problem areas where there is currently no focus of intensive management away from the summit loop trail.

Technical Considerations

We should note the technical considerations associated with our study design: spatial and temporal scaling issues. Various spatial scales were applied under the given assumptions: 1) small (0-30*m*), medium (0-60*m*), and large (0-90*m*) spatial scales for identifying the study extent, 2) the proximity analysis among the three spatial zones (0-30*m*, 30-60*m*, and 60-90*m*) for verifying the spatial patterns of vegetation changes, 3)

$10m^2$ plots for the sampling purpose, and 4) certain amounts of distances for creating the masking out layer. Although the multi-spatial scale approach for controlling the size of the extent was guided by various landscape ecology studies to cope with potential spatial scaling problems in observing the pattern of the changes, it is generally recognized that there is no single correct way to identify or select the exact spatial scales. Therefore, there might be a slightly different result, once we adopt and use different value/distances in defining spatial scales in each case. There is also a phenological issue from the temporal gap of imagery acquisition as well as different characteristics of imagery sensors. Although both imageries are leaf-on versions, and several recommended image enhancement techniques including histogram matching for a radiometric correction and maximum variation threshold for interpreting the NDVI result were used, there might be a different moisture level and canopy structure that may cause a false interpretation of the classified NDVI results. Additionally, sparse/isolated and low-lying vegetation families (mainly grass family) having extremely low greenness and productivity may not be detected effectively coupled with the problems related to the phenological issue and the different sensor characteristics (Paruelo & Lauenroth, 1995).

There was no direct effect of the pan-sharpening technique, one of the resolution merging processes producing $1m^2$ spatial resolution imagery of IKONOS 2001. Initially, uncertainty in the result of the pan-sharpening technique was proposed due to the two pre-processing techniques already applied in the 1m panchromatic dataset: Modulation Transfer Function Compensation (MTFC) and Dynamic Range Adjustment (DRA) (Baltsavias et al., 2001). In order to increase confidence in the results of the vegetation cover change detection analysis at $1m^2$ ground resolution, the same analysis procedures for comparing results were completed in $4m^2$ ground resolution that the pan-sharpening technique was not applied. Though the $4m^2$ ground resolution analysis was less sensitive than the $1m^2$ ground resolution analysis, the two analysis results had relatively similar trends in calculating the rates of increased and decreased vegetation areas as well as other areas such as "no vegetation area" and "vegetation, but no changed area." The statistical analysis results at the $4m^2$ ground resolution indicated the same results with the $1m^2$ ground resolution by showing no significant differences in terms of the rates of the increased and decreased vegetation areas between the experimental and the control site in the small spatial scale (all $p > 0.05$). In the medium and large spatial scales, it was also observed that the rates of increased and decreased vegetation areas in the experimental site were significantly different from those in the control site (all $p < 0.05$), showing more increased and less decreased vegetation areas in the experimental site.

Given the binary structure of the classified results (vegetation vs. non-vegetation), the overall accuracy level of the classified NDVI result was relatively low (76.19%) through the 300 randomly generated point dataset. Although the sub-meter accuracy GPS unit (Trimble GeoXT) was utilized to detect actual ground information for accuracy assessment purpose at the pixel level ($1m^2$), it is commonly agreed that there are always potential GPS errors caused by various factors such as atmospheric and topographic effects. Especially, it was discovered that there was maximum 1-2*m* positional error (maximum 2-3*m* error under a heavy canopy), when the GPS unit was tested before the field investigation for accuracy assessment. This technical limitation may cause difficulty in locating the reference points generated in less than 1-$2m^2$ homogeneous areas.

Conclusion

Basically, the summit of Cadillac Mountain is a tough place to recover vegetation due to the short growing season, thin/sandy soil, and shortage of available water. Monitoring the impact of the site over time is more challenging, since it has been intensively used over 90 years under the dual mandates of NPS. In spite of these apparent obstacles, the results of this study using the NDVI analysis indicate that the management strategies at the experimental site were effective relatively in minimizing vegetation impact and in enhancing vegetation recovery compared to the conditions of the control site from 2001 to 2007. From the perspective of obtaining a quality visitor-induced impact monitoring dataset, the value of remote sensing has not been well-recognized due to a dense canopy cover or a multiple vegetation layer that impedes discovering a localized impact in a study site. However, Cadillac summit has a completely open landscape having a mixture of sparse low-lying shrubs with bare-rock dominant. Accordingly, remote sensing technology appears to be a useful tool for capturing a localized, but extensively distributed impact at the summit environment beyond other traditional recreation ecology methods. In addition, measuring vegetation cover changes with the aid of multi-spectral bands of remote sensing datasets provides quantitative and scientific information on the vegetation change dynamics at Cadillac Summit, which has been seldom used in recreation ecology (Hammitt & Cole, 1998).

A future step for management is evaluating the effectiveness of implementation of the more intensive management actions around the summit trail. For example, depending on one's point of view, detection of vegetation recovery by 5.06% and vegetation impact by 0.02% within 30*m* of the trail from 2001 to 2007 might constitute real progress in terms of management goals, or alternately, insignificant changes. The development of clear objectives such as indicators and standards of resource conditions will become increasingly important for assessing management actions directed towards minimizing impact and maximizing recovery. The apparent visitor-induced impact and recovery 70-80*m* away from the summit trail may be viewed as progress, but the actual amount of that recovery might be targeted higher or closer to the summit trail. Only where specific objectives have been established can one consistently determine whether or not an impact and recovery of a given magnitude constitutes an effective management strategy. A temporal scale may also be necessary in establishing realistic goals, especially given the sub-alpine environment of Cadillac Mountain as compared to other areas in ANP.

A growing body of research has shown that spatial containment strategies are generally the most effective management practice in a frontcountry setting (Cole, 1981a; Cole & Monz, 2004; Marion & Farrell, 2002). As a result, identifying zone boundaries based on the spatial pattern of vegetation changes will become important for implementing management practices. In our study, it was shown that areas 70-80*m* from the summit loop trail showed the maximum recovery rate (the functional role of the intersite zone) on the basis of the proximity and the zoning concept. Therefore, the boundary between the fuzzy impact zone and the intersite zone at Cadillac Summit could be established less than 70*m* from the summit loop trail. Once the boundaries are identified, the deployed management practices currently focused within the summit loop trail could be monitored to assess effectiveness of minimizing the expansion of the impact and the intersite zones and perhaps further recovery occurring within each zone.

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CHAPTER 5

MONITORING VEGETATION IMPACT BY RECREATIONAL USE ON THE SUMMIT OF CADILLAC MOUNTAIN USING POST-CLASSIFICATION CHANGE DETECTION ANALYSIS: 2001 AND 2007

Abstract

Vegetation impact by recreational use is often concentrated along travel corridors and at destination areas so it tends to add up to only a small fraction of total park areas. However, such vegetation impact is a legitimate management concern since it affects areas that are ecologically or culturally significant in national parks. While recreation ecology has played an important role in identifying spatial patterns of vegetation impact as well as plant response characteristics to trampling or off-trail hiking, the challenge is to verify the patterns and characteristics when a site boundary is relatively large for on-site measurement. In this study, we suggest GIS/remote sensing technologies for identifying vegetation change dynamics at a large spatial scale and eventually for assessing efficacy of site and visitor management strategies designed to reduce vegetation impact and enhance recovery. By using multi-spectral high resolution remote sensing datasets obtained in 2001 and 2007, the rates of increased and decreased vegetation covers in the vicinity of the summit loop trail, Cadillac Mountain, Acadia National Park, were determined at three pre-defined spatial zones (0-30*m*, 30-60*m*, 60-90*m*) emanating from the edge of the summit loop trail and compared at similar spatial scales with a nearby control site with no/little visitor use. At the summit loop trail (experimental site), more impact was observed for the core spatial zone (0-30*m*) compared to the intermediate

spatial zone (30-60*m*) based on the proximity from the summit loop trail ($F = 3.9002$, $p = 0.02485$), while showing no significant difference in vegetation recovery among the pre-defined spatial zones ($F = 0.1406$, $p = 0.869$). With the control site for comparing the rates of vegetation cover changes, significant differences in the mean rates of increased vegetation covers between the two sites were detected (all $p < 0.05$) throughout the pre-defined accumulated spatial scales (0-30*m*, 0-60*m*, 0-90*m*), indicating higher recovery rates at the experimental site. In addition, significant differences were verified in the mean rates of decreased vegetation covers (all $p < 0.001$), indicating higher impact rates at the experimental site. Vegetation diversities, both evenness and richness, were lower at the experimental site using the 2001 and 2007 plant family level classifications (all $p < 0.001$), showing no positive relationship with the employed management strategies in terms of enhancing vegetation diversity during the examined analysis time frame. Within the experimental site, vegetation diversities varied among the three pre-defined zones (all $p < 0.05$), indicating lower vegetation diversities in the core spatial zones, 0-30*m* from the summit loop trail in 2001 and 2007, respectively. Our study results support findings of other recreation ecology studies on vegetation spatial impact patterns, with decreasing impact observed from the central part to the edge of site and a reduction in vegetation diversity at the core area of the site. Importantly, we examined this process at a much larger scale than typical recreation ecology studies. Management actions at Cadillac Summit showed overall positive effects in enhancing vegetation regeneration, but no direct effect in reducing vegetation impact as well as in enhancing vegetation diversity during the observed time frame. We also discuss strengths and limitations of remote sensing as a tool for monitoring recreation impact at larger spatial scales than typical campsite and trail systems at a recreation setting.

Key words: recreation ecology, vegetation, trampling, diversity, management, remote sensing, post-classification change detection

Introduction

The National Park Service (NPS) mission of preserving the natural character of an area while providing for visitor enjoyment poses some significant challenges. Vegetation loss and soil erosion are common signs of visitor-induced resource impact, and these can be easily pronounced over a period of time without appropriate site and visitor management strategies. One important characteristic of resource impact by recreational use is its highly concentrated nature because recreationists consistently tend to use the same places. For example, vegetation impacts are often concentrated along travel corridors and at destination areas so they tend to add up to only a small fraction of the total park area (Hammitt & Cole, 1998; Manning, 1979). However, these vegetation impacts are still an important management concern as these are the same places visitors are present with the potential to influence the quality of their experience and the unique ecological attributes that are likely to contribute to the national park being designated in the first place (Leung & Monz, 2006).

Recreation ecology is a relatively new field of scientific study beginning in the 1970s (Liddle, 1997) and refers to human recreation impact on the environment: vegetation, soil, water and wildlife (Leung & Marion, 2000). Specifically, the discipline focuses on identifying, assessing, understanding, and managing resource impact caused by visitors in a protected area (Leung et al. 2001). One of the major challenges that recreation ecology currently faces is how to develop a synthesized and integrated method to identify and evaluate the efficacy of management strategies designed to reduce human impact caused by recreational activities (Buckley et al., 2008). How can we prove or evaluate the effectiveness of site and visitor management strategies in a national park or protected area? This is particularly important because managers need methods to evaluate practices currently employed and to have at their disposal alternative management strategies to optimize their efforts towards the mission of the agency.

Recreation ecology studies that have focused on vegetation change dynamics with recreation use over time have concentrated on two areas: 1) amount of vegetation with the impact parameter being vegetation cover, and 2) vegetation composition with the impact parameter being species, species diversity and frequency (Hammitt & Cole, 1998). In most cases researchers have compared these measures at recreation sites with similar measures at adjacent undisturbed sites (control) to more fully understand the vegetation change dynamics. These approaches have assisted managers in identifying diverse characteristics of the landscape they manage and susceptibility of vegetation changes associated with recreational use, including spatial patterns of vegetation changes (Cole & Monz, 2004; Frissell, 1978; Marion & Cole, 1996; McEwen & Tocher, 1976), plant response characteristics (Cole, 1987, 1995a, 1995b; Cole & Monz, 2002; Cole & Trull, 1992; Hammitt & Cole, 1998; Liddle, 1997; Sun & Liddle, 1991) and species composition and diversity after being disturbed by trampling or recreational use (Cole, 1985; Green, 1998; Hammitt & Cole, 1998; Kobayashi et al., 1997; Scherrer & Pickering, 2006; Stohlgren & Parsons, 1986; Tasser & Tappeiner, 2002; Taylor et al., 1993;

Tolvanen et al., 2004). Most of the research efforts in understanding vegetation change dynamics have occurred in recreational use areas such as campsites, trails, and destination areas, and significant contributions have been made in terms of the identification of spatial patterns of vegetation impact as well as species response characteristics to trampling.

Particularly, McEwen and Tocher (1976) identified the spatial pattern of impact and recovery at campsites by applying a three zone concept at a cluster of campsites: *impact zone* (most severely impacted areas, that never recover as long as use continues), *intersite zone* (partially impacted areas with informal trails and satellite sites, but recovery will be higher than in the impact zone because the capacity of vegetation to regenerate is not severely compromised), and *buffer zone* (transitional zones between the developed and the natural areas). According to McEwen and Tocher's zoning method, most of vegetation impact occurs at the central portion of the sites, and decreasing vegetation impact and increasing recovery potentials occur with increasing distance from the sites. While the recovery will be higher in the intersite zone given disturbance and ability of vegetation to regenerate, the impact is hypothesized to exhibit a similar pattern to a two horizontal asymptotes curve line (arccot shape) (Figure 5.1). At a certain point away from the center of impact in the buffer zone, the rates of impact and recovery will exhibit more natural variation of vegetation conditions given that there is no severe human or recreational disturbance factor. Given these relationships, research and monitoring of vegetation impact have tended to focus on the impact zone or central point. We suggest several logical reasons for this focus on the impact zone areas: 1) vegetation changes are most severe with often a pronounced boundary that distinguishes the impact zone from the intersite zone and 2) evaluation of management strategies can be assessed by examining vegetation change dynamics within this zone because an often important management objective is limiting the expansion of the impact zone boundary further into the intersite zone.

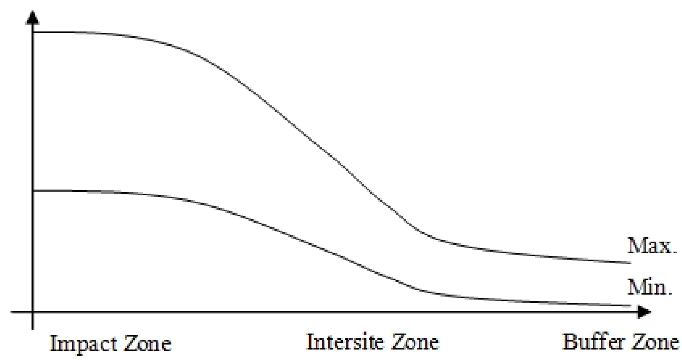

Figure 5.1. General impact pattern.
(*Impact Zone*: high impact, *Intersite Zone*: substantial impact, *Buffer Zone*: little impact) X: proximity, Y: rate of impact (percent change), Maximum impact line (top): areas having low rainfall and short growing season, low resistant vegetation characteristics, and high visitor use level, Minimum impact line (bottom): areas having plentiful rainfall and long growing season, highly resistant vegetation characteristics, and low levels of visitor use (Cole, 1988; Hammitt & Cole, 1998; Liddle, 1997).

We ascribe that management still needs to focus on those defined impact zone areas where recreational use is often concentrated with severe impact on vegetation. However, there are situations where recreational use behaviors are both concentrated as well as dispersed in natural settings. These recreation use patterns have been documented at destinations where visitor densities are high and terrain characteristics are conducive for visitors to spread out (Bullock & Lawson, 2007; Park et al., 2008; Turner, 2001). Particularly, in sub-alpine mountain summits where bare-rocks are dominant with sparse low-lying shrubs and grasses, the visitor flow is not uniformly identified along a trail in conjunction with the ambiguous site boundary and easy mobility of visitors. Using the traditional recreation ecology methods that often utilize intervals (distance) between sampled points may cause too much simplification for synthesizing the results of vegetation impact spatially. In this study, we apply remote sensing and geographic information systems by evaluating vegetation changes in amount and composition over a period of time as an alternative method for accessing vegetation change dynamics with dispersed recreational use in a sensitive sub-alpine environment.

Remote sensing refers to the detection and recording of values of emitted or reflected electromagnetic radiation with sensors in aircrafts or satellites (Ingle et al., 2003). A primary advantage of remote sensing datasets is that a relatively "big picture" can be captured easily in collecting datasets. Key to new investigations of utilizing remote sensing technology is knowing past limitations found in applying remote sensing to recreation problems and in particular to vegetation impact studies. A frequently identified problem utilizing remote sensing was the difficulty in assessing vegetation impact caused by recreation under a tree canopy where trails or campsites are located for shade or other reasons (Hammitt and Cole 1998). Another issue has been that localized impact was undetectable in a broad or medium spatial scale resolution remote sensing dataset (e.g., $30m^2$ pixel resolutions). However, recent advances in spatial resolution of datasets has helped to reduce a mixed pixel problem that is often pronounced in medium or coarse spatial resolution, and now provides a better opportunity to obtain more detailed information related to land cover and change (Lu & Weng, 2007). The use of remote sensing, therefore, will be continuously amplified in recreational resource management and analysis due to the technological advances in both software and hardware, eventually offering more credible and accurate products in terms of quality and ground resolution. More importantly, the value of high spatial resolution remote sensing datasets will be significantly increased for monitoring vegetation conditions in environments dominated by bare-rock with sparse low-lying shrubs and grasses, reducing the potential problems associated with the localized impact and multiple vegetation layers. Our study objectives were to explore the utility of remote sensing as a tool to enhance the overall quality of a monitoring dataset and gauging effectiveness of management strategies employed to minimize visitor impact on the environment.

Study Area Description

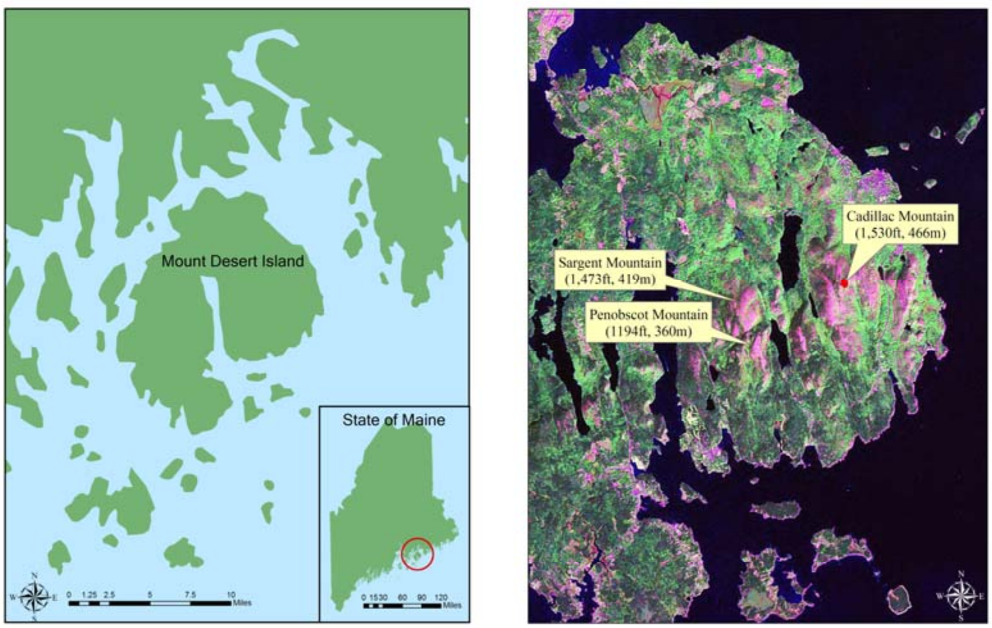

Figure 5.2. Acadia National Park: Mount Desert Island has three major mountains: Cadillac, Sargent, and Penobscot. The Cadillac summit is the highest point on the Eastern Seaboard of the U.S. (1,530 feet).

Our application of remote sensing technology focused on the summit of Cadillac Mountain, Acadia National Park (ANP). At 1,530 ft elevation, Cadillac Summit is the highest point on the Eastern Seaboard of the U.S. The Cadillac summit is a major destination for ANP visitors with an auto road providing convenient access to the top of the summit and beautiful scenic vistas of the Maine coast (Jacobi, 2001, 2003). Besides the access road there are three hiking trails leading to the summit of Cadillac as well as a popular summit loop hiking trail that is 0.3 miles long. According to a NPS visitor study, approximately 76% of the total visitors to the park visit the summit of Cadillac Mountain (Littlejohn, 1999). Although visitation levels have stabilized in recent decades, the summit receives an estimated 0.5 ~ 0.8 million visitors during the summer (June ~ August) each year (Jacobi, 2001, 2003). However, the sensitive sub-alpine nature of the site and the convenient accessibility via the auto road has created a scenario where vegetation degradation and soil erosion are at a high risk. This site represents a management challenge to balance the public's desire for visiting a popular destination and at the same time to maintain the natural conditions of the area for current and future generations.

Archived visitor photos show that the scenic overlook site on Cadillac Mountain was accessed by trails as early as the 1860s and 1870s, even before being designated as a national park in 1919. The automobile road was built between 1929 and 1932 and provided additional access opportunities for visiting the summit. Soon after the road was built, a paved summit loop trail was constructed using crushed rock and cement to blend with the exposed pink and gray granite surfaces intermixed with vegetation on the summit. Given the volume of visitors and general open nature with exposed granite, low vegetation and shallow soils, the summit was still experiencing trampling and soil erosion, leading management to implement more intensive visitor and site management measures to prevent vegetation loss (Park et al., 2008; Turner, 2001).

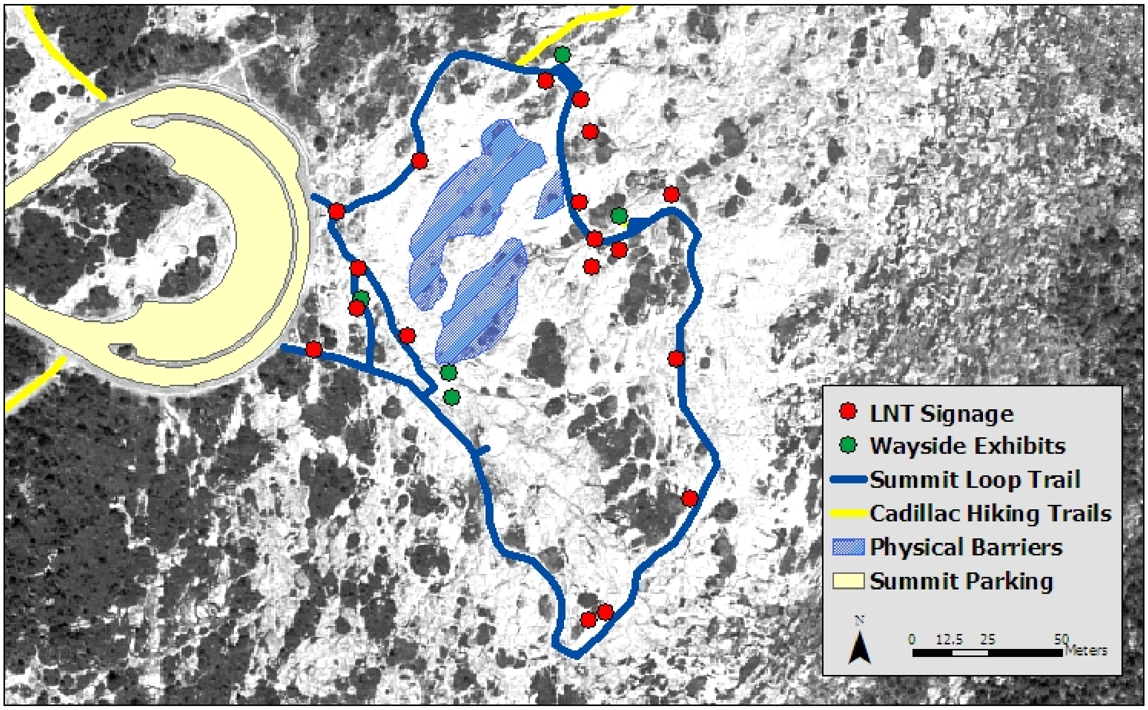

Figure 5.3. Locations of physical barriers (light blue) and LNT signage (red), captured by a GPS (Trimble GeoXT) and exported as an ESRI shapefile format.

Figure 5.4. Indirect management (left, LNT signage) and direct management (right, physical barriers): ANP has been utilized both management approaches since 2000 along the summit loop trail of Cadillac Mountain in order to reduce direct trampling effect, especially caused by off-trail hikers.

In 2000, a shift toward more intensive management was put in place to minimize visitor-induced vegetation impact (Figure 5.3 and 5.4). A combination of site and visitor management strategies using physical barriers and low impact education messages, respectively, were deployed in strategic locations to address vegetation loss on Cadillac Mountain. The current resource management chief and staff in ANP had constantly observed significant vegetation loss over the area, so these visitor and site management strategies were used as a management tool, not as a research mechanism (Turner, 2001; interview with the ANP resource management staff, 2007). Until now, several studies based on social science approaches have attempted to verify the effectiveness of the deployed management strategies coupled with visitors' perceptions and experiences (Bullock & Lawson, 2007, 2008; Park et al., 2008; Turner, 2001), but there has been little direct study examining the effectiveness of the management strategies focusing on the vegetation component.

It is our belief that, in order to support the park management initiatives newly adopted in 2000, a process to evaluate the effectiveness of these management practices along the summit loop trail should be implemented as part of a long-term monitoring program. Therefore, the goal of this study was to utilize remote sensing/GIS technologies for examining the effect of the management strategies to reduce human-induced vegetation impact and enhance vegetation recovery around the Cadillac Mountain summit loop trail. A post-classification change detection analysis based on two multi-spectral high resolution remote sensing datasets obtained in 2001 and 2007 was used to identify the amount of vegetation increase and decline in proximity to the summit loop trail as well as changes in vegetation composition. The research design of the remote sensing study had four important dimensions:

1) We hypothesized that the rate of increased vegetation would be higher and the rate of decreased vegetation would be lower over time at the summit loop trail (experimental site) as compared to an adjacent area without visitor use (control site) with more natural variability in growth and reduction of vegetation.
2) We hypothesized that the rate of vegetation recovery would increase and the rate of vegetation impact would decrease as we go away from the central part of the site, but may also exhibit different spatial impact and recovery patterns given the characterstics of terrain and prevalent off-trail use at the summit.
3) We hypothesized that the vegetation composition and diversity would be more dynamic and exhibit more variability over time at the experimental site as compared to natural variability of vegetation composition and diversity at the control site.
4) We hypothesized that vegetation composition and diversity would increase from the center of impact area, but may also exhibit different spatial patterns given the terrain characteristics and prevalent off-trail use at the summit.

Methods

Study Design

Two multi-spectral remote sensing datasets, high spatial resolution IKONOS 2001 and Airborne 2007, were used to detect fractional vegetation cover changes between 2001 and 2007. The IKONOS 2001 was obtained from ANP and the airborne 2007 was obtained from the John Deere AGRI Service. The IKONOS, captured on August 18, 2001, had five separate bands including 4*m* ground resolution blue, green, red, near-infrared, and 1*m* panchromatic (product level: PRO). Also, airborne 2007 imagery captured on June 24, 2007 had four separated bands including 0.98*m* spatial resolution blue, green, red and near-infrared. Other ancillary datasets including the locations of signposts and physical barriers in the vicinity of the summit loop trail were collected using a GPS (Trimble GeoXT) with an external antenna and bypass.

For better understanding the degree and magnitude of vegetation change dynamics in the vicinity of the summit loop trail, we selected a control site that maintains a natural variability with no/little visitor use using elevation and potential disturbance factors (Figure 5.5). In addition, to cope with the ambiguous site boundary problem at Cadillac, we adopted a "multi-spatial scale approach" that employs a series of varying sizes of study extents for comparing vegetation changes in amount and composition with the control site: small (0-30*m* buffering width from the summit loop trail), medium (0-60*m*), and large spatial scale (0-90*m*). This multi-spatial design also enabled us to test spatial patterns of vegetation impact, recovery and composition within the experimental site by dividing the large spatial scale into three different zones (core: 0-30*m*, intermediate: 30-60*m*, and periphery: 60-90*m*) (Figure 5.5).[3]

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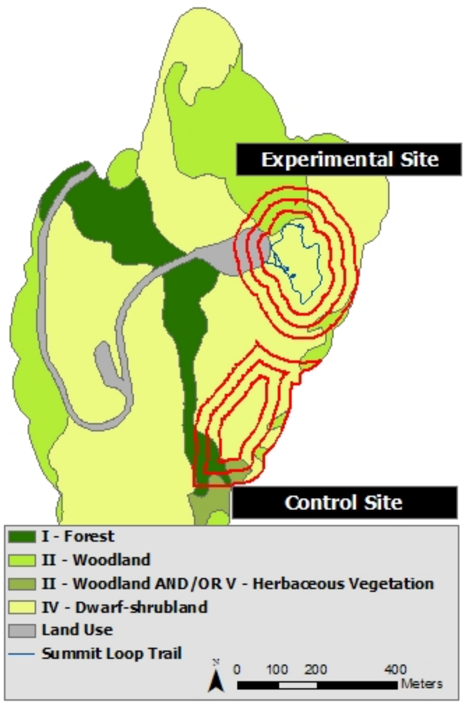
[3] More detailed information about the study design was described in Chapter 4, to be submitted to the *Journal of Environmental Management*.



Spatial Scale	Experimental Site	
	Area (m^2)	Vegetation Cover*
Small (0-30*m*)	33,497	Dwarf-shrubland: 93%
Medium (0-60*m*)	57,612	Dwarf-shrubland: 86%
Large (0-90*m*)	87,136	Dwarf-shrubland: 81%
Spatial Scale	**Control Site**	
	Area (m^2)	Vegetation Cover*
Small (0-30*m*)	13,524	Dwarf-shrubland: 99%
Medium (0-60*m*)	33,460	Dwarf-shrubland: 86%
Large (0-90*m*)	61,551	Dwarf-shrubland: 76%

Figure 5.5. Selected control site: the experimental site represents visitor impact and management strategies. In contrast, the control site represents no visitor impact and no management strategies. *Vegetation cover types based on the result of the Vegetation Mapping Project by NPS-USGS (Lubinski et al., 2003).

Post-Classification Change Detection Analysis

Pre-classification and post-classification change detection methods are both widely used analysis tools for identifying land use and cover changes (Lunetta et al., 2006; Rogan & Chen, 2004; Rymasheuskaya, 2007; Serra et al., 2003; Singh, 1989). Each method has unique pros and cons in terms of analyzing vegetation changes; however, the post-classification change detection method is more commonly used when developing land cover classification schemes (Fuller et al., 2003; Lu et al., 2004). One primary advantage of using the post-classification method is comparing two imageries from different sensors and platforms as it does not require performing a radiometric co-registration (Du et al., 2002; Lillesand et al., 2004). By using this method the radiometric correction process is not an essential factor in the image processing step. The two imageries can be separately classified and compared with each other to identify major vegetation changes between dates, minimizing the radiometric co-registration problem (Chen et al., 2005; Coppin et al., 2004).

Potential problems have been identified in the post-classification change detection analysis using a high resolution remote sensing dataset: 1) a radiometric variability of high resolution datasets often shows a wide range of distribution, even within homogenous vegetation species (Carleer & Wolff, 2006; Lu & Weng, 2007), 2) a relatively poor spectral resolution compared to other hyperspectral datasets (Carleer & Wolff, 2006), and 3) a salt-and-pepper effect which can be displayed as noises in the classified image (Herold et al., 2003; Hirose et al., 2004; Lu & Weng, 2007). Widely adopted methods to solve the problems related to the classification of high resolution remote sensing datasets include: 1) an image smoothing in a pre-processing step, and 2) a majority filtering in a post-processing step. The first is to remove local (high or low) variability by applying a mathematical transformation to the original dataset. It has been reported that class separability and classification accuracy can be improved by eliminating low or high frequencies in the pre-processing process (Carleer & Wolff, 2006; Cushnie, 1987; Hsieh & Landgrebe, 1998; Jacobsen, 2005; Katoh, 2004; Marceau et al., 1990; Quackenbush et al., 2000; Wulder et al., 2000). The second is to remove the salt-and pepper effect for better interpretation of results in the post-processing step. It is often recommended to perform this function to eliminate scattered and isolated pixels (Lu & Weng, 2007; Macleod & Congalton, 1998). Therefore, in our post-classification change detection analysis, a low pass filtering method in the pre-process and a spatial neighbor majority filtering method in the post-process were applied, respectively, to cope with the potential problems associated with a pixel-based classification using the high resolution remote sensing datasets.

Classification Scheme: Field Survey

An important element in the post-classification change detection analysis is to select an appropriate vegetation classification scheme (Jensen, 2005). The two high resolution datasets in our study have advanced spatial (ground) resolutions; however, a relatively small number of bands were captured by the different platforms and sensors that ultimately influenced the spectral differences used to classify vegetation. For developing a classification scheme, a sub-meter accuracy GPS unit (Trimble GeoXT) was used to collect 129 ground surface points covering 25 different plant genera, soil, bare rock, and human-made surfaces in the vicinity of the Cadillac summit during the summer of 2007. The main purpose of this field survey was to obtain ground information to be utilized for a spectral difference analysis and deciding on a vegetation classification scheme to maximize class separability and minimize confusion between classes (Table 5.1).

Table 5.1. Field survey summary.

Date	August 15-31, 2007
Place	Summit of Cadillac Mountain
Weather	Mostly Sunny
Number Collected	129 points covering 25 different genera
Plot type	Vegetation: 101 (82%) vs. Non-vegetated plots: 25 (19%)
Plot location	Open field: 94 (93%) vs. Under close canopy: 7 (7%)
Plot structure	Homogeneous: 73 (72%) vs. Heterogeneous: 28 (28%)
Cover size	3^2m, 4^2m, 5^2m
Coverage density	closed canopy, open canopy, sparse canopy
Coverage pattern	even, clumped
Others	height and stem diameter

A hierarchic plant classification system covering all investigated and sampled points (Judd et al., 2002), was used to develop a vegetation classification scheme at both the level of plant family (11 different classes) and the binary mode (2 different classes, vegetation vs. non-vegetated) for the each imagery. Two adjustments were made based upon the preliminary statistical analysis of the vegetation classification scheme for each image: 1) bare rock and soil were merged since there was no significant difference in terms of the spectral values at the level of plant family in both datasets; and 2) *Rhizocarpaceae* (lichen family) was significantly different from bare rock in the 2007 dataset, but not in the 2001 dataset. Therefore, for consistency in analysis between the two dates, *Rhizocarpaceae* was merged to bare rock/soil in both datasets. Table 5.2 shows the modified plant family and binary mode scheme using the spectral analysis of the collected 129 points and the hierarchic plant classification system.

Table 5.2. Classification scheme for post-classification change detection analysis (*n*: # of sampled plot).

	Family Level	*n*	*Anderson 4 level*	***Binary Mode***
1	*Aquifoliaceae*	5	Deciduous Forest	**Vegetation**
2	*Asteraceae*	5	Deciduous Forest	**Vegetation**
3	*Betulaceae*	6	Deciduous Forest	**Vegetation**
4	*Cupressaceae*	14	Evergreen Forest	**Vegetation**
5	*Ericaceae*	13	Mixed Forest	**Vegetation**
6	*Fagaceae*	4	Deciduous Forest	**Vegetation**
7	*Pinaceae*	17	Evergreen Forest	**Vegetation**
8	*Poaceae*	7	Deciduous Forest	**Vegetation**
9	*Rosaceae*	7	Deciduous Forest	**Vegetation**
10	Mixed Forest	19	Mixed Forest	**Vegetation**
11	Bare Rock & Soil	15	Non-Forest	**Non-Vegetated**

Image Processing Steps

ERDAS IMAGINE 9.1 was used for most image processing steps for the post-classification change detection analysis. As a pre-processing method, multi-spectral imagery of IKONOS 2001 having 1*m* ground resolution was first produced using a high-pass filter pan-sharpening technique. In addition, resampling of the Airborne 2007 imagery using a nearest-neighbor method for preserving spectral values was performed to have a consistency as 1*m* ground resolution dataset, while rescaling of the pan-sharpened IKONOS 2001 was performed to make 8 bit (0-255) imagery.

A geometric correction between the two imageries was completed using 20 ground control points (GCPs) and a second-order polynomial method. The IKONOS 2001 was used as a reference and Airborne 2007 as an input image, targeting to have less than a half-pixel accuracy registration (RMSE = 0.5). In addition, an image subset was performed to focus on the summit loop trail area of Cadillac Mountain as well as the control site (ULX: 561244.5, ULY: 4911505.5, LRX: 562050.5 563207, LRY: 4910714.5). Then, low pass filtering functions were applied in the two imageries to increase visual quality and class separability of the two imageries for the classification process.

In order to avoid confusion and false interpretation in the classified results, an image mask function was used to exclude the summit parking area (10*m* buffering to include additional parking areas close to the summit loop trail), automobile road (15*m* wide), hiking trails (2*m* wide), viewing platforms (2*m* wide), durable summit loop trail (2*m* wide), cloudy covered areas in the IKONOS 2001 (not included in the experiment and control site), and constructed buildings.

A supervised classification method was applied to produce the intended classification results (modified plant family and binary mode) for each date using two algorithms: 1) Minimum Distance to Mean and 2) Maximum Likelihood. The collected sampled points in the field survey were used as training sites, focusing on very well-known and large cover size points ($5m^2$) to minimize class confusion and maximize separability. In addition, as a post-classification process, spatial neighborhood majority filtering functions were applied to reduce the salt and pepper effect in the two classified imageries.

Accuracy assessments of the two classified results were completed using the randomly generated 300 point dataset that was collected in the field survey during the summer of 2007. By physically locating each generated point using the GPS (Trimble GeoXT) with an external antenna, ground information was concurrently recorded at the level of plant family. Using this collected information, an error matrix associated with the classified results was made to identify overall accuracies. Due to an accessibility issue over the study region (the control site), the collected accuracy assessment point dataset only covered the experimental site.

Vegetation cover changes between the two classified imageries were analyzed using an image differencing technique at the level of binary mode. To test our hypothesized relationship of relative efficacy of the management strategies for reducing vegetation impact and enhancing vegetation recovery, we computed the rates of increased and decreased vegetation covers for $30m^2$ plots that were systematically sampled in all three spatial zones at the experimental and control sites. For each plot, the rates of increased and decreased vegetation covers were calculated by an equation: *increased (or decreased) vegetation area / total vegetation area* × *100*. The mean rates of increased and decreased vegetation covers were calculated for small (0-30*m*), medium (0-60*m*), and large spatial scales (0-90*m*). T-test comparisons were used to compare the mean rates of vegetation cover changes in each spatial scale among the experimental and control sites at the $p = 0.05$ level. To test our hypothesized relationship of spatial patterns of vegetation impact and recovery within the experimental site, similar computations were made calculating the rates of increased and decreased vegetation covers based on 30m^2 plots that were systematically sampled at the experimental site. Mean rates of increased and decreased vegetation covers were calculated for core (0-30*m*), intermediate (30-60*m*) and periphery (60-90*m*), and one-way analysis of variance was used to compare the means of vegetation changes over the three spatial zones. Tukey post-hoc tests of pairwise differences in means were used to identify significant differences at the $p = 0.05$ level.

To test our hypothesized relationship of vegetation diversities with the control site, the Euclidean Distances at the large spatial scale (0-90*m*) were calculated to compare *beta* diversity between the two stands of the experimental and control sites in both 2001 and 2007 plant family level classification results. Additionally, the Shannon-Weiner (SW) diversity index, which is one of the representative *alpha* diversity metrics (Barnes et al., 1998), was statistically tested to directly compare *alpha* diversity between the two sites at the large spatial scale based on 30m^2 plots created at the $p = 0.05$ level. Additionally, to test our hypothesized relationship of vegetation diversities at the experimental site level, the same SW diversity index was statistically tested to directly compare *alpha* diversity among three zones based on the same 30m^2 plots created. At the $p = 0.05$ level, one-way analysis of variance was used to compare the means of SW diversity indices over the three spatial zones in both 2001 and 2007 plant family level classification results.

Results

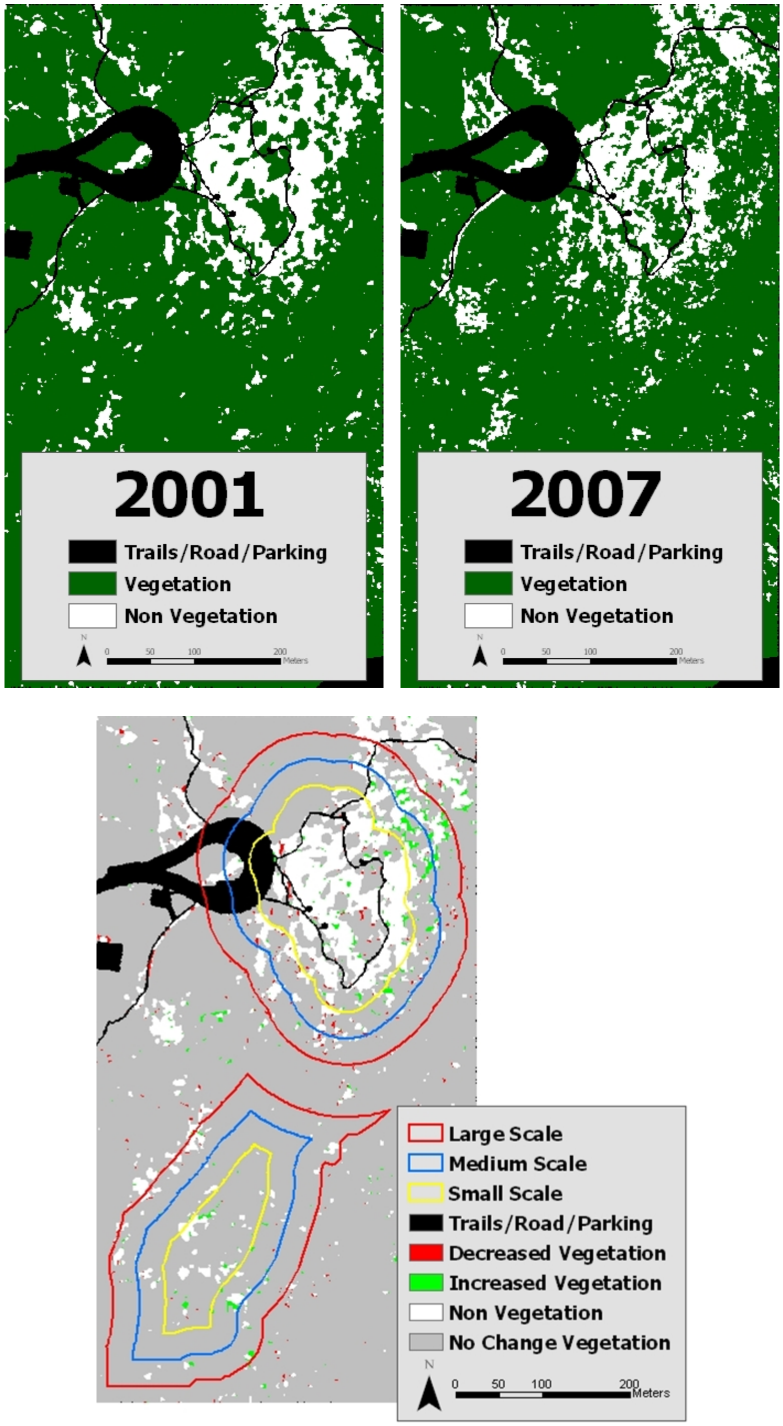


Figure 5.6. Post-classification change detection analysis based on “Minimum Distance to Mean” algorithm: the result was initially classified by the level of plant family and was recoded to the binary mode classification for calculating the rates of increased and decreased vegetation covers at both sites.

Figure 5.6 shows the result of the post-classification change detection analysis using the two high resolution remote sensing datasets. Overall estimated classification accuracies using the 300 randomly generated points over the study region were described in Table 5.3. The post classification change detection was analyzed on the basis of the results of the “minimum distance to mean,” since the algorithm has better accuracy levels than the “maximum likelihood” algorithm in all classification results including the binary mode and the level of plant family at both datasets. The rates of increased vegetation covers at the experimental site, based on the total vegetation cover, was 3.36% (483m^2) in the core (0-30*m*), 4.04% (689m^2) in the intermediate (30-60*m*), and 2.17% (518m^2) in the periphery zone (60-90*m*). The rates of decreased vegetation covers at the experimental site was 2.46% (354m^2) in the core (0-30*m*), 1.39% (237m^2) in the intermediate (30-60*m*), and 0.96% (229m^2) in the periphery zone (60-90*m*). The increased vegetation at the control site was 1.37% (171m^2) in the core, 0.78% (151m^2) in the intermediate, and 0.45% (120m^2) in the periphery zone. The decreased vegetation at the control site was 0.10% (13m^2) in the core, 0.06% (11m^2) in the intermediate, and 0.23% (62m^2) in the periphery zone. Overall, more recovery and impact rates were identified in all pre-defined spatial zones at the experimental site compared to the control site. In addition, there was a spatial relationship of decreasing vegetation impact from the core to periphery zones at the experimental site (core: 2.46% → intermediate: 1.39% → periphery: 0.96%), while showing no clear spatial relationship of increasing vegetation.

Table 5.3. Accuracy assessment.

Classification Algorithm	*Binary Mode Classification (Vegetation vs. Non-Vegetated)*	*Family Level Classification (11 different classes)*
2007 Minimum Distance	**78.08%**	**57.53%**
2007 Max Likelihood	73.88%	47.42%
2001 Minimum Distance	**76.71%**	**51.03%**
2001 Max Likelihood	69.66%	40.83%

Vegetation Cover Changes Between Experimental and Control Sites

As hypothesized, the rate of increased vegetation cover based on 30m^2 plots at the experimental site was more dynamic compared to the control site (Table 5.4). Throughout the three different spatial scale comparisons, the means of rates of increased vegetation covers were higher at the experimental site than the control site. However, the analysis results also indicated the means of rates of decreased vegetation covers were lower at the control site than the experimental site.

Table 5.4. T-tests summary: The increased and decreased vegetation areas between experimental and control sites based on 30m^2 plots at each spatial scale (*n:* # of plots, *M*: mean of percent change).

Spatial Extent (Variables)		*Experimental Site*		*Control Site*		*T*	*P*
		M (%)	*n*	*M (%)*	*n*		
Small Scale	Impact	3.81	21	0.04	6	-3.2879	0.003669
(0-30*m*)	Recovery	4.51	21	1.54	6	-2.3254	0.03328
Medium Scale	Impact	2.43	45	0.08	20	-4.0153	0.0002265
(0-60*m*)	Recovery	4.72	45	1.65	20	-3.1414	0.002548
Large Scale	Impact	2.15	72	0.08	49	-5.2341	1.589e-06
(0-90*m*)	Recovery	5.08	72	0.94	49	-4.3523	3.774e-05

The results of the T-test showed that there were significant differences in the means of rates of the increased and decreased vegetation covers between the two sites, indicating higher recovery rates (all $p < 0.01$) and higher impact rates (all $p < 0.01$) at the experimental site in all three spatial scaling approaches (Table 5.4). Therefore, within the three multi-spatial scales analysis, the employed management strategies had a positive effect in terms of enhancing vegetation regeneration and no effect in reducing vegetation impact compared to the control site from 2001 to 2007, using the post-classification change detection.

Spatial Patterns of Vegetation Cover Changes at Experimental Site

Table 5.5 contains the means of rates of decreased and increased vegetation covers for each spatial zone based on the same $30m^2$ plots within the experimental site. Although the percentage of recovery grew larger from the core to the periphery zone (core: 4.51% → intermediate: 4.91% → periphery: 5.68%), there were no significant differences among the three different spatial zones in terms of the rates of increased vegetation covers ($F = 0.1406$, $p = 0.869$). On the contrary, there was a significant difference among the three different spatial zones in terms of the rates of decreased vegetation covers ($F = 3.9002$, $p = 0.02485$). Specifically, Tukey post-hoc tests ($p < 0.05$ for all significant contrasts) for pairwise comparison indicated that there was a significant difference in the rate of decreased vegetation cover between the core ($M = 3.81$) and intermediate zones ($M = 1.30$), indicating that the mean of the rate of decreased vegetation cover was lower in the intermediate zone (30-60*m* from the summit loop trail). This result suggests that there was a clear zone difference between the two zones, supporting partially the general spatial pattern of vegetation impact by the proximity or zoning concept in a recreation site.

Table 5.5. One-way ANOVA summary for experimental site analysis: The rates of increased and decreased vegetation covers based on $30m^2$ plots at the three different spatial zones (*n*: # of plots, *M*: mean of percent change).

Variables	***Core*** (0-30*m*)		***Intermediate*** (30-60*m*)		***Periphery*** (60-90*m*)		***F***	***P***
	M (%)	***n***	***M (%)***	***n***	***M (%)***	***n***		
Impact	3.81	21	1.30	24	1.68	27	3.9002	0.02485*
Recovery	4.51	21	4.91	24	5.68	27	0.1406	0.869

*Significance of differences: impact at core > impact at intermediate (p = 0.0299476), impact at core = impact at periphery (p = 0.0667490), impact at intermediate = impact at periphery (p = 0.9082048)

Vegetation Diversity Comparison:

Euclidean Distance and Shannon-Weiner Diversity Index

The Euclidean Distance between the two sites at the level of plant family was 7,686*m* in 2001 and 13,542*m* in 2007, indicating the *beta* diversity gap between the two stands was wider over time (Figure 5.7). This result suggests that there was no positive effect of the management actions in terms of reducing the *beta* diversity gap from 2001 and 2007. Also, a one-way ANOVA and Tukey Multiple Comparison Test for *alpha* diversity analysis between the two sites showed no positive effect of the employed management strategies for enhancing the vegetation diversity at the experimental site between the two dates at the level of 10 different plant families (Figure 5.7). In our samples, the SW diversity index at the control site in 2007 was the highest and the SW diversity index at the experimental site in 2001 was lowest (the SW at the experimental site in 2001: M = 1.02, SD = 0.46, n = 72: the SW at the experimental site in 2007: M = 1.18, SD = 0.45, n = 72: the SW at the control site in 2001: M = 1.67, SD = 0.26, n = 49: the SW at the control site in 2007: M = 1.46, SD = 0.25, n = 49). There was a significant difference among the *alpha* vegetation diversity at the experimental and control sites in 2001 and 2007, one-way ANOVA, F (3, 238) = 34.314, $p < 0.001$.

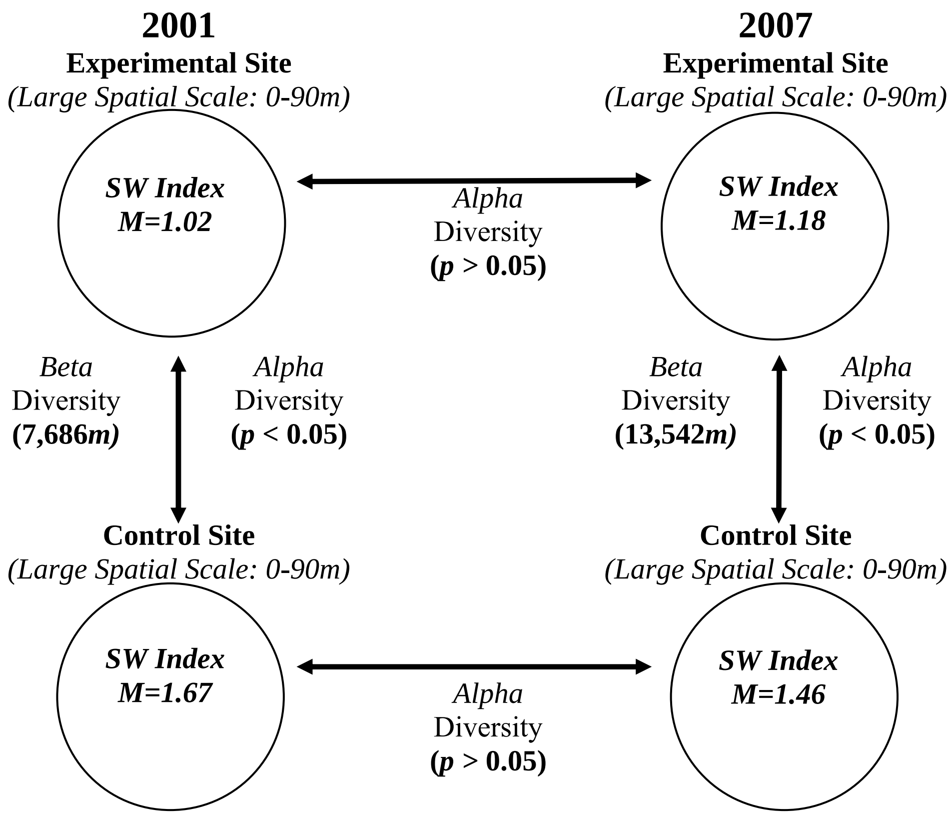


Figure 5.7. Statistical analysis results: *Alpha* (SW Diversity Index) and *Beta* (Euclidean Distance) diversities (*M*: mean of the SW).

Specifically, the Tukey post hoc tests for pairwise comparisons between the two dates at the experimental site showed that the mean of the SW diversity index ($M = 1.02$) in 2001 was not significantly different from the mean of the SW diversity index ($M = 1.18$) in 2007 ($p > 0.05$). Also, at the control site, the mean of the SW diversity index ($M = 1.67$) in 2001 was not significantly different from the mean of the SW diversity index ($M = 1.46$) in 2007 ($p > 0.05$). However, the analysis results indicated that the mean of the SW diversity index ($M = 1.67$) at the control site in 2001 was higher than the mean of the SW diversity index ($M = 1.02$) at the experimental site in 2001 ($p < 0.05$). Also, the mean of the SW diversity index ($M = 1.46$) at the control site in 2007 was higher than the mean of the SW diversity index ($M = 1.18$) at the experimental site in 2007 ($p < 0.05$).

This result suggests that the lower *alpha* vegetation diversity at the experimental site was already formed before 2001 and did not change regardless of the deployed management strategies.

Spatial Patterns of Vegetation Diversity Changes at Experimental Site

Vegetation diversities at the experimental site varied among the three zones based on the 2001 plant family level classification (Figure 5.8). The mean of SW diversity index increased going from the core to periphery zones (core: 0.84 → intermediate: 1.01 → periphery: 1.16). A one-way ANOVA for *Alpha* diversity showed there was a significant difference among the three different spatial zones in terms of the mean of vegetation diversity ($F = 3.1751$, $p = 0.04796$). Specifically, Tukey post-hoc test ($p < 0.05$ for all significant contrasts) for pairwise comparison indicated that there was a significant difference in the mean of vegetation diversity between the core ($M = 0.84$) and periphery zone ($M = 1.16$), indicating higher *alpha* vegetation diversity in the outer area, 60-90*m* from the summit loop trail ($p < 0.05$). In addition, vegetation diversities at the experimental site were varied among the three zones in 2007 (Figure 5.8). The mean of SW diversity index was also increased from the core to periphery zone (core: 1.00 → intermediate: 1.19 → periphery: 1.31). A one-way ANOVA and Tukey Multiple Comparison Test for *alpha* diversity analysis among the spatial zones showed there was a significant difference in the mean of vegetation diversity between the core ($M = 1.00$) and periphery zone ($M = 1.31$), suggesting higher *alpha* vegetation diversity in the same outer area ($F = 3.2547$, $p = 0.04459$). These analyses using the plant family level classifications of 2001 and 2007 support that vegetation diversity also differs based on the zoning and proximity from the central part of the site as well as the spatial patterns of vegetation cover changes by recreational use and trampling.

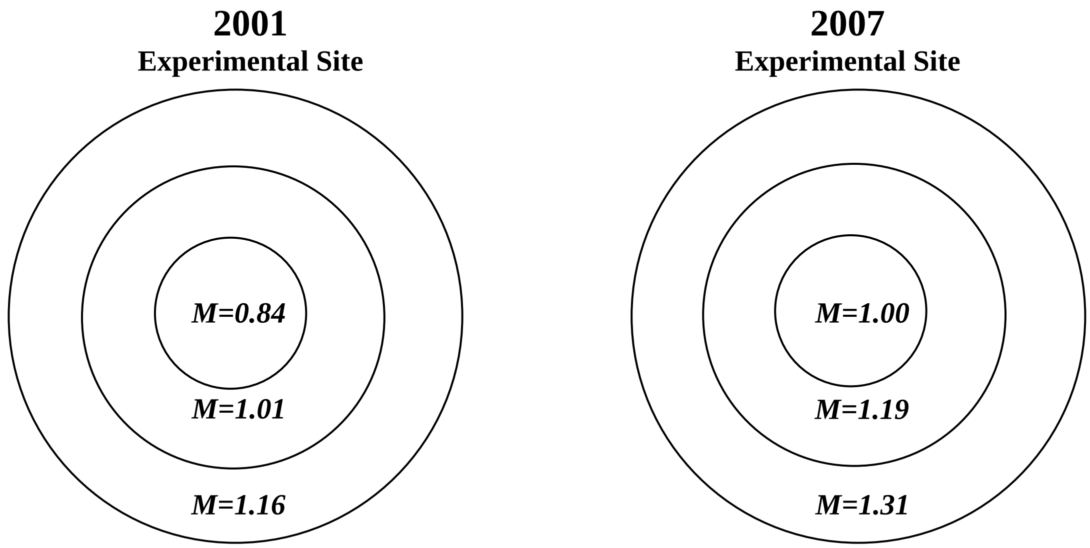


Figure 5.8. One-way ANOVA for vegetation diversity in the three different spatial zones (core → intermediate → periphery) at experimental site (*M*: mean of the SW index). Significance of differences: SW at core in 2001 < SW at periphery in 2001 ($p < 0.05$), SW at core in 2007 < SW at periphery in 2007 ($p < 0.05$).

Discussion

Diverse methods based on social and biophysical approaches have been utilized to verify the efficacy of management strategies by measuring vegetation change dynamics in amount and composition in the field of recreational ecology, but this study extended earlier work by adopting a multi-spatial scale analysis approach, and by extensively enlarging the study region with the aid of remote sensing technology. While no clear zone differences in vegetation recovery were identified at the experimental site, a similar pattern in vegetation impact based on the proximity and the zoning concept was identified in our study site between the core and intermediate zones (higher impact at the core zone). Unlike traditional recreation ecology study sites such as a cluster of campsites and backcountry trails, the Cadillac summit has a completely open nature of terrain characteristics and prevalent off-trail use. In spite of these landscape and visitor use differences, we believe that the spatial impact and recovery patterns based on the proximity or zoning concept is still a valuable tool to explain vegetation change dynamics at the recreation site as well as to establish the site boundary.

Cole (2004) indicates that the theory related to impact and recovery still remains poorly developed in the field of park and recreation management, even if data processing methods have become more sophisticated. In that regard, we attempted to define the site boundary using the impacted vegetation pattern that we observed in the vicinity of the summit loop trail. As described, we defined the general vegetation impact as a similar pattern to a two horizontal asymptotes curve line (arccot shape) on the basis of proximity (McEwen & Tocher, 1976) (Figure 5.1). The impact will be highest in the impact zone, reduced in the intersite zone (in our case, "intermediate zone" could be a better name), and finally stabilized at the buffer zone. Based on our study results, the calculated vegetation impact rates from 0 to 100*m* showed an overall decreasing impact pattern except the drastically decreased areas from 30-50*m* (Figure 5.9). This actual impact rate was used to presume the boundary between the impact and the intermediate zones based on the decreasing relationship of vegetation impact between the two zones. The calculated vegetation impact rates showed the decreasing relationships at two areas: 20 to 30*m* and 60 to 70*m* from the summit loop trail. However, considering the extremely high visitor density and widespread distribution observed in many social science studies at Cadillac, the first decreased areas 20 to 30*m* from the summit loop trail may be unrealistic to designate as a boundary between the impact and intermediate zone, and we suggest the second decreased areas 60-70*m* could be the middle of the intermediate zone at Cadillac Mountain (the functional role of the intermediate zone). Accordingly, this assumption suggests that the boundary between the impact and intermediate zones should be established below 60-70*m* in order to maximize the spatial containment strategies in the impact zone. We also suggest that the less impacted vegetation areas 30 to 50*m* in distance, unlike the general impact pattern in a recreation site, may be a direct effect of the management practices focusing on the closer proximity to the summit loop trail. Given the assumption of the decreasing relationship in vegetation impact as we go away from the central part of the site, the areas in distance 30 to 50*m* could be the portions that may be positively influenced by the management strategies. There is also a clue to presume the boundary between the intermediate and the buffer zone, since areas 70-100*m* from the summit loop trail showed the relatively stable vegetation impact rates maintaining around 1% impact (the functional role of the buffer zone). While this observed pattern was mainly demonstrated by the rates of decreased vegetation covers based on proximity, it could be used as a simple method to define a site boundary by detecting vegetation cover changes in a spatial context.

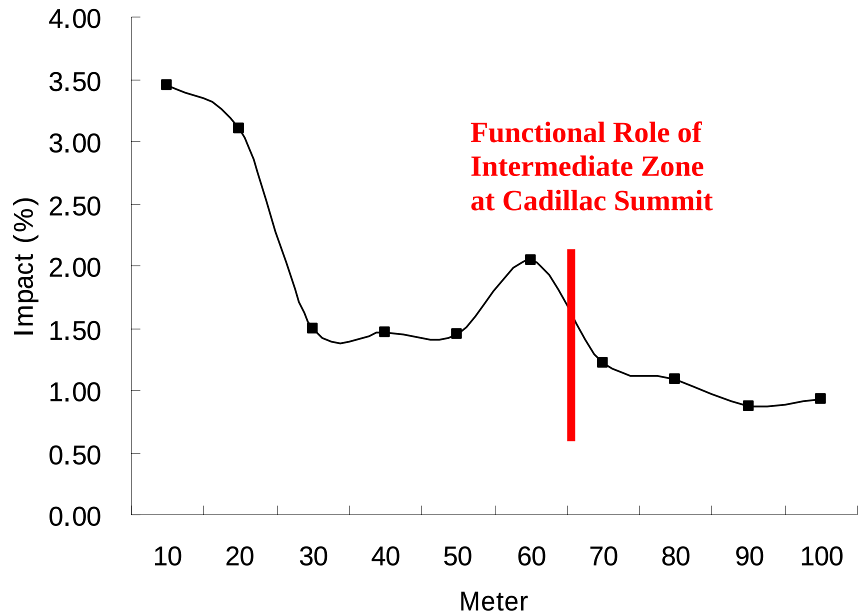


Figure 5.9. The rate of vegetation impact in the vicinity of the summit loop trail from 0 to 100*m* based on the post-classification change detection analysis (X: distance from the summit loop trail, Y: rate of impact, percent change).

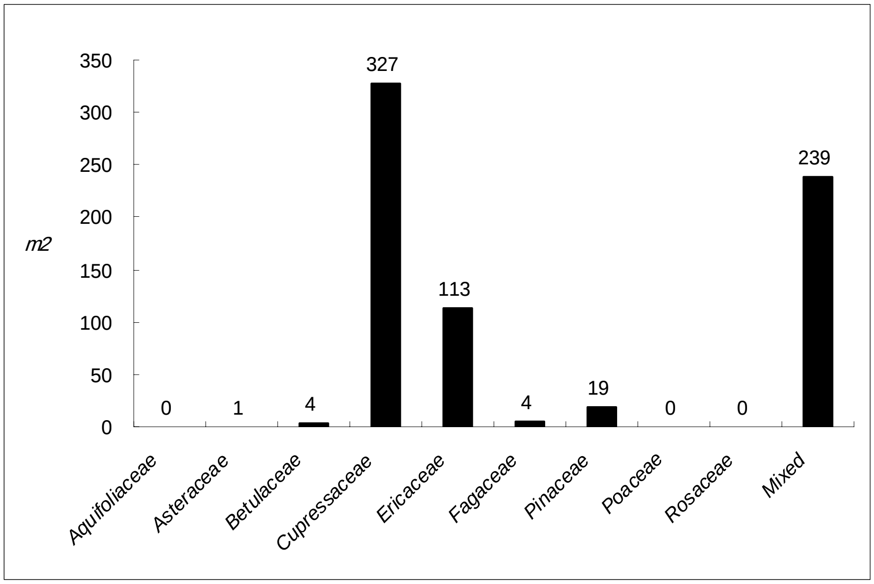
Given the fact that the experimental site showed higher impact rates than the control site with a natural variability, it is possible that the summit is still experiencing the amount of vegetation loss coupled with visitor use over time, even if the rates of impact were relatively lower than the rates of recovery. Particularly, vegetation impact was extensively distributed within 60*m* from the summit loop trail, while showing some of clustered areas at the periphery zone (60-90*m*). Outside of the large spatial scale at the experimental site, the Cadillac North Ridge Trail located on the northwest side of the parking lot and the Cadillac South Ridge Trail located on the south side of the concession area have been impacted without any distinctive site and visitor management practices. In these locations, there are less visible forms of intensive management actions such physical barriers and low impact signs. It is plausible that visitors may be going to these locations before the summit loop trail and unaware of management actions that inform visitors to walk on trail and durable surfaces. Therefore, more intensive management considerations in conjunction with the current management strategies in the summit loop trail are recommended to reduce vegetation impact at those areas.

Direct effect of the physical barriers to reduce vegetation impact at the summit loop trail is an important factor to verify the effectiveness of the site management practice. Currently, the three oval shaped physical barriers covering the total areas of 1,860m^2, mostly focusing on the northern part, were installed within the loop trail. The intrinsic objective of the physical barriers was to keep visitors out of specific areas where trampling and soil erosion were at high risk (Turner, 2001). It was verified that the rate of increased vegetation cover within the three exclosures between 2001 and 2007 was 5% (25m^2), while the rate of decreased vegetation cover was virtually 0% (1m^2), and non-changed vegetation was 95% (435m^2). This suggests that no dynamic vegetation cover changes by trampling or off-trail hiking occurred within the three physical barriers. Considering the nature of sub-alpine environments that usually take a long time to recover after being damaged, the 5% of recovery and the 95% of no-change rates may reveal the positive effect of the direct approach to reduce further vegetation impact at Cadillac Summit. Interestingly, visitors' experiences at the summit were not diminished by the exclosures, and visitors preferred more intensive management such as physical barriers along the summit loop trail (Bullock & Lawson, 2008). Therefore, reinforcing and expanding the utilization of the exclosures coupled with broader landscape issues on the summit near the parking area identified above could be utilized at those chronically susceptible areas.

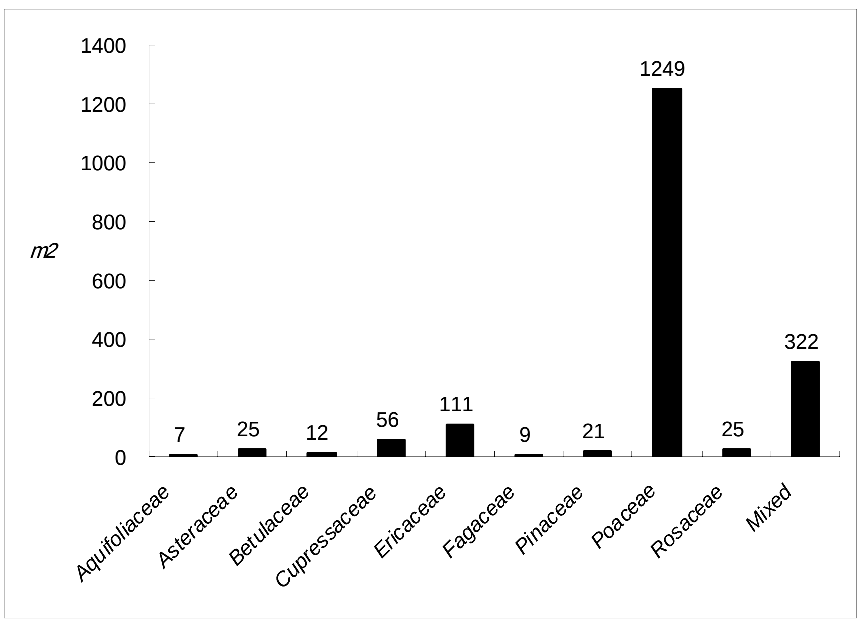
Within about 500*m* from the summit loop trail, facing west, there is another large parking area called as “Blue Hill Overlook.” While the site was not a part of this vegetation change detection analysis, it was verified that the level of vegetation impact in the vicinity of the Overlook was extensively high. In the mid of 1980s, the site was renamed from “Sunset Point” to the less enticing “Blue Hill Overlook” because of the popularity of this area, parking congestion, and vegetation degradation occurring in this vicinity. However, the site has served as an alternative location, especially when the summit vicinity was full and congested. In fact, during our field survey of August 2007, it was easily observed that a great number of visitors have been using the site for sunset sightseeing, even if the visitation level was not concurrently recorded. No particular management practices have been applied to maximize visitor satisfaction and to minimize resource impact at this site until now. Therefore, re-evaluation of the current non-management at the Blue Hill parking area near the summit might be warranted to reduce the level of vegetation impact.

Due to the low accuracies at the plant family level classifications in 2001 and 2007, it was assumed that analyzing family composition changes may not be applicable between the two dates. However, it was possible to identify impacted and recovered vegetation families by overlapping the increased and decreased vegetation polygon layers, the major outcomes of the binary mode change detection analysis, over each family level classification result of 2001 and 2007. Based on the large spatial scale at the experimental site, the vegetation families impacted the most were identified as *Cupressaceae* (327m^2, mainly low-lying *Juniper*), *Mixed Forest* (272m^2), and *Ericaceae* (128m^2). In addition, the vegetation families that recovered the most were identified as

Poaceae (1,249m^2, grass family) and *Mixed Forest* (322m^2) based on the same large spatial scale at the experimental site (Figure 5.10).



Impacted Vegetation Families



Recovered Vegetation Families

Figure 5.10. Impacted vs. recovered plant families at the experimental site between 2001 and 2007 (Y: square meter).

We observed *Cupressaceae* that mainly includes low-lying *Juniper* as the most impacted plant type (46% of the total impact layer). This suggests that vegetation impact in the vicinity of the summit loop trail was not limited to low-growing shrub, which is typically reported in recreation ecology as the most impacted vegetation type due to the poor recovery ability after initial trampling (Cole, 1995b; Cole & Monz, 2003). As well as low-lying *Juniper*, it is possible that *Ericaceae* (mainly blueberry) was one of the impacted plant types at Cadillac, since the major recreational activities in the vicinity of the summit loop trail involve berry-picking (Littlejohn, 1999; Turner, 2001). On the other hand, it was observed that *Poaceae* (grass family, mostly open-canopy) was dominantly recovered since 2001 (68% of the total recovery layer), which is one of the most resistant families to trampling in recreation ecology (Cole & Monz, 2002; Hammitt & Cole, 1998; Marion & Cole, 1996). The characteristics of grass on trampling are "high resistance" and "high resilience" based on a root system holding soil tightly, a relatively flexible stem structure, and rapid growth and spreading (Cole & Monz, 2003; Hammitt & Cole, 1998; Judd et al., 2002). Therefore, as suggested in the findings of traditional recreation ecology studies (Cole & Monz, 2002; Green, 1998; LaPage, 1967), it is plausible that the experimental site has been transformed toward more resistance after being trampled over time, replacing native plants as grass families and accelerating vegetation diversity to be lower in the vicinity of the summit loop trail.

The *alpha* vegetation diversity between the two sites was significantly different, indicating higher vegetation diversity at the control site over time. As described, it has been consistently reported that vegetation diversity in a recreation site would be significantly reduced after being trampled, eventually leading to vegetation changes in composition and structure (Cole, 2004; Green, 1998; Stohlgren & Parsons, 1986; Tolvanen et al., 2004). The vegetation diversity metric results in our analysis directly support the previous recreation ecology study findings and suggest that the experimental site had undergone a constant level of impact, as a form of trampling or off-trail hiking, even before 2001 when no management practices were applied except the paved trail. While the intrinsic objective of the two distinctive management practices was not designed to enhance vegetation diversity, it was shown that the management practices have no positive relationship with the trends in vegetation diversity at Cadillac from 2001 to 2007. Although we utilized a simplified vegetation diversity metric based on 10 different plant families, our study extended earlier work by investigating the spatial pattern of different vegetation diversity at the recreation site, which is a higher potential of low vegetation diversity in the core zone compared to the intermediate and periphery zones. As well as spatial pattern of vegetation cover changes, this spatial variance in the vegetation diversity eventually will be beneficial in designing specific management objectives and implications suitable for each zone.

Technical Considerations

Our post-classification change detection analysis design has spatial and temporal scaling issues to be investigated more in-depth. Various spatial scales were applied under the given assumptions: 1) small (30*m* buffering distance), medium (60*m*), and large spatial scale (90*m*) for defining the study boundaries, 2) 30m^2 plots for calculating the rates of increased and decreased vegetation covers as well as comparing vegetation diversity between the two sites, and 3) 2-15*m* distances for making the mask-out layer for reducing a false classification interpretation. It is obvious that there is no single correct answer in identifying or selecting the exact spatial scales, and it sometimes involves a trial and error procedure to capture a relatively similar result in analysis (Manly, 2001). Therefore, it is possible that there might be a slightly different result, once we adopt and use different spatial scales in each case.

There is also a potential phenological issue from the temporal gap of imagery acquisition (approximately 45 days), as well as different characteristics of imagery sensors and platforms. Although both imageries are leaf-on versions and no major natural disturbances were reported during the analysis time frame, there might be a different canopy structure that may cause a false interpretation of the classification results. While we utilized post-classification change detection analysis to minimize radiometric co-registration problem and a few recommended image enhancement techniques, performing the analysis with imageries captured from different sensors and platforms was challenging, especially using the same classification scheme (Serra et al., 2003). Particularly, due to the different sensor characteristics, *Rhizocarpaceae* (lichen family) was merged to bare rock/soil class in the 2007 dataset for consistency in analysis.

Given the binary structure of the classified results, the overall accuracy levels of the classified results were lower (76.71% in 2001 and 78.08% in 2007) through the 300 randomly generated point dataset. Although the sub-meter accuracy GPS unit (Trimble GeoXT) was utilized to detect actual ground information for the accuracy assessment purpose at the pixel level ($1m^2$), it is commonly agreed that there are always potential GPS errors caused by various factors such as atmospheric and topographic effects. Especially, it was discovered that there was maximum 1-2*m* positional error (maximum 2-3*m* error under a heavy canopy), when the GPS unit was tested before the field investigation for accuracy assessment. This technical limitation may cause difficulty in locating the reference points generated in less than 1-2m^2 homogeneous areas.

Conclusion

The study results indicate that by applying the vegetation comparison and the multi spatial scale analysis, the newly initiated site and visitor management practices in 2000 have been validated to enhance vegetation recovery in the vicinity of the summit loop trail during the analysis time frame. However, it was also discovered that the summit was still suffering vegetation impact associated with trampling and off-trail hiking as well as low vegetation diversity. Therefore, in order to maintain the dual mission of the agency, there is a need to reinforce the current site and visitor management practices more intensively to prevent additional vegetation impact in the vicinity of the summit loop trail. For a long-term purpose, alternative ways to strengthen vegetation diversity may be considered using a more active ecological restoration project and site protection based on direct management regimes.

A future step for management is evaluating the effectiveness of implementation of the more intensive management actions around the summit loop trail. For example, depending on one's point of view, detections of vegetation recovery by 3.4% and vegetation impact by 2.5% within 30*m* of the trail from 2001 to 2007 might constitute real progress in terms of management goals, or alternately, insignificant changes. The development of clear objectives such as indicators and standards of resource conditions will become increasingly important for assessing management actions directed towards minimizing impact and maximizing recovery. Only where specific objectives have been established can one consistently determine whether or not an impact of a given magnitude constitutes an effective management strategy. In addition, a future analysis must involve vegetation conditions before 2000, when almost no management practices were implemented except the paved trail. Although there have been limited remote sensing datasets before 2000 in ANP, directly comparing the rates of vegetation cover changes before and after 2000 would give more information about the effectiveness of the employed management practices.

The remote sensing technology used here offers opportunities for managers and researchers to take a big picture view of visitor-induced resource impact in national parks. Although the outcomes of our analysis approach may be less detailed in identifying the amount and composition of vegetation changes compared to traditional recreation ecology methods, the proposed post-classification change detection analysis using high resolution remote sensing datasets is useful for measuring the aggregated vegetation change dynamics at a larger spatial scale. Measurable vegetation changes in conjunction with GIS and statistical analyses would provide baseline data for detection in trends of changes over longer periods of time. The ability to compare these data with future imageries will add a valuable component to the current monitoring process in the park.

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CHAPTER 6

DETECTING VEGETATION COVER CHANGE ON THE SUMMIT OF CADILLAC MOUNTAIN USING MULTI-TEMPORAL REMOTE SENSING DATASETS: 1979, 2001, AND 2007

Abstract

This study examines the efficacy of management strategies implemented in 2000 to reduce visitor-induced vegetation impact and enhance vegetation recovery at the summit loop trail on Cadillac Mountain at Acadia National Park, Maine. Using single-spectral high resolution remote sensing datasets captured in 1979, 2001 and 2007, pre-classification change detection analysis techniques were applied to measure fractional vegetation cover changes between the time periods. This popular sub-alpine summit with low-lying vegetation and attractive granite outcroppings experiences dispersed visitor use away from the designated trail, so three pre-defined spatial scales (small: 0-30*m*, medium: 0-60*m*, large: 0-90*m*) were examined in the vicinity of the summit loop trail with visitor use (experimental site) and a site chosen nearby in a relatively pristine undisturbed area (control site) with similar spatial scales. Results reveal significant changes in terms of rates of vegetation impact between 1979 and 2001 extending out to 90*m* from the summit loop trail with no management at the site. No significant differences were detected among three spatial zones (inner: 0-30*m*, middle: 30-60*m*, outer: 60-90*m*) at the experimental site, but all were significantly higher rates of impact compared to similar spatial scales at the control site (all $p < 0.001$). In contrast, significant changes in rates of recovery between 2001 and 2007 were observed in the

medium and large spatial scales at the experimental site under management as compared to the control site (all $p < 0.05$). Also during this later period a higher rate of recovery was observed in the outer zone as compared to the inner zone at the experimental site ($p < 0.05$). Overall study results suggest a trend in the desired direction for the site and visitor management strategies designed to reduce vegetation impact and enhance vegetation recovery at Cadillac Summit since 2000. However, the vegetation recovery has been rather minimal and did not reach the level of cover observed during the 1979 time period. We discuss the advantages and some limitations of using remote sensing technologies in detecting vegetation change in this setting and potential application to other recreation settings.

Key words: vegetation, trampling, change detection, single-spectral image, remote sensing

Introduction

Acadia National Park (ANP) is part of the U.S. National Park System, which has as its dual mission to conserve biological and cultural resources as well as provide enjoyment for people (Daigle & Zimmerman, 2004). Visitation rates of the park are similar to many other national parks in that it has been relatively stable over the past few decades. For example, ANP received an estimated 2.2 million visitors in 2009, 2.3 million in 1990, and 2.7 million in 1980. However, given the acreage of the park and visitation rate, ANP is one of the most densely populated national parks in U.S. (Jacobi, 2001b; Manning et al., 2006; Wang & Manning, 1999). The summit loop trail at Cadillac Mountain is a major destination for ANP visitors and receives an estimated 0.5 ~ 0.8

million visitors during the summer (June ~ August) each year (Jacobi, 2001a, 2003). There are three hiking trails to the summit of Cadillac, as well as an auto road and the summit loop trail that is 0.3 miles long. A survey completed by the National Park Service (NPS) in 1998 showed 76% of the total visitors to the park visited the summit of Cadillac Mountain (Littlejohn, 1999). The sensitive sub-alpine nature of the site coupled with high levels of visitor use has created a scenario where vegetation degradation and soil erosion are at a high risk. The site represents a management challenge to balance the public's desire for visiting a popular destination and at the same time to maintain the natural conditions of the area.

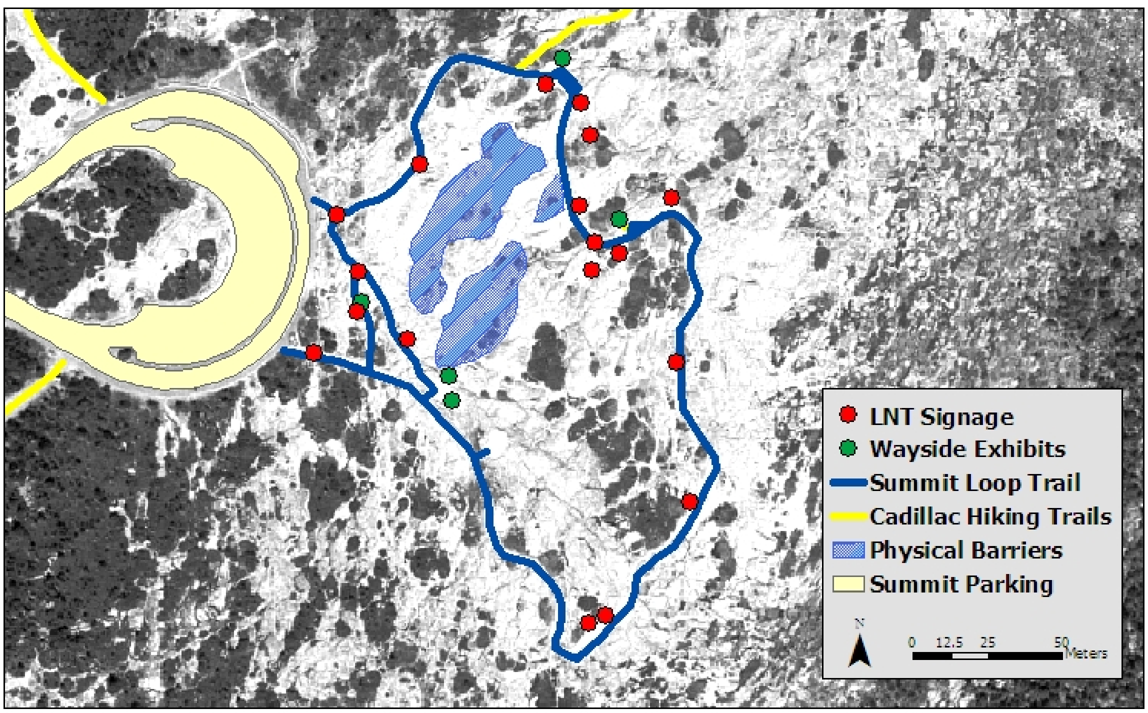


Figure 6.1. Locations of physical barriers (light blue) and LNT signage (red), captured by a GPS (Trimble GeoXT) and exported as an ESRI shapefile format.

Figure 6.2. Indirect management (left, LNT signage) and direct management (right, physical barriers): ANP has been utilized both management approaches since 2000 along the summit loop trail of Cadillac Mountain in order to reduce direct trampling effect, especially caused by off-trail hikers.

There have been efforts by management to concentrate visitor use on durable surfaces such as the installment of a paved summit loop trail and viewing platforms. However, more intensive management began in 2000 to minimize vegetation impact in the vicinity of the summit loop trail. Both indirect and direct management methods were employed using low impact educational messages (signposts) and physical barriers (exclosures), respectively (Figures 6.1 & 6.2). Over the past decade several studies have examined the implications of the employed management strategies on visitors' perceptions and experiences as well as visitor use patterns (Bullock & Lawson, 2007, 2008; Park et al., 2008; Turner, 2001). However, there has been little direct study examining the effectiveness of the management strategies on actual vegetation changes.

In order to support park management initiatives adopted in 2000, it is our belief that a process to assess the effectiveness of the employed management practices along the summit loop trail should be implemented as part of a long-term monitoring program.

This is particularly important under the dual mandate of NPS because the manager must choose an optimal way between current management (when effective) and other alternative management strategies (when not effective) by regularly evaluating the effectiveness of the management practices. The primary purpose of this study was to assess the efficacy of the site and visitor management strategies designed to reduce vegetation impact and enhance vegetation recovery in the vicinity of the summit loop trail, using pre-classification change detection analysis based on single-spectral high resolution remote sensing datasets: 1979, 2001 and 2007. Additionally, with the aid of remote sensing technology, the study was designed to identify large spatial patterns of vegetation changes at a recreation site with terrain characteristics of low vegetation and rocky outcroppings and consequently prevalent off-trail use.

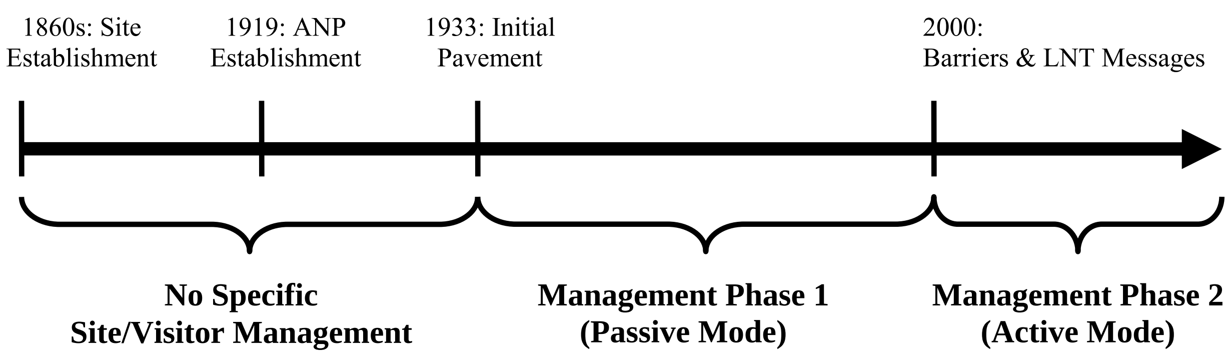


Figure 6.3. Site/visitor management at Cadillac Summit: In order to identify the effect of the employed indirect and direct management practices since 2000, three remote sensing datasets captured in 1979, 2001, and 2007 were used for a detailed vegetation change analysis.

Remote Sensing Technology for Park and Outdoor Recreation Management

Remote sensing refers to the detection and recording of values of emitted or reflected electromagnetic radiation with sensors in aircrafts or satellites (Ingle et al., 2003). Potential advantages of remote sensing include collecting large amounts of data very quickly and the availability of archived data that can be used to identify trends in resource conditions. In addition, the archived data including aerial photographs generally have a high spatial resolution such as 1*m* and sub-meter, and cover long time sequences of a target area (Carmel & Kadmon, 1998). From the perspective of park and outdoor recreation management, a growing body of research has begun to explore the potential usefulness of remote sensing technologies for 1) inventorying recreational resources (Burnett & Conklin, 1979; Dill, 1963; MacConnell & Stoll, 1968; Miller & Carter, 1979), 2) monitoring impact and change in recreational resources (Hockings & Twyford, 1997; Leung et al., 2002; Marion et al., 2006; Witztum & Stow, 2004), and 3) addressing the importance of remote sensing in park and outdoor recreation management (Butler & Wright, 1983; Draeger & Pettinger, 1981; Gross et al., 2006; Ingle et al., 2003; Monz & Leung, 2006).

Remote sensing technology has advantages over traditional and representative recreation ecology methods such as on-site measurement and experiments in its ability to examine large scale (albeit lower resolution) vegetation change. Typical recreation ecology studies involving assessments of trail impacts have tended to be relatively small in spatial scale within a few meters from the center of the trail. Turner (2001) observed at the Cadillac summit that visitor impact on vegetation and soil was not limited to just a few meters from the trailside of the summit loop trail. Visitor impact was occurring far beyond up to 50-90*m* from the summit loop trail on the basis of Turner's sampling plots for vegetation trampling and observations of visitor behavior. Many activities were witnessed with this off-trail hiking including photo-taking, berry-picking, and bird watching (Turner, 2001). Therefore, by using high resolution remote sensing datasets, more extensive vegetation change detection would be possible as well as nearby areas where accessibility was extremely low for assessing more natural variation of vegetation changes on the summit. This factor was important because we adopted a vegetation comparison mechanism by selecting a control site which maintains a relatively pristine or undisturbed environment with little or no visitor use. Also, it is important to mention that there were no field-based datasets available to verify the degree of vegetation impact before the site and visitor management were implemented in 2000. Therefore, it was expected that the remote sensing datasets captured in 1979, before the employed management practices, would give a unique opportunity to identify the effect of the management strategies by detecting fractional vegetation cover changes over time.

Methods

Study Design

Three high resolution remote sensing datasets were utilized in this study to detect fractional vegetation cover changes over time. All three datasets (1979, 2001, and 2007) were obtained from ANP. Other ancillary datasets such as the locations of signpost messages (Leave No Trace principle) and physical barriers on the top of Cadillac Mountain were collected using a Trimble GeoXT with an external antenna and bypass. After post-processing for differential positioning to increase accuracy, they were exported as an ESRI shapefile format with sub-meter accuracy. Table 6.1 gives more details of the imageries used for the analysis (Table 6.1).

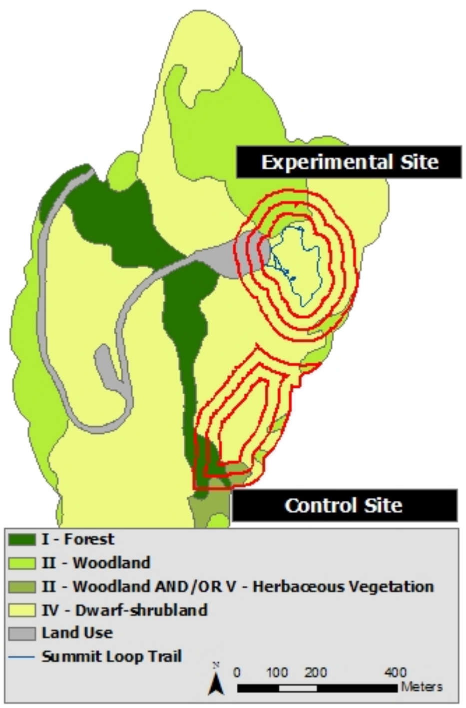
Table 6.1. Description of remote sensing datasets used.

Year	Dataset	Acquisition date	Spatial Resolution (*m*)	Spectral Resolution
1979	Scanned color-infrared Aerial photograph	August 17, 1979	submeter (0.45)	True Color (RGB)
2001	IKONOS panchromatic (PRO option)	August 21, 2001	1.00	Panchromatic (single)
2007	National Agriculture Imagery Program (NAIP)	July 26, 2007	1.00	True Color (RGB)

Two major methodological approaches were applied using the three high resolution remote sensing datasets in this study: 1) multi-spatial scale analysis that employs a series of varying sizes of study extents and 2) vegetation comparison mechanism. Because of the extensively distributed nature of vegetation impact, we expected it to be a challenge to identify a clear extent of the study impact area; therefore, we utilized three different buffering widths from the summit loop trail to verify the relative effectiveness of the employed management strategies as well as to cope with the ambiguous site boundary problem: small (0-30*m* buffering width), medium (0-60*m*), large spatial scale (0-90*m*). The adopted method was guided by various landscape ecology studies that attempt to discover appropriate spatial scale by controlling the size of impact extent (Kendall et al., 2003; Levin, 1992; Madrigal et al., 2008; Turner, 1989; Turner et al., 2001; Wiens, 1989). The three spatial extents were established with the assumption that there was limited visitor dispersion beyond 100*m* from the summit loop trail.

A vegetation comparison mechanism was used to better understand the degree of vegetation change in the vicinity of the summit loop trail by selecting a nearby control site in similar spatial scale with limited to little or no visitor use and therefore a more environmental characteristic of natural variation in vegetation changes (Cole, 1995;

Hammitt & Cole, 1998). For selecting the control site, we adopted "elevation" as an important factor as that shapes the vegetation community, especially in an alpine or sub-alpine natural environment with a short growing season (Barnes et al., 1998; Boughton et al., 2006; Kimball & Weihrauch, 2000). Other selection criteria were used to delineate the control site by including the same area close by that experienced the disastrous fire of 1947. Finally, additional areas were avoided to exclude potentially visitor accessible areas such as nearby structures including parking lots, auto roads, concession and restroom areas, and the hiking trail network.



Spatial Scale	Experimental Site: Management/Visitor Use	
	Area (m^2)	Vegetation Cover*
Small (0-30*m*)	33,497	Dwarf-shrubland: 93%
Medium (0-60*m*)	57,612	Dwarf-shrubland: 86%
Large (0-90*m*)	87,136	Dwarf-shrubland: 81%
Spatial Scale	Control Site: No Management/No Visitor Use	
	Area (m^2)	Vegetation Cover*
Small (0-30*m*)	13,524	Dwarf-shrubland: 99%
Medium (0-60*m*)	33,460	Dwarf-shrubland: 86%
Large (0-90*m*)	61,551	Dwarf-shrubland: 76%

Figure 6.4. Selected control site: the experimental site represents visitor impact and management strategies. In contrast, the control site represents no visitor impact and no management strategies. *Vegetation cover types based on the result of the Vegetation Mapping Project by NPS-USGS (Lubinski et al., 2003).

The study design enabled us to test the following: 1) The rates of vegetation cover change between 1979 and 2001 at the experimental site with no-management will have higher rates of vegetation impact and lower rates of vegetation recovery than at the control site; 2) The rates of vegetation cover change between 2001 and 2007 at the experimental site with management will have higher rates of vegetation recovery and lower rates of vegetation impact than at the control site; and 3) The rates of vegetation cover change will differ among the spatial zones at the experimental site with higher rates of vegetation recovery and lower rates of vegetation impact at the outer spatial zone as compared to the inner spatial zone in proximity to the summit loop trail.

Image Processing Steps

The following image processing steps were completed in Erdas IMAGINE 9.1. As a pre-processing step, geometric corrections among the three imageries were carried out using a second-order polynomial method. The IKONOS 2001 was utilized as a reference and the two other imageries as input imageries, targeting to have less than a half pixel accuracy registration. By focusing more on the study region that includes the experimental and control sites, 22 ground control points (GCPs) for geometric correction were used for the National Agriculture Imagery Program (NAIP) 2007 imagery (RMSE = 0.832) and 68 GCPs for the scanned color-infrared 1979 imagery (RMSE = 8.8). The high RMSE in the 1979 imagery was caused by more distorted levels in the process of the scanning. The two input imagery were resampled using a nearest-neighbor method to have a consistency as 1*m* ground resolution dataset of the IKONOS 2001, respectively (NAD 83, UTM Zone 19). In addition, image subsets were performed to focus on the summit loop trails areas of Cadillac Mountain as well as the control site (ULX: 561250, ULY: 4911505, LRX: 562047, LRY: 4910716).

To produce single-band structure images for a pre-classification change detection analysis, the two RGB colored imageries of 1979 and 2007 were spectrally degraded by averaging the RGB bands (Li et al., 2005; Wulder et al., 2000). As a radiometric correction process, histograms of the three images were matched using the NAIP 2007 as reference image, particularly recommended for a high resolution dataset radiometric normalization (Hong & Zhang, 2005). In order to avoid confusion and false interpretation in the classified result, an image mask function was used to exclude the summit parking area (10*m* buffering to include additional parking areas close to the summit loop trail), automobile road (15*m* wide), hiking trails (2*m* wide), viewing platforms (2*m* wide), summit loop trail (2*m* wide), cloudy covered areas in the IKONOS 2001 (not included in the experiment and control site), and buildings.

A pre-classification change detection analysis based on multi-temporal RGB analysis (Sader et al., 2003; Sader & Winne, 1992) was used to identify detailed vegetation cover changes over time. The analysis technique was originally designed to visualize vegetation cover changes using three dates of NDVI imagery concurrently and the interpretation concepts of color additive theory. Our application was re-designed to use single-spectral images based on the same analysis concept, considering higher radiometric reflectance values as non-vegetation areas, which is the reverse of the original multi-temporal NDVI-RGB analysis (Chapter 4). For interpretation of results, a maximum variation was utilized by controlling a boundary threshold (Long Dai & Khorram, 1999; Lu et al., 2004) that differentiates "change" from "no-change," in order to minimize illumination gaps among the images. In addition, spatial neighborhood majority filtering functions were applied to reduce the salt and pepper effect in the classified results (Lu & Weng, 2007; Macleod & Congalton, 1998).

A field study was completed in the summer of 2007 to help assess the accuracy of the classified results indicating vegetation and non-vegetation areas. A total of 300 reference ground points were randomly generated along with the classified results recoded in binary mode (vegetation vs. non-vegetation) by merging increased vegetation and no-change area as "Vegetation," and decreased vegetation and non-vegetation areas as "Non-Vegetated." A Trimble GeoXT with an external antenna was used to physically locate the 300 randomly generated reference points to record vegetation vs. non-vegetated information.

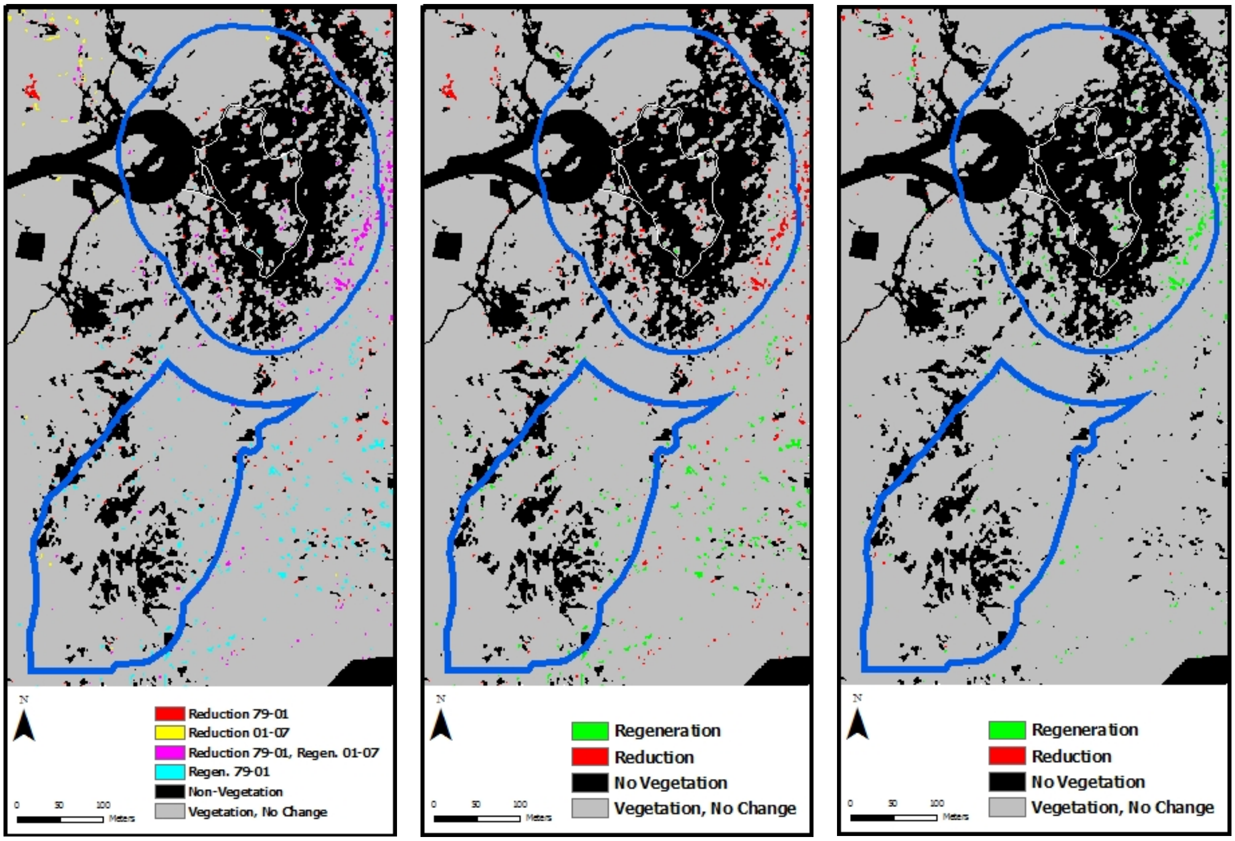
To test our hypothesized relationship with vegetation change between the experimental and control sites, we computed the rates of increased and decreased vegetation covers with $20m^2$ plots that were systematically sampled at the pre-defined spatial scales. For each plot, the rates of increased and decreased vegetation were calculated by an equation: *increased (or decreased) area / total vegetation area* × *100*. A mean rate of vegetation increase and decrease was calculated for small (0-30*m*), medium (30-60*m*), and large spatial scales (60-90*m*) and T-test comparisons were used to compare the mean vegetation increases and decrease over the three spatial scales among the experimental and control sites at the $p = 0.05$ level.

To verify spatial patterns of vegetation impact and recovery within the experimental site, similar computations were made calculating the rates of increased and decreased vegetation covers based on the same $20m^2$ plots at the experimental site. Mean rates of increased and decreased vegetation covers were calculated for separated inner (0-

30*m*), middle (30-60*m*) and outer spatial zones (60-90*m*) at the experimental site, and one-way analysis of variance was used to compare the means of vegetation changes over the three spatial zones. Tukey post-hoc tests of pairwise differences in means were used to identify significant differences at the $p = 0.05$ level. It should be noted that the plots having no vegetation areas (complete bare rock or masked-out areas) were not considered as a sample in each statistical test, since the analyses were intended to identify the rates of increased and decreased vegetation covers.

Results

Figure 6.5 shows the vegetation change detection analysis results. Overall estimated change detection accuracies using the 300 randomly generated points were 76.87% (user accuracy: 76.25%, producer accuracy: 74.71%). In the large spatial scale (0-90*m*) at the experimental site, the total decreased vegetation cover was 2.62% (1,169m^2) from 1979 to 2001, and 0.03% (14m^2) from 2001 to 2007. The total increased vegetation cover was 0.14% (64m^2) from 1979 to 2001, and 1.97% (871m^2) from 2001 to 2007. At the control site, the total decreased vegetation was 0.34% (182m^2) from 1979 to 2001, and 0.03% (15m^2) from 2001 to 2007. The total increased vegetation cover was 0.72% (385m^2) from 1979 to 2001, and 0.20% (107m^2) from 2001 to 2007. Although these calculated rates represented relatively small magnitudes in vegetation changes on the basis of the total vegetation areas in each large spatial scale, more impact and less recovery were found at the experimental site from 1979 to 2001. The trend was reversed at the site from 2001 to 2007, showing more recovery and less impact.



1979-2007 **1979-2001** **2001-2007**

	Experimental	*Control*	*Experimental*	*Control*
Regeneration	$64m^2$ (0.14%)	$385m^2$ (0.72%)	$871m^2$ (1.97%)	$107m^2$ (0.20%)
Reduction	$1169m^2$ (2.62%)	$182m^2$ (0.34%)	$14m^2$ (0.03%)	$15m^2$ (0.03%)
No Vegetation	$42{,}557m^2$	$8{,}439m^2$	$42{,}855m^2$	$8{,}514m^2$
Vegetation, No change	$43{,}338m^2$	$52{,}587m^2$	$43{,}388m^2$	$52{,}957m^2$

Figure 6.5. Vegetation change detection analysis results (top: experimental site at the large spatial scale, bottom: control site at the large spatial scale).

Spatial Patterns of Vegetation Change

Table 6.2 contains the means of rates of increased and decreased vegetation classified for each separated spatial zone within the experimental site from 1979 to 2001. Based on the proximity from the summit loop trail, there were no significant differences among the three spatial zones in terms of the rates of decreased vegetation covers (F =

1.9403, p = 0.1467). In addition, there were no significant differences among the zones in the rates of increased vegetation (F = 1.195, p = 0.3052). These results suggest that there were no clear spatial patterns of vegetation cover changes within 90*m* from the summit loop trail before the management practices were employed. However, rates of decrease in vegetation were much more prevalent than rates of increase in vegetation at all spatial zones. The prevalence of off-trail use may have contributed to the ability for recovering vegetation at all spatial zones.

Table 6.2. One-way ANOVA summary for spatial pattern of vegetation cover changes at experimental site: The rates of increased and decreased vegetation covers based on 20m^2 plots at the three separated spatial zones from 1979 to 2001 (*n*: # of plots, *M*: mean of percent change).

Variables	***Inner Zone*** (0-30*m*)		***Middle Zone*** (30-60*m*)		***Outer Zone*** (60-90*m*)		***F***	***P***
	M (%)	***n***	***M (%)***	***n***	***M (%)***	***n***		
Impact	2.58	59	1.33	54	2.56	65	1.9403	0.1467
Recovery	0.40	59	0.00	54	0.10	65	1.195	0.3052

Table 6.3 shows the means of rates of increased and decreased vegetation classified for each separated spatial zone within the experimental site from 2001 to 2007 when the management practices were put in place in 2000. Again, there were no significant differences among the zones in the rates of decreased vegetation covers (F = 0.8679, p = 0.4216). However, compared to the time period from 1979 to 2001, there was very little detection of vegetation loss. Unlike the spatial pattern of the rates of decreased vegetation from 2001 to 2007, there was a significant difference in the rates of increased vegetation between the spatial zones (F = 5.3061, $p < 0.05$). Tukey post-hoc tests for pairwise comparison verified that the recovery rate was higher in the outer zone (M = 2.20) than the inner zone (M = 0.42). This result suggests more vegetation recovery

occurring at the outer edge of the site since 2001, and especially since the time period from 1979 to 2001. At this point in time management strategies have reversed a trend of vegetation loss observed from 1979 to 2001, but it appears vegetation recovery has been slow to minimal and not recovered to the amount that existed in 1979.

Table 6.3. One-way ANOVA summary for spatial pattern of vegetation cover changes at experimental site: The rates of increased and decreased vegetation covers based on 20m^2 plots at the three separated spatial zones from 2001 to 2007 (*n*: # of plots, *M*: mean of percent change)

Variables	***Inner Zone*** (0-30*m*)		***Middle Zone*** (30-60*m*)		***Outer Zone*** (60-90*m*)		***F***	***P***
	M (%)	***n***	***M (%)***	***n***	***M (%)***	***n***		
Impact	0.00	59	0.00	54	0.06	65	0.8679	0.4216
Recovery	0.42	59	0.91	54	2.20	65	5.3061	0.005791*

*Significance of differences: recovery at inner = recovery at middle (p = 0.6934288), recovery at inner < recovery at outer (p = 0.0056236), recovery at middle = recovery at outer (p = 0.0689164)

Vegetation Cover Change Detection between 1979 and 2001

The comparison between the experimental and control sites generally supported our hypothesized assumptions related to examining the visitor-induced impact, when no management practices were deployed from 1979 to 2001 (Table 6.4). Throughout the three different spatial scales (0-30*m*, 0-60*m*, 0-90*m*), the means of rates of decreased vegetation were significantly higher at the experimental site than the control site (all $p <$ 0.001). Conversely, the means of rates of increased vegetation covers were higher at the control site than the experimental site. In addition, there was a significant difference in the rates of increased vegetation cover (T = 2.4807, p = 0.01368), indicating a higher recovery rate in the large spatial scale (0-90*m*) at the control site while showing no significant differences between the two sites in the small and medium spatial scales (all p > 0.05).

Table 6.4. T-tests Summary: The rates of increased and decreased vegetation covers between the experimental and control sites based on $20m^2$ plots at each spatial scale from 1979 and 2001 (*n:* # of plots, *M*: mean of percent change)

Spatial Scale (Variables)		***Experimental Site***		***Control Site***		***T***	***P***
		M (%)	***n***	***M (%)***	***n***		
Small Scale	Impact	2.58	59	0.20	18	-4.4922	2.892e-05
(0-30*m*)	Recovery	0.22	59	0.40	18	-0.513	0.6094
Medium Scale	Impact	1.98	113	0.23	56	-5.5509	1.633e-07
(0-60*m*)	Recovery	0.21	113	0.46	56	1.0844	0.2799
Large Scale	Impact	2.91	178	0.24	120	-6.6571	2.976e-10
(0-90*m*)	Recovery	0.17	178	0.54	120	2.4807	0.01368

Vegetation Cover Change Detection between 2001 and 2007

The comparison between the experimental and control sites also supported our hypothesized assumptions related to examining the efficacy of management practices from 2001 to 2007 (Table 6.5). While no impact rates were identified in the small and the medium spatial scales at the experimental site, there was no significant difference in the rates of decreased vegetation covers between the two sites in the large spatial scale analysis (T = -0.0247, p = 0.9803), indicating the same impact rates over the two sites. The rates of increased vegetation cover were the same in the small spatial scale comparison (T = -0.9491, p = 0.3461), and higher in the medium and the large spatial scales at the experimental site than the control site (all $p < 0.05$), indicating higher recovery rates at the experimental site. Overall, the results suggest a trend in the desired direction for management strategies to reduce vegetation impact and enhance vegetation recovery at the experimental site from 2001 to 2007, but again relatively small gains at this point in time.

Table 6.5. T-tests Summary: The rates of increased and decreased vegetation covers between the experimental and control sites based on 20m^2 plots at each spatial scale from 2001 and 2007 (*n:* # of plots, *M*: mean of percent change)

Spatial Scale (Variables)		***Experimental Site***		***Control Site***		***T***	***P***
		M (%)	***n***	***M (%)***	***n***		
Small Scale	Impact	0.00	59	0.00	18	-	-
(0-30*m*)	Recovery	0.41	59	0.20	18	-0.9491	0.3461
Medium Scale	Impact	0.00	113	0.00	56	-	-
(0-60*m*)	Recovery	0.65	113	0.14	56	-3.0031	0.00315
Large Scale	Impact	0.02	178	0.02	120	-0.0247	0.9803
(0-90*m*)	Recovery	1.22	178	0.13	120	-4.4182	1.688e-05

Discussion

Our study examined the potential of using remote sensing technology for monitoring visitor-induced impact, and possibly of some assistance where a recreation site boundary is relatively unclear at a high-use and dispersed-use site. The major literature in recreation ecology suggests that there is a spatial relationship of decreasing vegetation impact and increasing vegetation recovery based on the proximity in individual sites and specified impact zones (Cole & Monz, 2004; Frissell, 1978; Hammitt & Cole, 1998). The impact zones are typically smaller than other zones at campsites and trails, but vegetation impact is most severe within the impact zone. Given the prevalent visitor behavior of off-trail use on durable rock surfaces, interspersed patches of vegetation and the ambiguous site boundary, there were no significant differences in terms of the rates of vegetation cover changes among the three separated spatial zones within 90*m* from the summit loop trail when no management actions were applied from 1979 to 2001. Although no clear zone boundary of vegetation impact was being detected in the relatively same magnitude away from the trail, it is possible that a more extensive spatial zone of impact has formed at Cadillac without an active mode of management action that induces a concentrated visitor use along the trail during the first analysis time period.

However, some of our findings supported the spatial relationship of increasing vegetation recovery but at a much larger scale in the outer zone (60-90*m*) compared to the inner zone (0-30*m*) when the management actions were employed from 2001 to 2007. Therefore, based on this observed spatial pattern of vegetation recovery, more consideration might be given for defining the intensive management zone at Cadillac. It may be required to further enhance and monitor vegetation management strategies in these outer edges of the recreation site.

One potential advantage that might be utilized with large spatial scale vegetation change detection methods are potential clusters or patterns of impact. However, no significantly clustered areas in terms of negative vegetation impact were identified within the 90*m* spatial scale by the summit loop trail. There was an informal trail detected at a high ridge located on the west side of the parking lot (next to the Cadillac North Ridge Trail). While the specific area was not a part of this multi-temporal vegetation change analysis, the study results showed that vegetation impact occurred even before 2001 and has constantly impacted the area over time. In that location, unlike the summit loop trail, there are fewer visible forms of intensive site/visitor management actions such as physical barriers and educational signs. Given the fact that the area could be an alternative location due to the flatness and easy accessibility of the area, especially when the summit loop trail is extremely crowded during a summer, it is plausible that visitors may be going to the location before they walk the summit loop trail and are unaware that they should remain on the maintained trails and other durable surfaces. Therefore, targeted management may be necessary to prevent further development of the informal trail and additional vegetation impact.

An assessment was made of the direct management strategies. The three oval shaped physical barriers covered a total area of 1,860m^2, mostly focused on already heavily visitor impacted areas within the summit loop trail. The main purpose of the physical barriers was to keep visitors out of specific areas where trampling and soil erosion were at high risk (Turner, 2001). From 1970 to 2001 when no physical barriers were present, the rate of decreased vegetation cover in the same areas as the current three barriers was 2.78% (9m^2), while showing no increased vegetation. After installing the three physical barriers from 2001 to 2007, the trend changed by showing that the rate of increased vegetation cover was 0.94% (3m^2), while the rate of decreased vegetation cover was 0% (0m^2). Although the rate of increased vegetation cover was considerably low, there was no negative vegetation impact after installing the barriers since 2001 and one would expect a slow natural recovery of this previously heavily impacted area. No significant vegetation changes occurred within the three physical barriers by effectively prohibiting visitors from creating informal trails and shortcutting in these areas. Interestingly, visitors' experiences at the summit were not diminished by the deployed exclosures (Bullock & Lawson, 2007; Turner, 2001), and visitors generally preferred more intensive management such as physical barriers along the summit loop trail (Bullock & Lawson, 2008). The direct and indirect management techniques appear to be stemming the amount of vegetation loss in most areas, and evidence exists for recovery occurring, especially on the outer edges around the summit loop trail. Recovery rates are low however since 2000, and management may want to supplement with plant treatment if wanting to encourage more vegetation recovery on the outer edge where there appears to be less visitor use. Finally, reinforcing and expanding the utilization of the exclosures and Leave No Rrace signage could be a management supplement to targeted areas around the informal trail or other susceptible areas near the summit loop trail.

Conclusion

Study results indicate that the site and visitor management practices initiated in 2000 have been validated to enhance vegetation regeneration and reduce vegetation reduction at Cadillac Summit. Therefore, maintaining and reinforcing the current site and visitor management practices could be a continued management option for ANP rather than using highly regulated management strategies such as use limits and length of stay limit. We suggest that management strategies expand beyond the summit loop trail in the vicinity to prevent unintended and additional vegetation impact.

While the applied change detection analysis was useful for detecting vegetation cover over time, more detailed analysis about vegetation characteristic would be required to better understand vegetation change dynamics at Cadillac Summit. Studies have consistently shown that re-vegetated sites often consist of more resistant plant species and overall less vegetation diversity than the previous impacted condition (Green, 1998; LaPage, 1967; Stohlgren & Parsons, 1986; Tolvanen et al., 2004). Traditional on-site measurement and experiment may further enhance and supplement the findings of our study.

There are various scanned aerial photographs captured in 1944, 1953, and 1979 in ANP, and periodically the scanned aerial photographs as well as high resolution satellite datasets are likely planned for the future. Even though the spectral resolution is limited in the datasets, change detection analysis based on single spectral images can be useful to discover the general pattern of vegetation cover changes associated with visitor use for a long term period, particularly for the summit of Cadillac Mountain. Further imageries collected could be integrated into this assessment.

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CHAPTER 7

CONCLUSIONS

"When resources are abundant, we squander them. We value them when they become scarce. That day is rapidly approaching, but we seem to pretend and act as if that day will never come."

Emilio F. Moran (2006)

In this study, high spatial resolution remote sensing datasets from 1979, 2001 to 2007 and several different image-processing techniques were used to assess the effectiveness of management strategies to reduce vegetation impact and enhance recovery at Cadillac Mountain in Acadia National Park. Factors such as different mechanisms used in image processing techniques, quality of remote sensing datasets and size of sampling plots (different size of grain), created some disparities in results, but clearly a higher degree of vegetation recovery and a smaller degree of impact was detected in the vicinity of the summit loop trail (experimental site) than in the undisturbed control site (Table 7.1).

Table 7.1. Change in vegetation cover at the experimental and control sites.

Large Spatial Scale (0-90m)		***Experimental Site Mean (%)***		***Control Site Mean (%)***	
		1979-2001	***2001-2007***	***1979-2001***	***2001-2007***
Impact	Chapter 4*	-	0.12	-	0.64
	Chapter 5**	-	2.15	-	0.08
	Chapter 6***	2.91	0.02	0.24	0.02
Recovery	Chapter 4*	-	5.56	-	2.38
	Chapter 5**	-	5.08	-	0.94
	Chapter 6***	0.17	1.22	0.54	0.13

* Fractional vegetation cover change detection analysis based on pre-classification (*NDVI*) and 10m^2 plots. **Fractional vegetation cover change detection analysis based on post-classification (*supervised, minimum distance to mean algorithm*) and 30m^2 plots. ***Fractional vegetation cover change detection analysis based on pre-classification (*single-spectral, simple image differencing*) and 20m^2 plots.

The two pre-classification change detection analyses using the multi-spectral and the single-spectral as well as the post classification change detection analysis all showed detailed measureable vegetation changes in terms of vegetation regeneration and loss at relatively large distances away from the summit loop trail as compared to the undisturbed control site. Although not shown in Table 7.1, the post classification change detection analysis results showed little change in terms of vegetation diversity recovery in the vicinity of the summit loop trail as compared to what exists at the control site. The regrowth of vegetation is probably the result of more resistant and resilient vegetation where impacts formerly occurred and where visitor use still occurs at the site.

The summit of Cadillac Mountain is a tough place to recover vegetation after damage, due to the short growing season, thin soil, and shortage of available water. This is because Cadillac Summit, like most other recreation sites, experiences an asymptotic relationship between use level and vegetation impact (Hammitt & Cole, 1998) (Figure 7.1). That is, most of the impact occurs quickly with low to moderate use levels and then levels off in the immediate vicinity of where the use is concentrated but continues slightly upward as the site expands. Recovery through management efforts takes much longer especially if natural regeneration is allowed at the site. The rates of recovery vary depending upon the resilience of vegetation and other site factors, and Cadillac as described above is expected to be much slower (R_1) than in other recreation settings with deeper soils, warmer temperatures, and longer growing seasons (R_2) (Hammitt & Cole, 1998; Leung & Marion, 2000; Liddle, 1997). Given the long history of visitor use at the summit which has been documented form the late 1800s to the present the summit has probably been constantly changing with the many seasons of human use.

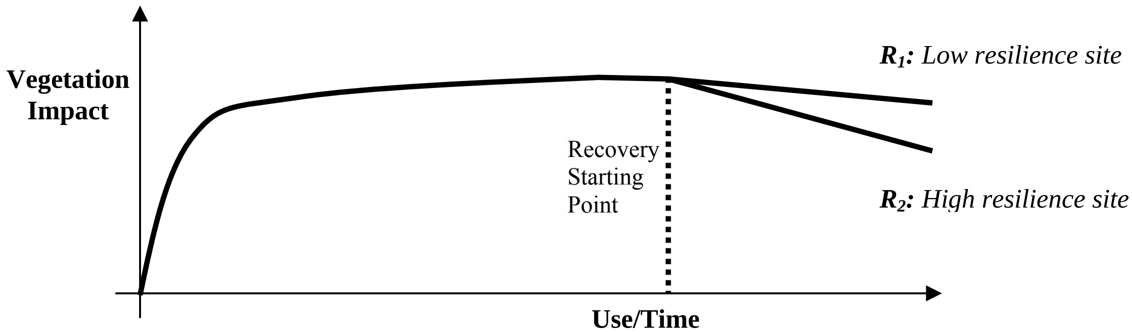

Figure 7.1. Conceptual model showing the temporal relationship between vegetation impact and visitor use over time with expected rates of recovery depending on resilience of vegetation. If there is no human disturbance factor, recovery rates will be influenced only by site resilience and environmental conditions. Therefore, taking a long time for natural recovery may not be effective for the Cadillac summit that maintains an extremely low resilience characteristic in a sub-alpine nature environment.

Based upon our work we suggest a similar conceptualization of the temporal relationship between vegetation impact and visitor use over time, but the large spatial scale quantifies vegetation impact differently as compared to impact measured close to the recreation site (Figure 7.2). While *line 1* generally represents a small spatial scale typical of the impact zone and immediate vicinity of the summit loop trail, *line 2* represents visitor use that is dispersed over more vegetation and thus lower in terms of impact to total percent of vegetation with use and associated levels of impact to vegetation in the intermediate and buffer zones of the recreation setting. It is assumed at both the small and large spatial scales that the impact by recreation use on the summit followed patterns of previous recreation ecology studies with vegetation impact occurring noticeably within the first few years of light to moderate use, especially around the current trail system and access points to the trail. In fact, the summit has likely experienced much vegetation damage during this length of visitor use and in some places permanent loss of vegetation due to the extremely shallow soil on bedrock and erosion by wind and water. It is important to note, however, that measurable vegetation loss was still detected on the summit from 1979 to 2001 and most likely provided motivation for implementing more intensive management in 2000. The employed management appears to have stemmed the upward trend in impact, and minimal gains were seen in vegetation recovery.

Although it is impossible to return to the pristine condition due to the already changed ecosystem and the amount of soil erosion accumulated, various recovery scenarios are possible given the deployed management strategies and future changes to the management strategies.

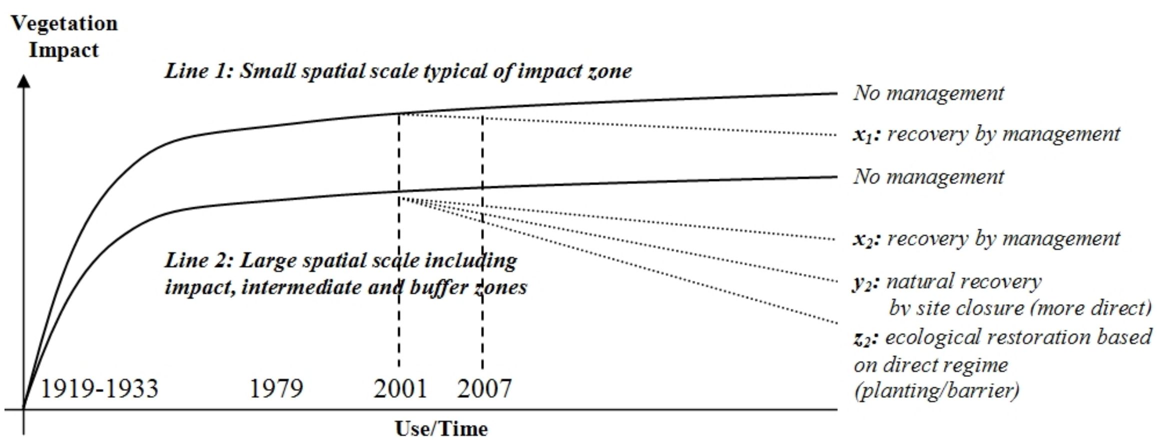

Figure 7.2. Conceptual model showing the temporal relationship between vegetation impact and use/time level at different spatial scales at Cadillac Mountain Summit, Acadia National Park.

In the reconceptualization of the temporal relationship between vegetation impact and use/time, there are measurable differences in the amount of vegetation recovery between those that occur in the small spatial scale and impact zone of x_1 **recovery** and large spatial scale and multiple zones of x_2 **recovery** (Figure 7.2). As hypothesized in McEwen and Tocher (1976), the amount of vegetation recovery is expected to be higher in x_2 **recovery** due to less soil compaction and alterations caused by constant visitor use so that vegetation has the ability to regrow in the outer zones. Our results support this hypothesized relationship with noticeable and significant recovery observed in the outer edges and especially at a distance characteristic of an intersite zone that has visitor disturbance and thus response of vegetation to regrow that is distinctly more than in the buffer zone that has regrowth slightly more than what can be seen through natural variability. This transition of less regrowth and reduction of vegetation in the buffer zone results from less visitor use (Cole & Monz, 2004), and vegetation impact mimics the control site. We feel there is still value in identification of the small spatial scale and identification of the impact zone boundary. Often management objectives are set around this boundary that is generally visible with the goal of limiting further expansion of this zone into the intersite zone. The stabilization of this zone expansion or reduction in size would assume positive effects with the amount of vegetation loss in the outer zones. This is likely true, but we add caution especially in the case where there is known dispersed use occurring at a site and how measurements are taken beyond the designated impact zone. This is where the larger spatial scale has value to managers as measurements and quantification of impact and recovery can be seen beyond the impact zone area. Our study results showed while minimal at this point in time there was measureable vegetation recovery and more in the outer zones than the impact zone close to the summit trail. Because the $\boldsymbol{x_2}$ **recovery** area is measurable and can be quantified, it is plausible that future management objectives could be created for a defined intersite zone to stabilize from further expansion or reduce in size the amount of vegetation impact occurring at this distance from the summit loop trail.

As indicated above, the amount of x_2 **recovery** by the management actions at Cadillac will be higher than the amount of x_1 **recovery** at the impact zone since natural recovery factors in the intermediate and buffer zones will be included, but the overall rate of recovery will remain minimal, especially if dispersed use continues at the site. If the site was closed or more intensive management was considered, it would likely increase the rate of recovery at the site (**y_2 recovery)** (Figure 7.2). Limiting visitor use would reduce the amount of vegetation impact and increase the likelihood of vegetation regrowth, but as indicated above the natural recovery would be slow in this environmental setting. Also, closure of the area or direct management such as charging a fine for traveling off-trail would be a rather drastic shift in management at the site. In addition, management would need to consider the policy implications of these management actions such as closure as well as consider possible shifts in visitor use to other areas in the park and thereby further increase vegetation impact at other locations. This may be an option at other parks but most likely one that would not be considered at Acadia National Park. The other alternative management option is to consider ecological restoration in certain areas and place more physical barriers in strategic locations (z_2 **recovery**) (Figure 7.2). The advantage of the plantings including soil and water would help bring back a variety of native species that might take longer under natural recovery conditions and competition with more dominant resistant and resilient species. As reported in previous chapters, the visitor research associated with reactions to physical barriers and signs did not degrade experiences, but one would expect that only a limited number of barriers would be permissible before it influences the visitor experience; therefore, monitoring this influence would be important as well. The planting would likely still need to be maintained given the current management regime with dispersed visitor use away from the summit trail.

Based on the remote sensing data and change detection analysis, we also suggest a need to map informal trails and heavily impacted areas near the vicinity of the summit loop trail. Informal trails were verified at the north ridge trail located on the northwest side of the parking lot, and the level of vegetation impact was extensively high in the vicinity of Blue Hill Overlook. While the two locations were not included in the original study area of our change detection analysis, the specific areas have experienced vegetation impact from 2001 to 2007. If the two locations have been alternative destinations to compromise a high visitor density at the summit loop trail during the summer, we suggest a reevaluation to include more intensive management as done at the summit loop trail in terms of barriers and low impact signs to reduce the level of vegetation impact. Simultaneously, a systematic analysis regarding how many visitors are using the locations, how visitors move from the locations to the loop trail, and vice versa (identifying the visitor flow), should be estimated through an observational study to identify current and future hot spots.

Given that both vegetation impact and soil erosion are major concerns in the vicinity of the summit loop trail, the efficacy of the employed management actions could be further understood by assessing the level of soil erosion. For this process, a high resolution digital elevation model (DEM) could be considered for a larger spatial scale analysis, in order to maximize the advantages of the remote sensing technology. Additionally, providing the spatial pattern and magnitude of soil erosion and vegetation impact would be a valuable source for planning future management action and infrastructure such as maintenance of trails. More diverse factors including soil/vegetation types, aspect, slope, elevation, and proximity from a trail/road could be combined as a modeling approach that explains an overall spatial pattern of resource impact associated with trampling (Arrowsmith & Inbakaran, 2002; Dixon et al., 2004). This will be particularly useful in prioritizing the loop trail segments that need more intensive management.

Currently, one of the most important processes at Cadillac Summit is physically defining the "site boundary" to reduce an unwanted or undesirable expansion of vegetation impact away from the durable summit loop trail. By dividing the impact and intermediate zones, more efficient site management strategies would be possible to induce visitor use on the impact zone. Various concepts could be utilized to establish the site boundary such as elevation and distance from the loop trail. For example, the boundary could be set at 1,450ft in elevation because the suggested elevation would capture all areas of interest and the areas already impacted (Jacobi, 2007). A closer proximity to the summit loop trail would be more desirable to minimize unintended impact in the intermediate zone and execute intensive management at the impact zone scale, but an unrealistic setup such as 10-20*m* from the summit loop trail may cause another problem related to the quality of the visitor experience as a way of potential conflict and displacement, considering the high use density during the summer. In the NDVI change detection analysis, it was identified that the areas 70-80*m* from the summit loop trail showed the maximum recovery rate (the functional role of the intermediate zone) on the basis of the proximity. Also, the areas 70-100*m* from the summit loop trail showed the stable vegetation impact rates maintaining around 1% impact (the functional role of the buffer zone) in the post-classification change detection analysis. Therefore, the Maginot Line between the impact and intermediate zones could be established less than 70*m* from the loop trail. Once the boundary is established, the deployed management practices currently focused within the summit loop trail should be expanded to cover relatively many portions of the impact zone. Again, most important is to define the impact zone first, manage intensively, and prevent expansion of the impact zone.

A future step for management is evaluating the effectiveness of implementation of the management actions around the summit trail. For example, detections of vegetation recovery by 3-5% and vegetation impact by 1-3% within 30*m* of the summit loop trail from 2001 to 2007 might constitute real progress in terms of management goals, or alternately, insignificant changes. The development of clear objectives such as indicators and standards of resource conditions will become increasingly important for assessing management actions directed toward minimizing impact and maximizing recovery. Only where specific objectives have been established can one consistently determine whether or not an impact of a given magnitude constitutes an effective management strategy. A temporal scale may also be necessary in establishing realistic goals, especially given the sub-alpine nature environment.

Utilizing remote sensing technology in recreation ecology has been limited due to difficulty in assessing localized vegetation impact caused by recreation, especially under a tree canopy where trails or campsites are located for shade or other reasons (Hammitt and Cole 1998). The localized impact was often undetectable in a broad or medium spatial scale resolution remote sensing dataset (e.g., $30m^2$ pixel resolution). However, the analysis on the basis of high resolution remote sensing datasets would be useful in verifying the effect of the management approach in a heavily visited site around a mountain summit environment. Although the outcome of our analysis approach might be less detailed in identifying the amount and composition of vegetation changes compared to a traditional recreation ecology method, our change detection analysis using high resolution remote sensing datasets offered an approach for measuring the aggregated vegetation change dynamics at a relatively larger spatial scale. There might be a potential barrier to transfer our study results to other national park units due to the various impact and recovery patterns that involve the environmental condition, site durability, and use level/type. It should be noted that one result from an Eastern park having specific conditions could not be applied simply to other Western parks having different environmental characteristics.

Vegetation change is a spatially explicit process driven by both social and physical elements (Evans, 2005). Identifying vegetation change, therefore, is one of the easiest ways to assess and analyze the change of ecosystems associated with those social and physical elements (Demers, 1991; Grossman, 1998; Mueller-Dombois & Ellenberg, 1974; Pauchard et al., 2000). In that regard, there is a strong need to emphasize the role of remote sensing in the field of recreation ecology. Remote sensing technology has the capability of providing multi-scale spectral, spatial, and temporal information in a standardized format to assist managers in the NPS to monitor conditions over time and has direct applicability to their dual mission of preserving the natural character of the area while providing visitor enjoyment.

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APPENDICES

Appendix A. Sampling Plots for Post-Classification Change Detection Analysis

Table A.1. Sampling Plots for Post-Classification Change Detection Analysis

Homogenous (Non-mixed)	***Family Name***	***Scientific Name***	***Common Name***	***# of samples***
	Adoxaceae	*Viburnum*	*viburnum*	1
	Aquifoliaceae	*Ilex*	*holly*	5
	Asteraceae	*Doellingeria umbellata*	*aster umbellatus*	1
		Symphyotrichum	*new york aster*	4
	Betulaceae	*Betula*	*birch*	6
	Caprifoliaceae	*Diervilla lonicera*	*bush honeysuckle*	1
	Cupressaceae	*Juniperus*	*juniper*	9
		Thuja	*cedar*	5
	Eriaceae	*Arctostaphylos*	*bearberry*	3
		Gaylussacia	*huckleberry*	1
		Vaccinium	*blueberry*	1
	Fagaceae	*Quercus*	*oak*	4
	Pinaceae	*Abies*	*fir*	7
		Picea	*spruce*	5
		Pinus	*pine*	5
	Poaceae	*Grass*	*grass*	7
	Rhizocarpaceae	*Rhizocarpon*	*world map lichen*	4
	Roaceae	*Sibbaldiopsis*	*shrubby fivefingers*	1
		Sorbus	*mountainash*	1
		Spiraea	*spiraea*	5
Mixed Group 1	**Family**	**Scientific Name**	**Common Name**	7
	Ericaceae	*Kalmia*	*laurel*	
	Ericaceae	*Rhododendron*	*rhododendron*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	
Mixed Group 2	**Family**	**Scientific Name**	**Common Name**	2
	Rosaceae	*Rosa*	*rose*	
	Rosaceae	*Spiraea*	*spiraea*	
	Ericaceae	*Vaccinium*	*blueberry*	

Table A.1. Continued

Mixed Group 3	Family	Scientific Name	Common Name	1
	Cupressaceae	*Juniperus*	*juniper*	
	Rosaceae	*Spiraea*	*spiraea*	
	Rosaceae	*Sibbaldiopsis*	*shrubby fivefingers*	
Mixed Group 4	**Family**	**Scientific Name**	**Common Name**	1
	Empetraceae	*Empetrum*	*crowberry*	
	Ericaceae	*Vaccinium*	*blueberry*	
Mixed Group 5	**Family**	**Scientific Name**	**Common Name**	1
	Rosaceae	*Rosa*	*rose*	
	Rosaceae	*Spiraea*	*spiraea*	
	Asteraceae	*Symphyotrichum novi-belgii*	*New York aster*	
Mixed Group 6	**Family**	**Scientific Name**	**Common Name**	1
	Ericaceae	*Gaylussacia*	*huckleberry*	
	Rosaceae	*Spiraea*	*spiraea*	
	Asteraceae	*Symphyotrichum novi-belgii*	*New York aster*	
Mixed Group 7	**Family**	**Scientific Name**	**Common Name**	1
	Betulaceae	*Alnus*	*alder*	
	Ericaceae	*Rhododendron*	*rhododendron*	
	Rosaceae	*Spiraea*	*spiraea*	
Mixed Group 8	**Family**	**Scientific Name**	**Common Name**	4
	Cupressaceae	*Jupierus*	*juniper*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	
Mixed Group 9	**Family**	**Scientific Name**	**Common Name**	2
	Cupressaceae	*Juniperus*	*juniper*	
	Pinaceae	*Abies*	*fir*	
	Ericaceae	*Vaccinium*	*blueberry*	
Mixed Group 10	**Family**	**Scientific Name**	**Common Name**	2
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Kalmia*	*laurel*	
	Pinaceae	*Abies*	*fir*	

Table A.1. Continued

Mixed Group 11	**Family**	**Scientific Name**	**Common Name**	1
	Ericaceae	*Arctostaphylos*	*Bearberry*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	
Mixed Group 12	**Family**	**Scientific Name**	**Common Name**	2
	Cupressaceae	*Juniperus*	*juniper*	
	Ericaceae	*Kalmia*	*laurel*	
	Ericaceae	*Rhododendron*	*rhododendron*	
Mixed Group 13	**Family**	**Scientific Name**	**Common Name**	1
	Rosaceae	*Sorbus*	*Mountainash*	
	Pinaceae	*Abies*	*fir*	
Mixed Group 14	**Family**	**Scientific Name**	**Common Name**	2
	Betulaceae	*Betula*	*betula*	
	Pinaceae	*Abies*	*fir*	
Non-vegetation	**Soil**			11
Non-vegetation	**Rock**			4
Non-vegetation	**Impervious Surface**			10
Total				**129**

Appendix B. Classification Scheme

Table B.1. Development of Classification Scheme at Plant Family Level

Homogenous (Non-mixed)	***Family Name***	***Scientific Name***	***Common Name***	***Classification Scheme (Family level)***
	Adoxaceae	*Viburnum*	*viburnum*	*Deciduous Shrub*
	Aquifoliaceae	*Ilex*	*holly*	*Aquifoliaceae*
	Asteraceae	*Doellingeria umbellata*	*aster umbellatus*	*Asteraceae*
		Symphyotrichum	*new york aster*	*Asteraceae*
	Betulaceae	*Betula*	*birch*	*Betulaceae*
	Caprifoliaceae	*Diervilla lonicera*	*bush honeysuckle*	*Deciduous shrub*
	Cupressaceae	*Juniperus*	*juniper*	*Cupressaceae*
		Thuja	*cedar*	*Cupressaceae*
	Eriaceae	*Arctostaphylos*	*bearberry*	*Eriaceae*
		Gaylussacia	*huckleberry*	*Eriaceae*
		Vaccinium	*blueberry*	*Eriaceae*
	Fagaceae	*Quercus*	*oak*	*Fagaceae*
	Pinaceae	*Abies*	*fir*	*Pinaceae*
		Picea	*spruce*	*Pinaceae*
		Pinus	*pine*	*Pinaceae*
	Poaceae	*Grass*	*grass*	*Poaceae*
	Rhizocarpaceae	*Rhizocarpon*	*world map lichen*	*Non-Forest*
	Roaceae	*Sibbaldiopsis*	*shrubby fivefingers*	*Roaceae*
		Sorbus	*mountainash*	*Roaceae*
		Spiraea	*spiraea*	*Roaceae*
Mixed Group 1	**Family**	**Scientific Name**	**Common Name**	*Eriaceae*
	Ericaceae	*Kalmia*	*laurel*	
	Ericaceae	*Rhododendron*	*rhododendron*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	

Table B.1. Continued

Mixed Group 2	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Rosaceae	*Rosa*	*rose*	
	Rosaceae	*Spiraea*	*spiraea*	
	Ericaceae	*Vaccinium*	*blueberry*	
Mixed Group 3	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Cupressaceae	*Juniperus*	*juniper*	
	Rosaceae	*Spiraea*	*spiraea*	
	Rosaceae	*Sibbaldiopsis*	*shrubby fivefingers*	
Mixed Group 4	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Empetraceae	*Empetrum*	*crowberry*	
	Ericaceae	*Vaccinium*	*blueberry*	
Mixed Group 5	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Rosaceae	*Rosa*	*rose*	
	Rosaceae	*Spiraea*	*spiraea*	
	Asteraceae	*Symphyotrichum novi-belgii*	*New York aster*	
Mixed Group 6	**Family**	**Scientific Name**	**Common Name**	*Deciduous Shrub*
	Ericaceae	*Gaylussacia*	*huckleberry*	
	Rosaceae	*Spiraea*	*spiraea*	
	Asteraceae	*Symphyotrichum novi-belgii*	*New York aster*	
Mixed Group 7	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Betulaceae	*Alnus*	*alder*	
	Ericaceae	*Rhododendron*	*rhododendron*	
	Rosaceae	*Spiraea*	*spiraea*	
Mixed Group 8	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Cupressaceae	*Jupierus*	*juniper*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	

Table B.1. Continued

Mixed Group 9	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Cupressaceae	*Juniperus*	*juniper*	
	Pinaceae	*Abies*	*fir*	
	Ericaceae	*Vaccinium*	*blueberry*	
Mixed Group 10	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Kalmia*	*laurel*	
	Pinaceae	*Abies*	*fir*	
Mixed Group 11	**Family**	**Scientific Name**	**Common Name**	*Eriaceae*
	Ericaceae	*Arctostaphylos*	*Bearberry*	
	Ericaceae	*Vaccinium*	*blueberry*	
	Ericaceae	*Gaylussacia*	*huckleberry*	
Mixed Group 12	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Cupressaceae	*Juniperus*	*juniper*	
	Ericaceae	*Kalmia*	*laurel*	
	Ericaceae	*Rhododendron*	*rhododendron*	
Mixed Group 13	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Rosaceae	*Sorbus*	*Mountainash*	
	Pinaceae	*Abies*	*fir*	
Mixed Group 14	**Family**	**Scientific Name**	**Common Name**	*Mixed Forest*
	Betulaceae	*Betula*	*betula*	
	Pinaceae	*Abies*	*fir*	
Non-vegetation	**Soil**			*Soil*
Non-vegetation	**Rock**			*Rock*
Non-vegetation	**Impervious Surface**			*Impervious Surfaces (masked-out)*

Appendix C. **List of Plants that did not meet plot size requirement** (mostly 1*1 plot sizes): not included in homogenous sampling plots, but some of them were included in mixed groups.

Table C.1. Family & Species Names

Family Name	***Species (Scientific Name)***
Rosaceae	*amelanchier bartramiana*
Rosaceae	*amelanchier spicata*
Lycopodiaceae	*dendrolycopodium hickeyii*
Cyperaceae	*eleocharis acicularis*
Scrophulariaceae	*euphrasia nemorosa*
Cistaceae	*hudsonia ericoides*
Asteraceae	*ionactis linariifolius*
Polypodiaceae	*polypodium virginianum*
Rosaceae	*prunus pensylvanica*
Dennstaedtiaceae	*pteridium aquilinum*
Asteraceae	*solidago altissima*
Asteraceae	*solidago bicolor*
Asteraceae	*solidago gigantea*
Asteraceae	*solidago leiocarpa*
Rosaceae	*sorbus americana*
Asteraceae	*symphyotrichum novi-belgii var. novi-belgii*

Appendix D. Log Book

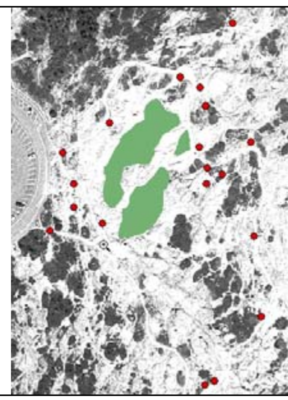
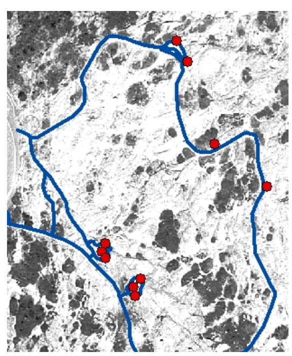
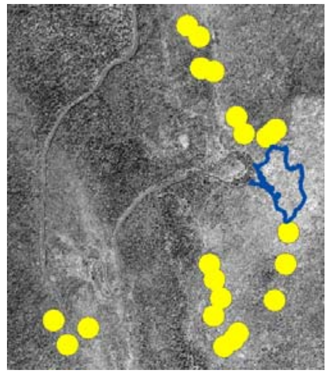
Date	Weather	Participant	Process & Result	
July 16 2007	Sunny	Min Kim, Wilfred Mercier		GPS unit accuracy test and assessment (Trimble GeoXT, a sub meter accuracy GPS unit) 1) 9 random points were created over the University of Maine, Orono Campus 2) Physically located at the 9 random points, and ground truth the positions 3) Checked differences of distance between two points dataset (1-3*m* error was discovered) depending on canopy conditions
July 18 2007	Sunny	Min Kim		Mapping spatial locations of direct and indirect managements 1) 19 indirect management (LNT) locations were mapped along with the summit loop trail 2) 3 direct management (physical enclosures) were mapped out inside of the summit loop trail
July 20 2007	Foggy & Windy	Min Kim, John Daigle		Mapping viewpoint platforms and other wayside exhibits for reference purpose 1) A center point was collected in each platform of the summit of Cadillac Mountain 2) Then, north and south edges were collected in each platform, as a point 3) Also, other noticeable point locations including wayside exhibits were collected

Figure D.1. Log Book

<table>
<tr><td>July 20
2007</td><td>Partly
Cloudy</td><td>Min Kim,
John Daigle,
Jeff Marion,
Charlie Jacobi</td><td></td><td>Selecting potential control sites comparing vegetation trampling in experimental site

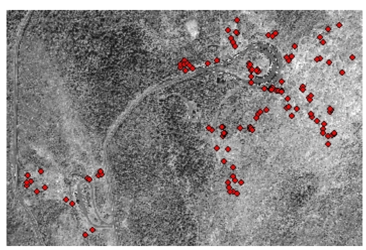
Three criteria were considered to selected a potential control site in order to compare with the experimental site
1) Bare rock portion: including minimum bare rock area
2) Pristine: not having soil exposure (no disturbance by recreational activities)
3) Elevation and same environment with experimental site (nearest areas)
Total 12 potential control sites were selected and spatially mapped</td></tr>
<tr><td>Aug. 6
2007</td><td>Sunny</td><td>Min Kim</td><td colspan="2">Investigation and taking pictures of major vegetation species in the vicinity of the summit loop trail, ANP</td></tr>
<tr><td>Aug.
15-18
2007</td><td>Sunny &
Partly
Cloudy,
Rain (Sat.)</td><td>Min Kim,
Michael
Burgess</td><td></td><td>Field sampling for vegetation classification
1) Tried to map at least 3-5 homogenous vegetation species plots considering physiognomic modifiers (coverage density, coverage pattern, height, stem diameter, etc)
2) Total 129 ground surface points in 19 different classes were collected by a random spatial sampling process at the summit of Cadillac Mountain, ANP</td></tr>
</table>

Figure D.1. Continued

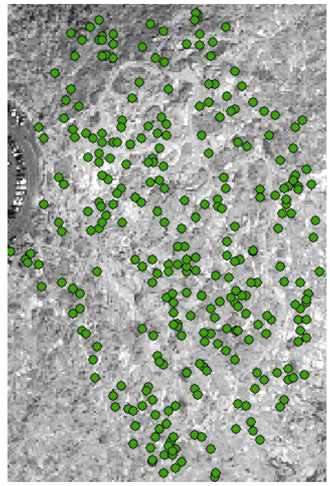
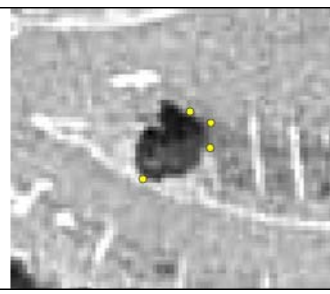
Aug. 30-31 2007	Sunny & Partly Cloudy	Min Kim, Michael Burgess		Ground truth for vegetation classification 1) 300 random points were created over the vicinity of summit loop trail for accuracy assessment 2) Physically located at the 300 random points, and ground truth the surfaces
Oct. 26 2007	Sunny	Min Kim		Mapping reference points for geometric correction (for image pre-processing)

Figure D.1. Continued
* All data collections were completed by using a sub-meter accuracy GPS unit (Trimble GeoXT). Then, datasets were post-processed for differential correction in the base station, located in Nutting Hall, University of Maine, adjusting the positions in the rover files accordingly.

BIOGRAPHY OF THE AUTHOR

Min Kook Kim was born in Seoul, South Korea on July 1, 1974. After graduating from Myungduk High School in 1993, he completed his Bachelor of Arts degree in Urban & Regional Planning from Chung-Ang University in 2000. A strong desire and enthusiasm for studying environmental issues such as sustainability and carrying capacity led him to pursue two advanced degrees: the Master of Arts degree in Environmental Education at Seoul National University in 2002, and the Master of Urban Planning degree at the State University of New York at Buffalo in 2005. In September 2005, he entered the School of Forest Resources at the University of Maine in Orono to study advanced park and protected area management. While attending the School of Forest Resources, he worked as a research assistant in the School and actively participated in the scholarly activities of the George Wright Society. He is a candidate for the Doctor of Philosophy degree in Forest Resources from the University of Maine in May, 2010.