EXAMINING SPATIAL PATTERN AND INTERACTION OF HUMAN-INDUCED VEGETATION IMPACTS AT CADILLAC MOUNTAIN IN ACADIA NATIONAL PARK

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Abstract
This study presents a novel method for examining spatial patterns and interactions of human-induced vegetation changes with spatial containment management practices, where visitors are asked to use established or designated sites to reduce the amount of vegetation impact and enhance vegetation recovery. By using K-function and cross K-function based on spatial statistics, we attempted to investigate spatial relationships and structure of vegetation changes as a way of identifying spatial efficacy of the management practices at Cadillac Mountain, Acadia National Park. Bivariate point pattern analysis results exhibited repulsive spatial relationships between vegetation changes and the locations of management practices in the vicinity of the summit loop trail, indicating that the two types of point events are not spatially distributed close together. While the applied spatial statistics would be useful to identify overall spatial patterns and interactions of vegetation changes, site characteristics such as the bare-rock dominant landscape and low resilience of vegetation in sub-alpine environments should be considered in future monitoring to effectively discover the degree of vegetation changes influenced by the spatial containment management strategies.

1.0 Introduction
Vegetation change in a recreational site is influenced by diverse factors, but overall impact and recovery patterns have been conceptualized as being affected by three main factors in the field of recreation ecology: 1) environmental condition (e.g., amount of rainfall and length of growing season), 2) site durability (e.g., different resilience and resistance characteristics of dominant plant species, and topographical factors such as slope, aspect and elevation), 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). Based on these factors, the magnitude of vegetation change dynamics has been investigated by considering spatial and temporal variability (e.g., node and linkage system in spatial impact pattern, asymptotic relationship in temporal impact pattern, slow recovery rate compared to impact rate, and slow recovery rate in a heavily used site) (Cole & Monz 2004, Frissell 1978, Hammitt & Cole 1998, Leung 1998, Manning 1979,

McEwen & Tocher 1976, Merriam & Smith 1974). In addition, recreation ecology studies have focused on vegetation change dynamics by investigating the amount of vegetation cover being impacted and vegetation diversity change in a recreation site (Hammitt & Cole 1998, Kim & Daigle 2012).

Although the spatial scales and extents used in the field of recreation ecology vary for observing patterns of vegetation changes, there is a general consensus that vegetation impact tends to decrease and vegetation recovery tends to increase as one moves farther away from recreation sites (Cole & Monz 2004, Hammitt & Cole 1998). This observed pattern, often referred to as regular radial pattern, also provided the foundation for adopting spatial containment management strategies that induce concentrated visitor use on designated or established sites to minimize impacts, especially for frontcountry settings (Cole 1981, Cole & Monz 2004, Marion & Farrell 2002).

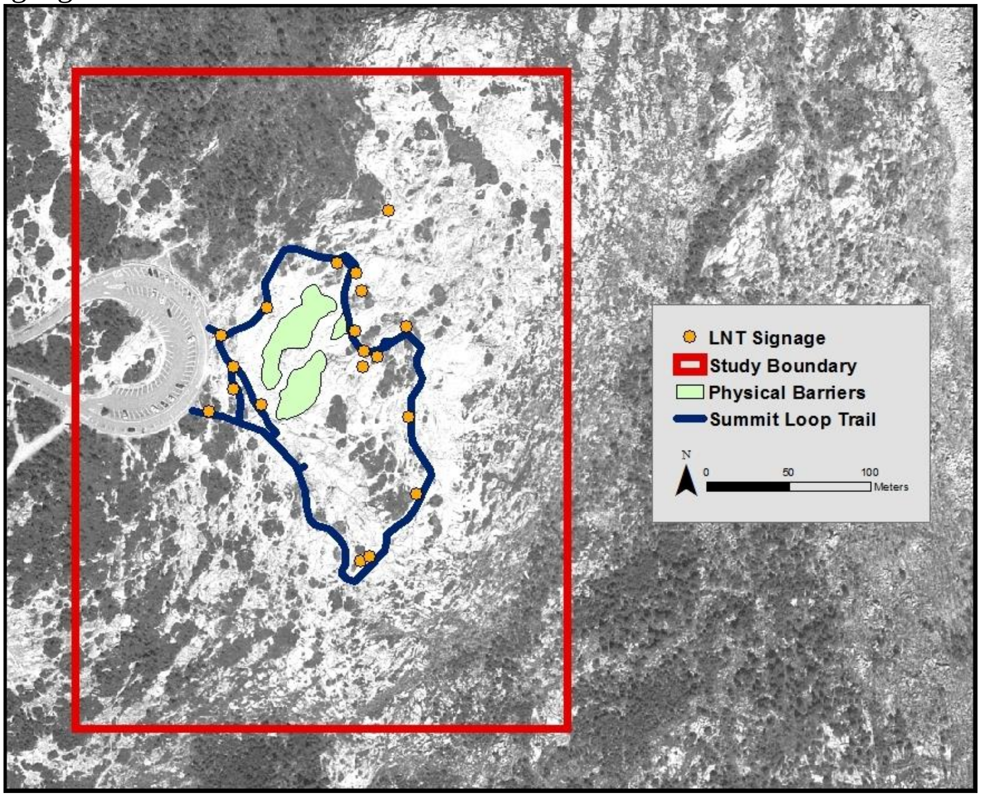
By estimating the current size and areal extent of recreation site boundaries, traditional recreation ecologists have focused more on the verification and development of spatial patterns related to vegetation changes within a cluster of campsites and trails. While the spatial pattern of vegetation change was considered an important monitoring tool for estimating the success of spatial containment management strategies, it is still challenging to identify the associated efficacy of the management strategies using onsite measurements if the boundary of recreation site is relatively large, and if the boundary grows or retreats as use level and density fluctuate. In this study, as an effort to develop a complementary monitoring technique in the field of recreation ecology, we present a simple and novel approach that investigates spatial structures and relationships of vegetation changes with management practices designed to induce concentrated visitor use.

2.0 Study site

The summit of Cadillac Mountain is the highest point on the U.S. eastern seaboard and one of the most popular visitor destinations in Acadia National Park (Jacobi 2003). A visitor survey completed by the National Park Service indicated that approximately 76% of park users visit the summit of Cadillac Mountain (Littlejohn 1999). This equates to approximately 500,000 – 800,000 visitors each year, and most visitation occurs during the summer season on a narrow (2 m wide) and short (0.3 mile long) summit loop trail (Hass & Jacobi 2002). The sensitive sub-alpine nature of the site and the convenient accessibility via the automobile road has created a situation where vegetation degradation is at high-risk. Efforts to concentrate visitor use and limit impact to vegetation on the summit were initiated as early as 1933, when the NPS installed the paved summit loop trail using crushed rocks (however, it was impossible to determine if this action was initiated to control impacts or for some other reason such as improving accessibility).

A park-wide ridgerunner program was initiated during the late 1990s to further educate visitors about minimum impact practices, and a leash regulation was established to better control impacts caused by roaming pets (Manning & Anderson 2012). In 2000, a shift towards more intensive management occurred. Specifically, spatial containment management strategies using physical barriers and Leave No Trace (LNT) messages were deployed to minimize impact and enhance recovery in the vicinity of the summit loop trail (Kim & Daigle 2012).

Figure 1. The summit loop trail, study boundary, and locations of physical barriers and LNT signage.

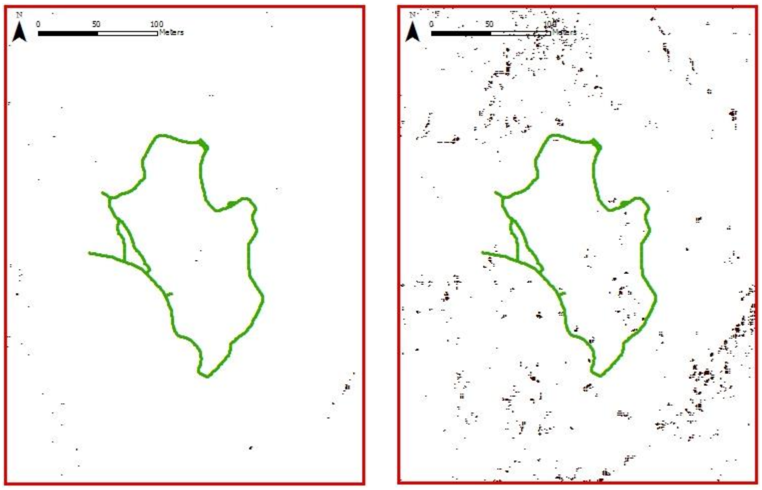


Did the management practices spatially influence the locations of newly created impact or recovery points since 2000? How can we estimate the "spatial efficacy" of the management practices? Although the questions are not easily answered, spatial analyses can provide a clue by discovering spatial interactions between vegetation changes and management practices. If the increased vegetation cover points (vegetation recovery) and the management practice points have an attractive spatial relationship, it could be assumed that the management practices are effective, at least in a spatial context. Likewise, if the decreased vegetation cover points (vegetation impact) and the management practice points have a repulsive spatial relationship, it could be regarded that the management practices are spatially effective. With these assumptions, we attempted to investigate spatial relationship and structure of vegetation changes as a way of identifying the spatial efficacy of the management practices by using K-function and cross K-function based on spatial statistics.

3.0 Methods

Since the direct logic of discovering the spatial efficacy of the deployed management practices has a close relationship with knowing the extent of the human-induced impact and potential areas to be influenced by the management practices, it was extremely important to define the boundary of the site for a spatial analysis. A previous observational study at Cadillac summit found that human-induced impact to vegetation and soil was not limited to just a few meters from the trailside of the summit loop trail (Turner 2001). Rather, the impact was occurring far beyond the loop trail and surrounding area, much of which was contained within a 50-90 m "buffer zone". Consequently, we utilized the mean center point of the summit loop trail to define the potentially impacted areas in the vicinity of the summit loop trail (300 m × 400 m rectangle). The established study boundary approximately covered the 90 m buffering areas from the summit loop trail (Figure 1).

*Figure 2***.** NDVI change detection analysis result within the established study boundary (Kim & Daigle 2012).



(a) *Decreased Vegetation Cover Points from NDVI Result*

(b) *Increased Vegetation Cover Points from NDVI Result*

Figure 2 shows the decreased and increased vegetation cover points obtained from the result of the Normalized Different Vegetation Index (NDVI) analysis between 2001 and 2007 using multi-spectral high spatial resolution remote sensing datasets (Kim & Daigle 2012). The decreased vegetation cover included 79 points (79 m^2) within the study boundary and the increased vegetation cover included 2,046 points (2,046 m^2). The dataset itself indicated a relatively high effectiveness of the management practices in terms of the amount of vegetation cover during the timeframe. A Trimble GeoXT (GPS) with an external antenna and bypass was utilized to verify the locations of LNT signposts (19 points) and the three physical barriers at Cadillac summit. The physical barriers (polygons) were converted into points by calculating their mean centers (3 points). Additionally, the summit loop trail line was converted into points at the 1 m interval (694 points).

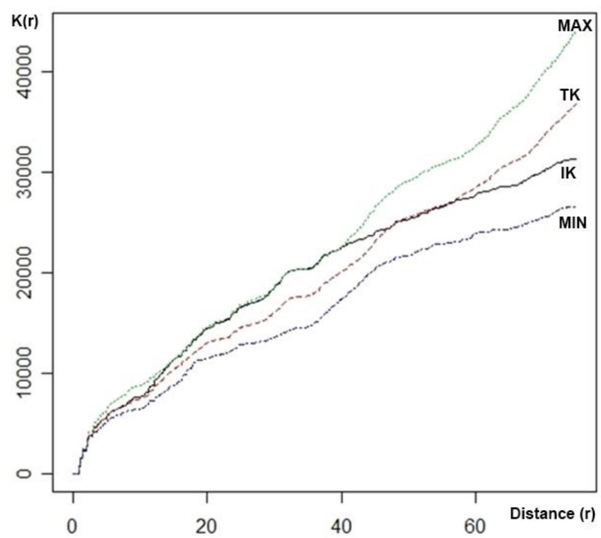
We first computed the single point patterns of vegetation cover changes (recovery & impact) and then bivariate point patterns between vegetation cover changes and the locations of the management practices. Ripley's K-function, often referred to as the reduced second moment measure, was initially applied to identify spatial patterns of the vegetation cover change points (Baddeley & Turner 2005, Bailey & Gatrell 1995, Ripley 1988). The types of relationship that can be identified using this approach include 1) clustering, 2) dispersion, and 3) complete spatial randomness (CSR). If an isotropic corrected line (observed value) is plotted over a theoretical K-function line (expected value) in a computation and simulation, it indicates clustering of the single point pattern. On the other hand, an isotropic corrected line plotted under a theoretical K-function indicates dispersion. However, in both cases, if the isotropic corrected line falls within the maximum and minimum envelopes, it fails to reject the null hypothesis and indicates CSR.

More importantly, cross K-function was utilized in order to verify spatial interactions among the locations of management practices, the summit loop trail and the vegetation cover change points (Baddeley & Turner 2005, Bailey & Gatrell 1995). The results of the function represent one relationship among 1) attraction (two types of point events tend to spatially distribute near each other), 2) repulsion (two types of point events tend not to spatially distribute near each other), and 3) independence (no spatial relationship between two types of point events). A border corrected cross K-function line (observed value) that is plotted over a theoretical cross K-function line (expected value) indicates an attractive spatial relationship between the two types of point events. On the other hand, a border corrected cross K-function line that is plotted under a theoretical cross K-function indicates a repulsive spatial relationship. In both cases, if the border corrected cross K-function line falls within the maximum and minimum envelopes, it fails to reject the null hypothesis and indicates that the two point patterns are spatially independent. For all computations and simulations, we used R (statistical software programming language) and spatstat (R package).

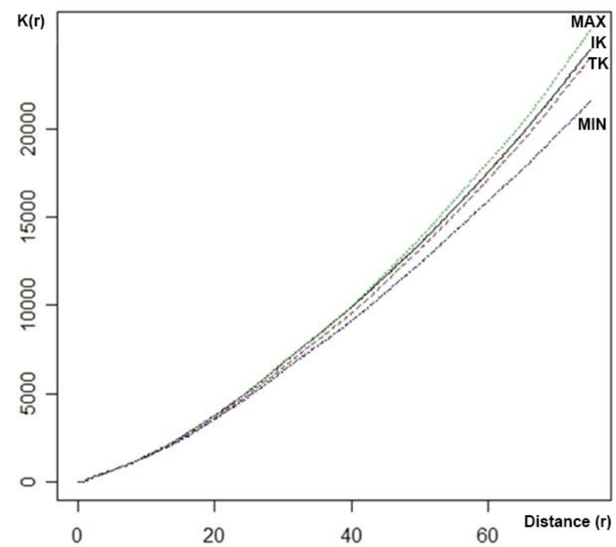
4.0 Results

Figure 3 illustrates the K-function differences between the isotropic corrected line (black) and the theoretical K-function line (red) as well as maximum (the upper green) and minimum (the lower blue) envelopes based on 99 simulations.

*Figure 3***.** Hypothesis Tests of Spatial Point Pattern, MAX (green): Maximum Envelope, MIN (blue): Minimum Envelope, IK (black): Isotropic Corrected K-function, TK (red): Theoretical K-function.



(a) *K-function Result of Decreased Vegetation Cover Points*

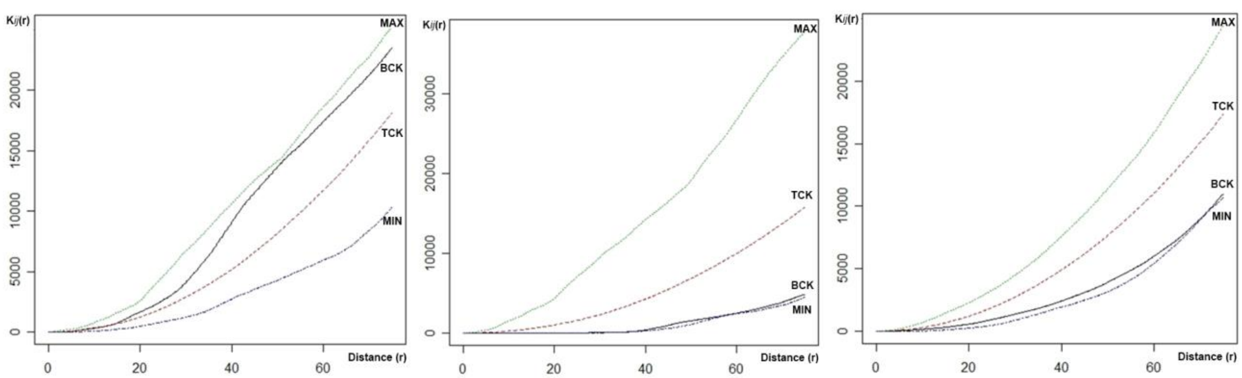


(b) *K-function Result of Increased Vegetation Cover Points*

The K-function result of the decreased vegetation cover points indicated a clustering pattern by showing that the isotropic corrected line was slightly plotted over the maximum envelope line around 35-40 m in distance (Figure 3a). On the other hand, the K-function result of the increased vegetation cover points exhibited CSR by showing that the isotropic corrected line fell within the maximum and minimum envelopes based on 99 simulations (Figure 3b). These results suggest that the impact points in the vicinity of the summit loop trail are spatially clustered, while indicating no distinctive spatial pattern in the recovery points.

The cross K-function result between the decreased and increased vegetation cover points was spatially independent by showing that the border corrected cross K-function line (black) fell within the maximum and minimum envelopes based on 99 simulations, indicating no spatial relationship between the two types of events (Figure 4a). The cross K-function result between the decreased vegetation cover points and the summit loop trail also showed that the border corrected cross K-function line (black) fell within the maximum and minimum envelopes based on 99 simulations, indicating the same independent relationship between the two types of events (Figure 4b). In addition, the cross K-function result between the increased vegetation cover points and the summit loop trail was spatially independent (Figure 4c).

*Figure 4***.** Hypothesis Tests of Spatial Interaction between Two Types of Events, MAX (green): Maximum Envelope, MIN (blue): Minimum Envelope, BCK (black): Border Corrected cross K-function, TCK (red): Theoretical cross K-function.



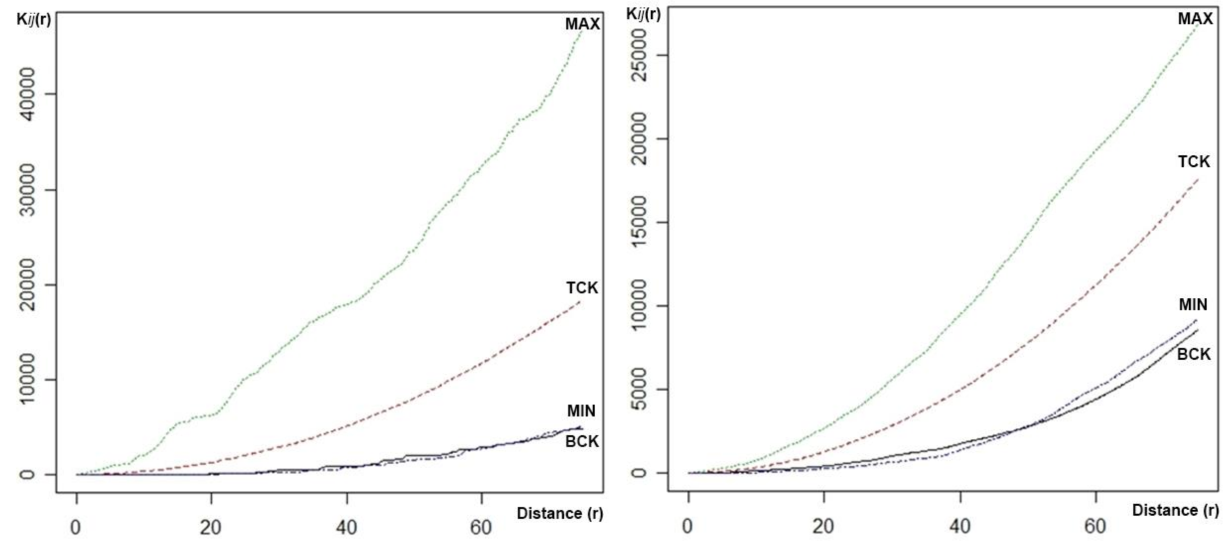
(a) *Cross K-function Result between Decreased and Increased Vegetation Cover Points*

(b) *Cross K-function Result between Decreased Vegetation Cover Points and Summit Loop Trail*

(c) *Cross K-function Result between Increased Vegetation Cover Points and Summit Loop Trail*

The cross K-function result between the decreased vegetation cover points and the locations of management practices exhibited a repulsive spatial relationship by showing that the border corrected cross K-function line was plotted under the minimum envelope line, especially from 70 to 80 m in distance (Figure 5a). Also, the cross K-function result between the increased vegetation cover points and the locations of management practices exhibited the same repulsive spatial relationship from 50 to 80 m in distance, suggesting that the two types of point events tend to not spatially distribute close together (Figure 5b).

Figure 5. Hypothesis Tests of Spatial Interaction Between Two Types of Events, MAX (green): Maximum Envelope, MIN (blue): Minimum Envelope, BCK (black): Border Corrected cross K-function, TCK (red): Theoretical cross K-function.



(a) *Cross K-function Result between Decreased Vegetation Cover Points and Locations of Spatial Containment Strategies*

(b) *Cross K-function Result between Increased Vegetation Cover Points and Locations of Spatial Containment Strategies*

5.0 Discussion and conclusion

The clustered impact point pattern clearly identifies that the vegetation impact regime at Cadillac summit is not widespread over the vicinity of the summit loop trail compared to the vegetation recovery, which exhibited CSR. This finding could be a direct benefit of the point pattern analysis at a large spatial scale. Identifying the susceptibility of the clustered areas would be a valuable step to prevent additional impact in the future. It should be noted that the localized vegetation impact can easily expand or creep with time in a recreation site (Cole 2004, Cole & Hall 1992, Hammitt & Cole 1998). Those clustered and impacted areas, therefore, could be potential candidates for installing physical barriers as a direct management approach to reduce the unintended proliferation of impact to adjacent areas.

The cross K-function results showed that the spatial containment management strategies have been validated to spatially repulse the creation of the impacted vegetation cover points in a closer proximity during the intended timeframe. However, contrary to our expectations, the results also indicated that vegetation regeneration tends not to occur near the location of management practices. According to the regular radial pattern and zoning concept in a recreation site (impact, intersite, and buffer zones), potential areas for vegetation regeneration are not in the near proximity of recreation sites or trails. The recovery would be greater and increased as one moves away from the sites and trails because the capacity of vegetation to regenerate is not severely impacted in those areas compared to the mainly used areas (Kim & Daigle 2012). In addition, there is a need to consider the long history of the site as a recreation destination with this observed repulsive spatial relationship. Given the fact that the site has been intensively used since the beginning of 20th century (even before 20th century unofficially), the accumulated impact may constitute an environment that is unfavorable for vegetation recovery, especially for the areas covered by the three physical barriers. It is plausible that the lack of recovery in a closer proximity to management structures was mainly influenced by natural and environmental conditions. Here is a need to investigate site characteristics such as the portion of bare-rock and types of plants to further support the study results. A proper temporal scale may also be necessary in verifying the spatial efficacy of the management practices, especially given the sub-alpine environment of Cadillac Mountain, which usually takes a long time to recover (Hammitt & Cole 1998).

The proposed study has a spatial scaling issue that requires more investigation. The 300 m × 400 m rectangle from the mean center point of the summit loop trail was utilized in defining the study boundary under the assumption that the area would be a potentially impacted zone by visitor use. However, there is a possibility that we may observe different spatial patterns and interactions among the point events, once we adopt a different extent (study boundary) at Cadillac. Therefore, multiple spatial scales associated with the extent should be utilized to cope with the sensitive issue of the boundary. In addition, it is important to mention that the concept of spatial efficacy is not well-defined and developed in the field of recreation ecology, unlike the development of spatial management strategies that include spatial segregation, containment, dispersal and configuration (Leung & Marion 1999). Thus, future research needs to develop criteria for evaluating the spatial efficacy of management actions under different environmental conditions.

Diverse monitoring techniques based on spatial and temporal variability as well as vegetation impact monitoring parameters such as the amount of cover and species composition have been utilized to estimate the effectiveness of the spatial containment management practices in the field of recreation ecology. We strongly believe that the inclusion of spatial analyses such as those used in this study can further our understanding and evaluation of the overall effectiveness of management practices.

6.0 References

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