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Long-term monitoring of vegetation cover changes by remote sensing, Cadillac Mountain summit, Acadia National Park

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ABSTRACT

The primary objective of this study was to detect vegetation disturbance resulting from visitor use by using remote sensing. A pre-classification change detection analysis based on the normalized difference vegetation index was utilized to measure the amount of vegetation cover changes at Cadillac Mountain summit, Acadia National Park, Maine. By analyzing new remote sensing data collected in 2010 and 2018, we compared the vegetation conditions at the summit (experimental site) with a nearby site with little or no visitor use (control site). Additionally, the study was designed to examine vegetation cover changes between 2001–2007 (the first time frame) and 2010–2018 (the second time frame). Similar to the results observed in the first time frame, the experimental and control sites exhibited more vegetation increase than vegetation decrease in the second time frame. The amount of vegetation increase was 1,425m² at the experimental site and 400m² at the control site. The amount of vegetation decrease was 150m² at the experimental site and 75m² at the control site. Measurable vegetation cover changes based on the remote sensing analysis could provide baseline data for monitoring further changes over an extended period of time. The advantages of using remote sensing in detecting vegetation conditions are also discussed, along with management and research implications.

Keywords: remote sensing, recreation ecology, vegetation, visitor impact monitoring, parks and protected areas

INTRODUCTION

Recent recreation ecology studies have made significant contributions to the conservation of natural resources by identifying recreation resource impacts and suggesting management strategies to minimize problems in parks and protected areas (Monz, Cole et al. 2010; Monz, Pickering, and Hadwen 2013). Also, diverse methods for inventorying and assessing vegetation disturbance resulting from visitor use have been developed to support management efforts and initiatives (Barros, Gonnet, and Pickering 2013; Ballantyne and Pickering 2015; Hammitt, Cole, and Monz 2015; Monz, Marion et al. 2010; Pickering and Norman 2017; Tomczyk et al. 2017). However, the challenge is to measure vegetation disturbance when a site boundary is relatively large for on-site measurements and when a site boundary grows or retreats as use or density fluctuates. Particularly, on a subalpine mountain summit where bare rock interspersed with sparse low-lying shrubs and grasses are dominant, examining visitor-induced impacts associated with trampling could be challenging due to an ambiguous site boundary and easy mobility of visitors. Consequently, a more effective and comprehensive approach is required to verify the overall trends and patterns of vegetation cover changes at a mountain summit environment.

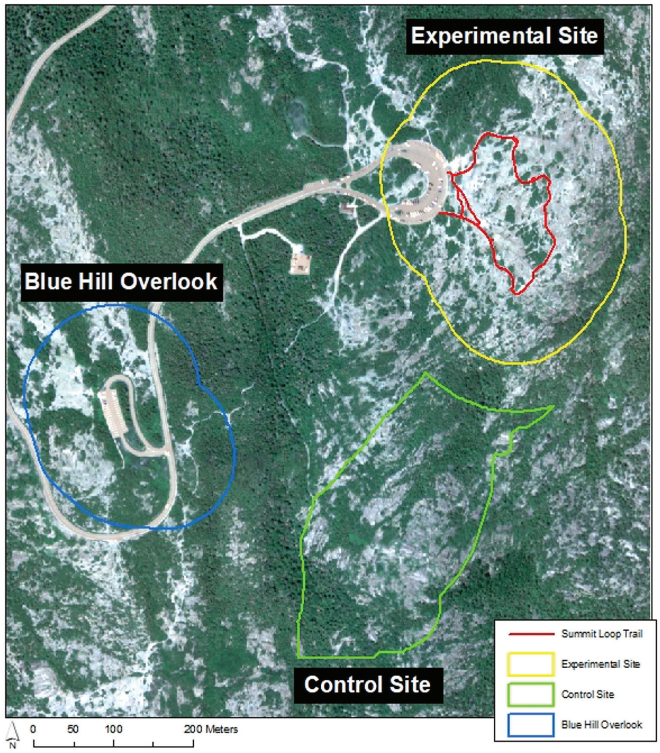
In this study, we suggest using remote sensing and high-spatial-resolution data, which have rarely been adopted to test the effectiveness of management actions that enhance vegetation regrowth and reduce vegetation disturbance caused by visitor use (Hammitt, Cole, and Monz 2015). Remote sensing analysis and data could provide several benefits in investigating visitor-induced impacts at a mountain summit environment. First, once data are acquired, an analysis could be quickly designed and carried out without on-site measurements and experiments that often require substantial fieldwork. Essential information derived from the analysis, such as hot spots and clustered areas, could be promptly shared with park and protected area managers. Therefore, this method can eventually promote data-informed decision-making related to deploying the management actions on time. Second, in many cases, as new data covering the same area/site are continually collected and archived based on their temporal resolution, further assessments over an extended period of time could be efficiently performed (Kim, Daigle, and Gooding 2014). Additional analysis can provide valuable information, such as detailed trends of vegetation cover changes and long-term effects of management actions, which cannot be obtained from the results of short-term or one-time studies. Third, it is worth noting that remote sensing technology is flexible in study design. Because analysis could contain not only an original site but also surrounding areas, if necessary, the spatial extent/scope of the analysis can be easily expanded to include nearby areas. Additionally, based on sensor characteristics and spectral resolutions, various change detection algorithms and techniques can be utilized to further confirm and compare the analysis outcomes.

The goal of this study was to better understand vegetation change dynamics due to trampling in a fragile subalpine environment. Specific objectives were to (1) detect direct vegetation cover changes by using high-spatial-resolution remote sensing data, and (2) verify the management efficacy designed to reduce vegetation disturbance and enhance vegetation regeneration.

METHODS

Study site

The study site is the summit of Cadillac Mountain, the most popular visitor destination in Acadia National Park (ACAD), Maine (Figure 1). According to an extensive vegetation study, most of the summit area is classified as dwarf-shrubland (Lubinski et al. 2003). While the elevation of the summit is 1,530ft (466m), severe stresses from the climate and erosion, such as strong winter wind, snow and ice, and rapid water run-off, formed a subalpine-like environment where low-growing plant communities are prevailing (Kidd et al. 2015; National Park Service 2012; Wessels 2002).



	Characteristics	Size (m²)
Experimental site	visitor use/impact, active management intervention (by indirect, direct, and ecological restoration)	87,136
Control site	no visitor use/impact, natural variability	61,552
Blue Hill Overlook	visitor use/impact, management intervention (by only direct management)	55,908

FIGURE 1. Characteristics of study site: Summit of Cadillac Mountain, Acadia National Park. To maintain the consistency of the change detection analysis, the experimental and control sites established in the previous study (Kim and Daigle 2012) were utilized.

The short growing season, low amount of water available, and shallow soil conditions, coupled with high levels of visitor use, have created a high risk of vegetation degradation and soil erosion (Kim and Daigle 2012; Manning 2014). This site currently represents a management challenge to balance the conservation of resources with enjoyment of the park by the public (Daigle and Zimmerman 2004; Kim and Daigle 2011; Worboys, Lockwood, and De Lacy 2005). For this reason, to support management at the summit, various studies have been conducted focusing on visitor experiences, visitor behaviors, resource impacts, and management

FIGURE 2. Low-impact educational messages based on Leave No Trace principles (left) and physical barriers (right) implemented in 2000. Physical barriers were initially constructed as wooden barricades, and updated with lines of ropes later.

preferences (Bullock and Lawson 2007; Bullock and Lawson 2008; Monz, Marion et al. 2010; Park et al. 2008; van Riper et al. 2011; Kid et al. 2015).

Since 2000, to address the management challenge, a combination of site and visitor management strategies using physical barriers and low-impact educational messages, respectively, have been deployed in strategic locations along the summit loop trail (Figure 2). As a supplementary management strategy, an ecological restoration project was initiated in 2015 to enhance vegetation recovery at this high-use destination (https://www.nps.gov/acad/learn/management/cadillac.htm) (Figure 3).

Previous vegetation cover change analysis studies between 2001 and 2007, which focused on assessing the recovery of vegetation after six years, suggested that the site and visitor management strategies employed starting in 2000 were beneficial in terms of enhancing the amount of vegetation at the summit (Kim and Daigle 2011; Kim and Daigle 2012). Notably, both studies indicated a relatively large amount of vegetation increase within the large spatial scale (as a spatial extent, 0–90m from the summit loop trail) or periphery area (about 60–90m from the summit loop trail), eventually suggesting the desired direction of Acadia's active management initiative. However, the studies also identified relatively large clustered areas of vegetation decrease away from the summit loop trail (e.g., near a gift shop and a nearby trail in the main parking lot, and at a tour bus stop located at the west side of the main parking lot). In 2015, based on the findings of the studies, ACAD installed several physical barriers (large exclosures) to mitigate this vegetation loss at the tour bus stop area where the north ridge trail is connected to the main parking lot. More importantly, both studies reported a relatively large amount of vegetation increase at the experimental and control sites compared to the amount of vegetation decrease. Therefore, as a critical next step for the management and the long-term monitoring at the summit, new remote sensing data collected recently were utilized to identify the trends of vegetation cover changes over 15 years.

Data, study design, and image processing

All satellite remote sensing data required for the analysis were obtained from the database maintained by Planet Labs (https://www.planet.com/) and the Planet's Education and Research Program (Planet Team 2018). Planet Labs is a private Earth-imaging company based in San Francisco, California, providing various satellite data that include medium- and high-spatial-resolution images. Specifically, two sets of RapidEye data between 2010 and 2018 were downloaded for detecting the vegetation conditions at the summit of Cadillac Mountain. The first set of remote sensing data was collected on August 30, 2010, and had five multispectral bands in 5m spatial resolution. The second set of data was collected on August 31, 2018, and had the same sensor characteristics (Table 1). RapidEye data have been widely used for monitoring vegetation cover changes and forest disturbances under various natural resource settings (Elatawneh et al. 2014; Gärtner, Förster, and Kleinschmit 2016; Traganos and Reinartz 2018). Other geospatial data pertaining to the summit loop trail, the boundary of the experimental site (90m from the summit loop trail), and the control site selected were obtained from a previous study (Kim and Daigle 2012).

The control site was originally developed by considering several factors, such as being at the same level of elevation, covering the same areas burned by a fire in 1947,

FIGURE 3. Ecological restoration project implemented in 2015. This project was used as a management tool, not as a research mechanism.

Remote sensing data used*		First NDVI (2010)	Second NDVI (2018)
RapidEye Analytic Ortho Tile: 5m spatial resolution, 5-band multispectral (blue, green, red, red edge, and near-infrared) First: August 30, 2010 Second: August 31, 2018	Min.	−0.67	−1.00
	Max.	1.00	1.00
PlanetScope Analytic Ortho Scene: 3m spatial resolution, 4-band multispectral, collected on August 29, 2018 (downloaded for additional accuracy assessment)	Mean	0.49	0.50
	Std. Deviation	0.24	0.23

* Source: Planet Team (n.d.)

TABLE 1. Characteristics of sensor and NDVI values extracted.

and including potentially human-accessible areas to ensure environmentally similar characteristics with the experimental site, except that there would be no visitor impact characteristics (Figure 1). Unlike the experimental site, the control site does not reflect management intervention. One of the traditional monitoring techniques in recreation ecology is establishing this type of control site to measure the relative degree of impact in a treatment/experimental site (Cole 1995; Cole and Bayfield 1993; Marion 1995). Then, a total or mean vegetation cover is often estimated and compared between the treatment/experimental and control sites (Hammitt, Cole, and Monz 2015). We primarily adopted this study design, which compares the vegetation conditions at the summit with the nearby control site having little or no visitors. By comparing the percent change of vegetation cover between the two sites (the amount of vegetation increase or decrease divided by the total amount of vegetation multiplied by 100), the study was designed to check the relative efficacy of the management actions employed at the summit. To better understand the effect of the management actions, we also measured the amount of vegetation cover changes at another site (Blue Hill Overlook) in the vicinity of the summit loop trail (the same spatial extent, 0–90m from the Blue Hill Overlook parking lot). More importantly, this analysis included the comparison between the monitoring result of the first time frame (2001–2007) and the new result by additional remote sensing data (from the 2010–2018 time frame) to explore the long-term trends of vegetation cover changes at the summit.

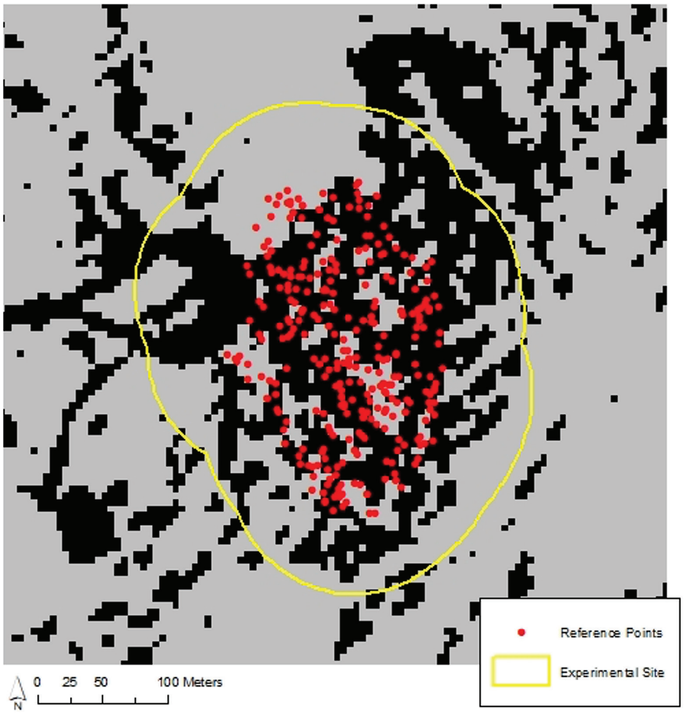
ERDAS Imagine 2015 and ESRI ArcMap (version 10.2) were utilized for image processing and change detection analysis. As a pre-processing step, to cover both experimental and control sites, the two images were subset to the summit loop trail, Cadillac Mountain. Haze reduction for both images (applied to all five bands) and histogram matching (master: 2018 data, slave: 2010 data) were carried out, respectively. A pre-classification change detection analysis based on the normalized difference vegetation index (NDVI), which was used in the previous vegetation change analysis study (Kim and Daigle 2012), was adopted for this new analysis as a primary change detection technique. NDVI uses two specific bands of remote sensing data (red and infrared bands) to measure vegetation cover representing photosynthetic activity, vegetation biomass, greenness, and vegetation canopy closure (Sader and Winne 1992; Wilson and Sader 2002). The value of NDVI can be ranged from −1.00 to 1.00, indicating that higher NDVI values, in general, represent healthy/dense vegetation (Pettorelli 2013; Pujiono et al. 2013; Filgueiras et al. 2019). Thus, the change in the NDVI value between the two dates can indicate an increase or decrease in the amount of green vegetation in each pixel of data. Table 1 shows the ranges, means, and standard deviations of the NDVI layers extracted from the two images.

In displaying the changes of pixel value, RGB-NDVI color composite was used to visualize the fractional vegetation cover changes (Sader and Winne 1992; Sader, Bertrand, and Wilson 2003; Pujiono et al. 2013). The result of the RGB-NDVI color composite was quantified by using an unsupervised classification with 100 classes (ISODATA algorithm, 99% convergence threshold, maximum iteration number of clusters: 100) (Sader et al. 2001). Then, the 100 classes generated were re-visited, visually inspected, and re-labeled using the following categories: Non-Vegetation (0), Vegetation Decrease (1), Vegetation Increase (2), and Vegetation, No-Change (3) (Table 2). In assigning a new label for each cluster (class), NDVI thresholds and significant changes in mean NDVI could be considered (Wilson and Sader 2002; Mackey, Lee, and Smith 2012; Pujiono et al. 2013; Guo, Lu, and Kuang 2017). Specifically, two major rules were utilized in the visual inspection process. First, a threshold of 0.35 in NDVI was established to distinguish vegetated areas from non-vegetated areas. If the majority of the pixels inspected in a cluster show NDVI values less than 0.35 on both dates, the cluster was assigned to "Non-Vegetation (0)." As exposed soil surfaces could exhibit positive NDVI values (Pettorelli 2013; Filgueiras et al. 2019), we attempted to reduce the likelihood of false interpretation by extensively removing potentially non-vegetated areas. Second, we adopted the maximum variation in NDVI value (the highest differences in NDVI decrease and increase), which was ±0.40 between the two dates. In other words, clusters showing less than or equal to −0.40 of NDVI variation were assigned to "Decrease (class 34: −0.40, class 77: −0.40)." For example, the mean NDVI in class 34 was reduced from 0.50 (first NDVI) to 0.10 (second NDVI), representing the highest decrease among the clusters. Clusters showing greater than or equal to +0.40 of NDVI variation were assigned to "Increase (class 84: 0.40, class 50: 0.42, class 30: 0.55, class 61: 0.60)." Table 2 shows the condition and outcome of the re-labeling based on the unsupervised classification. After re-labeling and re-coding, filtering methods were not applied because an isolated pixel could be a major vegetation cover change at this spatial resolution.

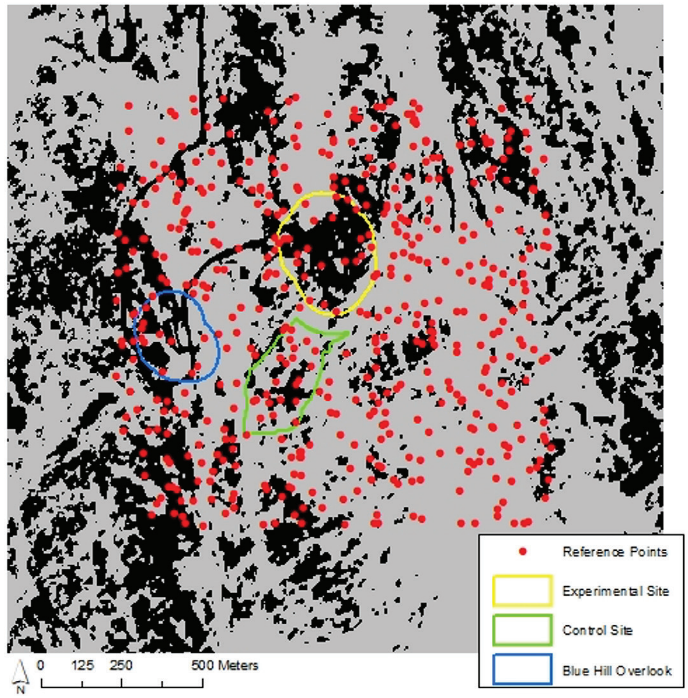
A set of field data collected in 2007 via a sub-meter-accuracy hand-held GPS (Trimble GeoXT), representing a total of 294 ground control points recorded in the binary mode (vegetation and non-vegetation), was used for accuracy assessment. These reference points were previously used for the accuracy assessment for the result of the first time frame analysis. Additional accuracy assessments were completed using ancillary data. PlanetScope (3m spatial resolution) data, collected on August 29, 2018, were obtained from the same database (Planet Labs). Vegetation cover information in the binary mode was generated from this higher-spatial-resolution data by extracting multiple NDVI layers at various levels: 0.25, 0.30, and 0.35 (Figure 4). For example, the NDVI layer at the level of 0.30 was composed of vegetated areas (if NDVI value is greater than or equal to 0.30) and non-vegetated areas (if NDVI value is less than 0.30). A shapefile that includes 500 random points over the experimental and control sites in the vicinity of the summit loop trail was created. Then, the vegetation cover information generated at each NDVI level was accordingly recorded in the shapefile as reference data for accuracy assessments.

TABLE 2. NDVI classification for re-labeling and re-coding.

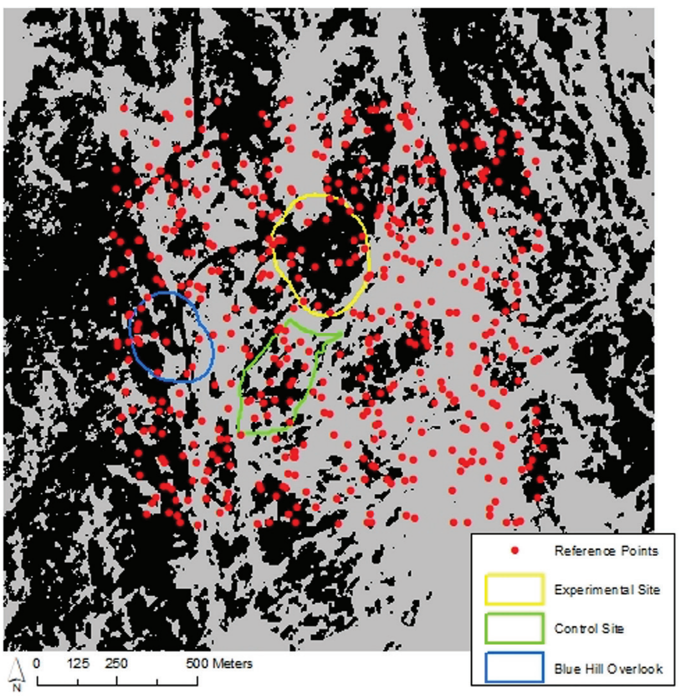
Condition for classification	Original class (cluster)	Re-labeling	Re-coding #
if both NDVIs are less than 0.35	class from 0 (unclassified) to 23, classes 26, 27 and 29	Non-Vegetation	0
if NDVI variation ≤ −0.4	classes 34 (-0.40) and 77 (−0.40)	Vegetation Decrease	1
if NDVI variation ≥ +0.4	classes 30 (+0.55), 50 (+0.42), 61 (+0.60) and 84 (+0.40)	Vegetation Increase	2
if −0.4 < NDVI variation < +0.4	all other classes	Vegetation, No-Change	3



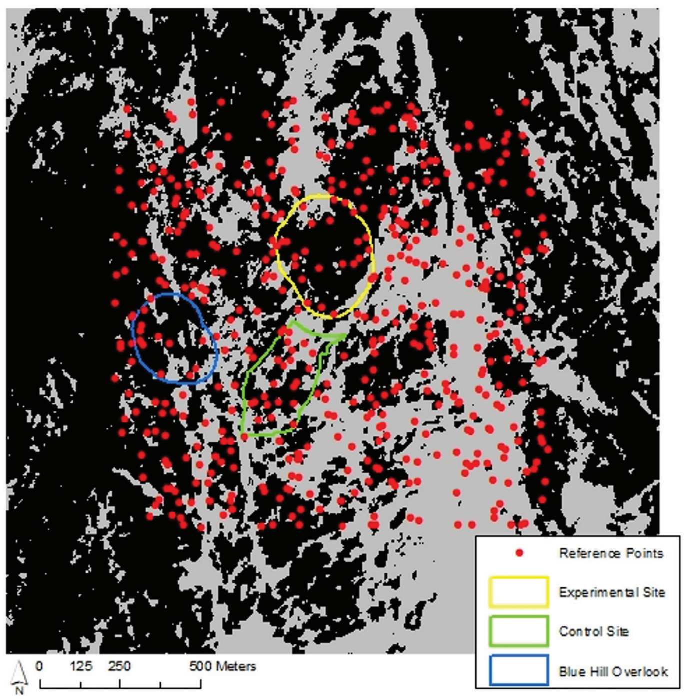
1) Assessment by the original reference data



2) Assessment by NDVI extracted from PlanetScope at the level of 0.25 (vegetation, if NDVI ≥ 0.25)



3) Assessment by NDVI extracted from PlanetScope at the level of 0.30 (vegetation, if NDVI ≥ 0.30)



4) Assessment by NDVI extracted from PlanetScope at the level of 0.35 (vegetation, if NDVI ≥ 0.35)

FIGURE 4. Accuracy assessment for NDVI change detection analysis from 2010 to 2018. (Gray: vegetated area; Black: non-vegetated area)

RESULTS

Overall accuracy estimated using the 294 reference points over the study area was 74.15% at the binary-mode level (Table 3). Compared to the accuracy assessment in the previous study (76.19%), the overall accuracy was down by 2.04%. The accuracy assessments estimated using the newly created 500 random points were 92.60% (NDVI layer at the level of 0.25), 82.80% (NDVI layer at the level of 0.30), and 65.20% (NDVI layer at the level of 0.35),

Original data	Non-vegetation	Vegetation	Total	User's accuracy	Based on NDVI 0.25	Non-vegetation	Vegetation	Total	User's accuracy
Non-vegetation	**167**	51	218	76.61%	Non-vegetation	**104**	7	111	93.69%
Vegetation	25	**51**	76	67.11%	Vegetation	30	**359**	389	92.29%
Total	192	102	**294**		Total	134	366	**500**	
Producer's accuracy	86.98%	50.00%		**74.15%**	Producer's accuracy	77.61%	98.08%		**92.60%**
Based on NDVI 0.30	Non-vegetation	Vegetation	Total	User's accuracy	**Based on NDVI 0.35**	Non-vegetation	Vegetation	Total	User's accuracy
Non-vegetation	**111**	0	111	100%	Non-vegetation	**111**	0	111	100%
Vegetation	86	**303**	389	77.89%	Vegetation	174	**215**	389	55.27%
Total	197	303	**500**		Total	285	215	**500**	
Producer's accuracy	56.35%	100%		**82.80%**	Producer's accuracy	38.95%	100%		**65.20%**

TABLE 3. Results of accuracy assessment.

respectively. The NDVI layer extracted at the level of 0.25 provided the highest overall accuracy.

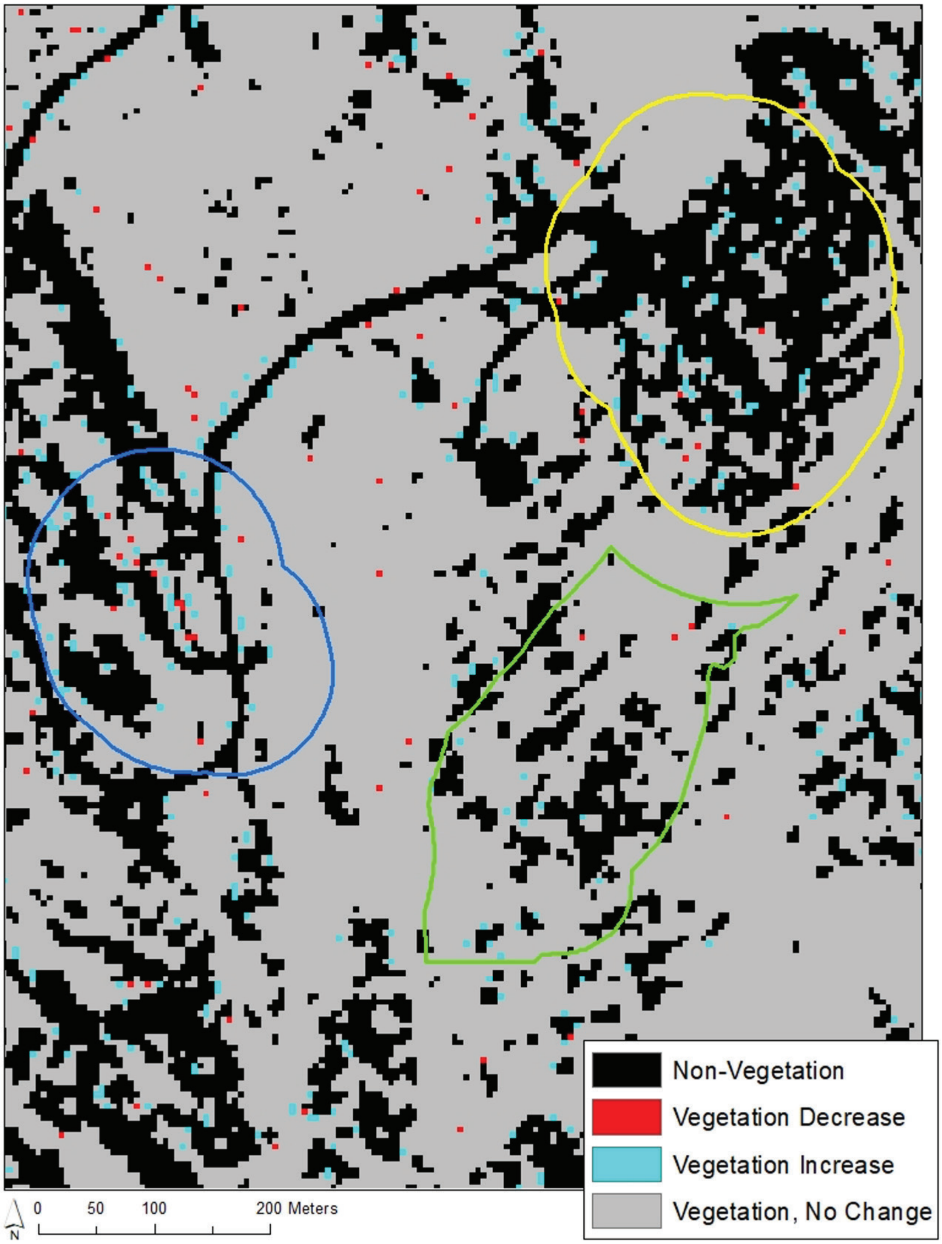
Figure 5 shows the result of the change detection analysis from 2010 to 2018 on the summit of Cadillac Mountain. Both experimental and control sites showed greater vegetation increase than vegetation decrease. The amount of vegetation increase was 1,425m² at the experimental site and 400m² at the control site. The amount of vegetation decrease was 150m² at the experimental site and 75m² at the control site. The rates of vegetation increase and decrease were less than 3.5% at both sites based on the total amount of vegetated areas.

More variations in vegetation cover changes were detected in Blue Hill Overlook. The amount of vegetation increase was 1,450m² (3.88%), showing a relatively similar level with the amount of vegetation increase at the experimental site (1,425m², 3.45%). However, the amount of vegetation decrease was 325m² (0.87%), indicating a higher level compared to the experimental site (150m², 0.36%).

A comparison was made between 2001–2007 (1m spatial resolution) and 2010–2018 (5m spatial resolution) (Table 4). Overall, similar trends were identified in the second period, showing that the rates of vegetation increase were higher than the rates of vegetation decrease at both sites. Compared to the first period, the rate of vegetation decrease was augmented from 0.12% to 0.36%, and the rate of vegetation increase was reduced from 5.56% to 3.45% at the experimental site. Both vegetation decrease and increase were diminished from 0.64% to 0.16% and from 2.36% to 0.87% at the control site.

DISCUSSION

Although the amounts of vegetation cover changes were relatively low at both sites, the analysis results provide useful aspects associated with the outcome and direction of current management actions. At both sites, like the results observed in the first period, the rates of vegetation increase were higher than the rates of vegetation decrease during the second period. Simultaneously, the rate of vegetation increase was greater at the experimental site than at the control site in the second period. Therefore, based on Acadia's management priority/objective, the current management actions that employ physical barriers, messages, and ecological restorations in an integrated way could be continually utilized to maintain similar trends in the vegetation conditions at Cadillac. However, it should be noted that, unlike the first period, the rate of vegetation decrease was higher at the experimental site than at the control site in the second period. Understanding the characteristics of vegetation cover changes spatially is essential to management. Also, information about the types of vegetation communities regenerating or disappearing is necessary to better understand plant diversity. In that regard, we suggest that the process of diagnosing the attributes and degrees of impacts in the second period requires re-visiting the locations showing vegetation decrease, especially at the experimental site. These locations could potentially be candidate sites for future ecological restoration projects. It was also observed that the majority of vegetation increase was located in the edges of sparsely vegetated areas at the experimental site. In such locations, biophysical characteristics (i.e., type of vegetation; topographic factors including slope, aspect, and elevation; proximity to the summit loop trail and locations of management) could be further investigated to better understand the complexity of vegetation cover changes. The role of predictive modeling is becoming more important in recreation ecology (Monz et al. 2020). Thus, the biophysical variables investigated will be useful in



2010–2018	Experimental site (0–90m)		Control site (0–90m)		Blue Hill Overlook (0–90m)	
	Unit (m^2)	%	Unit (m^2)	%	Unit (m^2)	%
Vegetation Decrease	150	0.36	75	0.16	325	0.87
Vegetation Increase	1,425	3.45	400	0.87	1,450	3.88
Vegetation, No-change	39,675	96.18	45,500	98.97	35,625	95.25

FIGURE 5. NDVI change detection analysis from 2010 to 2018. Yellow: Experimental site; Green: Control site; Blue: Blue Hill Overlook.

developing a spatially explicit model that tries to explain factors influencing vegetation cover changes (Kim, Daigle, and Gooding 2014; Kim and Graefe 2020).

Unlike the first study (Kim and Daigle 2012) that utilized a 1m spatial resolution, this study primarily employed a 5m spatial resolution to detect the fractional vegetation cover changes. While the spatial resolutions of the analyses are different, it was possible to identify similar trends and patterns in the vegetation conditions during the second time frame. Given that high-spatial-resolution remote sensing data are regularly added and archived in the database of Planet Labs, additional images could be considered for future analysis, if finer spatial resolution

Comparison	Experimental site				Control site			
	1st time frame 2001–2007*		2nd time frame 2010–2018		1st time frame 2001–2007*		2nd time frame 2010–2018	
	Unit (m^2)	%	Unit (m^2)	%	Unit (m^2)	%	Unit (m^2)	%
Decrease	23	0.12	150	0.36	180	0.64	75	0.16
Increase	1,668	5.56	1,425	3.45	791	2.36	400	0.87

* Results obtained from the previous change detection analysis study (Kim and Daigle 2012): calculations of the percentage in the previous study were based on $10m^2$ plots within the large spatial scale.

TABLE 4. Comparison between first time frame (2001–2007) and second time frame (2010–2018).

data is not available soon. As noted, one of the most significant advantages of using remote sensing is to collect the data required for analysis repeatedly. While establishing appropriate temporal scales of analysis is imperative, vegetation measurements by high-spatial-resolution remote sensing data are sensitive enough to reveal changes over a relatively short period of time in this fragile and harsh subalpine growing environment. Thus, periodic measurements of the vegetation condition over time would be necessary to further assess the efficacy of the current management actions. Within the same context, to increase the breadth of data available for long-term monitoring at the summit, unmanned aerial vehicles (UAVs) and drones could be considered for securing multispectral data as a primary platform. While more discussion is needed on whether flying these machines should be permitted in national parks (https://www.nps.gov/articles/unmanned-aircraft-in-the-national-parks.htm), we expect that the versatility of UAVs and drones will play an important role in visitor impact monitoring and recreation resource management in protected areas in the US and worldwide (Ancin-Murguzur et al. 2020; Lee et al. 2020; López and Mulero-Pázmány 2019).

The benefits of using remote sensing include obtaining a big picture of analytical outcomes. It was possible to identify other areas impacted in the vicinity of the summit loop trail. Those areas were not included within the original boundary of the study. For example, Blue Hill Overlook is on the west side of the summit loop trail, where the additional parking lot is located. The site is also a popular visitor destination to see the sunset at Cadillac Mountain. Unlike the integrated approach in the vicinity of the summit loop trail, only two physical barriers were installed in 2011 at this location. Thus, to minimize the amount of vegetation decrease identified, ACAD could consider additional management actions, such as messages and ecological restoration projects, to maintain the consistency of management actions within the summit of Cadillac Mountain. Effective management prescriptions often require the combination of site management (i.e., site protection techniques to induce more concentrated visitor use) and visitor management (i.e., providing more information regarding natural resource conditions), especially in a frontcountry setting (Manning 2009; Daigle 2020; Wu et al. 2021). We also recommend employing ecological restoration projects that could accelerate vegetation recovery significantly in a subalpine environment (Cole 2013). Such initiatives would be beneficial in addressing the importance and fragile characteristics of natural resources effectively to the public. Interestingly, the south ridge trail, which is located at the south side of the summit of Cadillac Mountain, has been rehabilitated recently (Jacobi, Flesh, and Stellpflug 2016). The primary mechanism applied in the rehabilitation project included similar types of management actions, which combined site management techniques such as hardening and shielding with educational messages based on Leave No Trace principles.

The overall accuracy of the analysis was 74.15%. However, as a limitation of the study, this accuracy assessment was done using the reference data collected in 2007. While ancillary data collected in 2018 was utilized for additional accuracy assessments, other field reference data collected recently should be utilized to better evaluate the result of this NDVI change detection analysis. Also, NDVI was adopted as a primary change detection technique only to maintain the methodological consistency with the first time frame analysis. However, other vegetation change detection techniques, such as simple image differencing, soil adjusted vegetation index, normalized difference red edge index, and transformed NDVI, could be used for comparison purposes to confirm the result of this analysis. As the vegetation structure at the summit is composed mainly of low-lying shrubs with soil and bare-rock, discovering the techniques that better detect such environments will also be helpful for future analysis. Further, the change detection analysis used is based on a certain NDVI threshold (0.35), variations in NDVI values (±0.40), and a certain number of clusters (100 classes). Therefore, for future research, adjusting the values of those parameters could be considered to control the sensitivity of the outcome in the change detection analysis.

CONCLUSION

The study provided a rapid and comprehensive assessment of vegetation cover changes at the summit of Cadillac Mountain. The rates of vegetation decrease and increase were less than 3.5% at the experimental and control sites. Additionally, like the similar trends found in the first time frame analysis, the rates of vegetation increase were higher than the rates of vegetation decrease at both sites. Given the low resilience characteristics of the environment at the summit, the trends observed (more vegetation increase and less vegetation decrease) suggest a desirable direction in terms of implementing management actions. However, the study also identified a relatively higher rate of vegetation decrease at the Blue Hill Overlook area. Thus, continuous measurements of the vegetation condition over time will be required to assess the efficacy of the current management actions as well as to detect newly disturbed areas by visitor use and trampling.

Managers in parks and protected areas often struggle with deciding how to maintain an appropriate balance between conserving natural resource conditions and providing quality recreation experiences for visitors. ACAD is no exception in having to face this dilemma between "restrictions on visitors" and "freedom to visitors." Under this circumstance, the role of monitoring is more critical, and the remote sensing analysis described here will be helpful to providing managers with the information in a timely manner, enabling data-informed decision-making. With the recent implementation of a reservation system for visitors who access Cadillac by personal vehicle, the remote sensing analysis described here may provide useful baseline information to show potential ecological gains as a result of controlling the number of visitors as part of this new management.

Due to a dense canopy cover and multiple vegetation layers, the value of remote sensing has not been well-recognized in the field of recreation ecology, which has typically tried to identify a localized impact close to recreational trails, campsites, and other visitor destinations. However, in this study, the utility of remote sensing was maximized in detecting vegetation cover changes, as the summit of Cadillac Mountain is an open landscape, having a mixture of sparse low-lying shrubs with bare rock dominant. The assessment method thus could be effectively applied to other subalpine mountain summits with similar landscape conditions.

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REFERENCES

Ancin-Murguzur, Francisco J., Lorena Munoz, Christopher Monz, and Vera H. Hausner. 2020. Drones as a tool to monitor human impacts and vegetation changes in parks and protected areas. *Remote Sensing in Ecology and Conservation* 6(1): 105–113. https://doi.org/10.1002/rse2.127

Ballantyne, Mark, and Catherine Pickering. 2015. Recreational trails as a source of negative impacts on the persistence of keystone species and facilitation. *Journal of Environmental Management* 159: 48–57. https://doi.org/10.1016/j.jenvman.2015.05.026

Barros, Agustina, Jorge Gonnet, and Catherine Pickering. 2013. Impacts of informal trails on vegetation and soils in the highest protected area in the Southern Hemisphere. *Journal of Environmental Management* 127: 50–60. https://doi.org/10.1016/j.jenvman.2013.04.030

Bullock, Steven D., and Steven R. Lawson. 2007. Examining the potential effects of management actions on visitor experiences on the summit of Cadillac Mountain, Acadia National Park. *Human Ecology Review* 14(2): 140–156.

Bullock, Steven D., and Steven R. Lawson. 2008. Managing the "commons" on Cadillac Mountain: A stated choice analysis of Acadia National Park visitors' preferences. *Leisure Sciences* 30(1): 71–86. https://doi.org/10.1080/01490400701756436

Cole, David N. 1995. Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology* 32: 203–214.

Cole, David N. 2013. Long-term effectiveness of restoration treatments on closed wilderness campsites. *Environmental Management* 51(3): 642–650. https://doi.org/10.1007/s00267-012-0015-3

Cole, David N., and Neil G. Bayfield. 1993. Recreational trampling of vegetation: Standard experimental procedures. *Biological Conservation* 63(3): 209–215. https://doi.org/10.1016/0006-3207(93)90714-C

Daigle, John J. 2020. Developing forestry recreation services. In *Achieving Sustainable Management of Boreal and Temperate Forests*. John Stanturf, ed. Cambridge, UK:

Burleigh Dodds Science Publishing, 807–830. http://dx.doi.org/10.19103/AS.2019.0057.26

Daigle, John J., and Carol A. Zimmerman. 2004. The convergence of transportation, information technology, and visitor experience at Acadia National Park. *Journal of Travel Research* 43(2): 151–160. https://doi.org/10.1177/0047287504268239

Elatawneh, Alata, Adelheid Wallner, Loannis Manakos, Thomas Schneider, and Thomas Knoke. 2014. Forest cover database updates using multi-seasonal RapidEye data—Storm event assessment in the Bavarian forest national park. *Forests* 5(6): 1284–1303. https://doi.org/10.3390/f5061284

Filgueiras, Roberto, Everado C. Mantovani, Daniel Althoff, Elpídio Inácio Fernandes Filho, and Fernando França da Cunha. 2019. Crop NDVI monitoring based on sentinel 1. *Remote Sensing* 11(12): 1441. https://doi.org/10.3390/rs11121441

Gärtner, Philipp, Michael Förster, and Birgit Kleinschmit. 2016. The benefit of synthetically generated RapidEye and Landsat 8 data fusion time series for riparian forest disturbance monitoring. *Remote Sensing of Environment* 177: 237–247. https://doi.org/10.1016/j.rse.2016.01.028

Guo, Wei, Dengsheng Lu, and Wenhui Kuang. 2017. Improving fractional impervious surface mapping performance through combination of DMSP-OLS and MODIS NDVI data. *Remote Sensing* 9(4): 375. https://doi.org/10.3390/rs9040375

Hammitt, William, E., David N. Cole, and Christopher A. Monz. 2015. *Wildland Recreation: Ecology and Management*. New York: John Wiley & Sons.

Jacobi, Charles. 2003. A census of vehicles and visitors to Cadillac Mountain, Acadia National Park, August 1, 2002. Acadia National Park Natural Resource Report no. 2002–05.

Jacobi, Charles, Rebecca Flesh, and Gary Stellpflug. 2016. *Cadillac Mountain South Ridge Trail Rehabilitation.* Waterman Fund Grant Report & ANP Natural Resource Report 2016-1. https://www.watermanfund.org/wp-content/uploads/2016WFReportCadillacMtn.pdf

Kidd, Abigail M., Christopher Monz, Ashley D'Antonio, Robert E. Manning, Nathan Reigner, Kelly A. Goonan, and Charles Jacobi. 2015. The effect of minimum impact education on visitor spatial behavior in parks and protected areas: An experimental investigation using GPS-based tracking. *Journal of Environmental Management* 162: 53–62. https://doi.org/10.1016/j.jenvman.2015.07.007

Kim, Min-Kook, and David Graefe. 2020. Geographically weighted regression to explore spatially varying relationships of recreation resource impacts: A case study from Adirondack Park, New York, USA. *Journal of Park and Recreation Administration* 39(2). https://doi.org/10.18666/JPRA-2020-10515

Kim, Min-Kook, and John J. Daigle. 2011. Detecting vegetation cover change on the summit of Cadillac Mountain using multi-temporal remote sensing datasets: 1979, 2001, and 2007. *Environmental Monitoring and Assessment* 180: 63–75. https://doi.org/10.1007/s10661-010-1772-1

Kim, Min-Kook, and John J. Daigle. 2012. Monitoring of vegetation impact due to trampling on Cadillac Mountain using high spatial resolution remote sensing datasets. *Environmental Management* 50(5): 956–968. https://doi.org/10.1007/s00267-012-9905-7

Kim, Min-Kook, John J. Daigle, and Andrew Gooding. 2014. Vegetation cover change detection by satellite imagery on Cadillac Mountain, Acadia National Park, Maine, USA: Does it have potential for hiking trail management? *Natural Areas Journal* 34(3): 282–289. https://doi.org/10.3375/043.034.0304

Lee, Shiou Y., Chengju Du, Zhihui Chen, Hao Wu, Kailang Guan, Yirong Liu, Yongjie Cui, Wenyan Li, Qiang Fan, and Wenbo Liao. 2020. Assessing safety and suitability of old trails for hiking using ground and drone surveys. *ISPRS International Journal of Geo-Information* 9(4): 221. https://doi.org/10.3390/ijgi9040221

López, Jiménez J., and Margarita Mulero-Pázmány. 2019. Drones for conservation in protected areas: Present and future. *Drones* 3(1): 10. https://doi.org/10.3390/drones3010010

Lubinski, Sara, Kevin Hop, and Susan Gawler. 2003. U.S. Geological Survey—National Park Service Vegetation Mapping Program. Acadia National Park, Maine. https://irma.nps.gov/DataStore/Reference/Profile/2166804

Mackey, Christopher W., Xuhui Lee, and Ronald B. Smith. 2012. Remotely sensing the cooling effects of city scale efforts to reduce urban heat island. *Building and Environment* 49: 348–358. https://doi.org/10.1016/j.buildenv.2011.08.004

Marion, Jeffrey L. 1995. Capabilities and management utility of recreation impact monitoring programs. *Environmental Management* 19(5): 763–771. https://doi.org/10.1007/BF02471958

Manning, Robert E. 2009. *Parks and People: Managing Outdoor Recreation at Acadia National Park*. Hanover, NH: University Press of New England.

Manning, Robert E. 2014. Research to guide management of outdoor recreation and tourism in parks and protected areas." *Koedoe: African Protected Area Conservation and Science* 56(2): 1–7. https://doi.org/10.4102/koedoe.v56i2.1159

Monz, Christopher A., David N. Cole, Yu-Fai Leung, and Jeffrey L. Marion. 2010. Sustaining visitor use in protected areas: future opportunities in recreation ecology research based on the USA experience. *Environmental Management* 45(3): 551–562. https://doi.org/10.1007/s00267-009-9406-5

Monz, Christopher A., Jeffrey L. Marion, Kelly A. Goonan, Robert E. Manning, Jeremy Wimpey, and Christopher Carr. 2010. Assessment and monitoring of recreation impacts and resource conditions on mountain summits: Examples from the Northern Forest, USA. *Mountain Research and Development* 30(4): 332–343. https://doi.org/10.1659/MRD-JOURNAL-D-09-00078.1

Monz, Christopher A., Catherine M. Pickering, and Wade L. Hadwen. 2013. Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. *Frontiers in Ecology and the Environment* 11(8): 441–446. https://doi.org/10.1890/120358

Monz, Christopher A., Kevin J. Gutzwiller, Vera Helene Hausner, Mark W. Brunson, Ralf Buckley, and Catherine Pickering. 2021. Understanding and managing the interactions of impacts from nature-based recreation and climate change. *Ambio* 50(3): 631–643. https://doi.org/10.1007/s13280-020-01403-y

National Park Service, 2012. *A Guide's Guide to Acadia National Park*. https://www.nps.gov/parkhistory/online_books/acad/guides_guide.pdf

Park, Logan O., Robert E. Manning, Jeffrey L. Marison, Steven R. Lawson, and Charles Jacobi. 2008. Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices. *Journal of Park & Recreation Administration* 26(1): 97–121.

Pettorelli, Nathalie. 2013. *The Normalized Difference Vegetation Index*. Oxford: Oxford University Press.

Pickering, Catherine M., and Patrick Norman. 2017. Comparing impacts between formal and informal recreational trails. *Journal of Environmental Management* 193: 270–279. https://doi.org/10.1016/j.jenvman.2016.12.021

Planet Team. n.d. Planet Imagery Product Specification. San Francisco: Planet Team. https://assets.planet.com/docs/Planet_Combined_Imagery_Product_Specs_letter_screen.pdf

Planet Team. 2018. Planet Application Program Interface: In Space for Life on Earth. San Francisco: Planet Team. https://api.planet.com

Pujiono, Eko, Doo-Ahn Kwak, Woo-Kyun Lee, Sulistyanto, So-Ra Kim, Jong-Yeol Lee, Taejin Park, and Moon-Il Kim. 2013. RGB-NDVI color composites for monitoring the change in mangrove area at the Maubesi Nature Reserve, Indonesia. *Forest Science and Technology* 9(4): 171–179. https://doi.org/10.1080/21580103.2013.842327

Sader, Steven A., Matthew Bertrand, and Emily H. Wilson. 2003. Satellite change detection of forest harvest patterns on an industrial forest landscape. *Forest Science* 49(3): 341–353. https://academic.oup.com/forestscience/article/49/3/341/4617502

Sader, Steven A., D.J. Hayes, J.A. Hepinstall, M. Coan, and C. Soza. 2001. Forest change monitoring of a remote biosphere reserve. *International Journal of Remote Sensing* 22(10): 1937–1950. https://doi.org/10.1080/01431160117141

Sader, Steven A., and J. C. Winne. 1992. RGB-NDVI colour composites for visualizing forest change dynamics. *International Journal of Remote Sensing* 13(16): 3055–3067. https://doi.org/10.1080/01431169208904102

Tomczyk, Aleksandra M., Marek W. Ewertowski, Piran C.L. White, and Leszek Kasprzak. 2017. A new framework for prioritising decisions on recreational trail management. *Landscape and Urban Planning* 167: 1–13. https://doi.org/10.1016/j.landurbplan.2017.05.009

Traganos, Dimosthenis, and Peter Reinartz. 2018. Inter-annual change detection of Mediterranean seagrasses using RapidEye image time series. *Frontiers in Plant Science* 9: 96. https://doi.org/10.3389/fpls.2018.00096

van Riper, Carena J., Robert E. Manning, Christopher A. Monz, and Kelly A. Goonan. 2011. Tradeoffs among resource, social, and managerial conditions on mountain summits of the Northern Forest. Leisure Sciences 33(3): 228–249. https://doi.org/10.1080/01490400.2011.564924

Wessels, Tom. 2001. *The Granite Landscape: A Natural History of America's Mountain Domes, from Acadia to Yosemite*. Woodstock, VT: Countryman Press.

Wilson, Emily H., and Steven A. Sader. 2002. Detection of forest harvest type using multiple dates of Landsat TM imagery. *Remote Sensing of Environment* 80(3): 385–396. https://doi.org/10.1016/S0034-4257(01)00318-2

Worboys, Graeme, Michael Lockwood, and Terry De Lacy. 2005. *Protected Area Management: Principles and Practice*. New York: Oxford University Press.

Wu, Chung-Chi, Cheng-Wei Li, and Wei-Ching Wang. 2021. Low-impact hiking in natural areas: A study of nature park hikers' negative impacts and on-site leave-no-trace educational program in Taiwan. *Environmental Impact Assessment Review* 87: 106544. https://doi.org/10.1016/j.eiar.2020.106544

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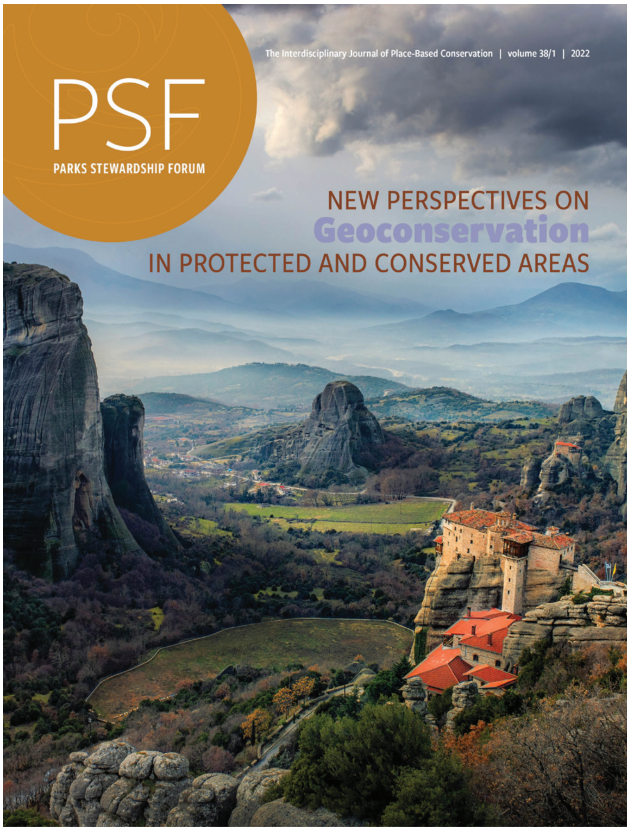

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