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Image Analysis to Monitor Experimental Trampling and Vegetation Recovery in Icelandic Plant Communities

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Received: 1 July 2019; Accepted: 14 August 2019; Published: 21 August 2019

Abstract: With growing tourism in natural areas, monitoring recreational impacts is becoming increasingly important. This paper aims to evaluate how different trampling intensities affect some common Icelandic plant communities by using digital photographs to analyze and quantify vegetation in experimental plots and to monitor vegetation recovery rates over a consecutive three-year period. Additionally, it seeks to evaluate the use of image analysis for monitoring recreational impact in natural areas. Experimental trampling was conducted in two different sites representing the lowlands and the highlands in 2014, and the experimental plots were revisited in 2015, 2016, and 2017. The results show that moss has the highest sensitivity to trampling, and furthermore has a slow recovery rate. Moss-heaths in the highlands also show higher sensitivity and slower recovery rates than moss-heaths in the lowlands, and grasslands show the highest resistance to trampling. Both methods tested, i.e., Green Chromatic Coordinate (GCC) and Maximum Likelihood Classification (MLC), showed significant correlation with the trampling impact. Using image analysis to quantify the status and define limits of use will likely be a valuable and vital element in managing recreational areas. Unmanned aerial vehicles (UAVs) will add a robust way to collect photographic data that can be processed into vegetation parameters to monitor recreational impacts in natural areas.

Keywords: monitoring; recreational trampling; experimental plots; nature-based tourism; image analysis; green chromatic coordinate (GCC); Maximum Likelihood Classification (MLC)

1. Introduction

There has been a rapid growth in tourism in natural areas in recent decades. This applies in particular to areas that have not yet been significantly altered by human exploitation and occupation [1]. Concurrent with growing tourism worldwide, this is emerging as a major environmental concern in many popular destinations, as tourism can have a severe impact on fragile ecosystems and wildlife, resulting in land degradation and disturbance in wildlife habitats. Accordingly, considerable attention is now given to developing frameworks to aid sustainable recreational management of natural areas to ensure their continuing survival and inherent durability [1–5]. With increasing environmental impacts from tourism on Earth's natural areas, a better understanding is required of the impacts tourism can have on different ecosystems and plant communities. This also includes improved techniques for tourism impact monitoring.

In Iceland, tourism has increased exponentially in recent decades, and more than seven-fold since the beginning of the millennium [6]. Over 90% of visitors state nature to be the main reason for their visit to Iceland [6]. Although this makes a meaningful contribution to the country's economic development, it has also been shown that recreational trampling can have a significant negative impact on Icelandic ecosystems and trigger deterioration of vegetation, and subsequently severe soil erosion [7,8]. Due to a short growing season, cold climate, and rich volcanic activities, the Icelandic ecosystems are very sensitive. Outdoor recreational activities can, thus, have a severe impact on biodiversity and vegetation, soil surface erodibility, surface water run-off, etc. General understanding of recreational activities' impact on Icelandic ecosystems is still limited, and so far only one experimental study on recreational trampling has been carried out [9,10].

This paper aims to evaluate how different trampling intensities affect some common Icelandic plant communities, i.e., grassland, moss-heath, and moss, by using digital RGB photographs to analyze and quantify vegetation in experimental plots and assess vegetation recovery rates over a three-year period. Furthermore, the use of image analysis for monitoring recreational impact in natural areas is evaluated. The trampling experiment was conducted in 2014 and the experimental plots were revisited in 2015, 2016, and 2017. The study is based on an experimental design developed by Ólafsdóttir and Runnström [9] for Icelandic conditions.

2. Background

Trampling has obtained considerable attention over the past decades. It has repeatedly been shown that trampling damages the vegetation, resulting in a decrease in vegetation coverage, a decrease in soil organic matter, and compaction of the topsoil, all of which can accelerate soil erosion [11]. There is extensive literature on recreational trampling describing different methods, from studying existing trails to hiking trails produced through experimental trampling [12–23]. Still, the major focus of most studies is the relationship between the amount of trampling and vegetative response, as well as on the susceptibility of different plant species and communities against trampling [16,23]. Different designs of research methodologies to study recreational impacts from trampling were thoroughly reviewed by Cole [11]. He points out that the most common design has been the descriptive field survey, where vegetation and soil parameters on recreation sites are measured to assess current condition. He emphasizes that if the goal is to understand the cause and effect then doing such research is the least useful research design, as it is only possible to speculate on cause and effect from correlational analysis, whereas true relationships can be missed due to the complexity of the dominant variables. Furthermore, he stresses that all variants of descriptive field surveys have the advantage of realism, and can thus provide highly relevant site-specific information; nevertheless, all suffer to a varying degree in their ability to identify cause and effect, and thus contribute to general knowledge in a limited way. According to Cole [11], the overall advance of an experimental approach is based on the premise that researchers "carefully can control use and environmental factors in a replicated design that maximizes insight into cause and effect". In order to facilitate comparisons of results in different environments, Cole and Bayfield [13] developed a standardized procedure to be used for experimental trampling. Their procedure still seems to be the most prevalent and widely used for experimental trampling, and was adapted to Icelandic conditions by Ólafsdóttir and Runnström [9].

The most common indicators of hiking trail disturbance are damage of vegetation, root exposure, soil erosion, and deepening and widening of the trail [22,24,25]. Research on hiking trail disturbances at several popular Icelandic nature destinations [7,8] identify the variable vegetation cover as the most important indicator for degradation of hiking trails in Iceland, and moss-heath as the country's most vulnerable type of vegetation. When vegetation worn down by trampling the underlying soil is revealed, the ratio between live green vegetation and soil provides a numeric value of vegetation cover per unit area.

Traditionally, the methods used to monitor vegetation cover have included visual assessment, point sampling, and transects, based on visual estimates by field personnel [26]. The fact that they are all based on individual assessments limits their accuracy and precision, which is fundamental in experimental studies. In an attempt to increase the accuracy, the potential of using close-range vertical digital photography to measure vegetation cover over small areas was first introduced in the late 1990s, but was at that time considered to be both time-consuming and equipment-intensive [27]. However, the use of digital close-to-earth photography in documenting and monitoring land cover changes has gradually improved. The possibility of analyzing spatially distributed digital data, as well as relationships between different variables, has greatly enhanced the combination of these tools, resulting in a better understanding of cause and effect regarding impacts on vegetation communities [7]. Furthermore, the acquisition of information on ground cover from digital photography is developing rapidly. Using digital images provides the potential to split an image into different wavelength channels (e.g., blue, red, near-infrared) to calculate a vegetation index. For example, the Green Chromatic Coordinate (GCC) measures greenness and the Normalized Difference Vegetation Index (NDVI) measures photosynthetic activity of the vegetation. Image analyses from digital photographs thus provide the possibility of objectively quantifying vegetation cover and options to assess vegetation quality from vegetation indices, and moreover change in vegetation parameters between years [28,29].

3. Methods

3.1. Study Areas

As a result of Iceland's position on the active Mid-Atlantic Ocean Ridge, the Icelandic soils are characterized by volcanic content, with the major soil types being Histosols, Andosols, and Vitrisols. The elevated sand content and lack of cohesion of these soils make them highly susceptible to erosion by wind and water [30]. The lowland's vegetation cover is dominated by grassland and moss-heath. Mosses and various types of lichens also dominate the vegetation on many of the extensive lava fields [31]. The interior highlands are comprised of the sub-arctic desert, with scattered plants or isolated patches of vegetation, mainly moss-heath, mosses, and lichens [31–33]. Certain moss species, such as the racomitrium mosses, mainly *Racomitrium lanuginosum* and *Racomitrium canescens*, are among the most common plant species in Iceland [34].

The experimental plots used in this study are located at four different sites: three in Þingvellir National Park (ÞNP) at ~134 meters above sea level (m.a.s.l.), representing the most common plant communities in the Icelandic lowland area, i.e., grassland, moss-heath, and moss covers; and one in Fjallabak Nature Reserve (FNR) at ~628 m.a.s.l., representing the highland area and its most common vegetation cover, moss-heath (Figure 1). The experimental plots were designed in July 2014 [9], and measurements and photographs were taken directly after the trampling. In order to monitor the recovery rate through a relative change in the vegetation cover over time, photos of the plots were acquired each summer over a period of three years (2015, 2016, and 2017). The experimental sites were fenced off to avoid further trampling and grazing to ensure consistency of measurement of the undisturbed recovery rate.

3.2. Experimental Procedure

Each experimental plot consists of five lanes and is 20 m long and 1.5 m wide. The trampling event was in line with the standard experimental trampling protocol recommended by Cole and Bayfield [16], i.e., 0 (control lane), 25, 75, 200, and 500 passes, symbolizing the trampling effect on each vegetation type from the same number of tourists. In each 20-meter long lane, 4–6 subplots (60 cm × 60 cm) were positioned at 2-, 4-, and 6-m distances from each end's baseline. The five lanes at each experimental plot were allocated a treatment class (0 (control), 25, 75, 200, and 500 hikers) through a random process (Figure 2).

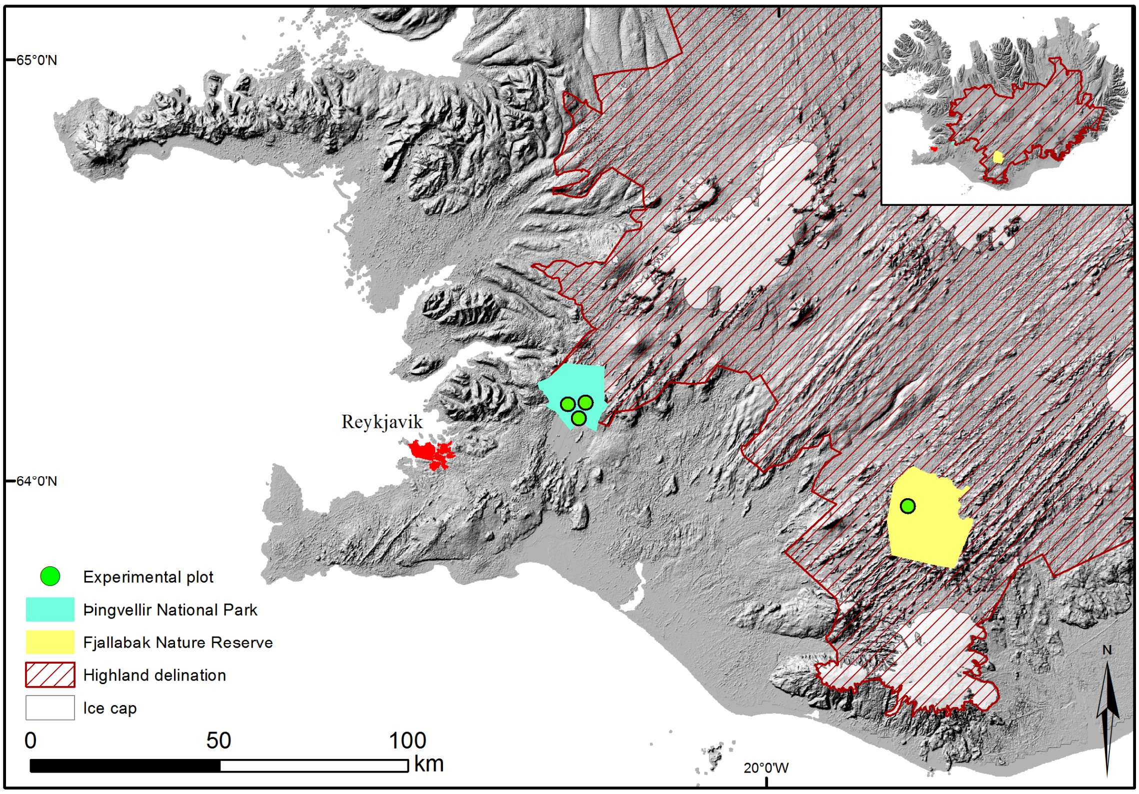

Figure 1. The location of the selected study areas, with Þingvellir National Park in the lowlands, Fjallabak Nature Reserve in the highlands, and the experimental plots (green dots).

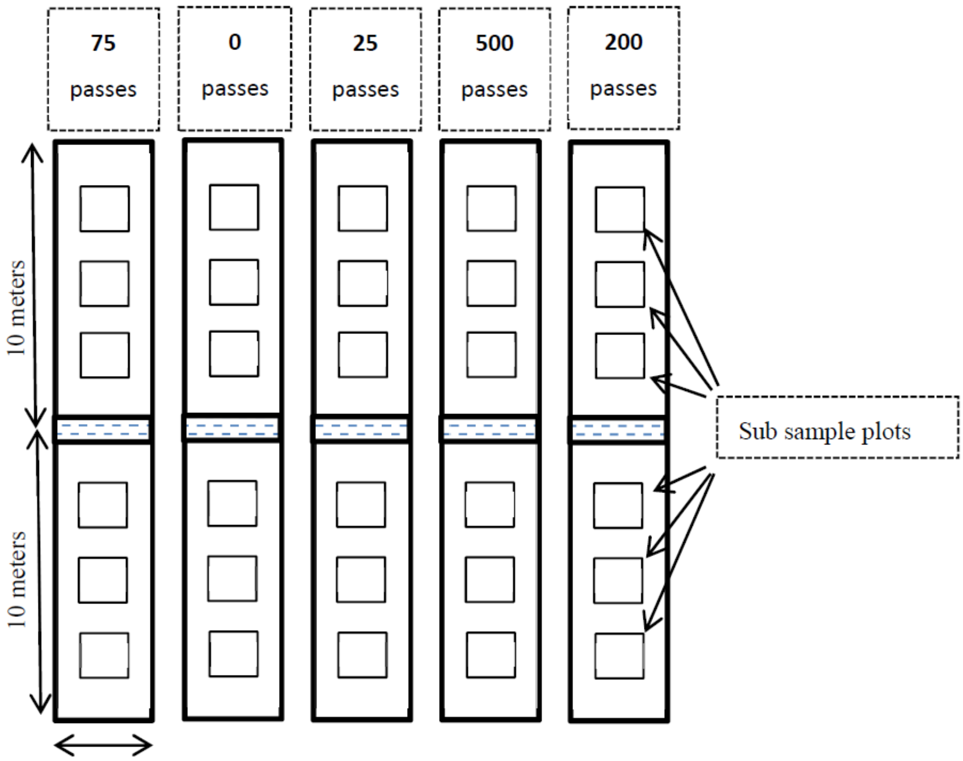

Figure 2. The design of the experimental plots used in each study area (modified from a previous study [9]).

3.3. Field Data Collection and Analysis

To quantify vegetation parameters for evaluating changes as a response to different trampling intensities (treatment class), a Canon PowerShot SX50 HS digital camera was used for the acquisition of 24-bit RGB images containing the three-color wavelength channels, i.e., red (R), green (G), and blue (B). The photographs were acquired at about 1.5 m height from a zenith position above the subplots using a tripod with an adjustable arm (Figure 3).

Figure 3. The tripod stand for photo acquisition of the subplots (**left**). A photograph of a subplot (**right**).

In the lowland plots (ÞNP) the trampling was applied, along with the subplots photographed in late July 2014 and in the highland plot (FNR) at the beginning of August that same year (Table 1). In 2015, only the lowland moss-heath and grassland subplots were photographed as the moss plot had not changed, and it was not possible to visit the highland plot. In 2016, all plots were again photographed, but in the grassland plot only the 500 treatment class, as the other lanes had fully recovered. In 2017, the highland plot could again not be visited, so photographs were only acquired of the lowland plots.

Table 1. The scheme for acquisition and number of subplot photographs in the experimental plots, 2014–2017.

	Lowland (ÞNP)															Highland (FNR)				
	Moss					Moss-Heath					Grassland					Moss-Heath				
	Treatment Class					Treatment Class					Treatment Class					Treatment Class				
Year	**Control**	**25**	**75**	**200**	**500**	**Control**	**25**	**75**	**200**	**500**	**Control**	**25**	**75**	**200**	**500**	**Control**	**25**	**75**	**200**	**500**
2014	/	4	4	4	4	6	6	6	6	6	6	6	6	6	6	2	2	2	4	4
2015	/	/	/	/	/	6	6	6	6	6	6	6	6	6	6	/	/	/	/	/
2016	4	4	4	4	4	6	6	6	6	6	/	/	/	/	6	6	6	6	6	6
2017	/	4	4	4	4	6	6	6	6	6	/	/	/	/	6	/	/	/	/	/

The images were rectified and cropped to retain only the 60 × 60 cm area of interest within each subplot frame for further analysis. Each RGB photograph was separated into individual R, G, and B wavelength bands to facilitate multi-spectral image analysis. Two different methods were applied to analyze the images regarding vegetation: (i) Green Chromatic Coordinate (GCC) index, and (ii) Supervised Maximum Likelihood Classification (MLC).

(i) Green Chromatic Coordinate (GCC)

To obtain a greenness value in each photographed subplot, GCC values were calculated, i.e., an index that represents the greenness in RGB images [35,36]. The GCC is a non-linear transformation of the measured green digital numbers to values representing the proportion of the greenness registered in each pixel, divided by the sum of the R, G, and B bands (Equation (1)). Thus, GCC corresponds directly to the changing levels of green pigmentation in vegetation and is calculated as follows:

$$GCC = \frac{G}{(R + G + B)} \tag{1}$$

where G represents the green wavelength band reflectance and $R + G + B$ the sum of the red, green, and blue color bands.

(ii) Supervised Maximum Likelihood Classification (MLC)

The MLC algorithm is a common method for classifying satellite images and aerial photographs into information classes of land use and land cover (LULC) [28,29]. It is based on a maximum likelihood procedure derived from a Bayesian probability theory that uses the mean, variance (pixel values distribution in a class), and covariance (tendency for pixel values to vary similarly in two spectral bands) data from a training set to calculate which class each pixel most likely belongs to. Polygons were drawn as delineated features in the images to create spectral signatures for the different information classes (e.g., green vegetation, flowers, bare soil, shadows). The signatures could then be used to apply a supervised MLC algorithm to distinguish the entire sub-plot area into the different information classes, which were used to calculate the percentage area of vegetation cover pixels.

3.4. Statistical Analyses

In order to test the effect of the number of hikers on the different vegetation types, an analysis of variance (ANOVA) was used. The null hypothesis to test is that subplots of a treatment class (number of hikers) are no different than the subplots located in the control lane (zero hikers). The derived subplot-values (GCC and % vegetation cover) in each treatment class were, therefore, tested to assess if the treatment class was significantly different from the control lane so that the null hypothesis could be rejected. If this was the case then the vegetation response after trampling, inferred by GCC or % vegetation cover, is related to hiking intensity or number of hikers.

In order to analyze the resistance of the different plant community types to trampling, a vegetation resistance index was also calculated to provide a comparable index to evaluate the resistance of each plant community to hiking pressure. According to Cole and Bayfield [16], a resistance index (RI) can be calculated based on the relative vegetation cover. It is defined as the mean percent coverage of a certain vegetation type after trampling in relation to the initial vegetation cover. Hence, the RI is expressed here as the average proportion of (i) GCC and (ii) vegetation cover (%) in the 500 treatment class subplots against the average subplot values in the control lane (Equation (2)). Thus, the RI express the disturbance that 500 hikers have on the different plant communities in percentages compared to the initial values.

$$RI = \frac{\text{Average (subplot values of 500 treatment class)}}{\text{Average (subplot values of Control treatment class)}} \times 100\% \tag{2}$$

4. Results

4.1. Grassland

The MLC for the grassland plot revealed no clear correlation between decreasing vegetation cover and increased trampling pressure (Figure 4). Vegetation cover stayed around 100% for all trampling intensities and bare soil did not emerge, suggesting that trampling of up to 500 hikers has a modest effect on the grassland. In 2016 and 2017, the results showed that vegetation cover continuously stays around 100%, likewise for the treatment class 500. Nonetheless, the GCC greenness index captured the reduced amount of greenness of the grass cover and showed a decrease in the GCC index along the different treatment classes for the base year of 2014 (Figure 5). The change in greenness is registered by the camera as the amount of trampling changes the content of chlorophyll in the grass leaves, which in turn changes the multi-spectral reflectance. In the following year (2015), this difference is no longer clearly visible, but instead the GCC index showed greater variance. For the GCC, values were relatively lower in both 2016 and 2017 compared to 2014 and 2015. This may be due to the grassland being slightly drier in 2016 and 2017 and consequently not as lush, and with high chlorophyll content, as in 2014 and 2015.

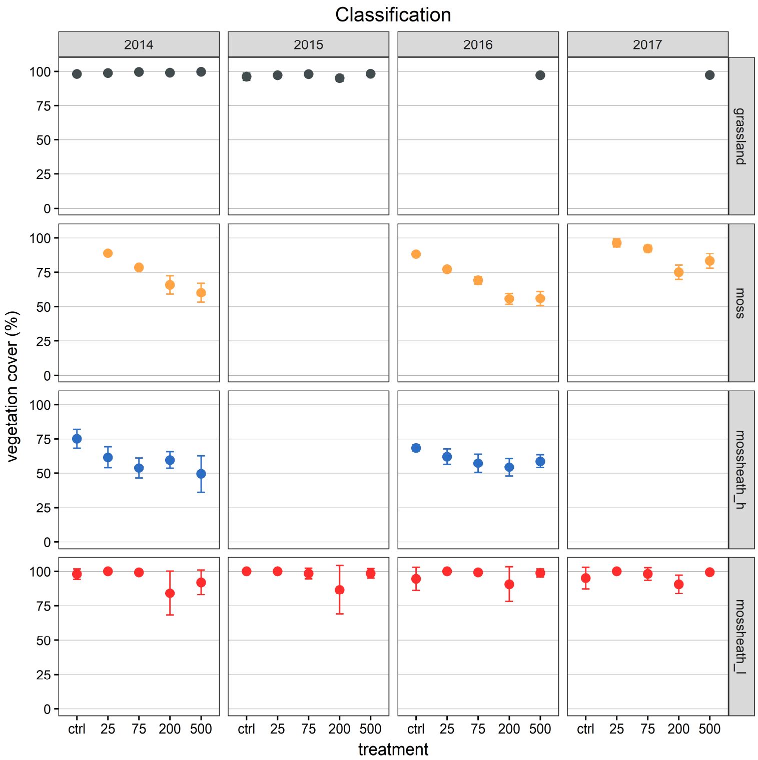

Figure 4. Vegetation cover (%) of healthy, undamaged vegetation derived from the MLC for the four experimental plots (i.e., grassland, moss, highland moss-heath (mossheath_h), and lowland moss-heath (mossheath_l)). Data is shown for four years (2014 until 2017) and five treatments classes (i.e., control (ctrl), 25, 75, 200, 500 passes). The points indicate the mean over the replicates, while the error bar indicates one standard deviation from the mean.

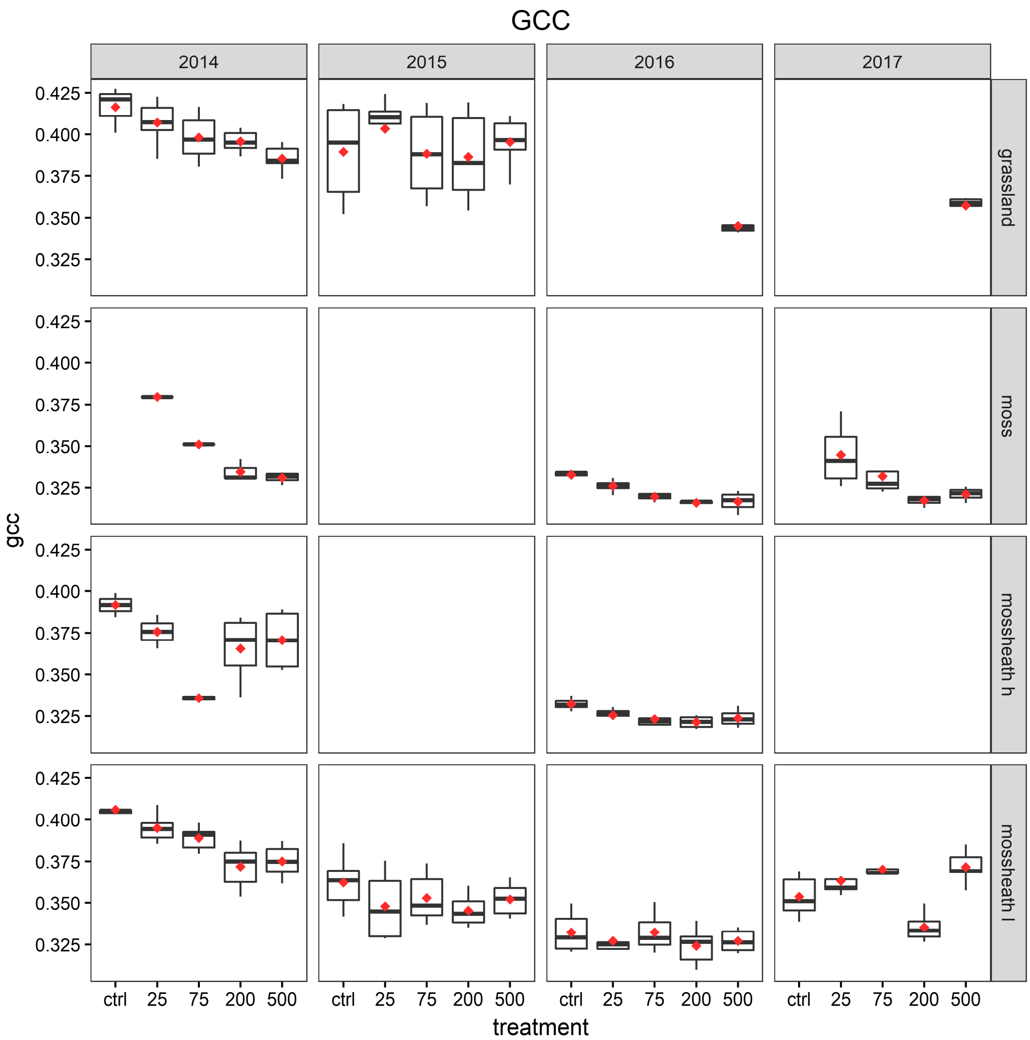

Figure 5. Vegetation greenness values, as quantified by the green chromatic coordinate (GCC) index, for the four experimental plots (i.e., grassland, moss, highland moss-heath (mossheath h) and lowland moss-heath (mossheath l)). Data is shown for four years (2014 until 2017) and five treatments classes (i.e., control (ctrl), 25, 75, 200, 500). The thick band indicates the median of all replicates, the red diamond the mean, and the bottom and top of the box indicate the 25th and 75th percentile, respectively.

The ANOVA analysis showed significant differences of the GCC values between the control plots and the treatment class of 200 ($p < 0.05$) and of 500 ($p < 0.01$) for the year 2014 (Table 2). In 2015, there were no significant differences between the treatment lanes, indicating that the grassland had recovered from the hiking damages in just one year.

Table 2. Analysis of variance (ANOVA) with f-values for vegetation cover in percent (MLC) and Green Chromatic Coordinate (GCC) greenness index. Significance levels: *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$); dash indicates missing data. Degrees of freedom (DF) can be assessed from Table 1.

			ANOVA							
			Vegetation Cover (MLC)				GCC			
			2014	2015	2016	2017	2014	2015	2016	2017
Lowland	Grassland	Con - 25	(0.8)	(0.75)	-	-	(0.97)	(0.8)	-	-
		Con - 75	* (8.79)	(2.03)	-	-	(3.47)	(0.01)	-	-
		Con - 200	(2.2)	(0.65)	-	-	* (10.09)	(0.03)	-	-
		Con - 500	* (9.62)	(2.68)	-	-	** (18.8)	(0.19)	-	-
	Moss	Con - 25	-	-	*** (67.14)	-	-	-	(5.92)	-
		Con - 75	-	-	*** (137.9)	-	-	-	*** (35.56)	-
		Con - 200	-	-	*** (212.5)	-	-	-	*** (67.0)	-
		Con - 500	-	-	*** (131.9)	-	-	-	** (19.53)	-
		25 - 75	-	-	** (22.51)	(4.82)	-	-	* (6.79)	(1.19)
		25 - 200	(9.06)	-	*** (89.53)	*** (52.28)	* (33.41)	-	** (18.8)	* (7.2)
		25 - 500	* (13.48)	-	*** (55.6)	** (19.03)	*** (168.6)	-	* (6.08)	(5.20)
	Moss-heath L	Con - 25	(1.66)	(11.22)	(2.5)	(2.32)	* (8.94)	(1.81)	(0.53)	(2.14)
		Con - 75	(0.54)	(1.0)	(1.7)	(0.66)	*** (27.12)	(1.11)	(0.0)	* (8.39)
		Con - 200	(4.3)	(3.44)	(0.43)	(1.18)	*** (38.26)	* (5.03)	(1.45)	* (8.9)
		Con - 500	(2.26)	(1.0)	(1.35)	(1.72)	*** (53.53)	(1.79)	(0.85)	* (7.78)
Highland	Moss-heath H	Con - 25	(3.41)	-	* (6.68)	-	(1.65)	-	* (7.87)	-
		Con - 75	(8.97)	-	** (15.4)	-	* (56.79)	-	** (13.02)	-
		Con - 200	* (7.85)	-	*** (25.75)	-	(2.39)	-	*** (30.01)	-
		Con - 500	(6.06)	-	** (20.8)	-	(1.91)	-	** (12.43)	-

4.2. Moss

The results stress that the moss cover is extremely vulnerable to trampling, even to the lightest pressure. The rapid deterioration of the moss cover due to trampling is evident by visual inspection at the site. Since the trampling quickly leads to black trails of damaged vegetation in the otherwise lush white and green moss cover (Figure 6).

After the experimental trampling in 2014, the vegetation cover dropped from ~100% to 89% for low trampling intensity (i.e., treatment class 25) to about 60% with high intensity (treatment class 500). The decrease is rather linear, with no saturation point visible (Figure 4). This trend is similar for 2016, where vegetation cover is even lower compared to 2014, indicating that the moss at the edges of the trails was damaged due to the trampling and later died, or just dried out at the edges as a consequence of the created trails. In 2016, the mean vegetation cover for the control subplots was 88% and the mean for treatment class 500 was about 56%. In this year, there was no notable difference between treatment class 200 and 500. In 2017, three years after the hiking experiment, the moss cover had recovered slightly; the 25 treatment class was back to approximately its original cover of close to 100% and the 500 treatment lane had recovered to about 80% coverage. The GCC values also showed a clear decreasing trend with increasing trampling intensity (Figure 5), with notably lower values for treatment class 500. Similar to the MLC results, the GCC values showed lower values in 2016 compared to 2014, and slightly higher values again in 2017 for treatment class 25, indicating that vegetation affected by light trampling intensity may be recovering.

Figure 6. The Moss plot in Þingvellir National Park directly after trampling in 2014 (**left**). The same plot after two years (2016)—all trampling lanes are still clearly visible (**right**).

There is a significant difference between the 25 and the 500 treatment classes based on the MLC ($p < 0.05$) and for GCC between 25 and 200 treatment classes ($p < 0.05$), and for 25 and 500 treatment classes ($p < 0.001$) (Table 2). In 2016, there were still highly significant differences between the control lane and all treatment classes for both MLC and GCC, except for the 25 treatment class. In 2017, the former black trails are still clearly visible but have become narrower, and some new vegetation has emerged. However, there were still significant differences between the treatment classes of 25 and 200 for GCC ($p < 0.05$) and for MLC between 25 and both 200 ($p < 0.01$) and 500 ($p < 0.001$).

4.3. Moss-Heath, Lowland

For the moss-heath lowland plot, the MLC did not result in a clear decreasing trend in 2014. The treatment classes 200 and 500 did show a negative impact on the vegetation cover but also a high variation (Figure 4). A slight increase in the vegetation cover was noted for the higher treatment classes in the succeeding years after the trampling, but again with high variation between the subplots. The GCC values showed a clear negative trend in relation to trampling intensity in 2014 (Figure 5). However, this trend flattened out in 2015 and 2016. Still, in 2017, all treatment classes showed increased GCC values except the 200 class, and oddly the 500 treatment class showed the highest GCC values.

The ANOVA analysis of the GCC values between the control and the different treatment classes revealed significant differences for the year 2014 (Table 2). In 2015, only the 200 treatment class is significantly different ($p < 0.05$), and in 2016 there were no significant differences between the control lane and the treatments. However, in 2017, the differences between higher trampling intensities (75, 200, and 500) were again statistically significant ($p < 0.05$). For MLC, there were no significant differences between the control and the treatment classes at any time.

4.4. Moss-Heath, Highland

The trampling damage in the highland was primarily noticeable by an increase in brown vegetation caused by a compression of the vegetation cover and uprooting of moss and the underlying soil (Figure 7). The MLC for the moss-heath highland plot revealed a rather clear decreasing trend of vegetation cover with increased trampling intensity (Figure 4). In 2014, the vegetation cover dropped from about 75% for the control subplots to 50% cover at the 500 treatment class subplots. However, there was a high variance between the subplots, and thus only the 200 treatment class was significantly separate from the control subplots ($p < 0.05$). In 2016, the vegetation cover was similar to the 2014 values, indicating that recovery is slow and suggesting that damage to the vegetation cover in the highlands is more sensitive and long-lasting than in the lowlands. The GCC values for 2014 did not show such a clear decreasing trend as the MLC (Figure 5). The treatment classes 25 and 75 did show a decreasing trend in GCC but the 200 and 500 treatment classes showed higher variance and mean values between the subplots, thus breaking the trend. A slight negative trend was shown for GCC in

2016, where also the difference between the treatments was not very high but was significant, and the variance of each treatment was extremely low. Furthermore, the ANOVA (Table 2) shows that all treatment classes (25, 75, 200, and 500) were significantly different from the control subplots in 2016 for both MLC and GCC. In 2014, the ANOVA analysis for GCC showed that only the 75 treatment class is significantly separate from the control subplots, while in 2016, all the treatment classes were significantly different from the control, indicating that recovery from the trampling impact is slow in the highlands.

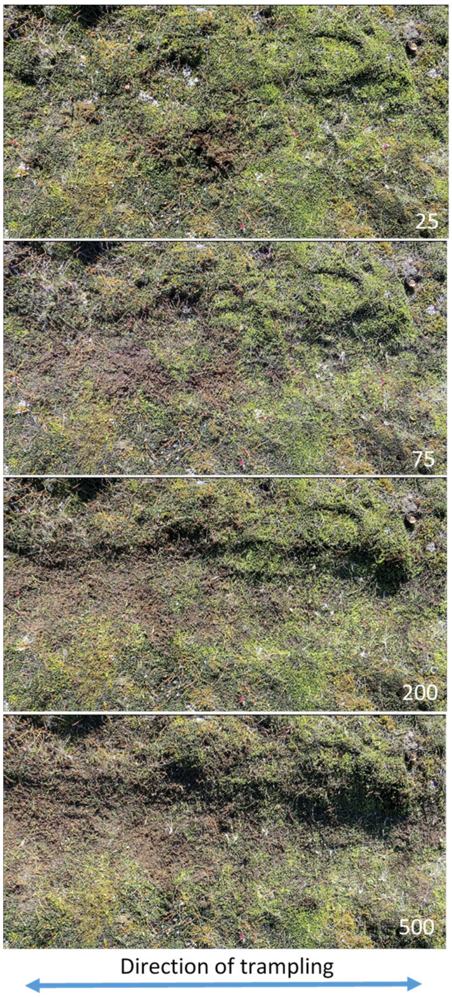

Figure 7. Sequence of photographs from the highland moss-heath plot, showing how the vegetation is changing and deteriorating with increased trampling (i.e., 25, 75, 200, and 500 hikers). Each photograph covers a ~0.76 × 0.4 m area.

4.5. Resistance Index

Resistance Index (RI) calculations for the two methods used in this study, i.e., MLC and GCC, reveal a general difference. The minor deviations in GCC values for the different treatment classes influenced the RI to show very modest relative changes compared to the control values (initial). The RI for MLC showed a higher variation between the treatment classes and the plant communities. However, both GCC and MLC show similar patterns (Table 3).

Table 3. Resistance Index (RI) calculated for the years 2014 and 2016, for both Maximum Likelihood Classification (MLC) and Green Chromatic Coordinate (GCC). RI is comparing the ratio between treatment class 500 and the control lane, or other comparison (see RI Ratio explanation) for the different plant communities: Grassland, Moss, Lowland Moss-heath (Moss-heath_L), and Highland Moss-heath (Moss-heath_H). Tclass = Treatment class, followed by a number (e.g., 500 = treatment class 500) or Control (0 passes). If followed by a year in parenthesis the Control was from a different year.

	Plant community	RI 2014	RI Ratio (2014)	RI 2016	RI Ratio (2016)
MLC	Grassland	102%	$Tclass_{500}/Tclass_{Control}$	101%	$Tclass_{500}/Tclass_{Control\ (2015)}$
	Moss	68%	$Tclass_{500}/Tclass_{25}$	78%	$Tclass_{500}/Tclass_{25}$
	Moss	68%	$Tclass_{500}/Tclass_{Control\ (2016)}$	63%	$Tclass_{500}/Tclass_{Control\ (2016)}$
	Moss-heath_L	94%	$Tclass_{500}/Tclass_{Control}$	101%	$Tclass_{500}/Tclass_{Control}$
	Moss-heath_H	66%	$Tclass_{500}/Tclass_{Control}$	86%	$Tclass_{500}/Tclass_{Control}$
GCC	Grassland	93%	$Tclass_{500}/Tclass_{Control}$	89%	$Tclass_{500}/Tclass_{Control\ (2015)}$
	Moss	87%	$Tclass_{500}/Tclass_{25}$	97%	$Tclass_{500}/Tclass_{25}$
	Moss	99%	$Tclass_{500}/Tclass_{Control\ (2016)}$	95%	$Tclass_{500}/Tclass_{Control\ (2016)}$
	Moss-heath_L	92%	$Tclass_{500}/Tclass_{Control}$	98%	$Tclass_{500}/Tclass_{Control}$
	Moss-heath_H	95%	$Tclass_{500}/Tclass_{Control}$	97%	$Tclass_{500}/Tclass_{Control}$

The RI values show that the grassland cover had the highest resistance to trampling, staying at around 100% in both 2014 and 2016. In contrast, the moss cover had the lowest resistance to trampling based on both the GCC and the MLC vegetation cover analysis. By comparing the $moss_{500}$ to an initial ~100% coverage (visual assessment in 2014), the RI index shows that only an average of 60% of the initial vegetation cover is left in the $moss_{500}$ treatment class. Comparing the MLC of the $moss_{500}$ with the $moss_{25}$ for the two years gives a RI value of 68% in 2014 and 78% in 2016, indicating that the relative difference between the treatment classes decreased between the years. The moss-heath cover in the highland had the second-lowest resistance to trampling based on the MLC, as the relative difference between the 500 treatment class and the control was 66%. In 2016, the difference was 86%, suggesting that the vegetation cover had improved during the two years but had still not fully recovered. Nonetheless, the moss-heath in the lowland showed that the trampling in 2014 caused the vegetation cover to reduce to 94%, and then two years after it had recovered to ~100%.

For the GCC, the same comparisons show lesser relative differences but a similar pattern and trend is indicated. It is clear that the GCC index values did not pick up the difference as well as the MLC of vegetation cover in percentages. For the moss cover, however, the relative difference of GCC for the 500 treatment class was 87% compared to the 25 treatment class, indicating a large change in greenness, but in 2016 they had almost the same index values. However, this is not the case when looking visually at the photographs of the moss plot from 2016, when the 500 and 200 lanes still have obvious black trails (Figure 6).

5. Discussion and Conclusions

5.1. Trampling Impact in Icelandic Plant Communities

With increasing tourism in the past decades, trampling pressure has increased considerably in many of Iceland's most popular destinations, resulting in severe vegetation and soil deterioration, as recognized by the Environmental Agency of Iceland [37]. The results from this study show that all plant communities tested (moss, moss-heath, and grassland) show a significant change in vegetation as a response to high trampling intensities (200 to 500 hikers). Furthermore, moss-heaths show a significant change at light trampling intensity (25 to 75 hikers), both in the lowlands and the highlands.

In the highlands, however, the moss-heath communities show more sensitivity to trampling than in the lowlands. Hence, of these three plant communities, grassland is the most resistant plant community to trampling, and moss the least. The results further show that the moss cover has a very slow recovery rate. This coincides with Törn et al. [38], revealing that mosses have a much slower recovery rate from trampling pressure than other plant communities. The moss-heath communities take a longer time to recover in the highlands than in the lowlands. This may possibly be explained by harsher climatic conditions and a shorter growing season in the highlands, which is supported by other studies in Iceland, emphasizing the importance of the length of the growing season for vegetation growth conditions and resistance [39,40].

These results concur with comparable studies in other ecosystems and geographic regions revealing grassland to be more resistant to trampling than other plant communities [41–45], and mosses and lichens to be very sensitive to trampling [46]. The results are further supported by Monz [18], showing that tundra plant communities subjected to moderate levels of trampling returned to pre-disturbance conditions four years after trampling, while trampling impact was still evident in plots subjected to higher levels of disturbance.

5.2. Image Analysis for Monitoring Recreational Impact

It is widely accepted that monitoring recreational impact is an essential element for managing natural areas [1]. With monitoring, better management plans can be acquired, which increases the effectiveness of measures applied; monitoring also provides a systematic base from which to allocate funds and resources. Monitoring the number of visitors and their perceptions are widely recognized within tourism studies [47,48]. However, without understanding the dynamic relationship between tourists' perception and the physical condition of the natural resources that tourism is based on, such information is of limited use. Hence, with increasing tourism development, monitoring becomes critical for understanding changes in recreational areas. This is especially true in order to define the limit of use in natural areas due to tourism development. Systematic monitoring of the environment is, thus, an important element to provide sustainable recreational use in natural areas.

In this study, two methods to monitor vegetation in relation to trampling from digital photographs were tested, facilitated by multi-spectral image processing to classify vegetation. Both methods provide a quantitative status of vegetation condition that can be compared to future monitoring for assessment of relative changes. The Green Chromatic Coordinate (GCC) index proved to be a more easily applicable method than the Maximum Likelihood Classification (MLC), as requires a small number of algebra calculations to derive GCC images, where a quantitative value of greenness is inferred into each pixel and shown to represent differences in healthy vigor and mortality in forest stands [36]. Conversely, to employ the MLC to calculate the percent area of vegetation coverage requires considerable time and skills, as the operator needs to supervise the MLC process by creating spectral signatures for different information classes that are needed in the classification algorithm. Rasmussen et al. [49] conclude that images acquired from unmanned aerial vehicle (UAV)-based imagery and derived vegetation indices have an almost equal possibility of quantifying crop response to experimental treatments as ground-based measurements by advanced sensors. The same may be expected for recreation. Managers of recreational areas are, thus, encouraged to keep a spatial database holding collected data, e.g., topography, climate, plant community types, photographs, GCC images, and hiking trail locations, which through a geographic information system (GIS) will provide a robust decision support system to take actions from assessed and quantified changes.

5.3. Management Implication

Hiking has long been one of Iceland's most popular forms of outdoor recreation practices [3,7]. With increased tourism during the past few decades, the impact of trampling has gradually been increasing. Additionally, the recent growth of nature marathons is likely to further increase the ecological impact of trampling. It is generally accepted that trampling results in a physical change of the vegetation and the topsoil layer, which in turn alters water infiltration and surface run-off, and subsequently may cause accelerated soil erosion [7,50,51]. Ecosystems in Iceland are particularly vulnerable to physical pressure due to harsh climatic conditions and a short growing season. A small wound in the vegetation cover that exposes the underlying soil bank may be enough to start an accelerating erosion process driven by the strong winds and runoff processes [3,40]. The impact of unsuitable forms of trampling can thus easily trigger severe land degradation. Therefore, in order to manage nature-based tourism in a sustainable manner, it is crucial to understand how diverse forms of trampling impacts the different plant communities.

The results from this study stress that the most sensitive vegetation coverage in Iceland are the moss communities, and the least sensitive are grassland communities. Recreational planners and managers should thus concentrate recreational activities and infrastructure, such as hiking trails, camping sites, and gathering areas, in grassland areas and not in the more sensitive moss and moss-heath areas, especially in the highlands. To better understand the ecological impact of trampling, however, monitoring is essential. Most of the traditional techniques for monitoring of vegetation damages and vegetation cover changes, such as line intercept and quadrant techniques, are time-consuming and consequently expensive. Most are also based on visual estimations, influencing their accuracy. Image analysis and classification have commonly been used to assess changes in the land use and land cover of the Earth's surface from satellite images or orthophotos, with good results [28,29,35]. The rapid development of UAV technology allows drones to carry cameras with larger lenses than before, thus being able to capture land cover changes with higher resolution than satellite images. With image analysis, managers and researchers can monitor and quantify impacts from recreational activities directly on site and with higher accuracy than conventional methods, without the need to design experimental plots.

The results from this study stress that processing of digital photographs can be used as a method to distinguish different levels of tourism impact on vegetation. Photographs provide a snapshot of the status of vegetation at a certain time, and additional temporal inputs provide an objective method to monitor how vegetation of a natural area is changing. If tourist statistics and climatic parameters are additionally collected, recreational impacts may be better assessed and understood. The use of cameras on drones will thus be a highly important method of monitoring vast natural areas, such as national parks and nature reserves, in the near future. Half a century ago, Burden and Randerson [50] stressed that management techniques are too often applied after signs of deterioration have become obvious, such as vegetation damages and soil erosion, consequently affecting the natural environment to which people were initially attracted. In many natural areas, unfortunately, this seems to still be the case. The need for quantitative monitoring cannot be overemphasized as a critical tool in the management policies for natural areas that are to be used for recreation.

Author Contributions: Conceptualization, M.C.R. and R.Ó.; Methodology, M.C.R. and R.Ó.; Validation, M.C.R. and R.Ó.; Formal Analysis, M.C.R., R.Ó., J.B., and B.B.; Investigation, M.C.R. and R.Ó.; Resources, M.C.R. and R.Ó.; Data Curation, M.C.R. and R.Ó.; Writing—Original Draft Preparation, M.C.R. and R.Ó.; Writing—Review and Editing, M.C.R. and R.Ó.

Funding: This research was partly funded by the Icelandic Tourist Board.

Acknowledgments: We are very grateful to Ólöf Ýrr Atladóttir, the former Director General of the Icelandic Tourist Board, for encouraging experimental studies on tourism environmental impacts in the Icelandic ecosystem. We are also grateful to Einar Á.E. Sæmundssen, park manager at Þingvellir National Park, Ingibjörg Eiríksdóttir, former specialist at The Environmental Agency of Iceland, and park rangers at Fjallabak Nature Reserve, Steinunn Ósk Konráðsdóttir, Sveinn Orri Tryggvason, and Hanna Runnström, for field assistance. We would further like to thank the reviewers and editors whose comments and suggestions have greatly improved this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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