Student thesis series INES nr 351

Assessment of trampling impact in Icelandic natural areas in experimental plots with focus on image analysis of digital photographs

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2015
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Maria Gatzouras (2015). ***Assessment of trampling impact in Icelandic natural areas in experimental plots with focus on image analysis of digital photographs***

Master degree thesis, 30 credits in *Physical Geography and Ecosystem Analysis*

Department of Physical Geography and Ecosystem Science, Lund University

Level: Master of Science (MSc)

Course duration: *January* 2015 until *June* 2015

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Master thesis, 30 credits, in *Physical Geography and Ecosystem Analysis*

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2015

Abstract

Increasing tourism in the spectacular but sensitive ecosystems in Iceland arises concern to the country's authorities how to best manage tourism in these natural areas within a level of acceptable change. Research is thus required regarding what affect tourism has on different environments. Deterioration of natural areas in Iceland from trampling by numerous hikers are causing visible vegetation loss, widening and deepening of existing hiking trails with subsequent soil erosion.

In this study, the primary goal was to assess the impact of controlled experimental trampling to three typical Icelandic vegetation types; grassland, mossheath and moss. Measurements in experimental plots of soil compaction, soil moisture, surface depth, and vegetation cover were analysed for different hiking pressures. The study areas include the two most popular areas of nature-based tourism in Iceland; Þingvellir [ˈθiŋkˌvɛtlɪr̥] National Park and Fjallabak Nature Reserve.

The second goal of this study was to assess the performance of digital photography and subsequent image analysis as a tool for estimating vegetation cover, a cost- and time effective method not previously used in the field of recreational trampling research. Three different methods are evaluated; supervised classification of the RGB images, segmentation of the images using the ExGR (Excess Green minus Excess Red) index and extraction of greenness information from the images through application of the Green Chromatic Coordinate (GCC). All three methods applied show ability to determine changes in live vegetation cover, the supervised classification method being the most accurate method for quantitative measurements.

All vegetation types show being significantly altered with added trampling pressure in terms of change of the physical properties of soil and of vegetation cover. Amongst the examined vegetation types, the mossheath type, especially in the highland (Fjallabak Nature Reserve), is verified as being the least resistant to trampling pressure. Relationships of soil compaction, surface depth and vegetation cover with trampling were curvilinear, suggesting higher rates of damage at initial stages of trampling.

Keywords: *digital photography, experimental plots, greenness index, natural areas, nature-based tourism, recreational trampling, RGB images, resistance, vegetation cover*

Sammanfattning

Den ökade turismen i de spektakulära men känsliga eko-system på Island har framträtt som ett bekymmer för landets myndigheter i frågan om hur att bäst leda turismen i dessa naturområden inom en nivå för acceptabel påverkan. Forskning krävs därför för att bedöma turismens påverkan på olika miljöer. Förslitning av naturområden på Island på grund av påfrestning av åtskilliga fritidsvandrare orsakar tydlig vegetationsminsking, vidgar och fördjupar vandringsleder med markerosion som följd.

Syftet med föreliggande studie var att utvärdera inverkan av reglerad fritidsvandring på tre vegetationstyper typiska för Island; grässlätt, hed och mossa. Mätningar i experimentella fältytor av markkompaktering, markfuktighet, marknivå och vegetationstäckning analyserades efter olika nivåer av påfrestning av vandrare. Föremål för studien är Islands två populäraste områden för naturbaserad turism; Þingvellir [ˈθiŋkˌvɛtlɪr̥] nationalpark och Fjallabak naturreservat.

Studien hade ytterligare ett syfte, nämligen att utvärdera utförandet av digital fotografi och påföljande bildanalys som ett verktyg för att utvärdera vegetationstäcket, en kostnads- och tidseffektiv metod som tidigare inte använts inom forskningen av fritidsvandringens påfrestning. Tre olika metoder har utvärderats; supervised klassificering av de digitala RGB-bilderna, segmentering av bilderna genom applikation av EXGR (Excess Green minus Excess Red) index och genom att extrahera grönskeinformation från bilderna genom applikation av den gröna kromatiska koordinaten (GCC). Alla tre metoder som tillämpades är lämpliga för att fastställa förändringar av levande vegetationstäcke, speciellt supervised klassificeringsmetoden, som är den mest exakta metoden för kvantitativa mätningar.

Alla vegetationstyper påvisar betydande förändring med ökad påfrestning av vandrare i form av förändring av markens och vegetationstäckets fysiska egenskaper. Av de undersökta vegetationstyperna så visas hed, speciellt den som återfinns på höglandet (Fjallabak naturreservat), vara den vegetationstyp som är minst motståndskraftig mot påfrestning av fritidsvandring. Förhållandet av markkompaktering, marknivå och vegetationstäckning till påfrestning av vandring var kurviljärt, vilket tyder på högre nivå av skada vid inledande fas av påfrestning.

***Nyckelord:** digital fotografi, experimentella fältytor, grönske-index, naturområden, naturbaserad turism, fritidsvandring, RGB-bilder, motståndskraft, vegetationstäcke*

Acknowledgements

First I would like to express my sincere gratitude to my supervisor Dr. Micael Runnström for giving me valuable insights, encouragement and guidance through this thesis. I would like to extend my gratitude also to include Prof. Rannveig Ólafsdóttir (Department of Geography and Tourism, Faculty of Life and Environmental Sciences, University of Iceland), for providing me the data and giving me the opportunity to participate in the ongoing recreational impact research project in Iceland. I am also grateful to Lars Eklundh and Jonathan Seaquist for their technical and statistical guidance respectively.

The data used in this study was collected by Ólafsdóttir, R. and Runnström, M. (2015), a research study supported by The Icelandic Tourist Board.

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1. INTRODUCTION

1.1. Background

Reflecting the need of humans in modern society to experience something unique and pristine, there has been a rapid growth during the last decades in tourism to natural areas. Defined as regions that have not been significantly altered by human exploitation and occupation (Newsome et al., 2013), natural areas tend to exist in remote places. Whilst visitors contribute to an economic boost to local communities an unavoidable and natural result from recreational activity in virgin environments is that the integrity of natural landforms and ecological processes is damaged. The result may be irreversible soil erosion and land degradation due to changes to the physical and chemical properties of the ecosystem components (Cole & Bayfield, 1993). This is emerging as a major environmental concern, and considerable attention is given on developing sustainable management programs for ensuring continued survival of natural areas (Newsome et al., 2013).

In less-developed and more remote areas of touristic interest with no engineered trails or nodes of activity for recreational use, the knowledge required to manage impacts of nature-based tourism is critical. The inherent durability of the natural environment, and how much of what types of use the environment can support will set standards for acceptable levels of impact (Cole, 2004).

In Iceland tourism has increased exponentially during the past decades and almost tripled since 2000 with over 90% of the visitors stating nature to be the major purpose of their visit (Icelandic Tourist Board, 2014). Whilst this can provide funds for ecological conservation and directly benefit the economic development and political empowerment of local communities, it has also been shown that nature tourism can have significant negative impact on Icelandic ecosystems causing deterioration and erosion (e.g. Gísladóttir, 2006; Ólafsdóttir and Runnström, 2013). The northern ecosystems are sensitive to erosive processes because of a very short growing season and harsh weather conditions, and high impact from humans engaging in outdoor recreation may cause irreversible changes to the country’s national parks and nature reserves in terms of erosion and desertification. Iceland is a country that highly depends on natural resources, it is hence of vital importance to plan and manage the growth of nature-based tourism in a sustainable manner in order to secure long-term economic benefit (Ólafsdóttir and Runnström, 2009).

1.2. Impacts of recreational trampling

Considerable attention has been focused on the impacts on vegetation from trampling in order to understand the effects of recreationists on natural environments. It is known that damage to both soils and vegetation can result at sites of concentrated use or where recreational activity is not confined to trails (Newsome et al., 2013). Sources of recreational trampling damage can be from humans engaging in nature-based activities such as off-road driving and biking, horse riding, hiking or backpacking.
Trampling results in change of the properties of soil components such as moisture and compaction in terms of reduction of soil pore space and thus water infiltration, but also more importantly in reduction in plant cover as well as species composition of the plant community (Cole and Bayfield, 1993). Deterioration of these components results in decreasing resistance of the environment to erosive forces and an irreversible situation may be the effect.

2. AIM OF STUDY

2.1. Part of a larger project – The Main Project

This project is part of an ongoing research project between the Department of Tourism and Geography, Faculty of Life- and Environmental Sciences, University of Iceland and the Department of Physical Geography and Ecosystems Science, Lund University, Sweden, referred to as the Main Project in this thesis. The Main Project aims to gain better understanding of how outdoor recreational activities in Iceland affects different types of vegetation and soil properties, knowledge that is critical to set standards for sustainable planning and management of tourist attractions in fragile environments such as nature reserves and national parks (Ólafsdóttir and Runnström, 2013).

To evaluate how natural area tourism activities affects the Icelandic ecosystems, a study was designed within the Main Project aiming first to develop experimental field plots for Icelandic conditions and second, to explore how the Icelandic vegetation types and soils responded to different levels of recreational pressure, i.e. trampling, biking and horse riding (Ólafsdóttir and Runnström, 2015). The first experiments were conducted in late July and early August 2014 with diverse levels of experimental human trampling on designed lanes (backpackers walking with and without hiking sticks). The time chosen for the experiments represents the time of the year in Iceland when vegetation cover is at its peak at the middle of the growing season, coinciding with the period when nature tourism is at its maximum. (Ólafsdóttir and Runnström, 2015).

Experimental plots were constructed on three common Icelandic vegetation types; grassland, mossheath and moss. Physical variables such as soil moisture, soil compaction, surface depth profile, and vegetation cover were measured in the field after different levels of controlled pressure was added.

The data collected from this first part of the experimental research was provided to me as I did not participate in the trampling experiment myself, and is the data processed and analysed in this thesis.

2.2. Thesis objectives

In this study, impacts from recreational trampling is assessed in experimental plots, confined to three different vegetation types in Þingvellir [ˈθiŋkˌvɛtlɪr̥] National Park (ÞNP) and Fjallabak Nature Reserve (FNR) in Iceland. The different vegetation types are grassland, mossheath and moss.

The impact from short-duration trampling to the vegetation types is analysed as regards soil moisture, soil compaction, surface depth profile and vegetation cover. Data collected on experimental plots on the sites is processed and assessed whereas;

- an increasing impact on soil variables and vegetation cover can be determined with increased level of trampling pressure.
- the impact to the variables measured differ between the different vegetation types and study areas.
- any significant discrepancy in the impact to all the variables can be determined if hiking sticks are used or not.

A major part of this thesis is the use of digital photography as a tool for detecting changes in vegetation cover from the experimental trampling and three methods of image analysis are tested;

- supervised classification method
- segmentation of the images with the application of the ExGR (Excess Green minus Excess Red) index
- extraction of Green Chromatic Coordinate (GCC) means from the images of each sub-plot

Damage to all variables directly after trampling is examined, without assessing recovery of vegetation due to lack of measurements on the plots (at this stage of the research) one year after the experiment.

Statistical analysis of the gathered field data is performed for hypothesis testing and regression analysis explained in the later section 'Methodology'. The resistance of each vegetation type to trampling pressure is calculated in the final analysis.

3. REVIEW OF PAST RESEARCH AND METHODS

3.1. Environmental impact from recreational trampling

Degradation of natural areas by overuse is a recognized problem worldwide and research identifies recreational trampling as one critical factor in terms of alteration of soil and vegetation properties resulting in disturbance of the ecosystem balance. Because trampling is the most visible form of disturbance from outdoor recreation activities (Monz, Cole, Leung and Marion, 2010b), extensive literature exists on impact from recreational trampling going back several decades (e.g. Wagar, 1964; Bayfield, 1979; Cole, 1983; Sun and Liddle, 1991; Cole and Bayfield, 1993; Littlemore and Barker 2001; Monz, 2002). As the most common effect from recreational trampling is degradation of hiking trails, methods vary from assessing already trampled areas, to controlled experimental trampling on designed hiking tracks. Common indicators of hiking trail disturbance is deepening and widening of the trail, root exposure, damage of vegetation and soil erosion (e.g. Cole, 1983; Leung and Marion, 1996; Tomczyk and Ewertowski, 2011).

Research on recreational trampling in arctic tundras (Monz, 2002) identifies a relatively low disturbance threshold of these ecosystems. In Iceland, Gísladóttir's research (2006) on hiking trail disturbances at several popular Icelandic natural areas identifies the vegetation type mossheath as the most vulnerable type of vegetation and also concludes that the variable vegetation cover is the most important indicator for degradation of hiking trails.

3.2. Procedures for recreational trampling research

Ecologists and natural resource managers are often put to the task to evaluate the relationship between amount of trampling and ecosystem response in terms of deterioration, changes to the properties of soils, and the relative vulnerability of different plant species and communities. An effective approach for assessing the impact of trampling to any ecosystem is isolating the effect of amount of trampling from other confounding variables. With the aim to increase the ability to compare results from different studies as regards the initial response of vegetation and soil components to different levels of trampling pressure and to characterize the vulnerability of different vegetation types with measurable terms, Cole and Bayfield (1993) suggests a protocol for standard experimental procedures.

The protocol suggests controlled levels of trampling to be applied to designed lanes on previously undisturbed sites. Measurements of changes to vegetation and soils are conducted directly after the added trampling pressure and once again one year after. Indicators of the change of the ecosystem are defined as relative proportions of the original conditions. The important indicator for vegetation cover is defined as:

(i) Relative vegetation cover

$$\text{Relative cover} = \frac{\text{Surviving cover on trampled sub-plots}}{\text{Initial cover on trampled sub-plots}} \times cf \times 100\%$$

$$\text{where } cf \text{ (correction factor)} = \frac{\text{Initial cover on control sub-plots}}{\text{Cover on control sub-plots one year later}}$$

After calculating the indicators of relative proportions the vulnerability of a vegetation type to trampling can be quantified by three vulnerability indices (Cole and Bayfield, 1993):

Resistance index; defined as the mean relative cover or height of a vegetation type from 0 to 500 passes (Cole, 1985) or as the minimum number of passes that caused the relative cover or height to fall below 50% (Liddle, 1975). In Cole's definition the resistance value of a vegetation type is equivalent to the area beneath the scatterplot curve describing the relationship between trampling level and vegetation cover or height, divided by the total area of the graph.

Resilience index; defined as the relative cover or height one year after where trampling caused reduction of at least 50% (Cole and Bayfield, 1993). The index quantifies the recovery of the vegetation type after the trampling impact.

Tolerance index; defined as mean relative cover or height after one year of recovery expressed as the number of passes a vegetation type can tolerate in order to still retain at least 75% of relative cover or height one year after the experimental trampling (Cole and Bayfield, 1993).

3.3. Assessment of vegetation cover

3.3.1. Traditional methods

Accurate, reliable and effective measurements of vegetation cover and plant distribution is crucial in all scientific fields within ecological research and in resource planning and management. Traditionally, the methods used for monitoring vegetation cover have included visual assessment, point sampling and transects, based on visual estimates by field personnel. A technique called point quadrat method was first developed by Daubenmire (1959), where observers visually estimate either percent cover or percent cover categories (e.g. 0-5, 5-25, 25-50, 50-75, 75-95, and 95-100%). However, in a statistical context, except from asking for a large number of quadrates to be sampled, accuracy is required and this subjective method is sensitive to observer bias (i.e. different observers will record different percent cover category for the same quantity; Kercher et al. 2003). This method has been further developed by scientists to include measurements of aboveground biomass and density of plant cover (point sampling) within the quadrate (Barbour et al., 1987, Cox, 1990), but even though there have been numerous attempts to account for the subjectivity and inconsistency in these sampling techniques, they still remain sensitive to observer bias, as they are costly and destructive.

In 1924, Cooper W.S. reported the use of film camera and a wooden camera stand for vertical photography of permanent quadrats. The photographs could provide a visual record of the conditions at the time of the field study, and estimation of vegetation cover could be simplified and enhanced in regards to time and accuracy at an indoor and friendlier environment, but still, the vegetation cover estimation was based on visual assessment.

In experimental studies, accuracy and precision are required to differentiate ground cover variation from treatment effects (Kennedy and Addison, 1987) and the traditional methods of vegetation cover estimation, as mentioned earlier, lead to errors in estimation that are either large, unknown or observer specific (Walker 1970, Sykes et al., 1983). The potential of using close-range vertical digital photography to measure vegetation cover over small areas have been previously explored by several authors. In 1997, Roshier et al. introduced digital imagery for recording of plant population data in plots. However these methods were time-consuming, equipment-intensive or were too early to take advantage of subsequent automated and objective image analysis (Bennett et al. 2000).

3.3.2. Digital photography and image analysis methods

With the leaps in technology of photography and computerised image analysis, the scientific community saw great potential for using digital close-to-earth photography in documenting and monitoring changes of land cover. The possibilities to analyse spatially distributed data and relationships between variables are greatly enhanced combining these tools, to result in better understanding of cause and effect regarding impact to ecosystems (Ólafsdóttir and Runnström, 2013).

Recent studies have demonstrated that ground-based high-resolution digital photography (although digital cameras are not certified as calibrated instruments) can be used successfully as imaging sensors (Richardson et al., 2007, Bennett et al., 2000), since it is inexpensive and easy to use with minimal training.

The images from conventional digital cameras represent combined brightness levels from the Red-Green-Blue (RGB) channels of the visible part of the electromagnetic spectrum. The color channel information can be extracted as separate RGB digital numbers (DNs) for subsequent processing and quantitative analysis. The near-infrared (NIR) spectrum useful for studying vegetation is often not available, unless a more sophisticated but also more costly NIR camera is used.

Digital photography and subsequent image analysis for measuring and identifying vegetation has previously been used in fields such as agriculture and forestry (e.g. Slaughter et al., 2008; Richardson et al., 2007, 2009; Sonnentag et al., 2012), as in ecological monitoring and natural resource management (e.g. Booth et al., 2004; Booth and Cox, 2008; Louhaichi et al., 2001). The cameras used for research in the above mentioned fields are typically mounted on instrumentation towers (in this case webcams), looking over the area of interest with a slight downward angle, or on camera stands such as tripods, looking vertically downward documenting a smaller quadratic plot area. This close-to-earth remote sensing technique has proven to result in increased sampling rate, measurement speed and accuracy by allowing for increased number of samples with geographical precision. Also, the use of webcams allows for documentation of the same areas over periods of time, providing data for time-series. The acquisition of information on ground cover from digital photography is rigorously developing.

3.3.2.1. Supervised classification of digital images of quadrats

After the advances in Geographic Information Systems (GIS) and image analysis tools the past two decades, researchers started to see the opportunities combining these tools for more objective and accurate measurements and records of surface conditions.

In year 2000, Bennett et al. describes a method of close-range vertical photography of permanent sub-plots and subsequent supervised classification to discriminate between plant and soil. An accuracy assessment of the method was conducted, comparing it to both visual estimation and point sampling, but it was concluded that neither of the subjective methods could provide measures of 'true' vegetative cover due to their variable errors. However, data presented in this work indicates that the photographic method with subsequent objective color analysis is sufficiently accurate and precise to measure treatment effects over time and to demonstrate relationships between treatment intensities and surface conditions. The ease and speed of the described photographic method in capturing and analysing images is pointed out. Finally, the use of wavelengths beyond the visible range such as infra-red, is suggested for areas where discrimination between plant and soil is a problem.

3.3.2.2. Application of vegetation indices

In the assessment of vegetation cover the most relevant image processing procedures require the identification of living plant material versus soil and residue backgrounds. Green vegetation has a very characteristic spectral signature. The important regions of the electromagnetic spectrum that provide significant and useful information about vegetation are the visible, near infrared (NIR), and shortwave infrared (SWIR). The most used regime in detecting green areas in remote sensing is the NIR. The chlorophyll pigments in a live plant absorbs visible, especially blue and red light to be used in photosynthesis, whereas near infrared light is of no use to the plant and therefore reflected very effectively. The reflectance of vegetation in visible wavelengths is low, as absorption extends across the entire visible portion of the spectrum, however, it presents a local maximum in the green wavelengths where there is a slight retrieve in absorption (Fig. 1). This peak in reflectance within the green wavelengths is to which vegetation owes its typical green coloring.

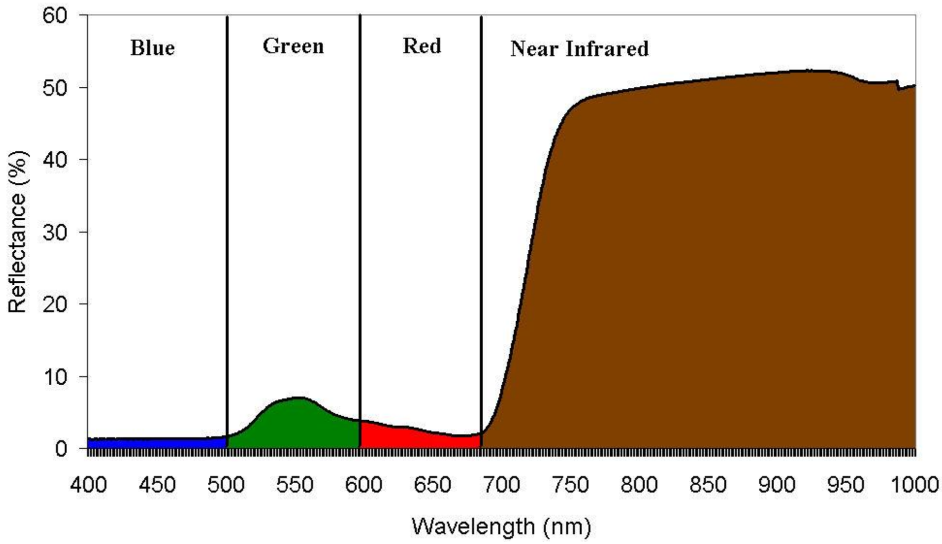

Fig.1. *Spectral signature of green vegetation showing the peak of reflectance in the green wavelengths within the visible spectrum and the high reflectance in the near infrared (NIR) wavelengths (*SEOS – Science Education through Earth Observation for High Schools*, www.seos-project.eu/).*

Since green vegetation has this distinctive spectral signature in the visible wavelengths, it was considered to combine information from the visible spectral bands to develop color vegetation indices, or greenness indices (Woebbecke et al., 1995). The theory is to enhance greenness information in digital images from the RGB channels in every pixel. Each pixel contains a DN for every color channel with a value of 0-255, which represents the brightness of every color. Applying a formula on the pixel DN values, the green channel information is enhanced.

Normalization of the RGB DN values

An important step in the computation of a greenness index is to recalculate the raw RGB DN values of a pixel into normalized RGB chromatic coordinates. Non-normalized RGB values are highly sensitive to the total light reflected from a surface (Woebbecke et al., 1995). The intensity of the illuminating source and its angle with the surface directly effects these values and can therefore be used to make conclusions about the color, but not the spectral reflectance of an object (Gonzalez and Woods, 1992). For example, sunlit green vegetation have overall higher RGB DN values than shadowed green vegetation. Computing vegetation indices directly on these values would result in inhomogeneity of greenness values for the same information class 'vegetation'.
Normalization of the RGB DN values is performed according to equation (ii):

(ii) $$\boldsymbol{r} = \frac{\mathrm{R}}{\mathrm{R+G+B}}\ ,\ \boldsymbol{g} = \frac{\mathrm{G}}{\mathrm{R+G+B}}\ ,\ \boldsymbol{b} = \frac{\mathrm{B}}{\mathrm{R+G+B}}$$

where the raw RGB DN values (R, G and B) are recomputed into red, green and blue chromatic coordinates (r, g and b) that range from 0 to 1.

Image segmentation through application of greenness indices

Optical detection of plants has been proposed for controlled spraying of herbicides from spot sprayers in the field of automated agriculture, (Haggar et al., 1983). The application of greenness indices on digital images establishing digital contrast between a plant and non-plant background has been widely studied.

Several contrast indices of RGB chromatic coordinates that enhance the signal from green plant material were originally tested and evaluated by Woebbecke et al. (1995). The objective was to obtain a binary image through application of greenness index, where plants were segmented from their soil/residue background. An ideal contrast is represented by a binary histogram, to which a threshold value can be applied for final segmentation. The Excess Green index ExG (Eq. (iii)) and the green chromatic coordinate *g* (Eq. (ii)) were found to be superior over other color indices in separating plants from soil/residue background.

The Excess Green index is calculated as:

(iii) $$\boldsymbol{ExG} = 2g - r - b$$

where r, g and b in the formula are the red, green and blue chromatic coordinates for each pixel according to equation (ii).

A variety of color indices for the RGB color space have been proposed over the years for the distinction between vegetation and soil/residue background;

(iv) *Excess Red:* ***ExR** = 1.4r – g (Meyer et al., 1998)*

(v) *Color index of vegetation extraction:* ***CIVE** = 0.441r – 0.811g + 0.385b + 18.78745 (Kataoka et al., 2003)*

(vi) *Excess Green minus Excess Red:* ***ExGR** = ExG – ExR (Neto, 2004)*

The above approaches need to fix a threshold for final segmentation of the image into green vegetation/non-vegetation and usually the Otsu's method (Otsu, 1979) is applied Otsu's algorithm performs clustering-based image thresholding and reduces a greylevel image to a binary image. According to the research of Neto (2004) the ExGR index provides an automatic threshold at 0 (Meyer and Neto, 2008) and therefore the Otsu's method is not required.

Green Chromatic Coordinate (GCC)

In order to better understand seasonal dynamics of forest canopy CO_2 photosynthetic uptake, Richardson et al. (2007) extracted the greenness from close-to-earth RGB digital photographs to detect trends of spring green-up of forests and to track phenological patterns. Instead of calculating greenness indices on every pixel of an RGB image for binary image segmentation (as described in previous section), raw DN values were extracted for each channel of every pixel within the image and then averaged and returned as mean RGB of the image. Two formulas could then be applied on the averaged RGB of the image, the Excess Green index ExG (Eq. (iii)) and the Green Chromatic Coordinate GCC, which is the same as *g* in Eq. (ii), but named GCC by Richardson et al. The greenness within each image is that way represented by one overall greenness mean value.

4. STUDY AREA

4.1. Environmental characteristics

Iceland is a volcanically active island in the middle of the North Atlantic Ocean extending approximately from latitude 63°23' to 66°32'N and longitude 13°30' to 24°32'W just south of the Arctic Circle, with elevation ranging from sea level to 2110 m. Characterized by climatic and physical fluctuations due to elevation, the Icelandic ecosystem is separated in the highlands and the lowlands. More than one-third of the country's surface area lies above 600m and only about a quarter below the 200m contour line (NLSI, 2015).

In the path of the North Atlantic Current, Iceland's climate is more temperate than would be expected for the country's latitude, giving rise to humid and cool temperate climate characterized by cool short summers and mild winters. However, the North Atlantic Current brings mild Atlantic air in contact with colder Arctic air resulting in a climate marked by strong fluctuations in weather, stormy winds and frequent rainfall (IMO, 2015).

Iceland is geologically young, the oldest bedrock being about 15 million years old (IINH, 2015), formed by the coincidence of the spreading boundary of the North American and Eurasian plates (the Mid-Atlantic Ridge) and the Iceland plume hotspot – an upsurge of abnormally hot rock in the Earth´s mantle (Iceland on the Web, 2015). The rift associated with the Mid-Atlantic Ridge, runs across Iceland from the southwest to the northeast (Fig. 2) and the volcanic and geothermal activity in Iceland is extensive. The result of this geological uniqueness to the Icelandic ecosystem is a very high volcanic content in the soil types (Histosols, Andosols and Vitrisols, Andosols being the predominant) and growing conditions are unfavorable. Also the high sandy content and lack of cohesion of these soils make the Icelandic ecosystem highly susceptible to erosion by wind and water (Arnalds, 2008, 2010).

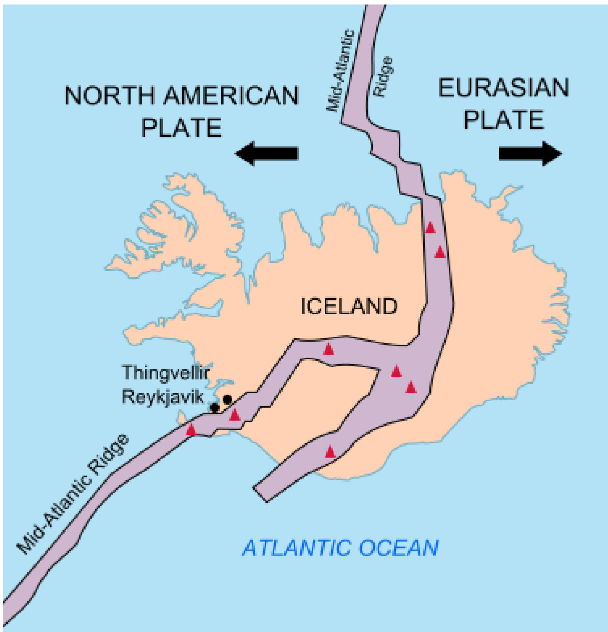

Fig. 2. *The Mid-Atlantic Ridge (purple) that runs across Iceland from the southwest to the northeast. Marked are also the capital of Iceland (Reykjavik) and the Þingvellir area (black dots), as the locations of some of the active volcanoes on Iceland (red triangles).* (USGS - U.S. Geological Survey, *www.usgs.gov/*)

Vegetation in Iceland is sparse, with more than half of all vegetation cover being mosses (IINH, 2015) with species in the racomitrium family accounting for the larger part, mainly *Racomitrium lanuginosum* and *Racumitrium canescens* (Jónsdóttir et al., 2005). The *Racumitrium lanuginosum* is usually the first to colonize lava fields and areas with unfavourable growing conditions, such as Iceland's extensive basaltic lava fields and the interior highlands (Jónsdóttir et al., 2005).

4.2. Selection of the study areas

The experimental sites were chosen as regards to homogeneity of vegetation cover and vegetation type within about one hectare in size (Ólafsdóttir and Runnström, 2015). Experimental lanes were created on sites of the most common vegetation types in the selected areas; grassland and mossheath. Also an area of 100 percent moss cover was included in the experimental trampling research.

In order to see if there was any significant difference in the resistance of vegetation and its recovery depending on elevation, it was decided (in the experimental trampling research of the Main Project) to undertake experimental sampling both in the lowlands and the highlands. Þingvellir National Park was chosen for the lowland area and Fjallabak Nature Reserve for the highland area (Fig. 3). Both areas are protected and have for a long time been among Iceland's most popular outdoor recreational areas (Ólafsdóttir and Runnström, 2015).
The ecosystem on both sites is sub-arctic and the most common vegetation types are mossheath and grassland. In the Þingvellir National Park there are also areas of moss cover.

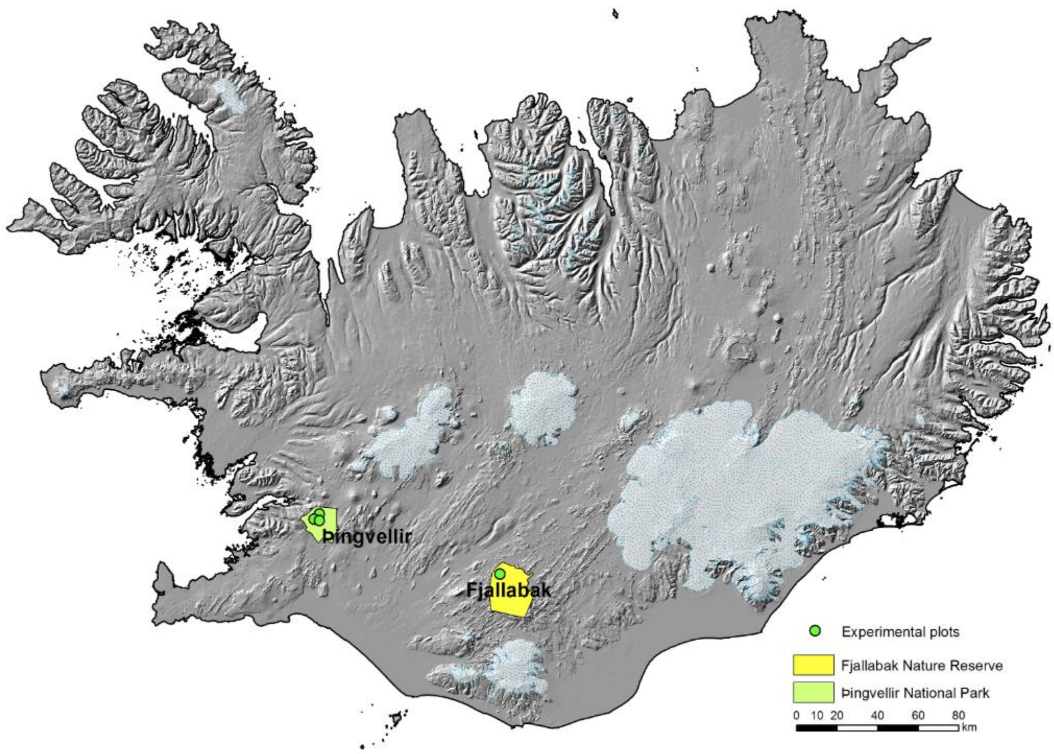

Fig. 3. *Map showing the location of the selected study areas at the lowland (Þingvellir National Park) and the highland (Fjallabak Nature Reserve), and the experimental plots (green dots) where the field research was conducted (Ólafsdóttir and Runnström, 2015).*

4.2.1. Þingvellir National Park (ÞNP)

Þingvellir National Park in southwestern Iceland is a site of historical, cultural, and geological importance and is one of the most popular tourist destinations in Iceland.

The continental drift between the North American and Eurasian Plates can be clearly seen in the cracks or faults which traverse the region (Fig. 4.). The predominant vegetation cover is mossheath, heathland and grassland. Forested land is only ~1% with mainly birches and willows (IINH, 2015).

Fig. 4. *Aerial view of Þingvellir National Park, showing a fissure zone (in shadow) that is an on-land exposure of the Mid-Atlantic Ridge. The photograph encompasses the historical tourist area of Þingvellir, the site of Iceland's first parliament, called the Althing, founded around 930 A.D.* (USGS - U.S. Geological Survey, *www.usgs.gov/*).

4.2.2. Fjallabak Nature Reserve (FNR)

The Fjallabak Nature Reserve located in the interior of Iceland in the southern Central Highlands is over 500 meters above sea level. The land is mountainous, sculptured by volcanoes and geothermal activity, covered by lavas, sands, rivers and lakes. Vegetation cover is thin and scattered and the largest and greenest vegetated areas are close to rivers and lakes. Because of the cold climate in the nature reserve, the vegetation's growing period is only about two months every year, and the formation of soil very slow (Arnalds, 2008) (Fig. 5).

Fig. 5. *Photograph from Fjallabak Nature Reserve showing the rigid and harsh land of the Icelandic highlands* (AITO - Association of Independent Tour Operators, *www.aito.com/iceland/).*

5. DATA COLLECTION

The data processed in this study was collected and provided to me by the researchers that participated in the Main Project. As recommended by Cole and Bayfield (1993), the field work was carried out in the middle of the growing season when the vegetation cover is at its maximum; 22nd -28th of July 2014 in Þingvellir National Park and 12th-15th of August 2014 in Fjallabak Nature Reserve.

Within each selected experimental plot five lanes with a length of 20 meters and width of 1.5 meter were constructed defined by sticks and wires, to be subjected to different hiking pressures. Between the lanes a buffer zone of ca 0.5 meter was kept for the ease of measurement execution and to avoid adding trampling to the lanes (Fig. 6).

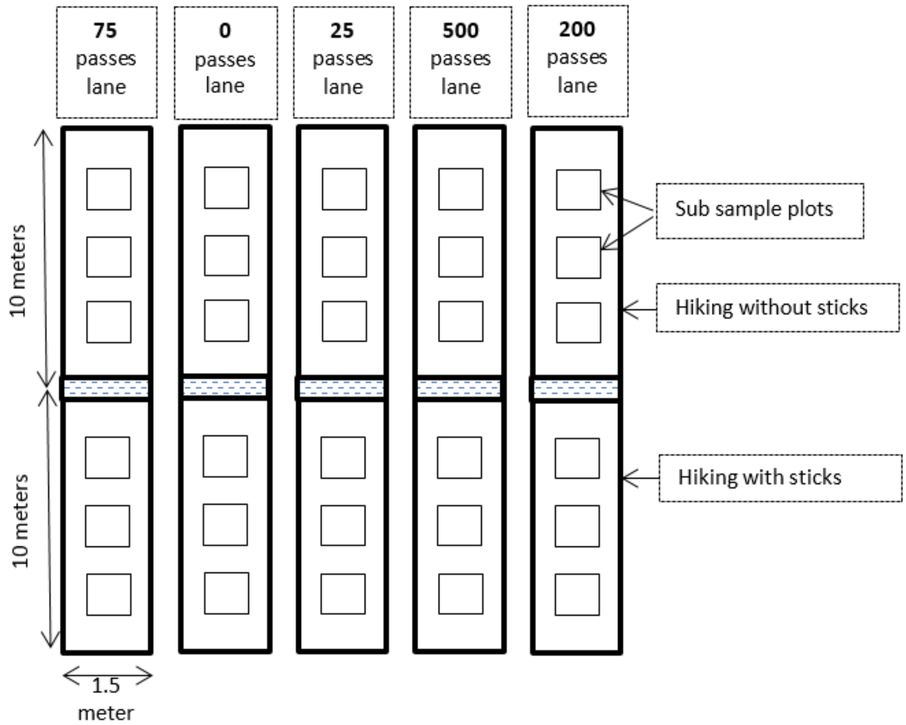

Fig. 6. *The experimental field design used in all study sites. The numbers on the top of the illustration indicate randomly assigned number of trampling to the lanes. The 0 passes lane is the control lane, i.e. no trampling added (Ólafsdóttir and Runnström, 2015).*

The experimental sites were subjected to trampling from hikers and conditions of tourists engaging in hiking and backpacking were recreated. Variables such as soil moisture, soil compaction and surface depth were measured in the field after the trampling experiment. The traditional quadrat method suggested by Cole and Bayfield (1993) to be used for measuring the variable vegetation cover, was exchanged by digital photography of the sub-plots. The reflectance properties of a photograph is altered by the change in the vegetation/bare soil relationship and should therefore be detectable through image analysis. Examining the use of image analysis to detect changes in vegetation cover after experimental trampling is of interest for the planning of future data capture within the Main Project (Ólafsdóttir and Runnström, 2015). The field measurements were conducted and photographs of the subplots were taken directly after the diverse trampling levels.

Each lane was subjected to different levels of trampling by humans recreating hiking conditions. Four hikers of 60-90 kg equipped with hiking boots and back-packs of 5-10 kg walked the lanes until the desired number of passes in each lane was reached. In order to detect any differences in pressure per unit area the hikers walked with hiking sticks during the last 10 meters of the lanes.

The number of passes at each lane, symbolizing the amount of tourists, was 0 (control lane), 25, 75, 200 and 500.

Four experimental plots were established in total, three in the Þingvellir National Park (ÞNP) and one in Fjallabak Nature Reserve (FNR) (Table 1).

Table 1. *The geographical location of the experimental plots and their vegetative characteristics. (Ólafsdóttir and Runnström, 2015)*

	Location (GPS)	**Vegetation Type**	**Altitude**	**Dominating species**
Plot 1 (ÞNP)	N64°29440; 64°29446; 64°29440; 64°29434 W21°06059; 21°06064; 21°06099; 21°06094	Grassland	152 m.a.s.l	*Galium verum; Galium boreale; Kobresia nyosuroides; Festuca richardsonii; Bartsia alpine; Thymus praecox*
Plot 2 (ÞNP)	N64°29361; 64°29362; 64°29346; 64°29345 W21°06214; 21°06230; 21°06231; 21°06218	Mossheath (lowland)	149 m.a.s.l.	*Calluna vulgaris; Empetrum nigrum; Dryas octopetala, Alchemilla alpine, Salix, callicarpaea; Salix phylicifolia, Racomitrium sp., Festuca richardsonii*
Plot 3 (ÞNP)	N64°28517; 64°28515; 64°28509; 64°28513 W21°08089; 21°08083; 21°08091; 21°08099	Moss	134 m.a.s.l.	*Racomitrium lanuginosum; Racomitrium canescens*
Plot 4 (FNR)	N64°05543; 64°05540; 64°05532; 64°05535 W19°29687; 19°29697; 19°29675; 19°29665	Mossheath (highland)	628 m.a.s.l.	*Dryas octopetala; Bistorta vivipara; Armeria maritime; Racomitrium sp.*

5.1. Field measurements

A total of six sub sample plots (60x60 cm) were set within each 20 meter lane at positions 2, 4, and 6 meters distances from each end. Measurements of the variables mentioned above were taken within each subplot. Also a digital photograph was taken of each sub-plot vertically from above the ground (approximately 1.5 m of height) using a tripod with a tilt arm for vertical and horizontal balance of the camera.

5.1.1. Soil moisture

Each sub-plot was divided into 9 mini-plots and soil moisture was measured about 10 cm below the soil surface at 9 points to compute their average. A simple digital meter for pot-plants was used with the display revealing digital values between 0.0 (dry soil) and 9.9 (moist soil).

5.1.2. Soil compaction (N/m^2)

Soil compaction was measured with a professional penetrometer at three points in the sub-plots along the path direction and the averaged value was used.

5.1.3. Surface depth

According to Cole and Bayfield (1993) the initial response to trampling is most often reduction in vegetation height followed by compaction of the soil forming a U-channelled surface profile of a hiking trail. Measurements of the surface depth within the sub-plots were taken at a cross section perpendicular to the lane direction, with a ruler at every 10 cm intervals.

5.1.4. Sub-Plot photography (RGB)

A Canon PowerShot SX50 HS digital camera was used and digital images were archived as Joint Photographic Experts Group (JPEG)-files of 24 bit-depth RGB color information (true color images) for subsequent processing. At experimental plot 4 (Þingvellir moss site) the Canon camera was out of power so unavoidably these photographs were taken with an iPhone 4 camera with lower resolution. Each pixel in a digital RGB image consists of three color channels (red, green and blue) that use 8 bits each with integer values from 0 to 255. This makes 256*256*256=16777216 possible colors where RGB = 0,0,0 is black, RGB = 255,255,255 is white and every other possible combination of values is a mixture of color tones. A total of 79 photos were used for the subsequent image analysis.

6. METHODOLOGY

The variables soil compaction, soil moisture and surface depth were measured and recorded in the field directly after the different levels of trampling. The averaged values of sample points within the sub-plots were used for subsequent statistical analysis in MS Excel. For the variable vegetation cover the statistical testing was carried out after the image analysis process.

In this thesis, the variable vegetation cover is expressed as a proportion of the original conditions as suggested by Cole and Bayfield (1993) (see Eq. (i)), but with an alteration as regards the formula. The factor *initial cover on trampled sub-plots* was lacking and was therefore substituted with the mean value of all sub-plots in the control lane (0 passes) which was considered a representative value for the initial vegetation cover over the entire experimental plot. Also the correction factor *cf* is not included as this factor accounts for natural variations of recovery one year after trampling (data not yet collected at this stage of the experimental trampling research of the Main Project). The indicator of vegetation cover change in this thesis is thus:

$$\text{(vii)} \qquad \text{Relative cover} \quad = \frac{\text{Surviving cover on trampled sub-plots}}{\text{Mean cover value of control sub-plots}} \; x \; 100\%$$

The vulnerability indices mentioned in section 3.2. cannot be computed, except for the resistance index from the relative vegetation cover. For the rest of the measurement variables actual values and not relative values are presented.

6.1. Statistics

The statistical method applied for determining whether a significant difference exists between measured variable means after added trampling pressure, is an analysis of variance (one-way ANOVA). In the cases where the test implicates that there is a significant difference, a more thorough description of the nature of the relationships between the variables can be done with a regression analysis to determine the strength and direction of the correlation between the measurement variables and trampling pressure. Also a two-way ANOVA for detecting differences between lanes trampled without and with hiking sticks is carried out.

Focus is set on detecting significant relationships between the variables measured, including the results from the image analysis, and trampling pressure. Also a comparison will be carried out between the results from the three image analysis methods for detecting vegetation cover change to see if they performed in a similar way. In figure 7 the methodology is described by a flow chart.

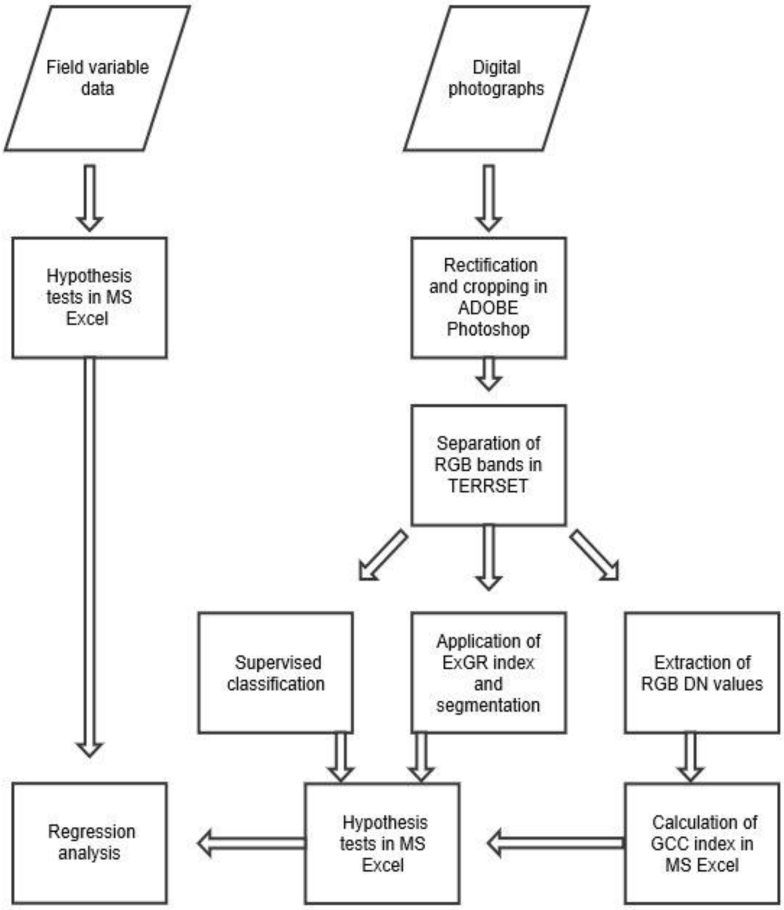

Fig. 7. *Flow chart describing the methods to process the variables measured in the field and the image analysis of the digital photographs.*

6.1.1. Hypothesis testing – Analysis of variance (ANOVA)

ANOVA uses the F test to determine whether there exists a significant difference among the means of two or more samples. In this case the samples are the measurements within each lane of different trampling level. It is a preliminary test that tells us if we should continue to undertake an investigation of the nature of the effect.

For each of the variables examined in this thesis the search for statistical evidence for rejection of the null hypothesis $\mathbf{H_0}$ is the main objective, which would implicate that the alternative hypothesis $\mathbf{H_1}$ can be accepted. $\mathbf{H_0}$ and $\mathbf{H_1}$ are described as:

$\mathbf{H_0}$ = there is no statistical significant difference among variable means between lanes of added trampling pressure, i.e. trampling pressure has no effect to the ecosystem.

$\mathbf{H_1}$ = the differences among the variable means between lanes of added trampling pressure are statistical significant, i.e. trampling pressure has an effect to the variables measured.

In statistical context throughout all scientific fields usually a level of significance alpha α<0.05 is used as a reference to accept or reject the null hypothesis. If the probability value $P < \alpha$ (i.e. P<0.05), there is less than 5 percent chance that the sample values differ significantly due to random variation. This means we reject the null hypothesis and accept the alternative hypothesis. We derive our P value through the F distribution test statistic:

(viii) $$F = \frac{S_B^2}{S_W^2}$$

where F expresses the variance between the means of a number of samples S_B^2, to the variance within the samples S_W^2 (McDonald, 2014).

6.1.2. Regression analysis

The P values from the initial statistical hypothesis testing are for most of the measurement variables expected to show significant difference among variable means between lanes of added trampling pressure, i.e. to reject H_0. For the relationships where the null hypothesis is rejected, a subsequent regression analysis is carried out to determine if the slope of the regression line is positive or negative (if the measurement variable is increasing or decreasing as trampling pressure increases), and the coefficient of determination r^2 is calculated which describes how tightly the two variables are associated, or in other words, how close the points on the graph are to the regression line.

6.1.3. Testing the variable hiking sticks usage – two-way ANOVA

An additional question in this thesis is if the variables measured after the experimental trampling experiment differ significantly between lanes trampled without and with hiking sticks. This is an effect which is not biologically obvious, nor visually detectable in the graphs. For the cases where the null hypothesis H_0 has been rejected a proceeded two-way ANOVA can test the significance of hiking sticks usage to the variable.

6.2. Image analysis

The color images were processed using the red, green and blue image bands to discriminate between vegetation and other cover types. Three different methods were applied to assess vegetation cover;

- supervised classification
- segmenting the images through applying the ExGR formula on pixel basis (Eq. (vi))
- calculation of GCC means of the images (g in Eq. (ii))

The JPEG images were all rectified and cropped so only the area of interest within the 60x60 cm sub-plot was analysed. This was easily accomplished in Adobe Photoshop CC 2014. There was no issue with picture warp, as all the photographs were taken with a close enough 90° vertical angle from the ground. The size of the images altered slightly in size after cropping them, but at a negligible level. No selective artificial enhancement was conducted to any of the archived images before the image analysis to ensure that results of comparable quality should be obtainable for likely future research within the Main project.

The cropped JPEG images were then imported in the TerrSet (Clark Labs Ltd.) program for further processing. The primary steps were conversion to raster file-type and subsequent separation of the red, green and blue bands.

6.2.1. Supervised classification

As the photographs at each experimental site were taken within a relatively small time-laps directly after the experimental trampling was undertaken, one might expect to have a homogenous set of photographs as regards RGB brightness levels. This was not the case as some photos were captured under direct sun resulting in dark micro-shadowing within the sub-plots, while others were taken during overcast conditions (clouds obscuring the sun). This made the classification method hard and time-consuming. Furthermore the inability to classify shadowed areas led to loss of information.
Tests of unsupervised cluster classifications of the images showed poor results for all vegetation types and it was hard to distinguish thresholds within the histogram that would define the classes that were visually distinguished in the digital images.

6.2.1.1. Determining land cover classes and signature creation

To find the proper number of classes that best would classify any image in the sets of photographs, many tests were run. In order to decrease the amount of unclassified pixels, the cover types had to be divided in different sub-classes based on their color information.

Grassland at ÞNP (Plot 1)

Within the Þingvellir grassland set of photographs ($\boldsymbol{n}$=30) no micro-scale shadowing from the sun was present as the photographs were all taken during overcast conditions. This resulted in consistency in RGB brightness levels between all photographs. Visual examination of the photographs as regard to changes in vegetative area revealed no tendency of the vegetation of having been worn-out after trampling into revealing bare ground. Increase of bare ground cover areas could not visually be detected. The grass was rather just being torn, resulting in change of color as the trampling level increased. The images of the trampled sub-plots revealed areas of grass that had a blue-green color compared to the grass in the reference sub-plots (trampling level 0) that were either green or white (Fig. 8).


Fig. 8. *Photograph of an untrampled sub-plot at Plot 1 (grassland at ÞNP) left) and of a trampled sub-plot (Plot 1; lane 200; without sticks) (right) revealing the change of color of the grass.*

Looking at the set of images one could easily detect 4 classes of cover types that increased or decreased with the diverse levels of trampling. It was decided to classify these images into the following 4 final classes:

1) Green vegetation
2) Blue-green vegetation
3) White vegetation
4) Gaps – Bare ground

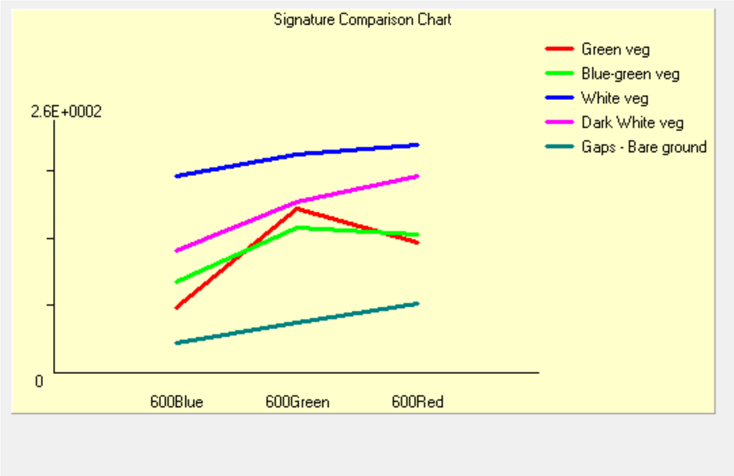

Fig. 9. *Spectral signatures for all sub-classes at the Þingvellir grassland site (Plot 1).*

During the classification procedure, white vegetation was subdivided in 'light' and 'dark', because of different brightness levels (high vs low RGB DN values) depending on the leaf height and orientation in respect to scene illumination. Signature mean DN values of all sub-classes are shown in figure 9.

Mossheath at ÞNP (Plot 2)

For the supervised classification of these images (n=27), the visually distinguished cover classes were tested and further evaluated through numerous test-classifications.

The day of the experimental sampling at Plot 2 the sun was shining, so in this set of photographs there is distinctive shadowing due to micro-scale topography within the sub-plots. This resulted in areas with very dark pixels and gave the same information classes spectral signatures that differed in brightness levels. These issues had to be accounted for in the image processing and they were dealt with as follows:

- Creation of a specific class for very dark shadowed pixels that could not be distinguished to which class they belong, which was later accounted for as unclassed pixels excluding them from the final area calculations
- Bare ground was divided in 'shadowed' and 'sunlit'
- Vegetation was separated in sub-classes due to differing colors.

The signatures for each class had to be repeatedly improved in order to be used in the classification procedure. Table 2 shows the initial spectral classes within the set of images of Plot 2.

Table 2. *Signature mean DN values μ and standard deviations σ for each class within the Þingvellir mossheath (Plot 2) set of photographs.*

Class:	**Band:**					
	Blue		**Green**		**Red**	
	μ_b	σ_b	μ_g	σ_g	μ_r	σ_r
1. Bare Ground in Shadow	38.5	*10.1*	54.1	*14.4*	79.3	*20*
2. Bare Ground in Sunlight	113.9	*22.7*	169	*24.5*	222.2	*24.7*
3. Green Vegetation (vascular plants & green mosses)	44.5	*32.8*	130.1	*50.3*	119	*51.5*
4. White Vegetation (lichens, mosses & heath)	149.3	*57.2*	175.2	*60.3*	189.1	*58.9*
5. Leaves and Grass	165	*34.4*	211.8	*22.5*	187.6	*28.1*
6. Flowers purple	152	*59.5*	124.7	*54.1*	173.3	*52.1*
7. Brown moss / Lichens	44.8	*30.1*	78.4	*30.7*	170	*32*
8. Flowers yellow	80.2	*55.6*	235.8	*20.9*	246.5	*10.8*
9. Vegetation other	25.2	*24.1*	187	*34.3*	141.9	*34*
10. Dark shadows /undefined	13.2	*7.2*	18.4	*7.2*	20.8	*8.4*

You can deduce from the numbers presented in Table 2, that the signatures of the classes determined for the Þingvellir mossheath site have combinations of DN values and standard deviations that would allow their distinctions from one another.

After the classification of the images, the sub-classes were assigned the same class values depending on their information classes. The final classes are:

1) Bare Ground
2) Vegetation
3) Unclassified

During the classification procedure of Plot 2, it was noted that the class 'white vegetation' was usually overrepresented in the final classified images, taking over pixels that actually belonged to 'bare ground in shadow'. Micro-scale shadowing within the white vegetation distorted the spectral signature of the class when digitization of the trainingsites was too broad. It was proven of great importance to verify very detailed polygons without including pixels of shade while digitizing the trainingsites for this class.

Moss at ÞNP (Plot 3)

The images from the moss site at Þingvellir National Park were few ($\boldsymbol{n}$=12), which can be explained by the fact that the scenery at this plot was characterized by homogeneity after trampling so it was considered meaningless from the field personnel to capture photographs from all the sub-plots. The response to trampling of the very fragile moss cover is clearly seen in the damaged and discolored vegetation with the increased trampling levels, forming a trail at the centre of the lanes (Fig. 10a).

During acquisition of all photographs clouds were obscuring the sun which made them objectively comparable in regards to brightness levels.

The moss species at the site are of different colors (white moss being the predominant) so signatures were created for each of the vegetation types and then merged into one 'vegetation' class. The most difficult cover type to be dealt with in this set of images was the dark trampled/damaged vegetation.

Unfortunately some pixels of the shadowed live vegetation was classified as damaged vegetation due to their similar combinations in the red, green and blue reflectance bands (Fig. 10b). To enhance the accuracy of the relationship live vegetation/damaged vegetation, dark shadowed pixels within both cover types had to be excluded from the final calculations as they were not separable. These pixels could only be classified as 'shadows' and was later included in the unclassified portion of the images. The issue with the misclassification was lessened this way but could not be overcome entirely.

The images from Plot 3 had another major dysfunction in regards to the classification process. The metal-plot used for the definition of the 60x60 cm sub-plots was divided in 9 mini-plots with wire (Fig. 10a). It was considered to subtract the pixels with the wire through classifying them into a separate class, but this was proven to be a faulty method. The color of the threads gave these pixels DN values very alike to pixels belonging to the vegetation. These two classes ended up being mixed up. A very time-consuming and tedious process of masking out the wires from the images had to be performed. Although necessary for greater statistical accuracy of the results from the classification method this also led to loss of information.

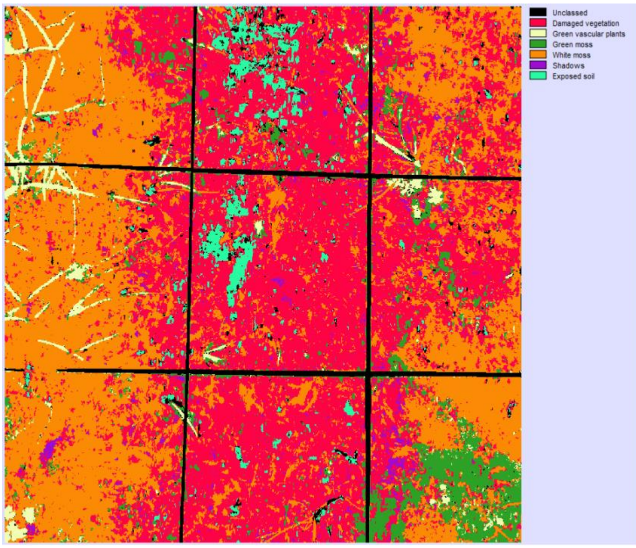

Fig. 10a. *(left) A cropped photograph from Plot 3 (Þingvellir moss); sub-plot 2; Lane 500; without sticks; showing the wire subdividing the sub-plot in 9 mini-plots and the damaged vegetation in the trail.*
Fig. 10b. *(right) Supervised maximum likelihood classification of the same sub-plot image. The dark shadows (purple) within the live white moss and the damaged vegetation in the trail were not separable and had to be excluded from the final calculations.*

Mossheath at FNR (Plot 4)

The photographs from the sub-plots at the mossheath site at Fjallabak ($\boldsymbol{n}$=10), illustrate the difficulty in separating the land cover classes within the quadrats through a supervised classification method. Except from the fact that this vegetation type consists of a gamma of species of varying shape and color, these images also included the wires that divided the sub-plot into 9 mini-plots. Repeated creations of signatures were necessary and the same masking process of the wires as in the ÞNP moss site had to be followed.

6.2.1.2. *Supervised Maximum Likelihood classification*

The best result for classifying any image within all data sets was obtained with the supervised hard-classifier Maximum Likelihood. In a supervised classification method the analyst identifies information classes which are then used to determine the spectral classes they represent. This classifier uses the maximum-likelihood estimation method of estimating the parameters of a statistical model and try to find the values of the parameters that would most likely produce the data we in fact observe.

With the given spectral signatures of each class, any value within the data set (pixel in the image) is assigned to a spectral class it most likely resembles. The maximum-likelihood probability function is characterized by the following assumptions and statistical logic:

- Highest probability is in the center of the data distribution and each pixel is assigned to the most likely class (highest probability value)
- Assumes normally (Gaussian) distributed training data
- Quantitatively evaluates both variance (DN values distribution in a class) and covariance (tendency for DNs to vary similarly in two spectral bands) in the spectral response data.

6.2.2. Applying the ExGR index for image segmentation

To test the possibility of using the ExGR function for segmentation of the images into live vegetation/non-plant background a random image was selected that included all visible cover types (both living plant material and bare ground). An overview diagram of the test method is shown in figure 11.

The objective is that through applying a greenness index to the image pixel values, the contrast between live plant material and soil/background material will be enhanced. Areas with high Vegetation Index (VI) should represent the green (live) vegetation and the areas with low VI, bare ground or decedent (dead) vegetation.

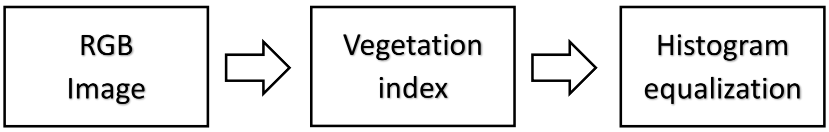

Fig. 11. *An overview diagram of the method to test the performance of greenness index application to an image to enhance the green plant information.*

In the test, the vegetation index computation was based on the ExG index (for computational speed compared to the ExGR index). Each pixel in the image is represented by ExG index normalized from 0 to 255. To visually enhance the information the histogram equalization method is used. If the resulting image would visually separate the vegetation from bare ground, the greenness index computation would show potential to be used for image segmentation. Figure 12 shows a randomly selected image from the mossheath vegetation type at ÞNP and its histograms during this procedure.

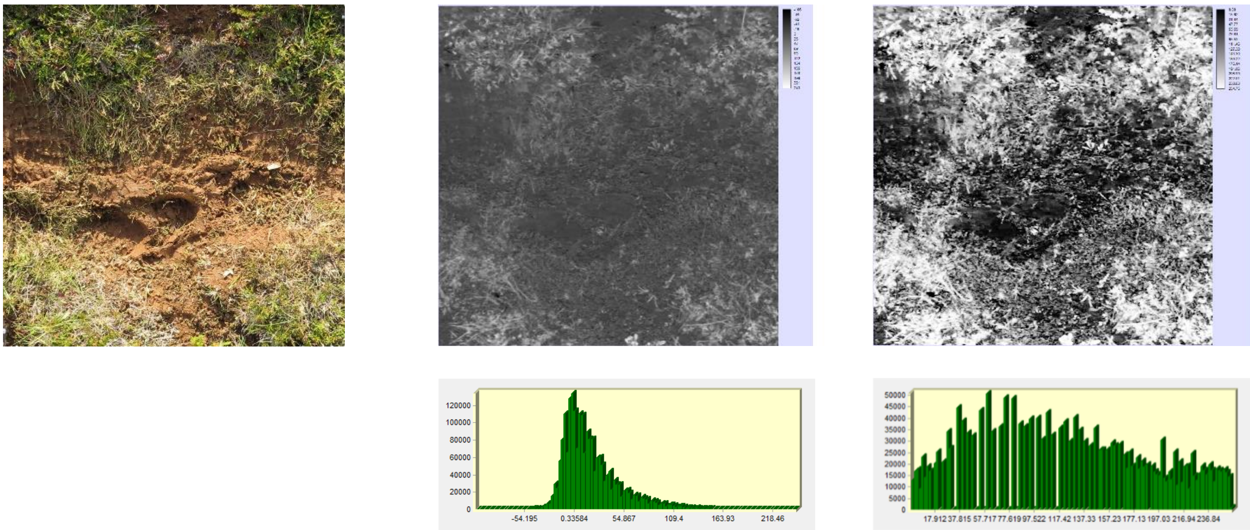

Fig. 12. *RGB image (left), ExG image and its histogram (middle) and enhanced image and its histogram (right). The ExG index is applied to each pixel in the RGB image and thereafter the ExG image is enhaced using histogram equalization.*

It is clearly revealed from the resulting image that this method works well, but with the restriction that pixels with vegetation of colors other than green are not enhanced by the greenness index. In vegetation types such as mossheaths and mosses that usually consist of different types of species of mosses and lichens with varying colors this is a problem. For final image segmentation a threshold method has to be used when applying the ExG index, but instead the ExGR index which provides an automatic threshold at 0 will be used.

6.2.3. Green Chromatic Coordinate (GCC)

When calculating greenness indices for images within a set or a time-series, differing RGB brightness levels make the images incomparable. The influence of weather-related (cloud cover and sun altitude) variations and thus RGB brightness levels at the time of image acquisition, give each image its unique scene illumination. Since this affects the color information derived from the images, when calculations on RGB levels are involved in the analysis, such as application of formulas to enhance greenness information, this is a great issue to be considered. Figure 13 shows two images from the mossheath vegetation type at ÞNP (Plot 2) with differing brightness levels due to sunny and cloudy weather conditions.

Fig. 13. *RGB images from Plot 2 with different scene illumination.*

According to Sonnentag et al. (2012) GCC is a superior method, compared to the ExG index, in suppressing these effects, therefore this method is used throughout this thesis. It is however pointed out the need to restrict the analysis to images with more or less the same overall RGB brightness levels (i.e images taken within a few hours of the day whilst similar sun altitude and intensity).
Using the Terrset program, camera color channel information (DNs) was extracted from the JPEG Images in the form of one mean value per color channel, that is, three values per image. These were imported in Microsoft Excel and calculated into GCC according to equation (ii).

In the image set of Plot 4 (mossheath at FNR) where the metal frame with the wires defining 9 mini-plots was used, the calculation of GCC values was performed without masking out these irrelevant pixels. The logic behind this is that the same wires are present in every image, and since we are interested in finding differences in the GCC values between the images of different levels of trampling, it was considered unnecessary. Nevertheless, it is important to point out that the GCC values in these two experimental plots do not represent real greenness values of the ground cover in the sub-plots.

7. RESULTS

7.1. Hypothesis testing

7.1.1. Field variables

As described in the methodology a one-way ANOVA was applied to test the significant differences of the field variable measurements after added trampling pressure. A two-way ANOVA could thereafter be conducted for the variable hiking sticks usage. The results are presented in Table 3.

Table 3. *F and P values of significance between field variables and added trampling levels (one-way ANOVA) and between lanes trampled without and with hiking sticks (two-way ANOVA). Bold values represent significant relationships between variables tested (P<0.05) and df is the degrees of freedom (n-1). Blank cells are where no tests could be conducted due to insufficient data for comparisons.*

			Soil moisture		**Soil compaction**		**Surface depth**	
Veg type	**Source**	***df***	***F***	***P***	***F***	***P***	***F***	***P***
Grassland ÞNP (Plot1)	Trampling level	29	0.40	0.808	1.94	0.134	22.12	**0.000**
	Hiking sticks usage	29	0.36	0.835	0.84	0.518	4.26	**0.012**
Mossheath ÞNP (Plot 2)	Trampling level	29	1.86	0.149	22.12	**0.000**	14.14	**0.000**
	Hiking sticks usage	29	2.78	0.055	1.57	0.220	0.52	0.719
Moss ÞNP (Plot 3)	Trampling level	19	1.61	0.223	–	–	9.73	**0.000**
	Hiking sticks usage	19	1.07	0.419	–	–	1.96	0.178
Mossheath FNR (Plot 4)	Trampling level	19	0.42	0.787	18.93	**0.000**	3.64	**0.049**
	Hiking sticks usage	19	–	–	0.82	0.542	–	–

7.1.1.1. Soil moisture

One can deduce from the P values in Table 3 that the variable soil moisture has no significant difference after added trampling pressure (P>0.05) in any vegetation type tested. A two-way ANOVA for detecting significance for the variable hiking sticks usage was not a natural next step, but was conducted for detecting whether any differences between lanes trampled without or with hiking sticks disturbed the overall significance in the relationship between the variable soil moisture and trampling pressure. This was not the case for any of the experimental plots (P>0.05).

7.1.1.2. Soil compaction

For the variable soil compaction significant differences are revealed for the vegetation types at Plot 2 and 4 (mossheath vegetation type in both the lowland and highland) (Figures 14a and 14b) as regards trampling pressure (P<0.05), but not for the variable hiking sticks usage (P>0.05). Measurements for this variable were not possible to acquire at the moss cover study site (Plot 3) as the rootless moss layer is growing directly on the post glacial lava field where no soil is formed. The grassland vegetation type shows no significant difference in soil compaction with increased trampling pressure.

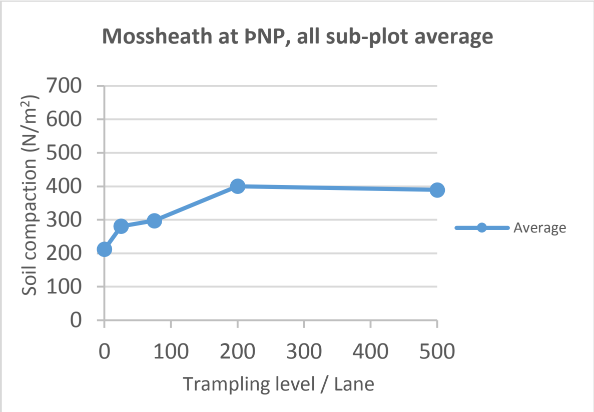

Fig. 14a. *Soil compaction; all sub-plot averages; Plot 2; mossheath at ÞNP.*

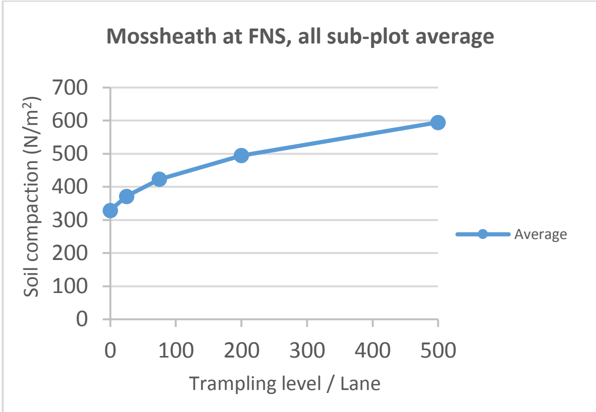

Fig.14b. *Soil compaction; all sub-plot averages; Plot 4; Mossheath at FNR.*

7.1.1.3. Surface depth

There is significant correlation between surface depth and trampling pressure at all experimental plots ($P<0.05$). In Plot 1 (grassland at ÞNP) there is a significant difference for the variable hiking sticks usage. After the diverse levels of experimental trampling a clear U-channel hiking trail formation could be visually detected in the field at all study sites (Ólafsdóttir and Runnström, 2015). The profiles of all sub-plots show a gradual deepening and widening of the channel with increasing trampling pressure as in figure 15.

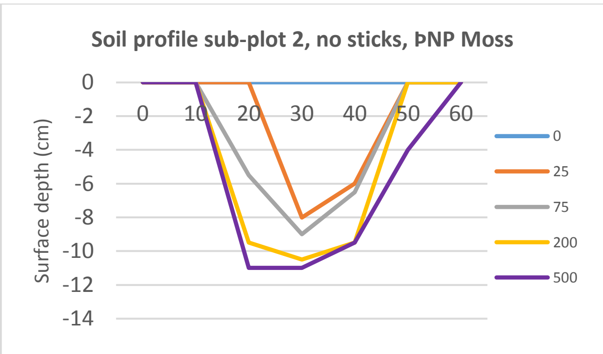

Fig. 15. *A typical U-channel formation developing in the path with increasing trampling pressure. All subplots at all vegetation types show the same pattern.*

If all surface profile measurements are averaged for each lane and vegetation type, an exponential trend is revealed in the graph in figure 16, which would implicate that the compaction of the vegetation and soil from hiking pressure will reach a potential maximum at some point. Thereafter eroding forces will naturally work their way through the path, deepening the channel even more.

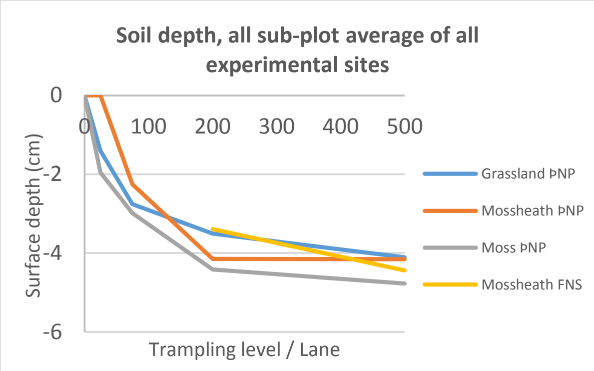

Fig. 16. *Averaged surface depth for all sub-plots of each lane revealing an increasing depth with increasing trampling pressure at all study sites.*

In the grassland vegetation type (Plot 1) the two-way ANOVA detected significant difference between lanes trampled without and with sticks. In figure 17 averages of sub-plots (500 passes) within the lane trampled without sticks is compared to the lane trampled with sticks. The graph suggests that a deeper surface profile is formed when no sticks are used.

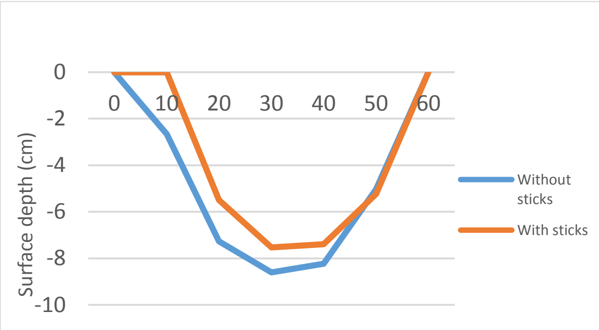

Fig. 17. *Surface profile sub-plot averages of lane 500 trampled without vs with hiking sticks, Plot 1.*

7.1.2. Image analysis of vegetation cover

The results of vegetation cover derived from the three image analysis methods were tested with ANOVA for significant differences as regards added trampling pressure and hiking sticks usage. The values are presented in table 4.

Table 4. *F and P values of significance between vegetation cover derived through the three different image analysis methods and added trampling levels (one-way ANOVA) and between lanes trampled without and with hiking sticks (two-way ANOVA). Bold values represent significant relationships (P<0.05) and df is the degrees of freedom (𝒏-1). Blank cells are where no tests could be conducted due to insufficient data for comparisons.*

			% Veg cover Superv classif method		**% Veg cover ExGR method**		**GCC Index**	
Veg type	**Source**	***df***	***F***	***P***	***F***	***P***	***F***	***P***
Grassland ÞNP (Plot1)	Trampling level	26	1.21	0.337	3.99	**0.014**	4.68	**0.007**
	Hiking sticks usage	26	2.99	**0.044**	1.38	0.275	0.79	0.547
Mossheath ÞNP (Plot 2)	Trampling level	29	6.97	**0.001**	16.92	**0.000**	13.21	**0.000**
	Hiking sticks usage	29	5.24	**0.005**	0.30	0.873	1.80	0.169
Moss ÞNP (Plot 3)*	Trampling level	11	34.81	**0.000**	–	–	11.75	**0.003**
	Hiking sticks usage	11	–	–	–	–	–	–
Mossheath FNR (Plot 4)	Trampling level	9	7.18	**0.027**	4.18	0.074	7.69	**0.023**
	Hiking sticks usage	9	–	–	–	–	–	–

* % veg cover is healthy vegetation cover vs severely damaged vegetation

7.1.2.1 Vegetation cover - Supervised classification method

With the supervised classification method the results for the vegetation cover shows significant relationships (P<0.05) to trampling pressure for all vegetation types except for Plot 1 (grassland at ÞNP) where on the other hand hiking sticks usage significantly seems to affect the relationship, as also for mossheath at ÞNP (P<0.05).

Grassland at ÞNP (Plot 1)

Vegetation cover at the grassland site shows no significant correlation to trampling pressure whereas lanes trampled without and with sticks have a significant difference. The assumption from this unreasonable relation is that a correlation between vegetation cover and trampling pressure actually exists also for Plot 1, but the values get disordered and messy when including the results from all sub-plots instead of separating them in sticks-no sticks in the initial hypothesis testing, thus no statistical significance as regards trampling pressure. This theory was tested and the result showed that there is a significant correlation (P<0.05) between lanes trampled with sticks and trampling pressure but not for lanes trampled without sticks. There is no more information or conclusion to derive from this reality and is considered a random fact. Worth mentioning for the grassland though, is that separating the 'green vegetation' class (see section 6.2.1.1.) from the rest of the vegetation showed statistical significance in relation to trampling pressure with a very low *P* value (not included in table 4).
When separating vegetation in sub-classes and plotting them in a graph, the class 'green vegetation' shows a clear decrease (Fig. 18).

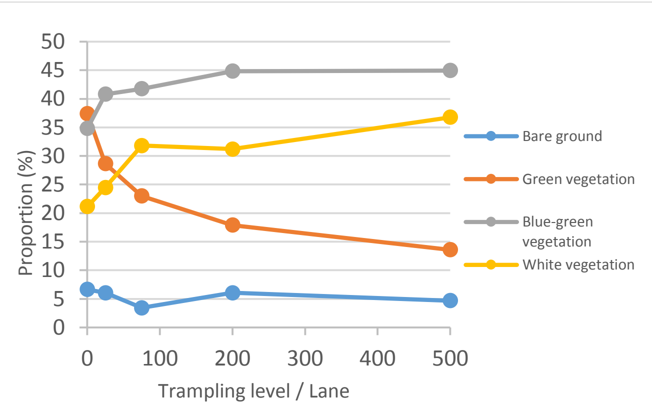

Fig. 18. *Results from maximum likelyhood classification of the images (n=27) at Plot 1 (grassland at ÞNP) showing how the proportions of the different vegetation classes change in relation to trampling pressure whilst no such correlation can be detected for the bare ground class.*

Mossheath at ÞNP (Plot 2)

The vegetation cover at this site before trampling was patchy and after the trampling experiment the bare soil areas show slight increase. A large issue in the classification process of the images from this site was the distinctive dark shadowing within the vegetation but also in the bare ground due to strong sun beams.

Figure 19 shows the averaged values of each lane for the final classes 'bare ground' and 'vegetation' after the unclassified pixels (unclassified pixels + dark shadowed pixels) were subtracted from the results. A slight retreat of the vegetation giving room for exposed soil is detected, but in search for obtaining a clearer picture, the vegetation was divided in two types; 'green vegetation + flowers' (live), and 'white vegetation' (decaying).

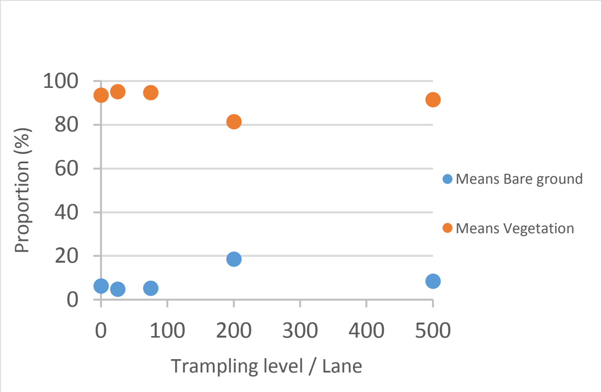

Fig. 19. *Proportions of bare ground vs vegetation at Plot 2 (mossheath at ÞNP) revealing small decrease of vegetation and increase in exposed soil area.*

In figure 20 it is clearly revealed that although the area of vegetation might not show any remarkable decrease with added trampling pressure, the plants are subject to change of color after being torn and stressed. The 'green vegetation + flowers' class is observed to decrease substantially while reversibly the area of 'white vegetation' increases.

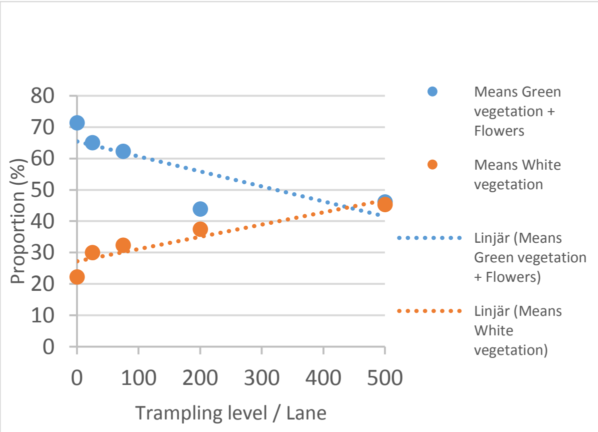

Fig. 20. *Relationships of different types of vegetation types at Plot 2, showing that the white vegetation increases as the green vegetation and flowers retreat.*

Moss at ÞNP (Plot 3)

This site reveals great damage to the moss cover after trampling, which probably will degrade in the long term, but in general the underlying soil was not exposed.

As mentioned in the methodology, the photographs from this site are few (n=12) and are insufficient for analysing any differences in vegetative response in relation to hiking sticks usage. Also due to the masking process of the wires in the sub-plot images a great portion of information was lost. Nevertheless, relationships between area of healthy vegetation and area of damaged vegetation and trampling pressure can be clearly revealed in the graph in figure 21.

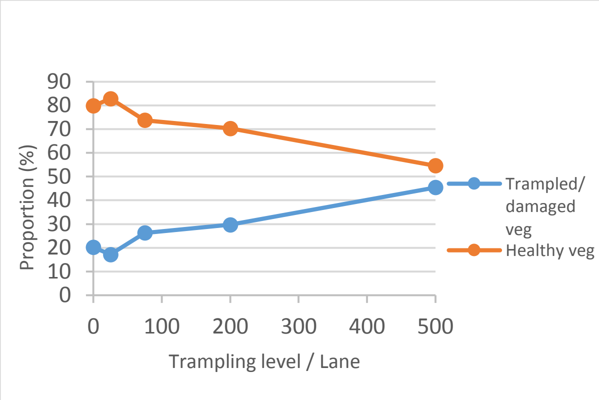

Fig. 21. Proportions of final cover types after supervised maximum likelihood classification of the images at Plot 3 (moss at ÞNP) revealing a decrease of healthy vegetation and increase of trampled and damaged vegetation.

Mossheath at FNR (Plot 4)

At this site the photographs were taken after the experimental trampling only in the lanes where no hiking sticks were used, so no comparison is possible for differences in the impact to vegetation area between sticks vs no sticks usage. The results from the maximum likelihood classification method show little exposure of the underlying soil after being subject to trampling pressure. This is also clearly revealed when visually estimating vegetation cover in the photographs, as is another fact in regards to vegetation cover change; the least resistant species such as the fragile moss types retreat and/or disappears from the trail, while the species more resistant to trampling are left dominating the trail. Although great fluctuations are seen in the averaged values (Fig. 22), one can detect decreasing and increasing trends in relation to trampling pressure. The fluctuations are due to the very patchy vegetative cover at this site.

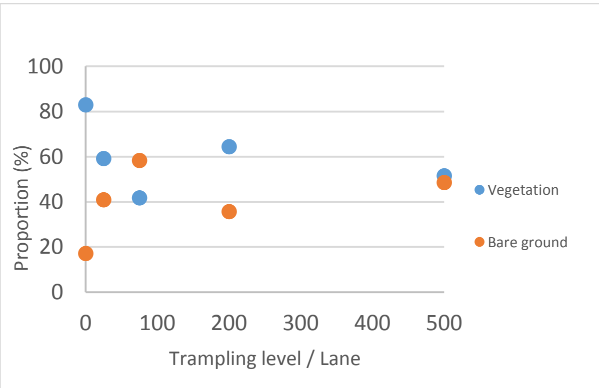

Fig. 22. Proportions of final cover types after supervised maximum likelihood classification of the images at Plot 4 (mossheath at FNS) revealing a slight trend of decrease of vegetation, as increase of bare ground.

***7.1.2.2.** Vegetation cover - ExGR method*

The ExGR index was applied on the images of experimental Plot 1, 2 and 4 for segmentation into two classes; vegetation and non-vegetation (Fig. 23a-23c). It was decided not to test this method for Plot 3 (moss at ÞNP) as the color of the vegetation at that study site was mainly white. It was considered unlikely that the ExGR index or any other greenness index would enhance the vegetation in these images.

Using this method for the other three vegetation types, showed significant correlation ($P<0.05$) between vegetation cover and trampling pressure at Plots 1 and 2 only.

This result for Plot 1 is in contradiction to the result from the supervised classification method where no significance was spotted. In section 6.2.1.1. it was pointed out that the images did not show any major differences in vegetation cover after trampling but there was an interrelated change of the color of the grass with descending green color and increasing white color. This has been captured with the ExGR method.

The lack of significance at Plot 4 was expected because of the various colors of the plant species at this vegetation type.

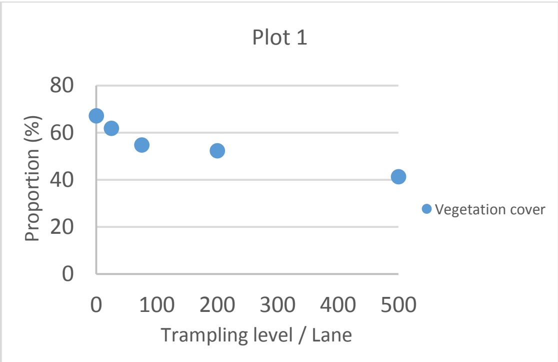

Fig. 23a. *Proportions of vegetative area derived from segmentation of the images from Plot 1 (grassland at ÞNP) with application of the ExGR index on pixel basis.*

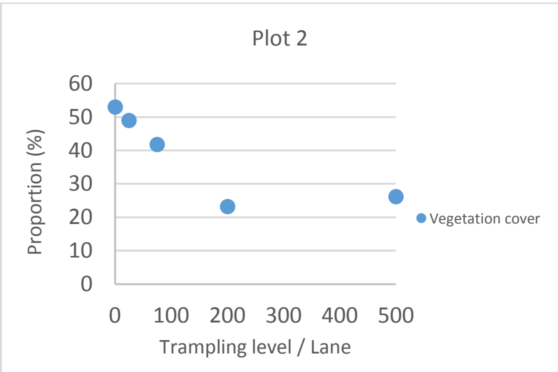

Fig. 23b. *Proportions of vegetative area derived from segmentation of the images from Plot 2 (mossheath at ÞNP) with application of the ExGR index on pixel basis.*

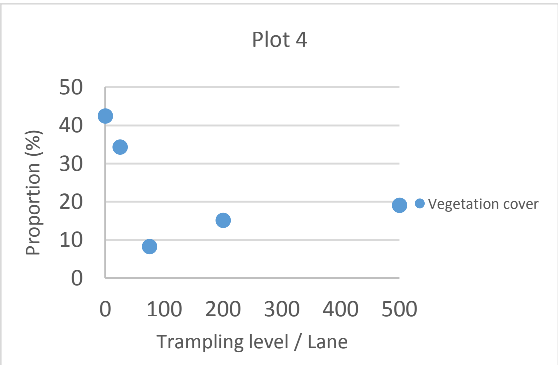

Fig. 23c. *Proportions of vegetative area derived from segmentation of the images from Plot 4 (mossheath at FNR) with application of the ExGR index on pixel basis (all sub-plots without sticks).*

7.1.2.3. GCC Means

The GCC mean values show significant differences (P<0.05) after added trampling pressure for all vegetation types, which was a surprise for the white moss cover at ÞNP (Plot 3), but also for the mossheath at FNR (Plot 4). Inspecting the images from these study sites more closely, it was revealed that the reason for this at Plot 3 is that there are areas of green moss in the sub-plots of lower trampling levels, while no such moss is spotted anywhere in the lanes of higher trampling levels. This fact is considered random and the results from the GCC method for this vegetation type are therefore not trusted.

Whilst the ExGR method did not detect any significant relationships between vegetation cover and trampling pressure for Plot 4, the GCC method did. A reminder: the GCC index is directly sensitive to fluctuations in the green color information derived from the images, whilst the ExGR method uses a threshold to separate green vegetation from non-vegetation. This means that plants 'not green enough' to pass the threshold are excluded from the vegetation cover area, most probably explaining the circumstance that the GCC index performed differently from the ExGR method at this vegetation site that consists of varying colors.

The box plot diagrams in figures 24a and 24b illustrate how the data from the GCC calculations was spread for all sub-plots between lanes for Plots 1 and 2. An adequate normal distribution is spotted, which implies that regression analysis can be conducted. For Plot 4 (Fig. 25) no such diagram is possible due to insufficient number of images (two for each lane).

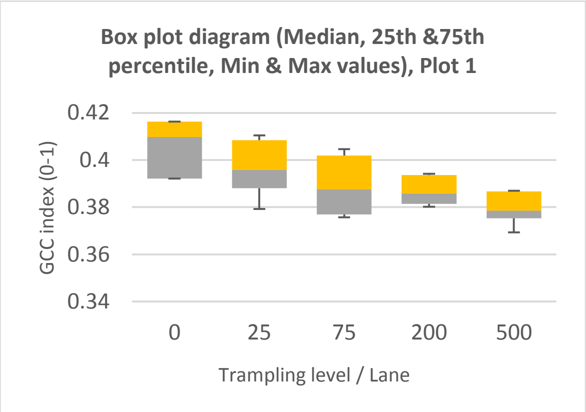

Fig. 24a. *Box plot diagram for GCC means per lane; grassland at ÞNP (Plot 1).*

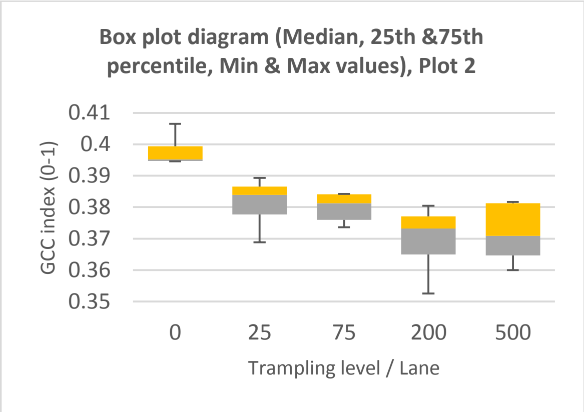

Fig. 24b. *Box plot diagram for GCC means per lane; mossheath at ÞNP (Plot 2).*

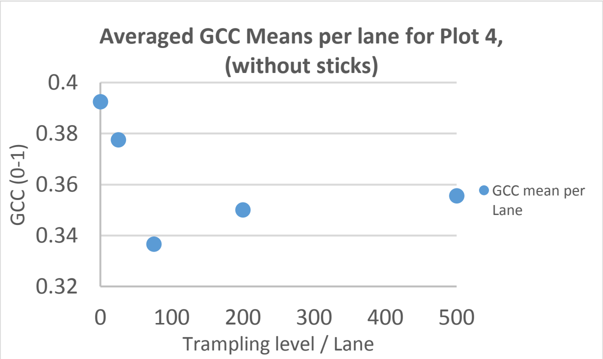

Fig. 25. *Averaged GCC for each lane extracted from the images captured at Plot 4 (mossheath at FNR).*

7.2. Regression analysis

For the variables where a significant relationship as regards trampling pressure was determined after the analysis of variance described above, a regression analysis was conducted to further describe these relationships. Since the one-way ANOVA uses the F test to determine whether there exists a significant difference among the means of two or more samples, the mean values of all sub-plots within each lane can be used for the regression analysis. The relationships between the variables that were significantly correlated to trampling pressure were approximated through linear and curvilinear (2^{nd} order polynomial) regression models. In all cases a polynomial regression model fitted best to the data. For all the variables except from soil compaction that shows increase after trampling, the following quadratic function was fitted:

(ix) $y = ax^2 - bx + c$

where y is the variable, x is the level of trampling (number of passes), a and b are the slope coefficients and c is a constant.

In table 5 the second-order polynomial regression models are presented with the coefficients of determination r^2**.** Also linear regression coefficients of determination are presented. All variables analysed show decrease (negative slope) after added trampling pressure except from soil compaction that increases (positive slope).

Table 5. *Second-order polynomial regression models that fitted the relationships between variable mean values of each lane and trampling pressure (**n**=5). Coefficients of determination r^2 are provided also for the linear regression models fitted to the data.*

Veg type / variable	**Regression model**	**Polynomial r²**	**Linear r²**
Grassland ÞNP (Plot 1)			
Veg height/Soil depth	$y = 3\text{E-}05x^2 - 0.0231x - 0.5691$	0.91	0.67
Veg cover ExGR method	$y = 9\text{E-}05x^2 - 0.0893\,x + 64.737$	0.94	0.89
GCC index	$y = 2\text{E-}07x^2 - 0.0001\,x + 0.4017$	0.87	0.72
Mossheath ÞNP (Plot 2)			
Soil compaction	$y = -\,0.0018x^2 + 1.2227\,x + 226.99$	0.96	0.62
Veg height/Soil depth	$y = 5\text{E-}05x^2 - 0.0315\,x + 0.2329$	0.97	0.66
Veg cover Sup Cl method	$y = 0.0002x^2 - 0.0896\,x + 96.683$	0.72	0.10
Veg cover ExGR method	$y = 0.0003x^2 - 0.2117\text{x} + 53.983$	0.99	0.64
GCC index	$y = 2\text{E-}07x^2 - 0.0002\,x + 0.3919$	0.85	0.50
Moss ÞNP (Plot 3)			
Veg height/Soil depth	$y = 4\text{E-}05x^2 - 0.0283\,x - 0.6914$	0.93	0.65
Veg cover Sup Cl method*	$y = 2\text{E-}05x^2 - 0.0614\,x + 81.053$	0.96	0.96
GCC index	$y = 3\text{E-}07x^2 - 0.0002\,x + 0.374$	0.78	0.62
Mossheath FNR (Plot 4)			
Soil compaction	$y = -\,0.001x^2 + 1.0117\,x + 340.83$	0.99	0.93
Veg height/Soil depth	$y = 2\text{E-}05x^2 - 0.0216\,x + 0.5203$	0.92	0.85
Veg cover Sup Cl method	$y = 0.0004x^2 - 0.2416\,x + 75.116$	0.52	0.23
GCC index	$y = 6\text{E-}07x^2 - 0.0003\,x + 0.3824$	0.59	0.17

***** *Vegetation cover for the Moss at ÞNP is healthy vegetation cover vs severely damaged vegetation.*

The same method was used to explain the relationships between lanes trampled without and with hiking sticks for the cases where this relationship was proved to be significant through the two-way ANOVA. The results are presented in table 6.

Table 6. *Polynomial second-order regression models (n=5) explaining relationships between mean values of lanes trampled without/with hiking sticks and trampling pressure for the cases where the one-way ANOVA test proved significant difference for the variable hiking sticks usage.*

Veg type / variable	**Regression model**	**Polynomial r²**
Grassland ÞNP (Plot 1)		
Surface depth		
Without hiking sticks	$y = 3\text{E-}05x^2 - 0.0202x - 1.1221$	0.69
With hiking sticks	$y = 4\text{E-}05x^2 - 0.026x - 0.016$	1.0
Mossheath ÞNP (Plot 2)		
Veg cover Superv method		
Without hiking sticks	$y = 0.0003x^2 - 0.1668x + 97.965$	0.78
With hiking sticks	$y = 4\text{E-}05x^2 - 0.0304x + 95.401$	0.55

7.3. Relative vegetation cover

The three different methods used for detecting vegetation cover change in this study are plotted in relative values in the graphs below (Fig. 26a-26c). One goal of this thesis was to characterize the resistance of the vegetation types studied as regards their ability to resist being altered by trampling. For characterizing the vulnerability of a vegetation type measurements are needed one year after the experimental trampling that are at this point lacking.

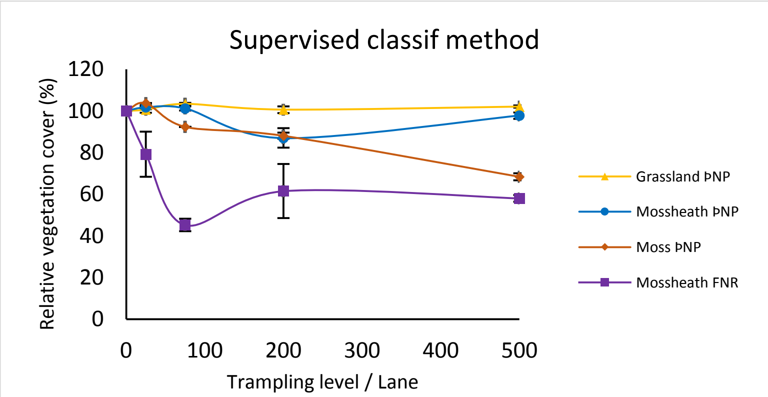

Fig. 26a. *Relative vegetation covers for all vegetation types derived from the supervised classification method. Vertical bars represent one standard error above and below the mean. Relative vegetation cover for the Moss at ÞNP is actually healthy vegetation cover vs severely damaged vegetation expected to degrade soon after the trampling experiment.*

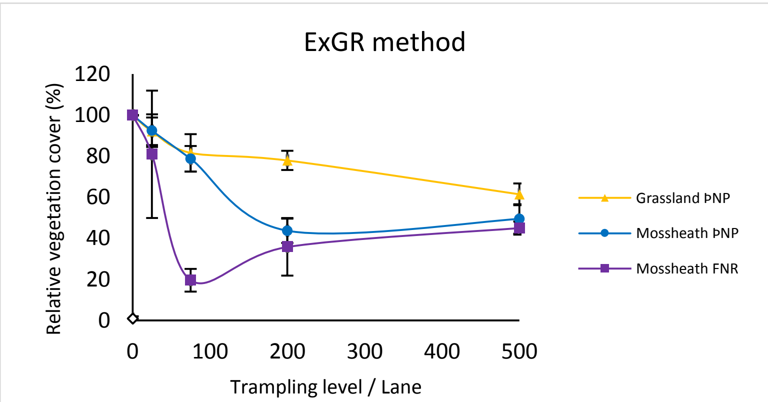

Fig. 26b. *Relative vegetation covers derived from the ExGR segmentation method for the three vegetation types grassland and mossheath at ÞNP (Plots 1 and 2) and mossheath at FNR (Plot 4). Vertical bars represent one standard error above and below the mean.*

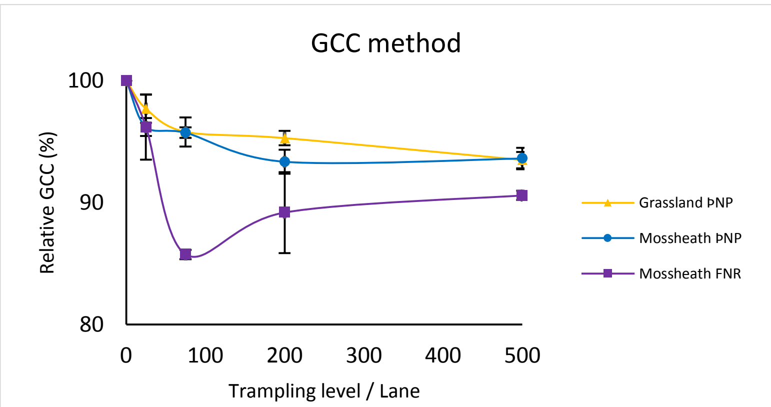

Fig. 26c. *Relative GCC index values revealing percent change in greenness read from the images through the GCC method. Vertical bars represent one standard error above and below the mean.*

7.4. Resistance index

Through calculating the area beneath the curves where relative vegetation values are plotted against trampling pressure the resistance index of each vegetation type is retrieved according to each image analysis method tested in this thesis (Table 7). The three different methods used to derive information on vegetation cover correlate as regards to the order from higher to lower resistance value of the vegetation types.

Table 7. *Resistance indices for the vegetation types studied based on the three different image analysis methods to derive vegetation cover information (Supervised classification and ExGR method) and greenness information (GCC method).*

	Resistance index		
Veg type	Superv classif method	ExGR method	GCC method
Grassland ÞNP	102	75	95
Mossheath ÞNP	94	57	94
Moss ÞNP	84	--	--
Mossheath FNR	60	41	90

8. DISCUSSION

8.1. Results discussion

Trampling impact soil compaction, surface depth and vegetation cover in all Icelandic vegetation types assessed in the trampling experiment. The relationships between these variables and level of trampling are curvilinear, characterized by a more pronounced and rapid deterioration at initial stages at low levels of trampling, proceeding more slowly with increased trampling. This suggests that even low levels of trampling pressure has a large impact, but may also implicate that a maximum threshold would be reached with continued trampling from which the ecosystem does not react to trampling pressure any longer. Let us not forget the fact though, that when the variables of the ground cover are altered and weakened, the path has opened for larger impact from eroding forces.

Impact from trampling pressure on vegetation cover differ between different vegetation types and study areas. These results imply that the mossheath in the highland (Fjallabak Nature Reserve) is the most sensitive of the vegetation types included in the trampling experiment analysed in this thesis, with the moss in the lowland (Þingvellir National Park) taking the second place. The most resistant vegetation type to trampling is grassland with deeper soil formation and well-developed root system.

For the hiking sticks usage, the statistical tests show that hiking sticks affects only the variable vegetation cover. As this was only detected through the supervised classification method of quantifying vegetation cover, and as there were no sufficient data to test the variable for all vegetation types, it is difficult to conclude that hiking sticks usage actually makes a difference in the impact of damage to vegetation.

The three image analysis methods used for quantifying vegetation cover demonstrated the value of using digital photography as a tool for estimating vegetation cover. All methods correlate as regards to the order from higher to lower resistance value of the vegetation types. Nevertheless, in the choice of which method to use to assess impact from trampling pressure to vegetation depends on the goal of the research. To objectively quantify change in vegetation cover the supervised classification method is recommended for best estimate of the actual vegetation cover. The ExGR and GCC methods are recommended for greater computational speed when the goal of a research is to assess whether an impact to vegetation from an action can be detected and the extent of the impact. Relationships between different vegetation types as regards vulnerability can be determined, knowledge useful for natural area managers to detect sites in need of greater attention in terms of engineered trails and restriction of recreational activity.

8.1.1. Field variables

Soil moisture

Statistical analysis showed no significant ($P>0.05$) correlation between soil moisture and increased trampling pressure. Worth mentioning though is how soil moisture is lower at the Fjallabak mossheath study site (plot 4) than at any of the other vegetation types examined, which may be explained by the fact that the soil top coat in the highlands is very thin and wind velocities higher.

Soil compaction

For the vegetation type mossheath both in the lowland and highland, this variable is clearly increasing in relation to added trampling pressure. This vegetation type has a lesser developed root system to protect the soil from being compacted while trampled. The grassland has generally higher soil compaction, probably due to deeper soil formation and well-developed root system characterizing grasslands, and is therefore more flexible when trampled upon.

Surface depth

For all vegetation types tested in this thesis, the high r^2 values of the polynomial regression models fitted to the curves describing the relationship between surface depth and added trampling pressure, prove that the relationship is strong. This variable is an important component in the resistance of an ecosystem to erosion by surface water runoff. When vegetation height and soil depth decreases due to trampling causing a U-channel formed trail, surface water is accumulated in the trail resulting to further deepening. In Iceland where there is great surface water runoff during the spring when snow melts the results are deep and wide scars in the ground that are impossible for the ecosystem to recover from.

8.1.2 Image analysis methods for quantifying vegetation cover

Quantified by the three different image analysis methods described in this thesis, vegetation shows decrease in terms of cover and greenness at all vegetation types tested, but each feature is captured best with different method. A problem that arises when evaluating methods for vegetation estimation is that the actual cover is not known. A source for comparison would be the point quadrat method, or more reliable even, NDVI data when available. Statistical tests and methods are used to detect relationships between the data sets, but in this thesis evaluation of the photographic methods to estimate actual vegetation cover cannot be executed due to lack of a source for comparison.

The poor, but not unexpected, results from the segmentation of the images from the mossheath site at Fjallabak Nature Reserve was proved to be directly related to the high variety of colors of the live vegetation within this study site. The use of this approach to distinguish living plant material within an image, can only be used in research fields where the living plant material to be detected has higher reflectance values ('green' peak) in the green wavelengths than in the red and blue wavelengths, that is, revealing a green color to the human eye.

Mosses and lichens have spectral signatures that vary significantly from those typical of vascular plants (Bubier et al., 1997). In the visible portion of the spectrum, mosses reveal typical absorption in the blue and red regimes, but differ from vascular plants in having a 'green' peak reflective of the individual color of the species (red, brown or green). Mosses with a 'green' peak in other than the green region of the visible spectrum will thus not be enhanced by a greenness index. In the near infrared (NIR) and the short-wave infrared (SWIR) regions, mosses are typically less reflective than vascular plants, making the two different vegetation types separable in these regimes (Bubier et al., 1997), but reveal a peak great enough to enable their separation from bare soil. In the visible portion of the spectrum, lichens in this study show most dissimilar characteristics of those for both mosses and vascular plants. Except from the peak in the red wavelength region, they reveal highly saturated (high) DN values, resulting in their characteristic white color.

The deterioration of the plants in the grassland vegetation type after trampling was clearly captured using the greenness index methods, but as grasslands are more resistant to trampling (Newsome et al., 2013) compared to other vegetation types, it is expected to soon recover from these trampling effects.

A fact worth mentioning is the way that the curves of relative vegetation cover for all vegetation types show the same trends with all image analysis methods. The results from the GCC and the ExGR method show high correlation to the graphs from the maximum likelihood classification especially for the grassland and mossheath cover types. Hence, a fast way to detect any changes due to trampling would be the use of greenness indices, but one must consider the fact that the changes in vegetation cover of plants with other colors than green are not captured.

8.1.3. Correlation

The results from the regression analyses show strong correlation (high r^2 values) between the variables and trampling pressure. This implies that the regression models would let us predict the change of the measurement variables with added trampling pressure quite accurate. Considering that an ecosystem is a living organism this is not the case at this stage of data collection within the experimental trampling research of the Main Project. For prediction of how a vegetation type reacts to trampling pressure, measurements are needed to be conducted also one year after trampling in order for the recovery of vegetation to be included in the calculations. There is also a very complex relationship in the Icelandic ecosystems between the slow recovery of vegetation (due to the short growing season) and strong erosive forces (due to the harsh weather conditions). For Iceland recovery might not at all be the case one year after trampling, but the exact opposite.

8.2. Data and method discussion

The use of the visual bands of the spectral wavelengths compared to the near-infrared was likely to be less effective in determining vegetation areas, but this was unavoidable.

As regards changes to the area of vegetation cover versus bare ground only the two mossheath vegetation types (Plots 2 and 4) revealed actual decrease. This could be visually detected just by looking at the photographs of the sub-plots. A supervised classification method would quantify these changes and the result of the trampling research would be that the vegetation cover at the grassland and moss vegetation types suffers no impact from trampling. This would be a great mistake though. The images from the grassland may not reveal bare ground after trampling, but there is a change of the colors of the plants with increasing trampling pressure due to wear. Grasslands are resistant to trampling in terms of relative vegetation cover, but changes of the plant community and species composition may occur resulting in decrease of plant diversity (Newsome et al., 2013).

The images from the moss site follows the exact same characteristic except that the altered vegetation after trampling in terms of color is also severely damaged and is expected to degrade after a short period of time (Ólafsdóttir and Runnström, 2013). The portion of the healthy vegetation of the images from this site is therefore quantified through the supervised classification method considered to represent the proportion of the vegetation that survived after the trampling experiment in relation to the severely damaged vegetation considered as the proportion that did not survive.

For vegetation types consisting of great portions of mosses and lichens, such as the greater part of the Icelandic vegetative areas, the use of greenness index calculations for detecting vegetation changes is a method that cannot be used for quantitative analysis. Mosses, lichens and flowers of colors other than green are not enhanced by applying greenness formulas to the DN values, so they are excluded from the vegetation class throughout all the images. A change of the portion of the green vegetation can be detected using this method, but these results cannot be used for any objective analysis to conclude to the size of the change or the sensitivity of the vegetation type itself. Although time consuming and dull, the supervised classification method works best for such vegetation types. Detection of all information classes within the images prior to the classification is thus recommended to avoid several remakes of the process until best results are obtained. Detailed creation of trainingsites is also non-negotiable for best results.

8.3. Future recommendations for the field protocol

The results of the different methods described in this study to detect changes in vegetation cover point to some conclusions worth considering in regards to the construction of the experimental field protocol and the light conditions during photographing the quadrats. There is a need of continued data collection for future evaluation of the vulnerability of the different vegetation types.

- Vegetation cover estimation through any of the image analysis methods described above, is confound by shadowing from the sun. Shadows from tall vegetation or uneven surface alter the color information in shaded areas. Booth et al. (2004) suggest a roll-up-window shade of medium-weight light-filtering vinyl for eliminating shadows and providing more saturated colors.

- It is recommended that the photographs from the sub-plots are clear from disturbing objects such as the threads in the described metallic frame used at Plots 3 and 4. The process of cropping the threads from the images of the experimental quadrats, except from being time consuming, also led to unnecessary data loss. The threads, if needed in the metal-plot for measurements of the other field variables, should have a color not existent in the vegetation type for enabling these pixels to be classified in a class of its own.

- More accurate results of a supervised classification method for vegetation classification would be acquired if a NIR camera is used. As these are costly, there are techniques to modify a digital camera to leverage the NIR sensitivity.

- Finally, the vegetation type mossheath in both the lowland and highland are very patchy so for evaluation of vegetation change after trampling and to assess vulnerability of this vegetation type, photographs are needed for each sub-plot also before trampling. For this patchy vegetation type, the mean values of vegetation cover of the reference plots cannot be considered a good representation for initial cover at all sub-plots.

9. CONCLUSIONS

This study has showed that trampling has a profound impact to natural areas with vegetation loss as the major indicator. The variables measured were proven to have a curvilinear relationship to added trampling pressure, i.e. a more profound impact at initial stages of trampling and a lessening impact with higher levels of trampling.

Typical Icelandic mossheath vegetation types are generally intolerant of trampling and more specifically in the highland where the soil layer is thinner. Most resistant to impact from trampling are grasslands explained by their deeper soil formation. Even if results from this study point to the need of further investigation for the variable hiking sticks usage, it is considered an attribute not worth further evaluating as the results implicate that there is very little difference to impact where discrepancies confirmed, but also that different vegetation types are affected in opposite directions.

The use of digital photography for vegetation cover estimation proves to be effective in terms of relative cover values and not actual cover. When assessing change of vegetation in a monitoring program or a research project, any method described in this thesis works well for detecting and maybe even quantifying relative cover change. Depending on the goal of a research one can use the supervised classification method for more accurate estimates, and the ExGR or the GCC method for acquiring fast but more subjective information on vegetation cover.

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