FERÐA MÁLA STOFA

HÁSKÓLI ÍSLANDS

Impact of recreational trampling in Iceland:

a pilot study based on experimental plots from Þingvellir National Park and Fjallabak Nature Reserve

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Cover photo: Experimental lanes in Bolabás, Þingvellir National Park © Rannveig Ólafsdóttir

Áhrif gönguferðamennsku á gróður og jarðveg – athuganir og mælingar frá tilraunareitum

Umhverfisáhrif vegna gönguferðamennsku hafa verið rannsökuð víða um heim í yfir hálfa öld. Niðurstöður sýna ítrekað að traðk ferðamanna veldur gróðurskemmdum, eyðir lífrænum efnum jarðvegs, þéttir jarðveg og ýtir undir jarðvegseyðingu. Álag vegna traðks getur þannig leitt til óafturkræfrar landhnignunar fari það yfir ákveðin þolmök. Íslensk náttúra hefur lengi verið megin aðdráttarafl Íslands sem ferðamannalands og er ótvírætt mikilvægasta stoð íslenskrar ferðaþjónustu. Vegna legu Íslands norðarlega í miðju Atlantshafi og á miðjum Atlantshafshryggnum, sem orsakar stutt vaxtartímabil og rofgjarnan jarðveg, er þessi stoð sérstaklega viðkvæm. Það er hins vegar þessi viðkvæmni sem gerir íslenska náttúru að þeirri verðmætu auðlind sem hún er í augum ferðamanna. Samfara vaxandi ferðamennsku er því brýnt að auka þekkingu okkar og skilning á viðbrögðum íslenskra vistkerfa við auknu álagi ferðamennsku. Meginmarkmið þessa rannsóknaverkefnis er annars vegar að auka þekkingu á notkun tilraunareita (e. experimental plots) fyrir ferðamennsku í íslenskri náttúru. Einungis með mælingum í tilraunareitum er unnt að styðjast við þekktar stýribreytur. Hins vegar var markmiðið að kanna viðnám íslenskra vistlenda við álagi ferðamanna með því að meta mismunandi álag frá gönguferðamönnum í mismunandi vistlendi. Vistlendi er samkvæmt Náttúrufræðistofnun Íslands (www.ni.is/grodur/vistgerdir) samheiti yfir vistgerðir sem eru flokkaðar saman eftir skyldleika. Vistgerð er skilgreind sem landeining sem býr yfir ákveðnum eiginleikum hvað varðar loftslag, berggrunn, jarðveg, gróður og dýralíf. Innan sömu vistgerðar eru aðstæður með þeim hætti að þar þrífast svipuð samfélög plantna og dýra. Í þessu verkefni er fyrst og fremst horft til gróðurs og jarðvegs.

Vettvangsvinna fór fram í júlí og ágúst 2014, annars vegar í þjóðgarðinum í Þingvöllum, sem var valinn sem láglendissvæði, og hins vegar á Friðlandi að Fjallabaki, sem var valið sem hálendissvæði. Bæði þessi svæði hafa um langt árabil verið á meðal vinsælustu ferðmannastaða landsins. Algengustu vistlendi þessara svæða eru graslendi, mólendi, og moslendi sem voru valin til að setja upp tilraunareiti sem hver um sig var 20x7,5 m^2. Við framkvæmd rannsóknarinnar var stuðst við erlendar rannsóknir, m.a. til að byggja upp gagnabanka fyrir samanburðarrannsóknir, en jafnframt lagður grunnur að aðferðafræði fyrir íslenskar aðstæður. Álag frá 25, 75, 200, og 500 göngumönnum var metið, sem gengu 20 metra, þar af 10 metra án göngustafa og 10 metra með göngustafi. Á hverjum göngustíg voru mælingar gerðar á breytingum á þversniði stígs, gróðurþekju, þéttni og raka jarðvegs. Til samanburðar voru mælingar einnig gerðar á reitum með engu álagi. Enn fremur voru settir upp ákveðnir vöktunar staðir sem verða mældir áfram næstu fimm til tíu árin til að meta hraða endurheimtunar gróðurs og jarðvegs. Niðurstöður sýna að mólendi er viðkvæmari fyrir álagi gönguferðamanna en graslendi hvað varðar allar breytur, sem er í samræmi við fyrri rannsóknir hér á landi. Niðurstöður gefa einnig til kynna að álag göngumanna með göngustafi er minna hvað varðar mældar breytur en göngumanna án göngustafa, sem virðast valda meira álagi á miðju stígsins og orsaka hærri þéttni jarðvegs í göngustígnum, á meðan að álagið dreifist hjá göngumönnum sem nota göngustafi. Mæligögn sem söfnuðust í þessari rannsókn lögðu grunn að meistaraverkefni við landfræðideild háskólans í Lundi í Svíþjóð sem beinir sjónum að þróun aðferðafræði við myndvinnslu til að meta breytingar á gróðurþekju við mismunandi álag gönguferðamanna.

Rannsóknin var styrkt af Ferðamálastofu, sem gerði kleyft að ýta þessu mikilvæga þróunar- og vöktunarverkefni úr vör. Kærar þakkir.

Preface

Environmental impacts of recreational trampling have obtained considerable attention over more than halve a century. It has been repeatedly shown that trampling damages vegetation, eliminates soil organic matter, compacts the soil and causes soil erosion. Hence, when stress from trampling exceeds an area's environmental carrying capacity it may result in irreversible land degradation.

Concurrent with increased tourism it is of vital importance to increase our knowledge and understanding of the responses of Icelandic ecosystems to increased impact from recreational pressure. Still, the general understanding of the impacts from recreational trampling on Icelandic ecosystems is limited. Reflecting the need for experimental research to address the impact of recreational activities on Icelandic ecosystems, this study aims firstly to increase the knowledge and understanding of the use of field experimental plots for tourism impact studies. Secondly, to explore the resistance of Icelandic ecosystems to recreational trampling, by assessing the impact of diverse levels of use applied in three Icelandic ecosystems. The field study was undertaken in areas that for a long time have been among Iceland's most popular outdoor recreational areas, i.e. in Þingvellir National Park and Fjallabak Nature Reserve, and was conducted in late July and early August 2014, representing the time when the vegetation cover is close to its maximum at the middle of the growing season as well as the tourism high season in Iceland. The study concentrated on tourism trampling effects on the most common vegetation types in the study areas, i.e. grassland, moss-heath and moss. Variables tested in field are soil moisture, soil compaction, soil surface profile, and vegetation cover. The results indicate moss-heath to be more vulnerable to trampling than grasslands as regard all variables. An interesting notion from this study is the difference in impact between tourists using hiking sticks and those who do not. Tourists without hiking sticks seems to have more impact on the development of the inner track making the soil surface profile, deeper resulting in higher soil compaction. Thus, using sticks seem to divide the weight of the hiker with the sticks. This will however need further research.

As an additional result from this pilot project is a master project that now is being carried out at the Department of Ecosystem Analysis and Physical Geography at Lund University in Sweden, and will be completed and defended in June 2015. We wish to thank Maria Gatzoura helping us interpret the digital photographs.

It is important to use the experience obtained in this study and the databank created to build further knowledge on the impact of outdoor recreational activities on Icelandic ecosystem so that the Icelandic outdoor tourism may be planned and managed in a sustainable manner..

Contents

Figures and tables

1. Introduction

"Dream Vacation – Environmental Nightmare?"

This question is set forward by David J. Tenenbaum (2000) in his paper "Trampling Paradise" focusing on the world's increasing environmental impact from tourism. It has been shown that tourism can have significant impact on Icelandic ecosystems when trampling in natural areas (e.g. Ólafsdóttir & Runnström, 2013; Gísladóttir, 2006). When physical impact from outdoor trampling exceeds an ecosystem's resistance in order to recover it may results in irreversible land degradation. It has also been shown that stress from bike and horse tourism often is more harch on sensitive environments compared to trampling (e.g. Pickering, et al 2011), and many signs indicate that this might also be the case in Iceland.

Icelandic nature is unique and has long been the major attraction of Iceland as a tourist destination (e.g. ITB, 2014) and as such the Icelandic nature is the most important pillar of the Icelandic tourism industry. General understanding of the impacts of recreational trampling on Icelandic ecosystems is however still limited. The few studies that hitherto have been undertaken on recreational trampling in Iceland, have all focussed on the condition of existing trails (i.e. Ólafsdóttir & Runnström, 2013; Gísladóttir, 2006). So far, no experimental studies on recreational trampling exist in Iceland. Same applies to other types of outdoor recreation. Concurrent with increased tourism impact it is of vital importance to increase our knowledge and understanding of responses in Icelandic ecosystems to increased impact from recreational use and pressure.

Reflecting the need for experimental research to address the impact of recreational activities in Iceland, this research project aims to explore the resistance of Icelandic ecosystems to different recreational pressures, i.e. trampling, biking and horse riding, by assessing the impact of diverse levels of use applied in representative Icelandic sub-arctic ecosystems, as well as the long term recovery of the ecosystems. Owing to the fact that very few studies have been carried out in Iceland as regard environmental impact of tourism in general, and the fact that no experimental studies on recreational pressure exist, there is a need to build up a methodological approach for experimental outdoor recreation in Icelandic environments. Therefore, the main focus of this first part of the research project is on experimental recreational trampling as well as to build up know how and a methodological database for experimental sampling. Hence, the overall aim of this report is firstly to increase the knowledge and understanding of the use of experimental plots for recreational impact assessment in Icelandic environments. Secondly, to examine the impact from experimental trampling on common Icelandic sub-arctic vegetation types affected by diverse levels of hiking pressure. The specific aims are to:

- review the use of experimental plots for assessment of recreational pressure in the academic literature
- develop appropriate methodology for using experimental plots to analyse recreational pressure in the Icelandic environments
- select study areas in diverse Icelandic natural areas for implementing the experimental methodology
- measure important physical variables in experimental plots to determine how these variable are related to different levels of hiking pressure.

The report proceeds in six chapters. After this introduction, the second chapter focuses on the use and development of experimental plots for assessing the environmental impact of recreational trampling, biking and horse riding as it emerges in the academic literature. The third chapter gives a short outline of major characteristics of Icelandic ecosystems, and the fourth one details the applied methodology. Chapter five presents the results from the field measurements of soil moisture, soil compaction, soil surface depth profile and vegetation cover. The results along with the literature review are then deployed in chapter six discussing the results and potential for the next steps to be taken.

2. Literature review

Environmental impact from recreational trampling have obtained considerable attention over more than halve a century. It has been repeatedly shown that trampling damages vegetation, eliminates soil organic matter, compacts the soil and causes soil erosion (e.g. Cole, 1989; 2004). Methods have varied from studying areas already trampled while others have produced hiking tracks through experimental trampling. Hence, extensive literature exists on experimental trampling (e.g. Wagar, 1964; Bayfield, 1979; Emanuelsson, 1984; Sun and Liddle, 1991; Cole and Bayfield, 1993; Littlemore and Barker, 2001; Monz, 2002; Whinam and Chilcott, 1999; 2003; Mingyu, et al., 2009; Pickering, et al., 2011), but still only few on experimental biking and horse riding (e.g. Törn, et al., 2009; Pickering, et al., 2011;).

According to Cole and Bayfield (1993) the major focus of most studies are the relationship between the amount of trampling and vegetative response, as well as on the susceptibility of different plant species and communities towards trampling. Different designs of research methodologies to study recreational impact from trampling are thoroughly reviewed by Cole (2004). He points out that the most common design is the descriptive field survey where vegetation and soil parameters on recreation sites are measured for the purpose of assessing current condition. He emphasizes that if one's goal is to understand the cause-and-effect then doing such research is the least useful research designs, as one can speculate about cause and effect from correlational analysis, but apparent relationships can be spurious and true relationships can be missed due to the complexity of the dominant variables. He furthermore states that all variants of descriptive field surveys have the advantage of realism and can thus provide highly relevant site-specific information, but all suffer to a varying degree in the ability to identify cause and effect and to contribute to general knowledge. The alternative is, according to Cole (2004), the simulated experimental approach. The advance of experimental approach is based on that researchers "carefully can control use and environmental factors in a replicated design that maximizes insight into cause and effect" (Cole, 2004, p. 45).

Cole and Bayfield (1993) developed standardized procedure to be used for experimental trampling in order to facilitate comparisons of results in different environments. Their procedure still seems to be the most prevalent and widely used procedure for experimental trampling and in this study it has been adapted to Icelandic conditions. Still, however the experimental lanes or plot size, seems to vary among authors. Cole and Bayfield (1993) consider length of 1.5 m and a width of 0.5m for each treatment lane separated by a 0.4 wide buffer zone to fulfil requirements for experimental trampling measurements. While Whinam and Chilcott (1999) base their experimental trampling on lanes that were 10m long and 1,5m wide suggesting that this lane size is appropriate to allow walkers to obtain their natural gait when walking within the lane, and allowed walkers to avoid natural obstacles. The weights of the hikers are by many furthermore considered to be an important factor (e.g. Whinam and Chilcott, 2003; Pickering, et al., 2011). However, Cole and Bayfield (1993) suggest that there is no substantial difference in the responses caused by tramplers of differing weight or shoe type. They state that heavier people most often have larger shoes, so the pressure per unit area may be constant across a range of weights. Apparently, standardizing weight and shoe type is not critical.

3. Environmental characteristics

Iceland extends approximately from latitude 63°23’ to 66°32’N and longitude 13°30’ to 24°32’W. Its location in the middle of the North Atlantic Ocean, give rise to humid and cool-temperate climate characterized by cool summers and mild winters. The growing season is short influencing the vegetation sensitivity to external impact, such as from recreational activities. This sensitivity is intensified by active volcanism due to the island’s position on the Mid-Atlantic Ocean Ridge where the boundaries of the American and Eurasian tectonic plates are constantly spreading apart (e.g. Ólafsdóttir 2001).

Elevation ranges from sea level to 2110 m a.s.l., with > ⅓ being above 600 m and < ¼ below 200 m (NLSI, 2015). The lowland‘s vegetation cover is dominated by mossheath, heathland and grassland. Only ~1% is forested land, mainly birches and willows (Guðjónsson and Gíslason 1998). Large part of the highlands comprises sub-arctic desert with scattered plants or isolated patches of vegetation (Þórhallsdóttir 1997; Arnalds, 2011). Certain moss species, like the racomitrium mosses, mainly *Racomitrium lanuginosum* and *Racomitrium canescens,* are among the most common plant species in Iceland (Jónsdóttir, et al, 2005), and according to the Icelandic Institute of Natural History (www.ni.is) account for more than half of all vegetation cover in Iceland. The *Racomitrium lanuginosum* is usually the first pioneer to colonize the new lava fields, and is predominant in areas where growing conditions are unfavorable, such as on many of the country’s extensive basaltic lava fields as well as in the interior highlands (Jónsdóttir, et al, 2005). The racomitrium mosses with its wooly soft scenery (Figure 1) are furthermore very striking in the Icelandic landscape. This vegetation cover is likewise very sensitive.

Figure 1 *Moss cover (Racomitrium lanuginosum) on post glacial lava at Þingvellir National Park.*

4.

Methodology

4.1 Field preparation

The results from the literature review included essential methodological inputs (*cf.* appendix 1) that were used to set the scene for the field experimental design and sampling in this study. As regard selection of study sites, it was decided to undertake the experimental sampling both in the lowland and the highland in order to see if there was a significance difference in the resilience of vegetation and its recovery. Þingvellir National Park was selected for the lowland area and Fjallabak Nature Reserve (FNR) for the highland area (Figure 2). Both areas have for a long time been among Iceland's most popular outdoor recreational areas. Þingvellir is Iceland's first national park, designated by a special law on the protection of the area in 1928 (Icelandic Statutory Law Gazette, 1928). Fjallabak Nature Reserve is located in the southern central highlands of Iceland, and was established as a nature reserve in 1979 (Icelandic Statutory Law Gazette, 1979). Written official permission to perform the experimental field work in both study sites was obtained. The project's contact person at Þingvellir National Park is Einar Á.E. Sæmundssen, interpretive officer, and in FNR Ingibjörg Eiríksdóttir specialist at The Environmental Agency of Iceland.

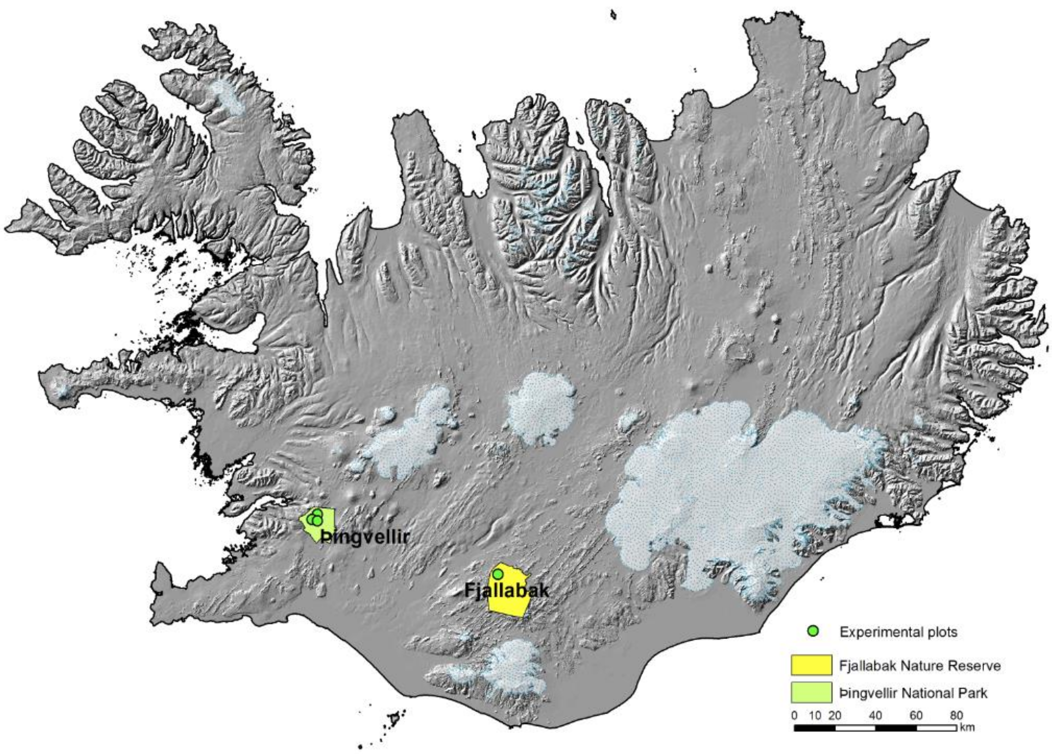


***Figure 2**. Location of the study sites*

An experimental plot protocol was designed largely based on the standardised protocol development by Cole and Bayfield (1993) to facilitate comparative studies. The protocol included five common variables to be measured in field, i.e. soil moisture, soil compaction, vegetation cover/bare soil, vegetation height/soil surface depth, and the last one was photograph (*cf.* appendix 2) an added variable not seen in the reviewed literature, to be used for examining the use of image analysis to detect changes of the diverse levels of hiking pressure. In Cole and Bayfield (1993) protocol it is suggested that there is no substantial difference in the responses caused by tramplers of differing weight or shoe type, as heavier tramplers most often have larger shoes, so the pressure per unit area become constant across a range of weights. Thus they consider that standardizing weight and shoe type is not critical.

Devices aiding the field work included GPS for positioning the experimental lanes and subplots, quadrate for delineating subplots for the field measurements, each quadrate was 60x60cm in size and was further divided into nine smaller subplots to facilitate the measurements (Figure 3), soil moisture meter, hand held penetrometer from Eijkelkamp kindly obtained by the Icelandic Soil Conservation Service, and digital camera and tripod for obtaining photograph of each subplot.

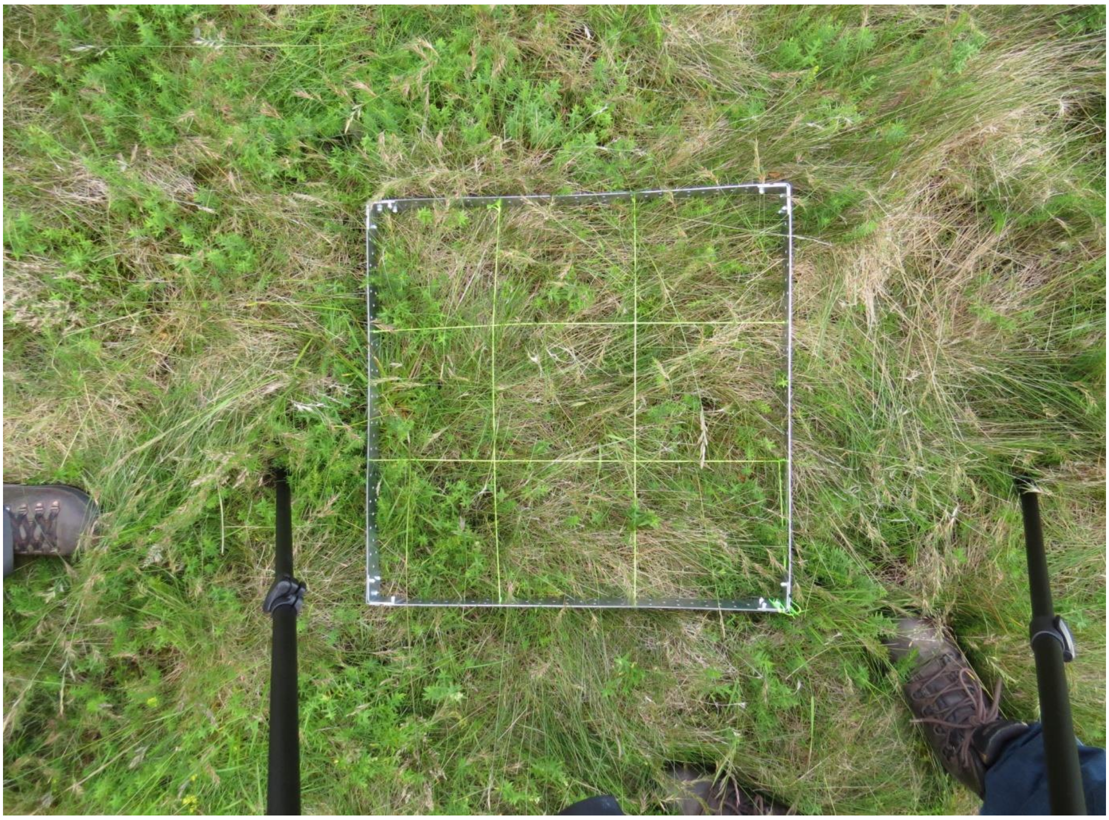


Figure 3. *The quadrate used in the study*

4.2 Field data sampling

4.2.1 Experimental field design

Field work was carried out in Þingvellir in 22nd -28th of July 2015 and in FNR in 12th – 15th of August 2015. That time represent the time when the vegetation cover is close to its maximum at the middle of the growing season as recommended by Cole and Bayfield (1993) as well as the tourism high season in Iceland. The study concentrated on tourism trampling effects on the most common vegetation types in the selected study areas, i.e. grassland, moss-heath and moss. Five lanes, each 20 m long and 1.5 m wide, were created for experimenting different trampling pressure (number of hikers). Areas fitting the criteria for the experiments, i.e. that the vegetation cover and vegetation type should be homogenous for about one hectare in size, were met to the extent as possible but the Icelandic vegetation is characterized largely by its complexity and unhomogeneity. Lanes for the experiment were allocated, marked with poles and strings (*cf*. Figure 4). A total of four experimental sites were established, three in Þingvellir and one in FNR (Table 1; Figures 4-7).

Table 1. *The experimental plots undertaken and their characteristics*

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

Each site encompassed of five lanes, each lane 20 meters long and 1.5 meter wide. The lanes were marked out by entering sticks in the corners and connecting these with coloured wire thus forming separate lanes. A lane length of 20 meters was considered appropriate for hikers to obtain their natural gait when hiking within the lane. Each lane was further divided into two 10 meter lanes at the midpoint to experiment if there was any different of trampling pressure from hikers with and without hiking poles, i.e. during the first 10 meter length of the lane the hikers had no poles, and on the last 10 meter length they hiked with hiking poles (Figure 8).

Figure 4. *Experimental lanes in Bolabás, Þingvellir National Park – Plot 1: Grassland:*

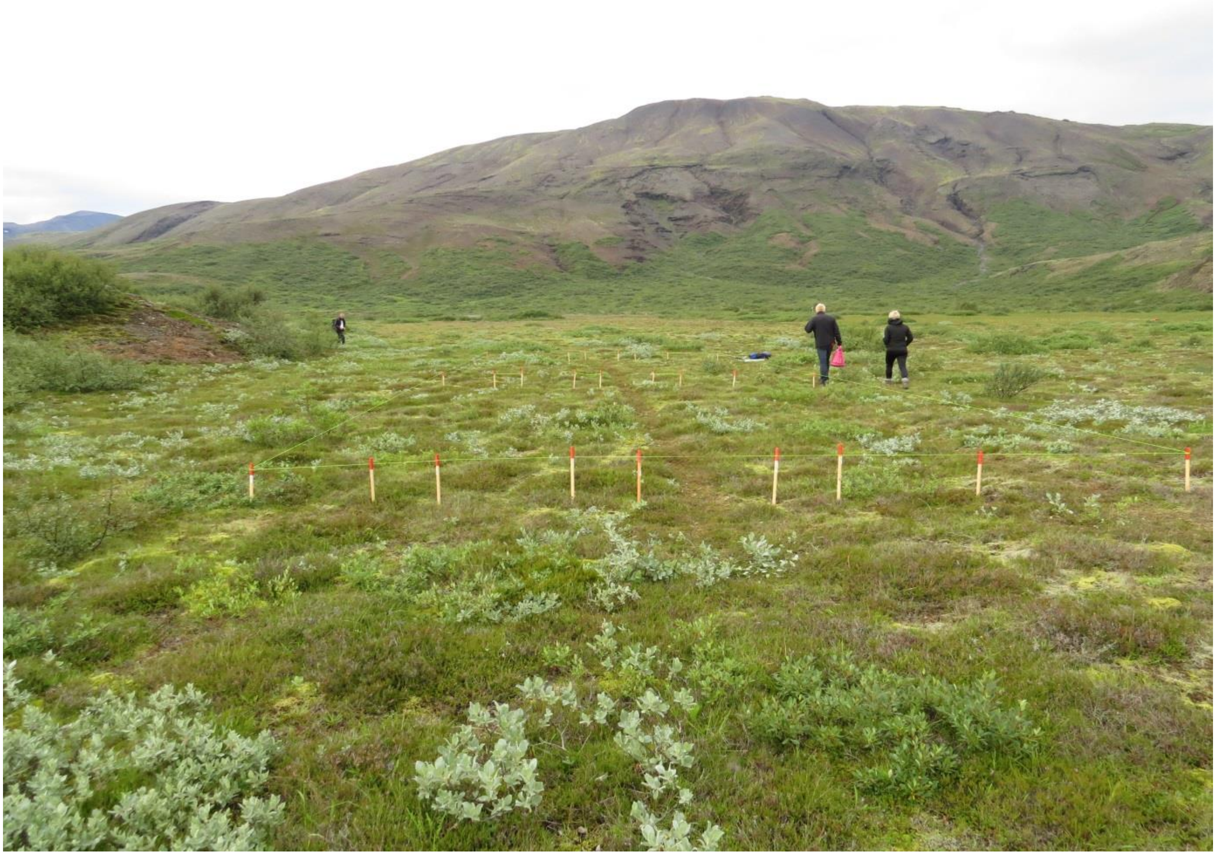


Figure 5. *The experimental lanes in Bolabás, Þingvellir National Park – Plot 2: Mossheath*

***Figure 6.** The experimental lanes in, Þingvellir National Park – Plot 3: Moss*

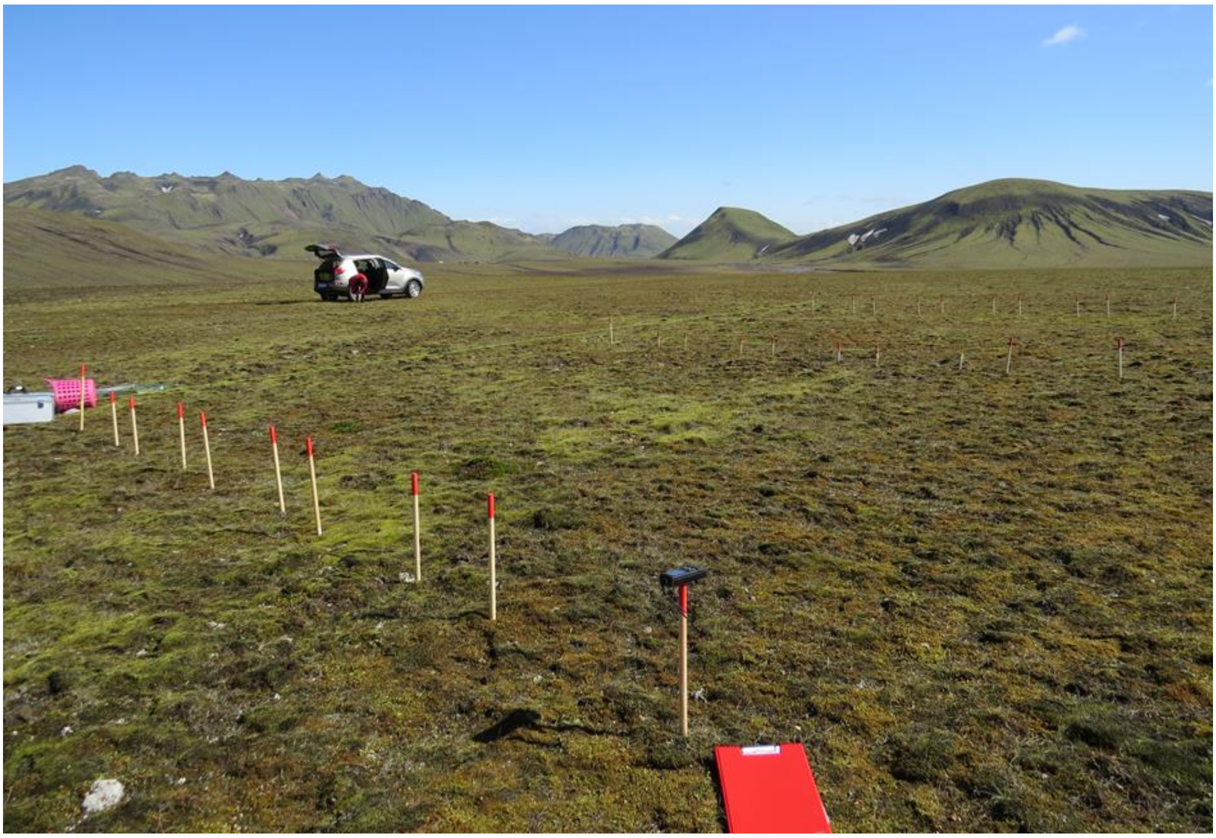


***Figure 7.** The experimental lanes in Fjallabak Nature Reserve – Plot 4: Mossheath*

Figure 8. *Hikers at work!*

The number of passes was in line with the standard experimental trampling protocol recommended by Cole and Bayfield (1993), i.e. 0 (control lane), 25, 75, 200, and 500 passes symbolizing the trampling effect on each vegetation type from the same amount of tourists. The control lane (0 passes) is used to compare the undisturbed vegetation to the lanes with different trampling effect. A buffer zone (0.5 m) was kept between the lanes to have a safe place to walk between lanes during measurements and to avoid additional trampling to the lanes. Each experimental lane was then randomly assigned the number of passes. Four hikers between 60 and 90 kg, with backpacks of 5-10 kg and equipped with hiking boots, trampled the lanes back and forth until the correct number of passes were reached.

4.2.2 Field measurements

In each 20 meter lane a total of six sub sample plots (60x60 cm) were positioned at 2, 4, and 6 meter distances from each end's base line (Figure 9). Within each subplot measurements of soil moisture, soil compaction, vegetation cover, and vegetation height/soil surface depth were taken as stated above. Furthermore, a photograph from above (approximately 1.5 meter of height) using a tripod with a tiltable arm was taken of each subplot to be used for digital image analysis of changes in vegetation cover, which also was approximated subjectively by dividing the 60 cm^2 subplot into 9 mini-plots within the quadrate (*cf.* Figure 3). The number of trampling in each lane was randomly assigned as proposed by Cole and Bayfield (1993).

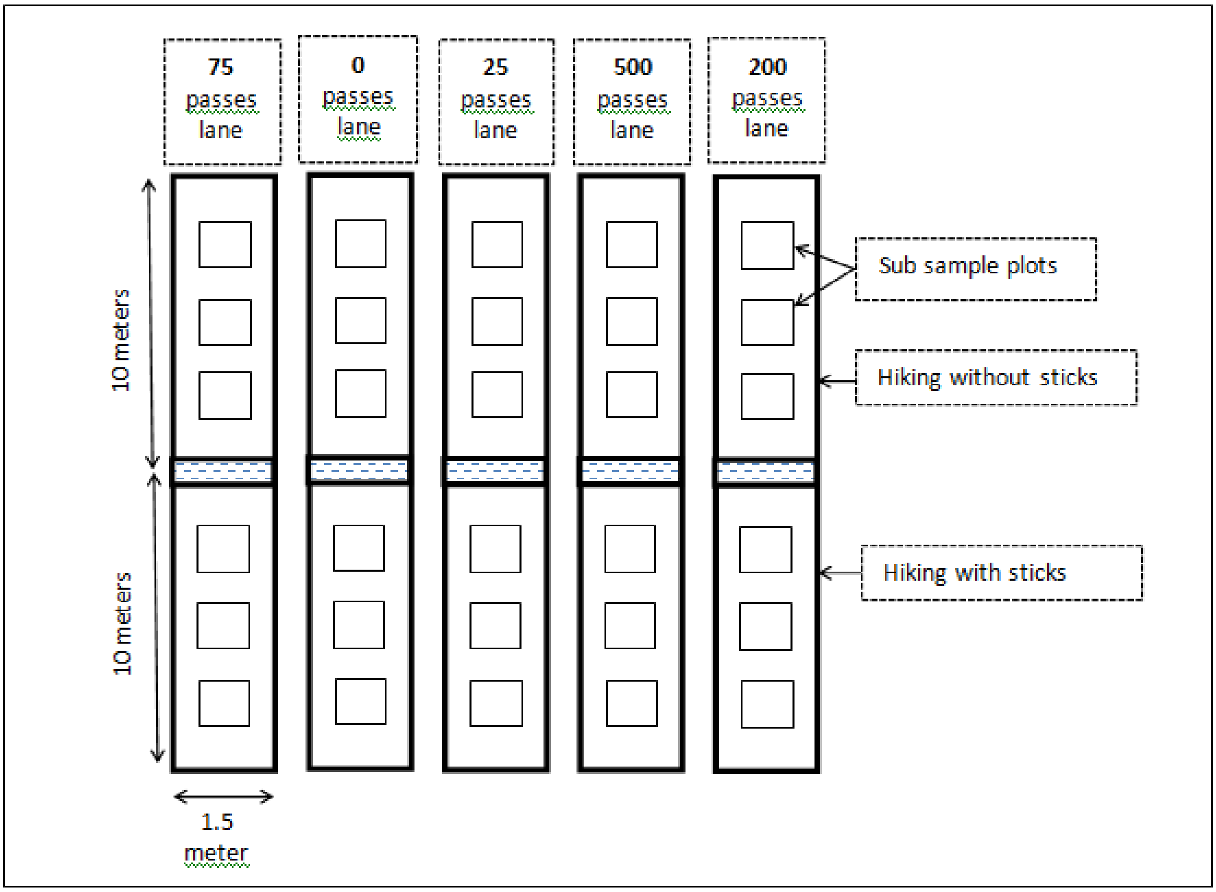


Figure 9. *The design of experimental lanes set up used in both study sites. The number listed on the top of the illustration indicate number of trampling that was randomly assigned. The 0-passes lane is the control lane, i.e. no trampling.*

Soil moisture

Soil moisture was measured by a simple digital meter used for pot-plants. The display reveals digital values between 0.0 and 9.9 of soil moisture where 0.0 is dry and 9.9 is wet soil. The measurement of soil moisture is thus only relative between the study sites. Soil moisture was measured about 10 cm below the soil surface. Each subplot that was divided into 9 mini-subplots allowed measurements to be taken at each mini-subplot. Hence a total of 9 measurements were taken in each subplot and the average number used for each subplot.

Soil compaction (N/m^2)

Soil compaction was first measured by hand held soil penetrometer as recommended as the most handy in most of the literatures reviewed. After repeated trials it was simply not suited for Icelandic condition. A professional penetrometer (Figure 10-11) was kindly obtained from the Icelandic Soil Conservation Service. Soil compaction was measured at three locations in the subplot along the path direction. The compaction measurement (N/m^2) for each subplot was averaged to analyse against the different trampling pressure lanes.

Figure 10. *Penetrometer used to measure soil compaction*

Vegetation height/soil surface depth profile

According to Cole and Bayfield (1993) the reduction in vegetation height is most often the initial response to trampling. In this study a profile of the vegetation height/soil surface depth according to the different trampling pressures was measured perpendicular to the lane direction at each subplot. The profile was measured by a ruler at every 10 cm intervals of the total of 60cm subplot length to derive a cross section of the path cannel.

Vegetation cover - Photographs

The proportion of vegetation cover/bare soil was visually assessed by dividing each 60 cm^2 subplot into 9 mini-plots using the quadrate method. The change in the vegetation/bare soil relationship alters the reflectance properties in a photograph and thus should be detectable through image analysis. Therefore a photograph was additionally acquired of each sub-plot, a total of 120 photos, in order to through digital image analysis classify the distribution of resistant living plant matter in relation to amount of soil / dead matter.

4.3 Data processing

In order to evaluate how each variable measured in field correlates to the diverse level of pressure from trampling by hikers, and to assess how the variables differ between the different vegetation types and study areas, as well as if differences exist if hiking sticks are used or not, the following hypotheses were formed and tested for each variable:

- **Soil moisture: H_0**: Soil moisture increases with increasing trampling pressure in the top soil layer as the soil is compacted from the weight of hikers, and thus water held by the soil particles by capillary forces are pressed out and accumulate in the top soil layer.

- **Soil compaction: H_0**: Soil compaction increases with increasing trampling pressure in the top soil layer as the soil is compacted from the weight of hikers. The soil will then contain less air pockets and soil particles are subsequently tighter pressed together. This creates impermeable soils that hinder rain water to infiltrate. The rain water will then instead flow as surface runoff and thus potentially increase eroding forces.

- **Soil surface depth profile: H_0**: The soil surface depth profile increases with increasing trampling pressure as soil particles are being compacted. This will create a typical U-channel form of the "hiking lane" where water can accumulate and cause increased surface run-off and erosion processes to accelerate causing the soil depth to deepen further.

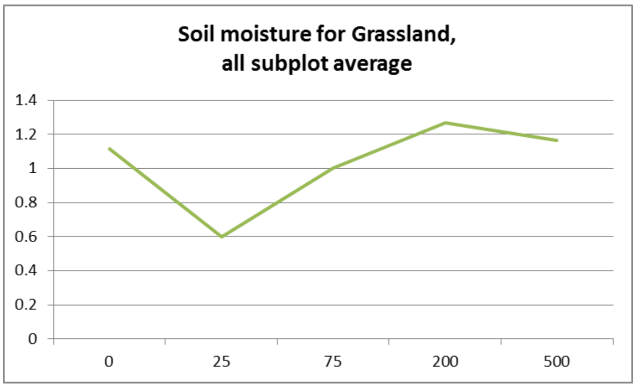
- **Vegetation cover change: H_0**: The vegetation cover decreases with increasing trampling pressure and reversely the area of bare exposed soil increases. An increasing area of bare soil equals more exposure to erosion processes, like wind and water erosion.

All data measurements collected in field for the selected variables were entered into MS Excel for further statistical analysis to test the above hypothesis.

5. Results

5.1 Soil moisture

The results of the soil moisture measurements show no apparent trends of soil moisture in relation to trampling pressure (Figures 11-14). The simple digital meter used in field is primarily aimed for pot-plants and is likely not suitable for outdoor field condition, as suspected during field work. However, indication of higher soil moisture in the top soil is weakly shown in grassland and moss heath at the lowlands Þingvellir experimental plots sites supporting the H_0 hypothesis. The study site at Fjallabak Nature Reserve is located on much higher altitude (628 m a.s.l. compared to about 150 m a.s.l. at Þingvellir) and soil moisture is in general lower, and the variation in soil moisture in relation to trampling pressure is less. No apparent difference is noted between hikers using hiking sticks or not. The soil moisture measurements for each study area are shown in graphs below. These are averaged values from all subplots for the each vegetation types (to the left) and relationship between hikers with and hikers without hiking sticks (to the right).



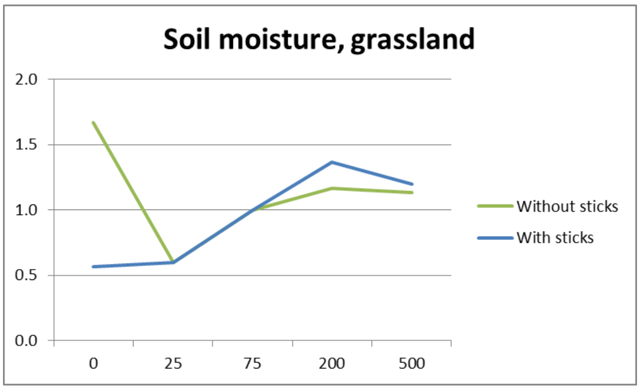
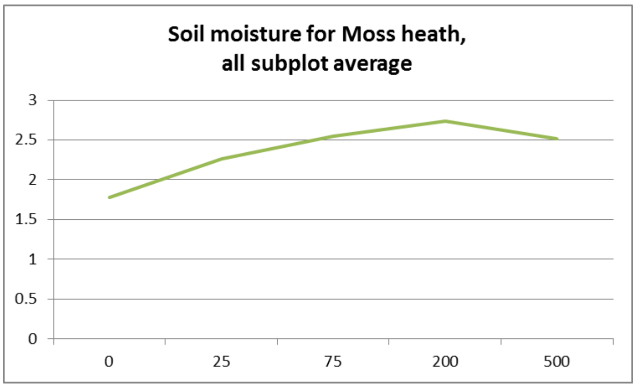


Figure 11. *Plot 1: Grassland, Þingvellir (N°64.29; W°21.06; Altitude 152 m.a.s.l)*



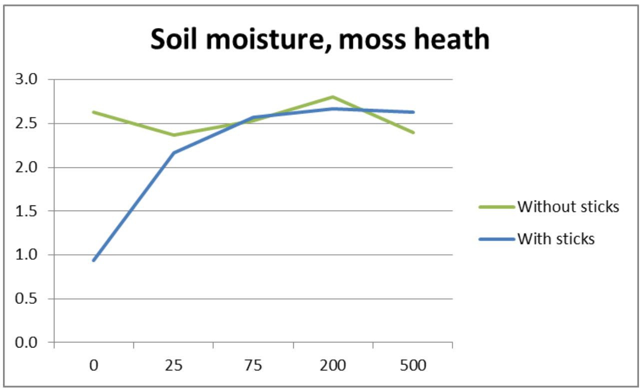


Figure 12. *Plot 2: Moss heath, Þingvellir, (N°64.29; W21.06; Altitude 149 m.a.s.l)*

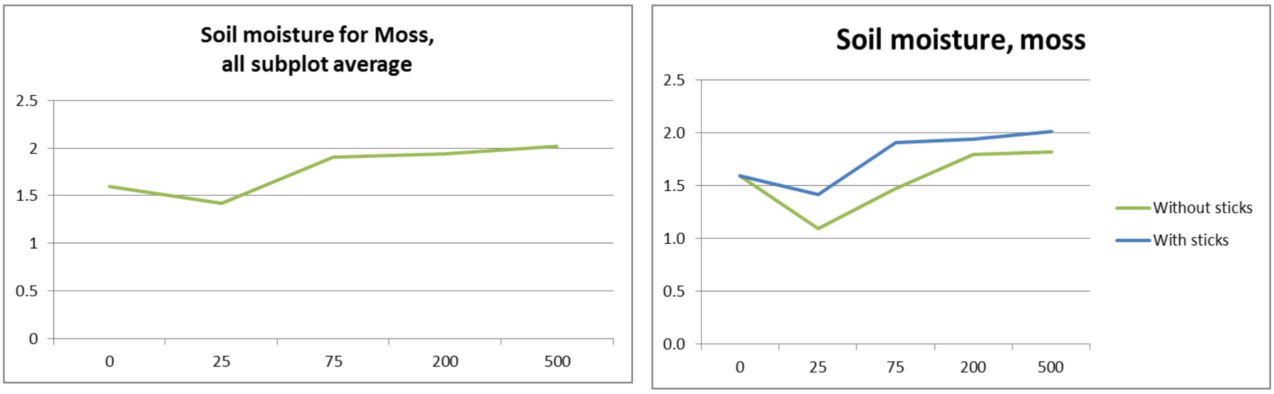


Figure 13. *Plot 3: Moss, Þingvellir, (N°64.28; W°21.08; Altitude 134 m.a.s.l)*

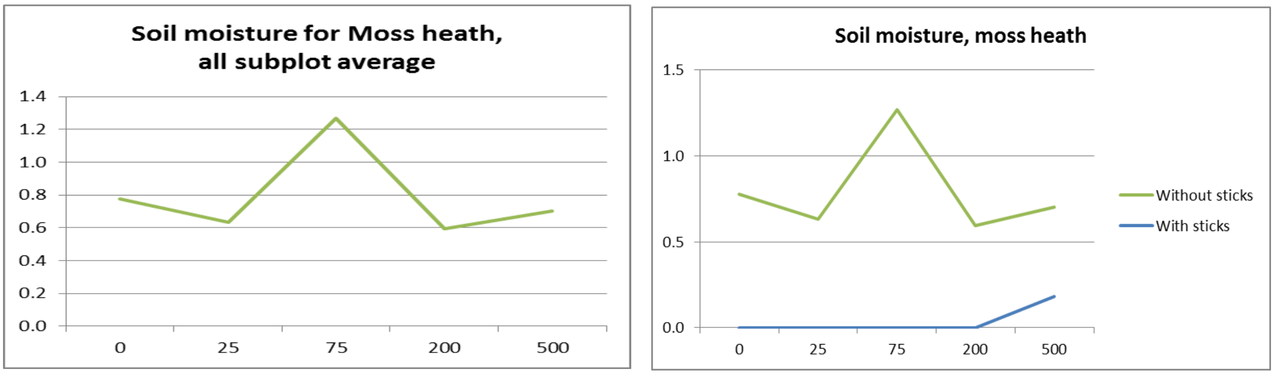


Figure 14. *Plot 4: Moss heath, Fjallabak NR, (N°64.06; W°19.30; Altitude - 628 m.a.s.l)*

5.2 Soil compaction

The results from the soil compaction measurements show clearly that soil compaction increases in relation to trampling pressure (Figures 15-17). Hence, as hiking pressure increases soil gets more compact supporting the H_0 hypothesis. In the grassland type ecosystem there is no observed difference in soil compaction between hikers using hiking sticks and not. But notable differences may be seen in the moss-heath type ecosystem in both Þingvellir and in Fjallabak Nature Reserve. The generally higher compaction on the grassland study site, about twice as high compaction, is likely related to the well-developed root system characterising grasslands. The measurements are affected when the soil penetrometer is entered through the dense root system. Likely the root system also protects the soil from being compacted as it is works as a flexible spongy layer that bounces when trampled upon. This correlates with the assumption that the Icelandic grasslands are more resistant to trampling pressure from the hiking tourism (i.e. Gísladóttir 2006; Ólafsdóttir and Runnström 2013).

The measurements of soil compaction are shown in the graphs below. Soil compaction was measured at three positions in each subplot accross the trail direction. Remarkably, the measurements vary substantially depending on where in the subplot the measurement is acquired in relation to where the majority of trampling has occurred. Soil compaction was not possible to measure in the moss cover study site as the moss layer is growing right on the top of the post glacial lava field, without any roots or soil formation.

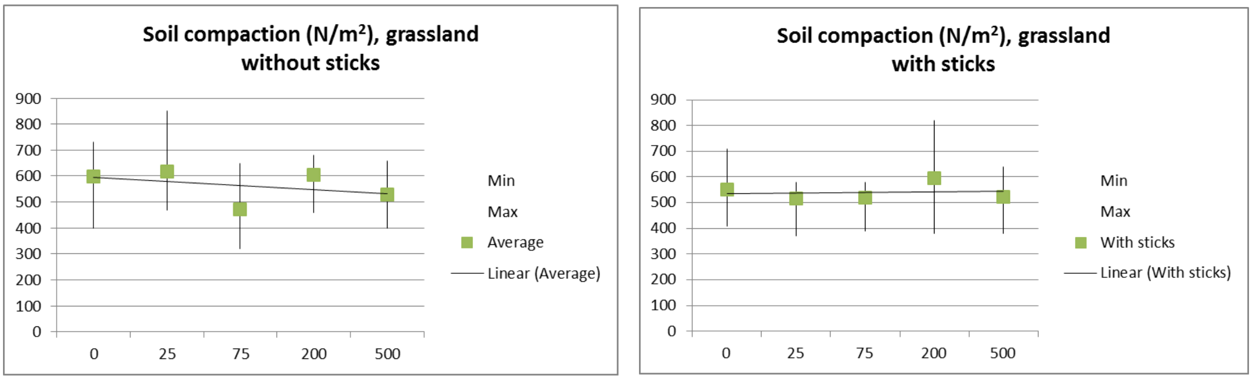


Figure 15. *Plot 1: Grassland type ecosystem, Þingvellir*

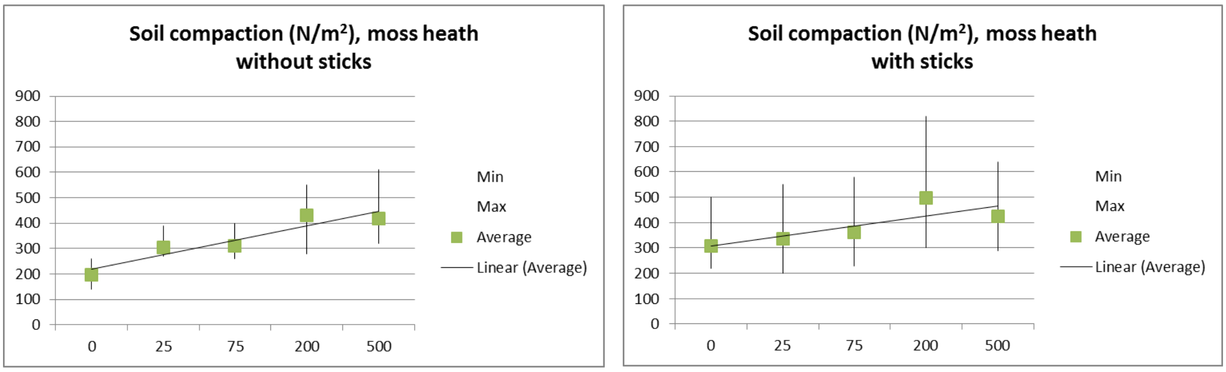


Figure 16. *Plot 2: Moss heath type ecosystem, Þingvellir*

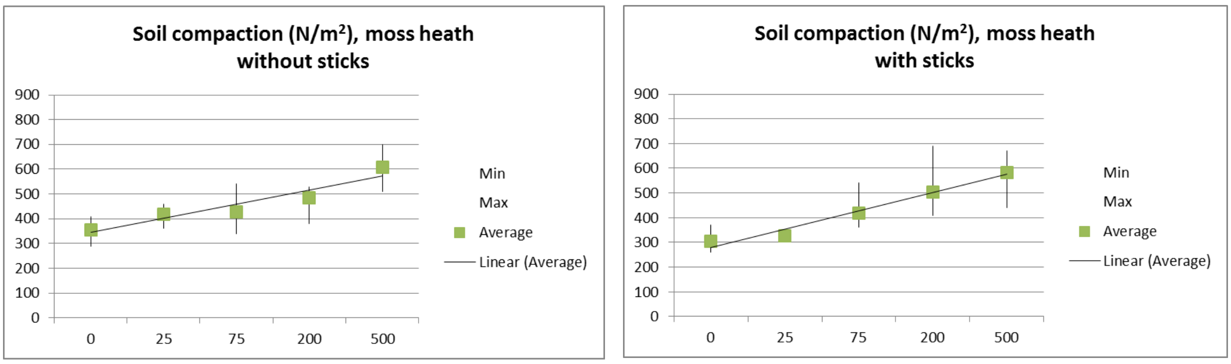


Figure 17.*Plot 4: Moss heath type ecosystem, Fjallabak Nature Reserve*

5.3 Soil surface depth profile

As regard the effect of trampling on the creation and development of a typical U-channel hiking trail in a soil profile, the results show a relatively clear trend of the soil profile formed by trampling that deepens with increased trampling pressure at all study sites and for all vegetation types tested (Figures 18-22). Subplots show different patterns but when averaged, the path channel clearly deepens in relation to the trampling pressure strongly supporting the H_0 hypothesis. The results indicate differences in the soil profile depth in relation to if hiking sticks were used or not. Hence, when using hiking sticks the path channel forms less rapidly and intense creation as the hiker's weight is also distributed to the ground through the sticks, and boot marks less severe. On average the depth of the path channel is about 4-5 cm after 500 passes. It is however likely that the depth of the path channel reach a level when it does not deepen anymore, as indicated in the graphs. The compaction of the soil seems to reach a potential maximum from hiking pressure and after that the deepening of the path channel occur instead by a physical movement of soil particles by hiking boots and surface water runoff.

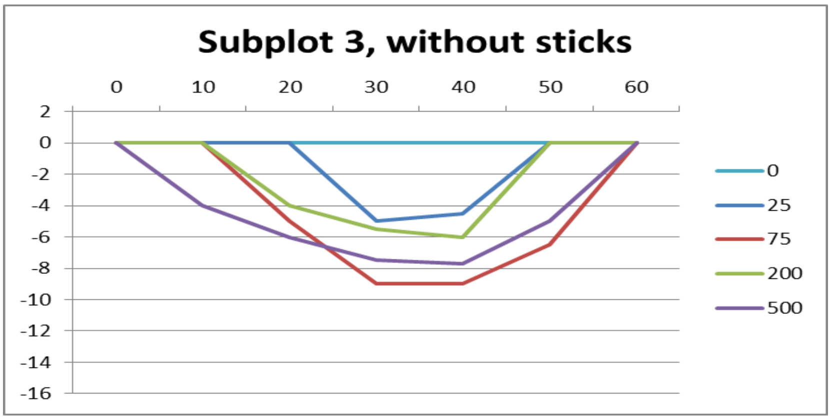


Figure 18. *An example of a formation and development of U-channel hiking path with increasing trampling pressure. The path both deepens and widens as the pressure increases. This pattern is seen in all subplots.*

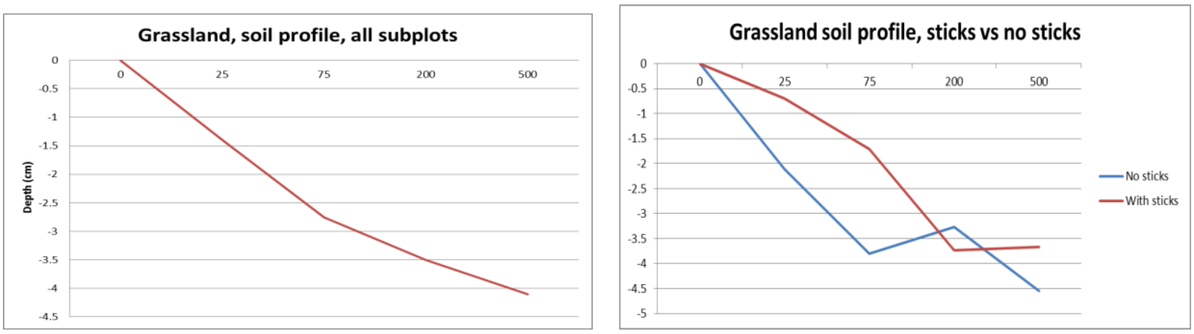


Figure 19. *Plot 1: Grassland type ecosystem, Þingvellir*

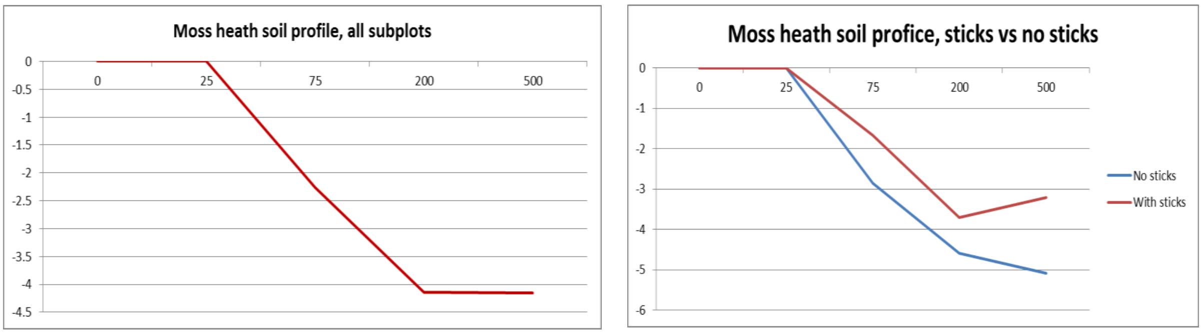


Figure 20. *Plot 2: Moss heath type ecosystem, Þingvellir*

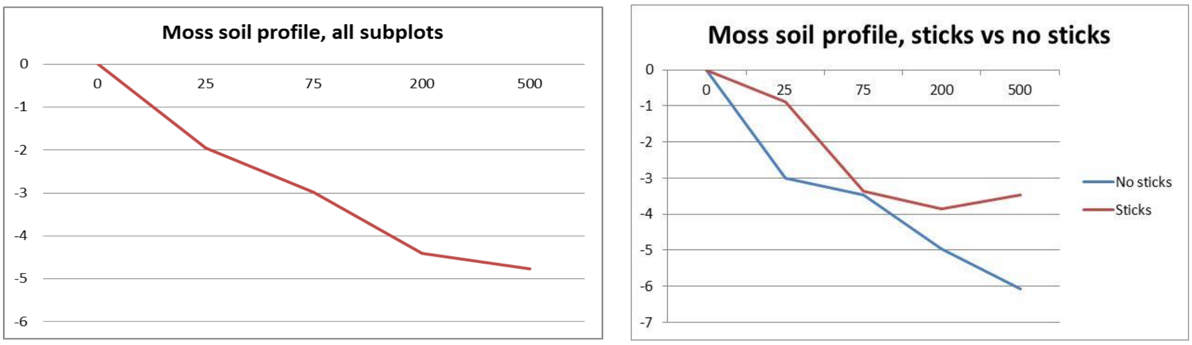


Figure 21. *Plot 3: Moss type ecosystem, Þingvellir*

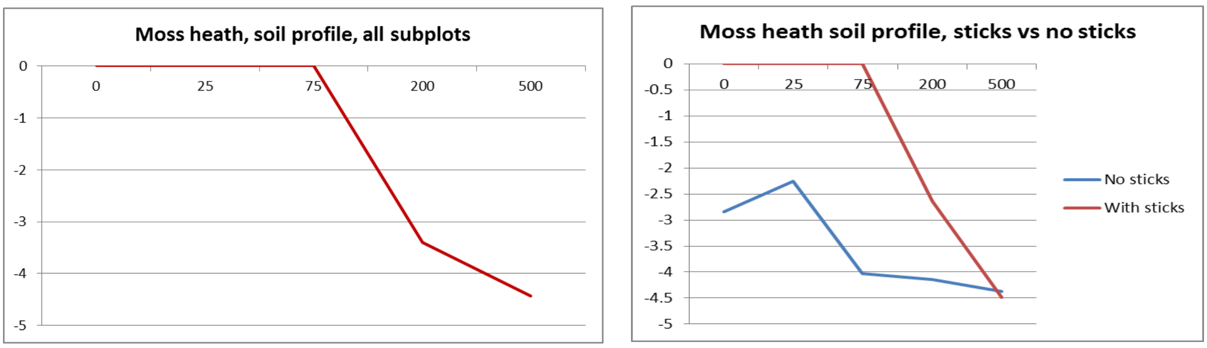


Figure 22. *Plot 4: Moss heath type ecosystem, Fjallabak Nature Reserve*

5.4 Vegetation cover change

In all study sites, except Plot 2, the moss-heath ecotype in Þingvellir, the vegetation cover were relatively dense in all subplots. When trampling the hikers compressed and damaged the vegetation cover, but in most cases did not expose the underlying soil cover (except in plot 2, where the vegetation cover was patchy). This was even true for plot 3, the moss cover. Major observed changes as regard vegetation cover change is that species retreat from the trail while other more resistant to trampling become dominate in the trail, i.e. in the grassland flowering plants retreated and/or disappeared from the trail, and the often underlying moss appeared. In the moss-heath areas the trampling more often resulted in damage to the sensitive moss cover. The moss-heath study site in the Fjallabak Nature Reserve, was characterized by heavy grazing, weakening the vegetation cover for additional external impact like trampling. In the moss area the moss cover was seriously damaged and will likely degrade in the long term, but still the vegetation cover was nearly 100% after 500 hikers (Figures 23-26). Therefore it was decided to focus on the use the photograph technique to assess this variable.

Figure 23. *Plot 3: The results from the experimental hiking. The 500 hikers lane with hiking sticks is in the front. 200 to the right, and 75 to the left.*

Figure 24. *Plot 1: The results from the experimental hiking.*

Figure 25. *Plot 2: The results from the experimental hiking.*

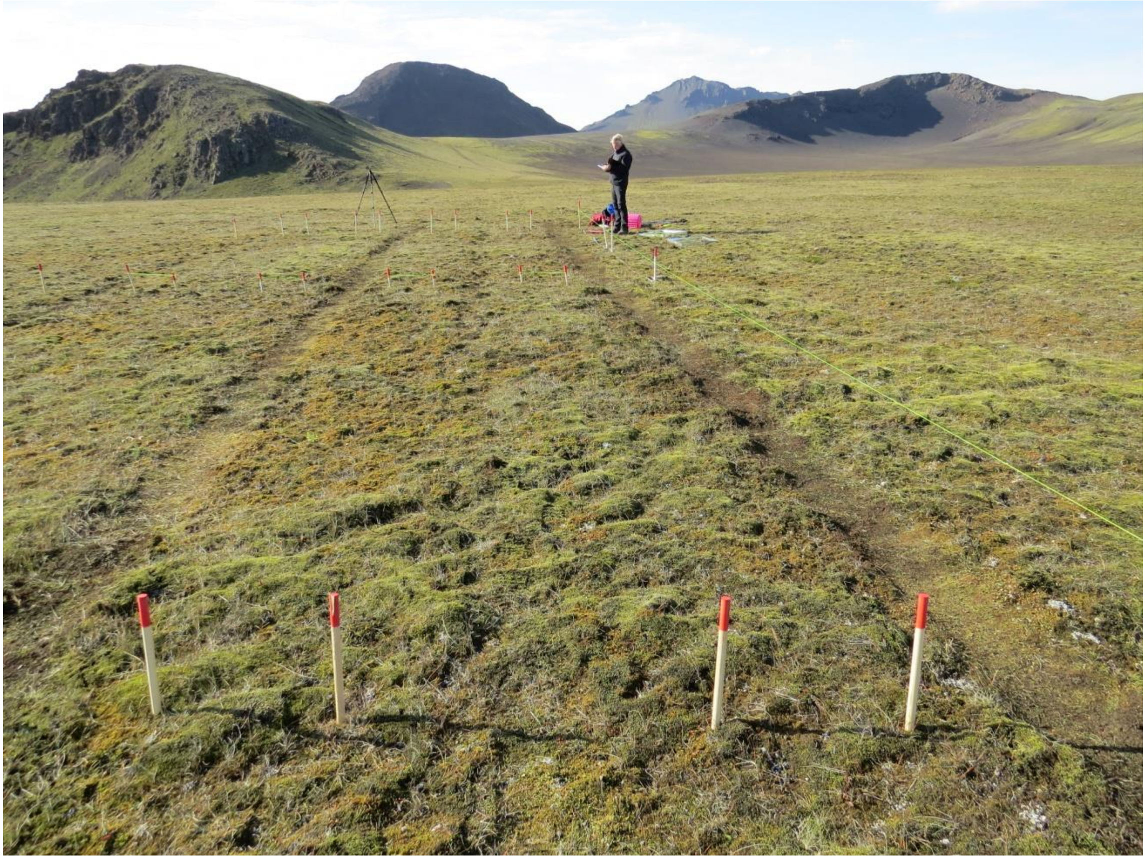


Figure 26. *Plot 4: The results from the experimental hiking.*

The photographs taken at each subplot (Figure 27) were clipped to the extent of the sub-plot frame (Figure 28) as the classification of the vegetation/bare soil should represent the situation within the sub-plot only. The sub-plot photographs were then rectified to be able to implement digital image analysis. Each subplot was classified and some different methods will be tested, e.g. maximum likelihood classification where training areas for the different classes are entered (Figure 29).

The image analysis proves to be quite time consuming as each photograph (total of 30 photos for each study site) needs to be pre-processed. The subplot area is first clipped out from the photograph and then rectified (perpendicular square). The image analysis process tests different methods to separate green vegetation matter from e.g. bare soil and dead matter. Shadows, blended colours from different vegetation types, illumination differences etc. make this process complex and delicate. Each subplot photograph will then be classified using different methods such as supervised maximum likelihood classification where training areas for the different classes are entered; different greenness/vegetation indices.

This part of the study is currently being carried out as a master thesis project at the Department of Ecosystem Analysis and Physical Geography, Lund University, Sweden, and will be completed and defended in June 2015. Some preliminary results are provided below.

Figure 27. *The full-extent photograph example (Þingvellir; moss-heath; Lane 200; No hiking sticks; Subplot 2)*

Figure 28. *Left: The clipped image (clipped from Figure 27) only containing the interior of the sub-plot frame (60*60 cm). Right: Undisturbed reference sub-plot with no hiking pressure clipped to fit the same 60*60 cm frame.*

The subplot image (Figure 28 left) was classified into base ground / vegetation classes based on their spectral reflectance values in the RGB image. Bare ground classes are needed to be separated into sun-lit soil and soil in shadow. These classes can later be merged. The vegetation class also requires sub classes as vegetation consist of different types and some are sun-lit and some are in shadow.

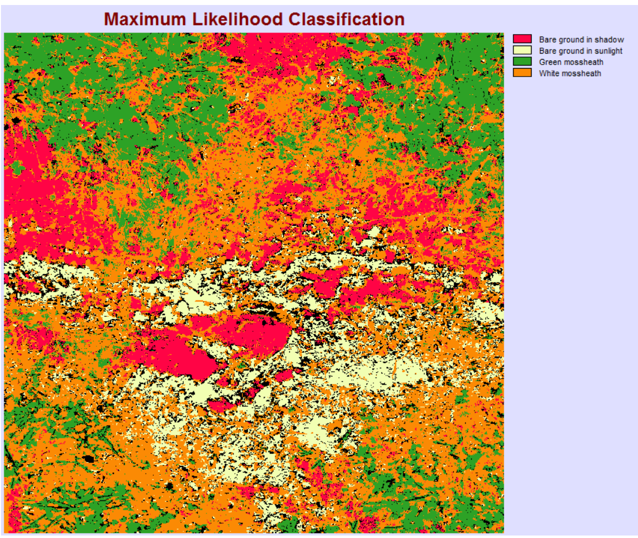


Figure 29. *An example of supervised maximum likelihood classification of the clipped subplot image (Figure 28 left).*

The proportional result for the classification is shown below in Table 2. The proportion between vegetation / bare soil is in this sub-plot 62.3 %/27.1 % (10.6 % unclassified = spectral properties cannot clearly be inserted in any of the 4 classes). The histogram below shows the same but in pixel counts (Figure 30).

Table 2. *The result of maximum likelihood supervised classification on photograph 638: (Þingvellir; Moss-heath; Lane 200; No hiking sticks; Subplot 2).*

Class	Proportion (%)
0 – Unclassified pixels	10.6 %
1 – Bare ground in shadow	15.0 %
2 – Bare ground in sunlight	12.1 %
3 – Green vegetation	20.0 %
4 – White/sunlit vegetation	42.3 %
Total	100 %

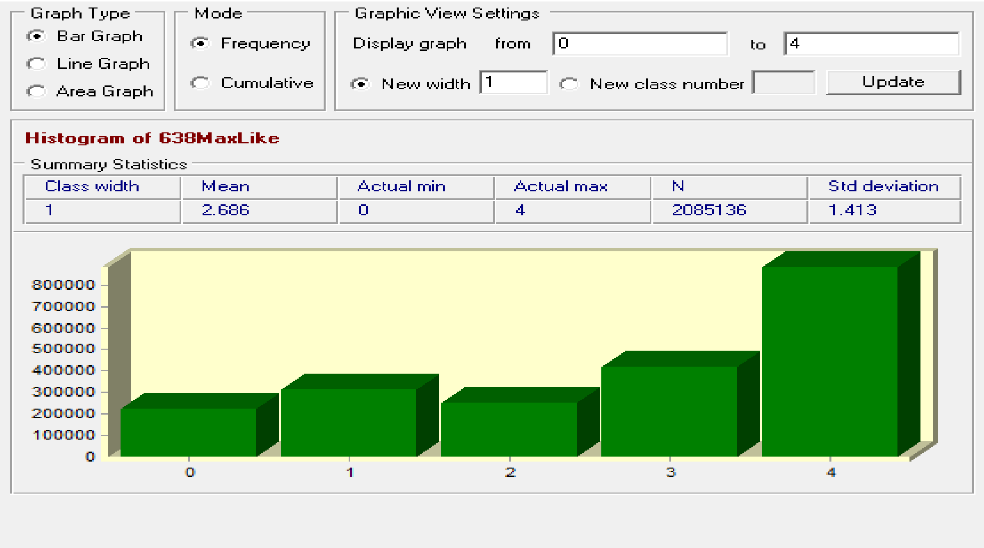


Figure 30. *Histogram of maximum likelihood supervised classification on photograph 638: (Þingvellir; mossheath; Lane 200; No hiking sticks; Subplot 2)*

Another method that is tested is to calculate different greenness indices e.g. green chromatic coordinate (GCC = G / [R +G+ B]), where the RGB photograph is split up into separate R,G, B bands. This method calculates the average GCC for the entire image and the GCC-values can then be compared against the different hiking pressure lanes. The first results from the analysis of GCC for the heath moss study area at Þingvellir are motivating, although the difference is small for the different trampling lanes. In general, Figure 31 shows that GCC may be correlated to increasing pressure from trampling through loss of green matter; vegetation.

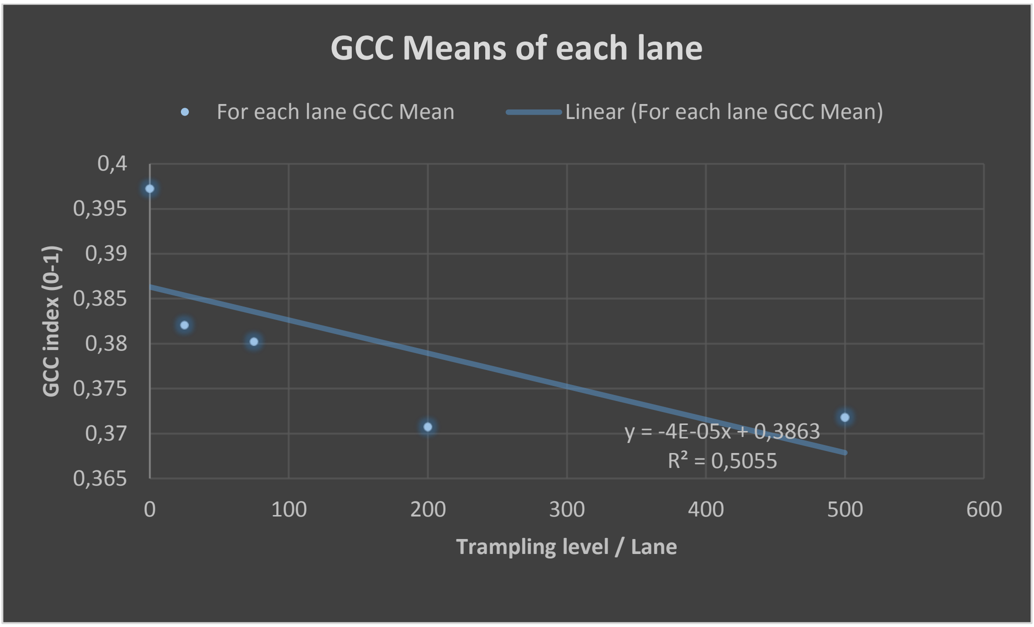


Figure 31. *Green Chromatic Coordinate (GCC) for heath moss in Þingvellir.*

6. Discussion and next steps

During the past decade the number of tourist visiting Iceland has grown with exponential rate. The annual average increase the last four years (2011-2014) has been 20% (ITB 2014). Large majority of foreign tourists visiting Iceland come to experience nature (ITB 2014), and outdoor activities have over the past decades also gained increased popularity among native Icelanders. It may thus be assumed that ecological pressure from outdoor recreation will increase significantly in Iceland in the nearest future. This is especially true for the most popular tourists' sites. It is therefore of vital importance to understand the resistance of Icelandic ecosystems to different recreational pressures, in order to prevent severe or even irreversible land degradation.

Currently there is almost a total lack of the scope and intensity of tourism environmental impact in Iceland. As emphasized by Leung (2012) baseline data about visitor use and visitor impacts is crucial in understanding the intensity and patterns of natural resource impact. This study is the first attempt to undertake experimental research as regard tourism ecological impact in Iceland. As such it has provided valuable experience in building an essential base for continuing experimental research. The advances of experimental approaches over simply focusing on existing hiking trails is that such approaches maximize insight into cause and effect as the researchers can control both the use and environmental factors in a replicated design, and thus provides better understanding of tourism impact from the different outdoor activities as pointed out by Cole (2004). The overall aim of this study was firstly to get acquainted with field experimental plots for tourism impact studies, such as finding important variables to be measured and how these should be measured and at what spatial scale.. Secondly, to examine the impact from experimental trampling on common Icelandic sub-arctic vegetation types affected by diverse levels of hiking pressure.

This study used traditional methods used in other countries in order to learn from others as well as to be able to undertake comparable studies. Two new approaches were furthermore tested; firstly to separate the experimental plots in lanes where hiking sticks are used and not used to assess if impact is different between the two hiking categories. Secondly to investigate the use of image analysis for assessing the trampling impact on vegetation covers.

The size of the experimental subplots (0.6m x 0.6m) was sufficient to cover the tracks being formed in the lanes, even with sticks. Inside the subplot 9 equally size squares (20x20 cm) were created with lines allowing for a rather dense and systematic capturing of data. Soil moisture varies spatially significant in the subplot and therefore 9 measurements was acquired. Soil compaction changes across the trail and thus should be measured across the lane. Three measurement across seems to be sufficient. The soil profile was also measured across, at every 10 cm. Denser measurements would provide a more detailed profile but then also need more time to collect data in the field.

The results are giving interesting insights to how trampling in Icelandic environments affects the ecosystem regarding soil compaction, soil surface depth profile, soil moisture, and still progressing project for vegetation cover analyses. They support Gísladóttir's (2006) results that moss-heath is more vulnerable to trampling than grasslands both as regard all variables. The much denser root system in grasslands is likely to protect the underlying soil bank to be compact, strengthen all other variables from effects from trampling.

An interesting notion from this study is a clear difference seen between tourists using hiking sticks and those who do not. Tourists using hiking sticks have more impact on the soil surface profile, i.e. make deeper profile, resulting in higher soil compaction. This might be as the total weight of the hiker distributes over larger unit. On the other hand the hikers that use hiking sticks impact a wider area of the vegetation cover. Another interesting notion from this study is a slight different pattern is seen in the variables tested, i.e. most changes do not occur with little use, i.e. 25 hikers, as many studies show (e.g. Cole 2004), instead the changes increases steadily in relation to increased pressure, with most impact being around 200 hikers.

The experience obtained and the databank created from this study will be used to build further knowledge on the impact of outdoor recreational activities on Icelandic ecosystem. All variables tested in this study will be measured same time annually over the next five years in order to monitor the recovery process. New studies will also be carried out as regard trampling build on the obtained experience, and impact from biking and horse riding will be added. More variable also need to be taken into concern, such as slope and aspect of trails, the impact on individual plant species and the varying relationships between trampling and soil organic matter. It would also be interesting to measure the impact in different seasons and with different repetition of hikers/bikers e.g. 50 every day, and how that would affect the physical environment in the experimental plots. Better acquired data also give rise to more precise statistical data analysis.

Acknowledgements

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Appendices

1. **Literature methodological approaches as regard experimental studies on recreational trampling**
2. **Experimental plot protocol for tourism ecological impact measurement**

Reviewed methodological approaches as regard experimental studies on recreational trampling used as a base for this study

Authors	Parameters/variables to be measured (indicators of damage)	Comments
Whinam &Chilcott 1999; 2003 (assess shrubland & grassland)	Biomass of broken plant material	Collect all broken plant material; sort into lifeform groups and dry; weight for each lifeform (vistland)
	% vegetation cover	1999: % veg cov vs bare ground was measured for 3 equally spaced 0,36 m2 quadrates in each treatment line. % cover was recorded for all vascular plant species. Total % cov for each quadrate was calculated as the sum of individual species cover. 2003: % veg cov vs bare ground was estimated for 3 50x50cm quadrates located at the beginning, middle and end of each treatment lane. % vegcov was recorded by two people working together using …
	Change in surface profile	Data were collected from 3 cross sectional transects in each treatment lane. Data were collected by measuring the distance from a level horizontal bar to the ground surface (soil or vegetation) at 5 cm intervals across the central 1 m of the treatment lane.
	WHA track monitoring method *(not taken specially out as indicator in the 2003 paper)*	3 impacts variables (depth, width free of vegetation and width trampled) were measured at each of 10 transects located at 1m intervals along the track.
Cole & Bayfield 1993	Visual estimates of veg cov	Measure only green photosynthetic material, i.e. exclude the cover of surviving stems that had been defoliated by trampling.
	Visual estimates of bare ground cov	Ground not covered by live vegetation.
	Measures of vegetation height using a point quadrate frame with 5 pins	The frame should be placed a minimum of 10 times, systematically, along the length of each subplot.
Littlemore & Barker 2001	Plant cover (%) using subjective estimates	
	Plant height (in cm) using a point quadrate, with 25 replications per 30x50 cm quadrate	Heights of plants and soil compaction measurements were recorded directly after trampling, and quadrats were re-assessed for vegetation cover two weeks after trampling. **Vulnerability indices:** 1. Resistance index 2. Resilience index 3. Tolerance index
	Soil compaction measurements (in kg/cm-2) using a hand held soil penetrometer, with five random measurements per quadrate.	
	In addition, the impact of experimental trampling on the flower and seed production of Hyacinthoides non-scripta were also recorded after an one year after trampling by….	
Guðrún Gíslad. 2006	Width of the track and the adjacent area affected by trampling	Measures existing tracks (NOT experimental plots)
	Maximum track depth	
	Slope and aspect of the track and the surroundings	
	Coverage of vegetation and bare ground in the track; in the adjacent affected area and in undisturbed reference area outside the track,	using frame of 33*100 cm using the Braun-Blanquet method. … and the Mann-Whitney test used to test if there were a significant difference …
Mingyu et al 2009	Visual assessment of canopy coverage of each vascular plant species	30x50cm subplot Comparisons of trampling differences between horses and men (type B) 30 passes (low) vs 100 passes (high)
	Vegetation canopy height	
	Visual assessment of the cover of organic soil litter (soil organic material and plant litter)	

	Soil compaction was estimated using a pocket soil penetrometer	
Monz 2002	Visual estimates of canopy coverage of each vascular plant species	30x50cm subplot ATH: Measurements were performed appr. 10 days after trampling to assess initial resistance tor trampling
	Visual estimates of the cover of bare ground	
	Determinations of vegetation height using a point quadrat frame with five pins 5cm apart …	
	Soil compaction was estimated using a pocket soil penetrometer	
Pickering et al 2011	Vegetation height	[comparing effects of bike and hiking 200 passes (moderate usage) and 500 passes (high usage) Height was the maximum height of vegetation at each point in mm.
	Soil compaction	Vegetation height and soil compaction were measured at 24 evenly spaced points along the middle section of each of the 4m long lanes. Compaction was measured using a pocket penatrometer in kg/cm2
	Absolute cover of vegetation and litter	

EXPERIMENTAL PLOT PROTOCOL FOR TOURISM ECOLOGICAL IMPACT MEASUREMENTS

Location:_____________________________________ Type of impact:_____________________________

GPS corner coordinates:N_______________________;,__________________;,______________;,________________
W_______________________;,__________________;,______________;,________________

Eco type:_________________________________ Soil type:____

Dominating plant species:____

Random Lane arrangement:

Subplot 1

Measurement	Unit	0 (Control)	25 units	75 units	200 units	500 units
Soil moisture						
Soil compaction	Kg/ cm^2					
Veg. Cover/ Bare soil	%					
Veg height	cm					
Photo	#					

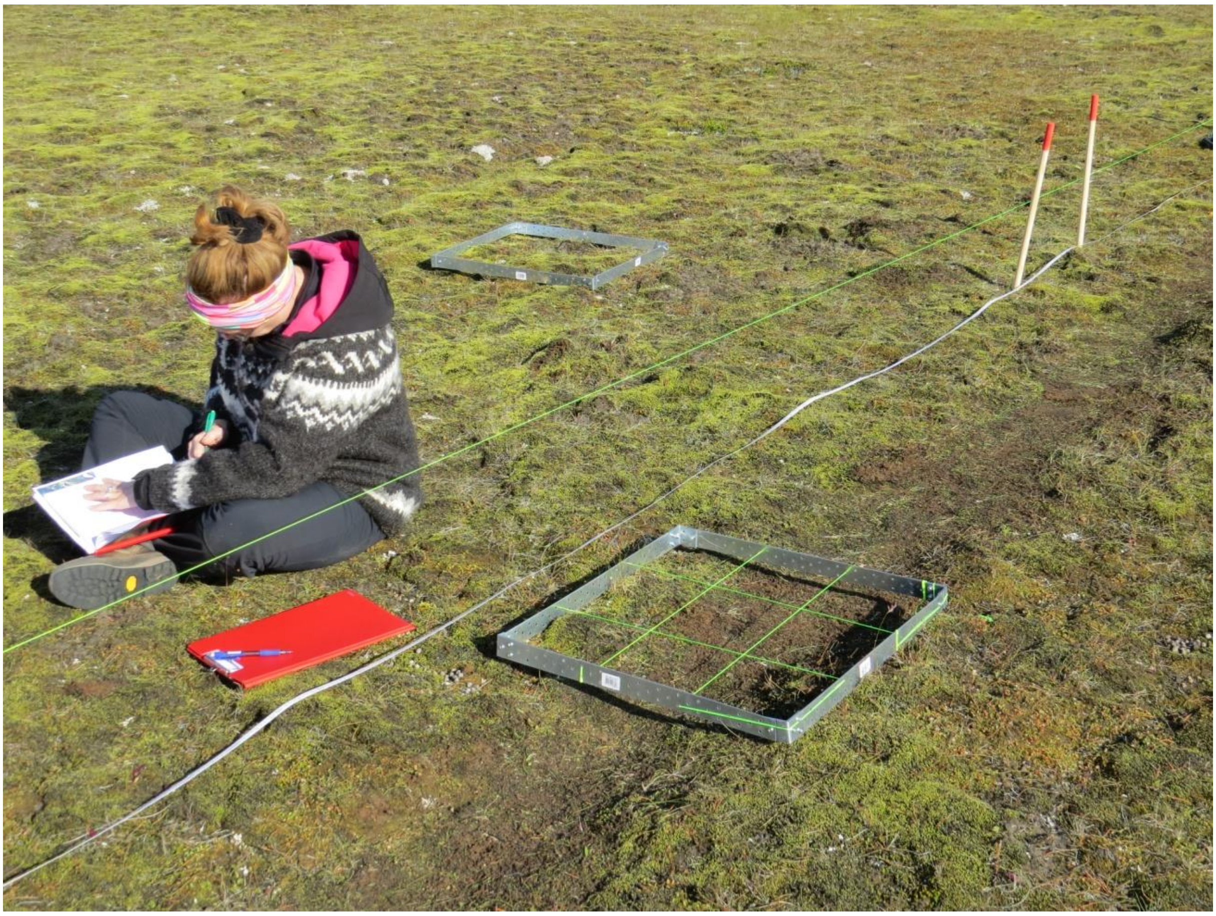
Subplot 2.

Measurement	Unit	0 (Control)	25 units	75 units	200 units	500 units
Soil moisture						
Soil compaction	Kg/ cm^2					
Veg. Cover/ Bare soil	%					
Veg height	cm					
Photo	#					

Subplot 3.

Measurement	Unit	0 (Control)	25 units	75 units	200 units	500 units
Soil moisture						
Soil compaction	Kg/ cm^2					
Veg. Cover/ Bare soil	%					
Veg height	cm					
Photo	#					


HIKING



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