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Assessing hiking trails condition in two popular tourist destinations in the Icelandic highlands

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ABSTRACT

Nature-based tourism in the fragile Arctic environments is emerging as a major environmental concern, mainly due to extreme seasonality in these locations, the lack of suitable infrastructures and planning, and its interference with fragile ecosystems. In Iceland tourism has increased exponentially during the past decades, causing more environmental impacts on the country's natural recourses. Hiking is one of the most popular tourist activities in Iceland, especially in the interior highlands. This study had two goals: to map the current status of hiking trail conditions in two popular tourist destinations of the southern highlands, Þórsmörk and Fjallabak Nature Reserve (FNR); and to examine the relationship between trail condition assessment and local physical properties, such as elevation, gradient, soil type, and vegetation cover, in GIS. The current status of the hiking trails is much worse in the Þórsmörk area, where over 30% of the trail system is classified as being in bad and very bad condition, compared to 12% for the FNR. Of the analyzed physical properties only elevation has a clear relationship with hiking trail condition in both study sites and gradient in the Þórsmörk area. Importantly, severe conditions never apply to a whole trail, suggesting that trail conditions are a function of trampling magnitude and local physical properties. Hence, when maintaining hiking trails in vulnerable environments, such as the Icelandic highlands, a holistic understanding of the environmental impact of trampling is critical.

Management implications

When nature-based tourism enters very fragile environments, good monitoring techniques become even more important. Such is the case on hiking trails in the highlands of Iceland, where the study produced the following findings:

- Monitoring the conditions of hiking trails is vital for understanding the major causes of trail degradation in the Icelandic highlands. Implementing a visual field assessment with a condition scale based on simplified classification system, a whole trail system can easily and cost-effectively be monitored and changes recorded. Visual interpretation of the spatial patterns of a trails' condition can further aid managers to identify problem areas and to avoid this type of area in future planning.
- During new trail design, steep slopes should be avoided as trampling easily intensifies solifluction and thus contributes to soil instability and soil erosion. In flat areas trails should be designed so hikers do not easily walk off the trails and thus increase the area of their impact.
- Inevitably, the number of users contributes the most to trail degradation. Therefore in the most vulnerable areas of the highlands the flow and number of tourists should be restricted.
- Gathering high resolution geographical data for use in Geographical Information Systems (GIS) are important in order to monitor and track changes of hiking trail conditions. The possibilities to analyze spatially distributed data and relationships between variables further provides better understanding of cause and effect regarding tourism impact in sensitive natural environments.

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1. Introduction

Over the past few decades Arctic regions have experienced increasing interest from tourists. At the same time, many rural areas in the Arctic face considerable out-migration, and therefore tourism often constitutes one of the few positive economic sectors for these regions. They offer vast natural areas and mainly attract tourists who are interested in experiencing nature and nature-based activities. Newsome, Moore, and Dowling (2013) report that natural area tourism has over the past few decades grown significantly worldwide, which subsequently increases tourism impact that has the potential to change natural areas as well as tourism itself. This increased popularity of natural area tourism is likely to exert severe stress upon the planet's most vulnerable ecosystems, many of which are found in Subarctic and Arctic areas.

In Iceland tourism has grown rapidly over the past decades, from approximately 4000 foreign visitors in 1950 to 672,000 in 2012, with a mean annual increase of 8% over the last ten years (ITB, 2013). Just over half a million visitors may not seem extreme, but these annual arrivals amount to double the Icelandic population (321,800 in January 2013; Statistic Iceland, 2013). Tourism is currently the third largest industry in Iceland, contributing 19% of the entire value of exports (Statistic Iceland, 2012a). Furthermore, Iceland was ranked as a top destination for 2012 by many of world's leading travel media such as *National Geographic*, *Lonely Planet* and *The Sunday Times Travel Magazine* (National Geographic, 2012; Lonely Planet, 2012; The Sunday Times Travel Magazine, 2012). Thus, the number of visitors to Iceland will most likely continue to increase significantly over the next few years. Given the fact that most visitors to Iceland visit the outdoors, one ought to expect additional impacts on Iceland's ecosystems.

Iceland's ecosystems are highly susceptible to external physical impacts (e.g. Arnalds et al. 1997; Arnalds, 2011; Ólafsdóttir & Runnström, 2009). To a large part Iceland owes its ecological fragility to its young geological origins and its location in the middle of the North Atlantic Ocean. The oldest known geological formations are no more than 15 million years old and the youngest are still in the making (e.g. Jóhannesson & Sæmundsson, 2009). The volcanic content of the Icelandic soils greatly reduces the soil's capacity to resist erosion as it lacks cohesion and has a high sandy content (Arnalds, 2008, 2010). Iceland's location in the North Atlantic exposes it permanently to strong winds and intense precipitation, leading to intensive wind and water erosion (Arnalds, 2010; Arnalds, Gísladóttir, & Orradóttir, 2012). The short summer season reduces the extent of the vegetative cover, and intensifies the main period of tourism further. Consequently external impact, as caused by tourism can easily disrupt the delicate equilibrium of Icelandic ecosystems and be a catalyst for severe land degradation resulting in loss of geo- and biodiversity. Therefore, it is of vital importance to increase our knowledge and understanding of the environmental impact of tourism in such environments in order to support future mitigative interventions, as well as the development of suitable tourism policies for sustainable visitor use in vulnerable Arctic environments.

For a long time hiking has been one of the most popular tourist activities in Iceland, especially in the interior highlands. Research on recreational trampling in arctic ecosystems identifies trampling as one critical factor in the alteration and degradation of ecosystems (e.g. Chrisfield, Macdonald, & Gould, 2012; Forbes, Monz, & Tolvanen, 2004, Monz, 2002; Scott & Kirkpatrick 1994; Pounder 1985). Monz (2002) proved that the disturbance threshold of the Arctic tundra is relatively low and emphasized the importance of managing tourism so that its impact is kept below each area's disturbance threshold. Degradation of hiking trails by overuse is a recognized problem worldwide. The most common indicators include trail widening and deepening, multiple tread formations, root exposure and damage, and soil erosion (e.g. Cole, 1983, 1986; Leung & Marion, 1996, 1999; Jewell & Hammitt, 2000; Rochenfort & Swinney, 2000; Dixon, Hawes, & McPherson, 2004; Hawes, Candy, & Dixon, 2006Marion, Leung, & Nepal, 2006; Tomczyk & Ewertowski, 2011). Monz, Cole, Leung, and Marion (2010b) believe that trampling is the most widespread and systematically-studied mechanism of recreational disturbance on natural systems, largely because trampling is the most visible form of disturbance from outdoor recreation activities. However, most studies focus on comprehensive field measurements that are time-consuming and economically unfeasible for large areas. In Iceland very few studies have been carried out about the environmental impacts of tourism in general and trail disturbances in particular. Hitherto, only Gísladóttir (2001, 2003a, 2003b, 2006) has undertaken research into tourist trampling, focusing on detailed measurements of the change in vegetation cover, vegetation resistance to trampling, and changes in soil properties on selected hiking trails at several popular tourist sites in Iceland. She concludes that of these three variables assessed vegetation cover is the major indicator for trail condition, and that moss-heath is the most vulnerable type of vegetation cover to trampling. Yet moss heath is the most typical type of vegetation on the Icelandic interior highlands (Guðjónsson & Gíslason, 1998).

In order to manage the environmental impact of nature tourism and to plan tourism in a sustainable manner, a holistic overview of the condition of hiking trails in Iceland's most popular tourist destinations is critical, together with a better understanding of the relationship between the trails' location and their physical properties. This paper aims to evaluate environmental trail conditions as a function of tourism use in two popular tourist destinations within the Icelandic southern highlands, firstly by mapping and analyzing the severity of current trampling impacts, and secondly by using GIS to examine the spatial relationship between trail condition and select physical properties related to the trail's location, such as elevation, gradient and ecological sensitivity.

2. Study areas

2.1. Environmental settings

Iceland has a land mass of approximately 103,000 km^2 extending approximately from latitude 63°23′ to 66°32′N and longitude 13°30′ to 24°32′ (NLSI, 2012). The country is a volcanically active island situated on the Mid-Atlantic Ridge where the boundaries of the American and Eurasian tectonic plates are continually spreading apart. Elevation ranges from sea level to 2110 m. More than one-third of the country's surface area lies above 600 m and only about a quarter below the 200 m contour line (NLSI, 2012).The Icelandic population inhabits the coastline, leaving the interior highlands uninhabited. The highlands are characterized by a large mountainous plateau and in many place a desert-like terrain. It is mainly made up of vast post-glacial lava fields, glaciofluvial deserts, and ice caps which currently cover approximately 11% of the country's surface area (NLSI, 2012), the majority of them located within the highlands. Yet to date there is no official definition of the Icelandic highlands. In 1998 the first and only regional plan for the highlands was produced (i.e. Icelandic Central Highlands, 1998) and appropriate boundaries for the central interior highlands were proposed, stating that it encompasses 40% of the country's surface area (Fig. 1). The Icelandic interior highlands have for a long time attracted both native and foreign nature lovers and are today regarded as a valuable resource for Icelandic tourism.

Icelandic soils are mainly of volcanic origin with *Histosols, Andosols* and *Vitrisols*, Andosols being the most common (Arnalds, 2008, Arnalds & Óskarsson, 2009). The volcanic content of the Andosol makes them highly susceptible to erosion because of their high sandy content and lack of cohesion, which result in an increased susceptibility to erosion by wind and water, but according

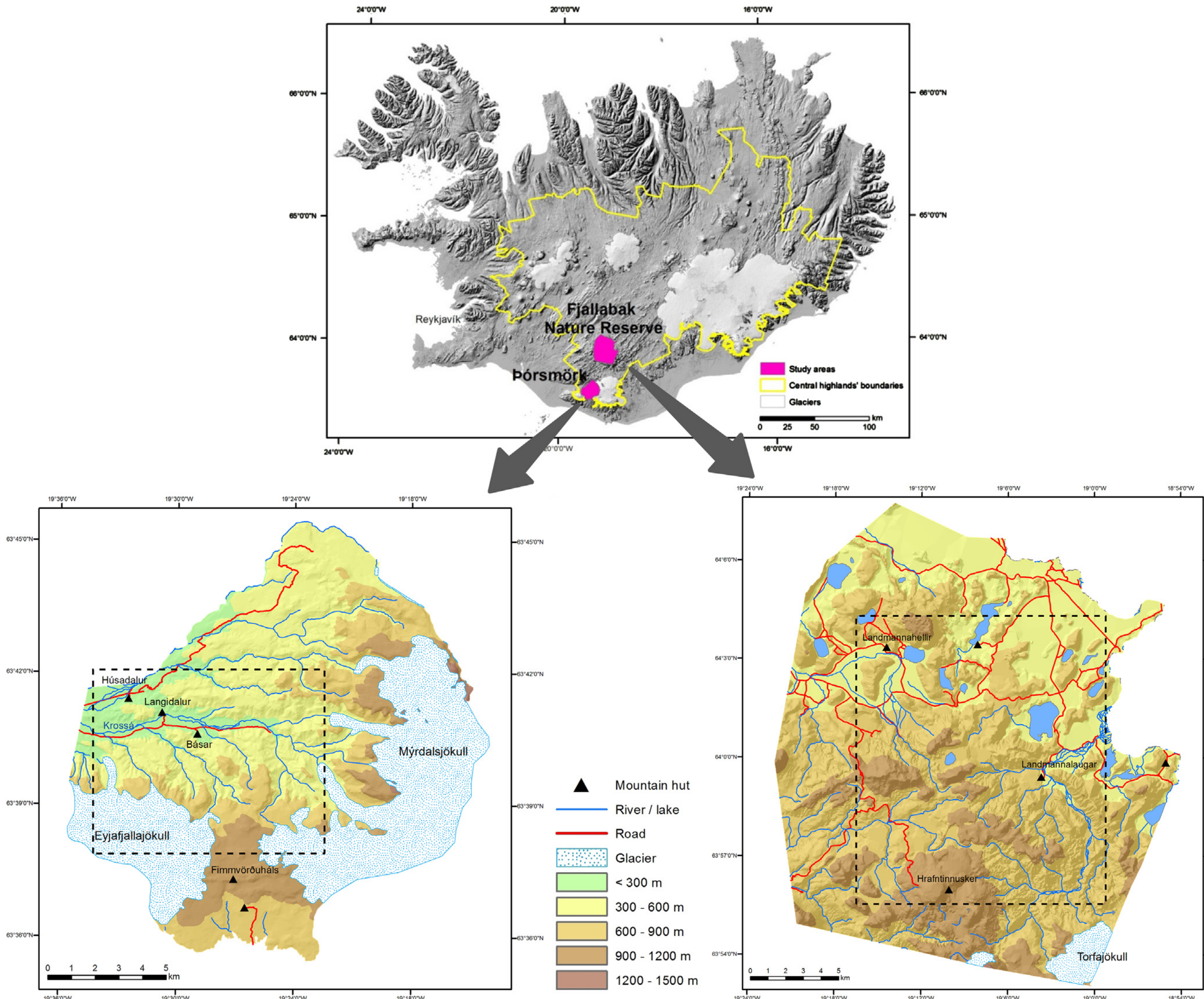

Fig. 1. Location of the two study areas, i.e. Fjallabak Nature Reserve and Þórsmörk. The yellow line indicates the proposed boundaries of the Icelandic interior highlands. The dotted frames refer to areas presented in Fig. 3. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to Arnalds et al. (2012) Iceland contains some of the most active areas of wind erosion in the world. Currently about 42% of Iceland is covered with vegetation, of which only 1.2% contains woody species (Arnalds, 2011). The most common vegetation types are heathland and sparsely vegetated land (i.e. vegetation cover $<50\%$ with the number of species and their composition varying depending on local conditions). However, mosses and various types of lichens dominate the vegetation over large areas of the interior highlands as well as many of the extensive lava fields. The uppermost limit of continuous vegetation is currently around 700 m in the north-eastern part of the highlands. The majority of the highlands, however, is comprised of subarctic desert with scattered plants or isolated patches of vegetation which cover no more than 2–5% of the highland area. All Icelandic vegetation is characterized by a short growing season and excessive vulnerability to changes caused by climatic and anthropogenic pressures (e.g. Arnalds, 2011; Ólafsdóttir, Schlyter, & Haraldsson, 2001). The fieldwork for this study was undertaken in the Fjallabak Nature Reserve and the Þórsmörk area (Fig. 1).

2.2. Fjallabak Nature Reserve

Fjallabak Nature Reserve (FNR) is located in the southern central highlands of Iceland. It contains some of the most popular tourist spots in Iceland, such as the hot springs area, Landmannalaugar (Fig. 1). The Nature Reserve was established in 1979 (Icelandic Statutory Law Gazette, 1979). It comprises 47,000 ha and is located between 450 and 1250 m above sea level. The FNR is situated in the middle of the active volcanic rift zone. It is characterized by diverse geology and a mountainous landscape sculptured by colorful rhyolite and basaltic mountains mixed with black lava and sand plains as well as glaciers, rivers and lakes. About half of the Nature Reserve is part of a huge caldera, i.e. Torfajökull central volcano, containing Iceland's second largest geothermal area within its rim. In the FNR vegetation cover is scarce and continuous vegetation cover is very rare. Furthermore, due to the areas altitude the growing season lasts only about two months with cold climate and frequent storms for the rest of the year (e.g. Haraldsson, 2010; The Environment Agency of Iceland, 2012).

The first tourist hut in the area was built in 1952 in Landmannalaugar (Haraldsson, 2010). Before very few people visited the area, except farmers who spent some time in the highlands each autumn to round up the sheep they had left there for grazing over the summer. Since 1952 the access into the highlands has greatly improved and so has the tourism infrastructure within the Nature Reserve. In the years 1977–1979 small and primitive tourists huts were constructed at three locations between Landmannalaugar in the North and Þórsmörk in the South by the

Icelandic Touring Association (Ingunn Sigurðardóttir, office manager at the Icelandic Touring Association; personal communication, 27.07.2012). Subsequently, a walking trail between the huts was marked with poles, opening the country's still most popular hiking route between Landmannalaugar and Þórsmörk, over a total distance of 55 km. Today these old huts have been replaced by larger ones fulfilling the modern demands of increased tourist facilities and services. No accurate statistic exists for the number of tourists hiking between Landmannalaugar and Þórsmörk, but they are estimated at approximately 8000 hikers per annum (Ingunn Sigurðardóttir, office manager at the Icelandic Touring Association; personal communication, 27.07.2012). Similarly, no accurate data exists on the annual number of visitors to the FNR. Estimates based on counting vehicles on major access routes and multiplying this figure by the average number of people in each vehicle indicate that around 120,000 tourists visited the Nature Reserve during the summer of 2011 (Sæþórsdóttir & Ólafsson, 2012).

2.3. Þórsmörk

Þórsmörk has for a long time been one of Iceland's most popular highland destinations. Located at the roots of the stratovolcano Eyjafjallajökull, the area received increased attention from foreign visitors following its eruption in 2010. Þórsmörk is located between three glaciers, namely Mýrdalsjökull to the east, Eyjafjallajökull to the south and Tindfjallajökull to the north (Fig. 1). Its elevation ranges from 150 m to 1500 m above sea level. The area is characterized by a diverse geology and contrasting landscapes of black basaltic mountains, melting glaciers, vigorous glacial rivers and striking vegetation. Bedrock is largely made up of soft and erosive volcanic material formed by subglacial eruptions and valley floors of glaciofluvial deposit constantly produced by the ever-changing glacial rivers (e.g. Jóhannesson & Sæmundsson, 2009). The surrounding glaciers and mountains provide exceptional climatic conditions for the vegetation cover of heathland and birch woodland (Guðjónsson & Gíslason, 1998). The soils are composed of thick eolian and volcanic material that is particularly vulnerable to erosion once the vegetation cover is removed.

The name Þórsmörk originally included only part of the study area, namely the area north of Krossá, a vigorous glacial river flowing westwards from the glacier Mýrdalsjökull. Goðaland is the name of the area south of Krossá. In 1919 farmers that had been using Þórsmörk for grazing, in response to severe vegetation and soil degradation, decided to protect the area from grazing. In 1924 Þórsmörk and the surrounding area was fenced off and placed under the protection of the Iceland Forest Service, which to the present day remains responsible for the wooded land in the area (Iceland forest service, 2012). Until today, Þórsmörk and the surrounding area is not protected by law. However, a proposal has been made for protecting a 205 km^2 area encompassing Þórsmörk. For the purposes of the present study the name Þórsmörk will refer to the proposed protected area.

The first tourist hut in Þórsmörk was built by the Icelandic Touring Association in 1954 and enlarged in 1972 (Morgunblaðið, 1994). In 1980 another tourist hut was built in Goðaland south of Krossá (Útivist, 2012) and a couple of years later a third hut was built in Húsadalur, a valley northwest of the first hut. Today all of these huts and facilities have been enlarged and extended several times to meet the demands of the growing number of visitors. The number of visitors to the Þórsmörk area is limited by difficult access. For example, the access route must cross several unbridged vigorous glacial rivers and requires 4WD vehicles and experienced drivers. The area can also be reached by foot, either via the highland in the north or over Fimmvörðuháls from the south, which is a popular hiking route between the glaciers Mýrdalsjökull and Eyjafjallajökull. However, no accurate counts of visitors to Þórsmörk exist.

3. Methodology

3.1. Field assessment and measurements

An integrated approach of point sampling and condition class assessment methodologies was chosen to analyze the severity of current trampling impacts and the proportion of tracks subject to deterioration within the two study areas. Each of the assessed trails was hiked by two or three observers simultaneously to minimize subjectivity in the visual assessment, and sampling points were located every 100 m. At each sample point the trail's width and depth were measured and a visual assessment was made of the trampling impact on the ecosystem and severity of soil erosion. A total of 817 sample points were collected and classified within the two study areas, 293 in the Þórsmörk area and 524 in the FNR. Such a sampling approach provides a relatively precise overview of the current condition in a time saving and cost effective way. The field inventories were carried out in Þórsmörk in August 2010, and in FNR in July 2011. All hiking trails in each of the two areas that are marked with poles and shown on tourist hiking maps were selected for the study (see: http://www.re.is/media/PDF/walkmap2004.pdf; http://www.landmannalaugar.info/Design/Kort2005/Map2005Landmannalaugar.pdf). In the Þórsmörk area the hiking trails assessed are confined to one area, while in FNR the trails are located in Landmannalaugar, Landmannahellir and Hrafntinnusker (Fig. 1). A new trail located between Landmannahellir and Hrafntinnusker which was first marked with poles in 2011 was also assessed, but these measurements were excluded from our assessment because its condition as a new trail without any visible impact would have skewed the results. However the data relating to this new trail will be valuable for later monitoring.

To obtain the proportion of tracks subject to deterioration, a systematic point sampling method was used for data collection. Marion and Leung (2001) conclude that the point sampling method provides more accurate and precise measures of trail character than the problem census method. Leung and Marion (1999) also conclude that using a systematic point sampling method to assess the extent of trail impact problems gives an adequate level of accuracy for most impact types if the sampling intervals are between 100 m and 500 m, and an excellent level of accuracy for most impact types examined at sampling intervals of less than 100 m. However, Hawes et al. (2006) argue that the frequency of occurrence is heavily underestimated when using the point sampling method at all scale intervals. A recent study by Hill and Pickering (2009) focusing on the comparison of several methods in assessing hiking trail condition underlines the importance of point sampling in the need of detailed information and monitoring. They also suggest using a condition class assessment method to obtain an overview of a trail system condition in a fast and simple way.

3.2. Field data scales and metrics

To obtain a holistic overview of hiking trail condition in the various tourist sites in Iceland, a compatible condition scale for the Icelandic condition is critical. For managers to be able to use such a scale it needs to be well-adapted, reasonable and easily applicable. Condition class systems are commonly used in assessing hiking trail degradation (e.g. Leung & Marion 1996; Nepal & Nepal, 2004; Jewell & Hammitt, 2000; Hill & Pickering, 2009; Monz, et al 2010a). The major advantage of using such a system is the ease of its application and simplicity in presenting its findings (Marion et al., 2006). It also allows the assessment of much larger areas in less time and at a lower cost than other methods of hiking trail assessment (Marion et al., 2006).

The condition scale used in this study is developed from descriptions by Marion et al. (2006) and adjusted to Icelandic conditions according to Table 1. The scale is based on the assessment of four key indicators of trail degradation, namely the (i) width of the trail, (ii) depth of the trail, (iii) ecosystem type, and (iv) visible soil erosion (Table 2). The third indicator, ecosystem type, refers to the condition of vegetation and soil cover on the trail compared to the condition of vegetation and soil cover surrounding the trail. Hence, by classifying the surrounding ecosystem regarding vegetation type and coverage, the condition on the trail can be compared to assess the degradation caused by tourism. The hiking trails in the Icelandic interior highlands pass through ecotypes that range from total absence of vegetation to 100% vegetation cover. Therefore, when assessing the trails' surroundings, an area of 2 by 2 m on each side of the trail was evaluated. To prevent over-complexity in interpretation of the class assessment definitions, a classification system presented by Ólafsdóttir (2007) was developed further for Icelandic condition in this study. Each key indicator was thus assigned a score ranging from zero to three according to its condition (Table 2). The total condition scale at each point is determined by simply summarizing the evaluations for these four variables. The added benefits of utilizing such a classification system is ease of use, and that comparisons between different areas will become easier.

Table 1
Condition scale for hiking trails in Iceland.

Scale	Condition	Score according to classification	Definition
0	Very good	0–1	No stress. Trail is hardly seen. Little or no disruption to the vegetation cover and/or the parent material. No erosion.
1	Good	2–4	Little stress. Trail noticeable. Disruption of vegetation cover and/or the parent material significant. No erosion.
2	Acceptable	5–7	Some stress. Trail obvious. Disruption of vegetation cover and/or the parent material considerable. Significant erosion.
3	Bad	8–10	Much stress. Vegetation heavily degraded or dead. Parent material eroded. Active erosion.
4	Very bad	11–12	Very heavy stress. Vegetation dead and soil erosion striking. Active gully erosion from trail.

Table 2
Classification system for hiking trail condition assessment.

Indicator	Definition of assessment	
1. Width	**0 score**: Trail is hardly seen (unclear). **1 score**: Simple trail $<0{,}5$ m **2 score**: Trail 0,5–1,0 m, 1–2 side paths **3 score**: Trail >1 m. Multiple side paths	**0 score**: Total width of affected area <1 m **1 score**: Total width of affected area 1–10 m **2 score:** Total width of affected area 11–20 m **3 score:** Total width of affected area >20 m
2. Depth	**0 score**: <5 cm **1 score**: 5–24 cm **2 score**: 25–44 cm **3 score**: $\geq$ 45 cm	Depth is based on the deepest part of the trail
3. Ecosystem type	**0 score**: No apparent impact on the area's ecosystem. Trail is hardly seen (unclear). **1 score**: Visible impact, but no major impact on the ecosystem in the trail compared to the surroundings (2×2 m^2). Depression seen in the vegetation cover and/or in the top soil. **2 score**: Clear impact on the ecosystem. Vegetation dead and/or clear vegetation changes. Soil compacted. **3 score**: Significant and permanent impact on the ecosystem. Vegetation and/or top soil has disappeared. Clear and permanent changes in the soil/gravel cover.	
4. Soil erosion	**0 score**: No erosion **1 score**: Breaking starting at the edges **2 score**: Gullies in the edges – vegetation roots striking **3 score**: Transformation of material due to wind and water erosion both in the trail itself and off the trail	

When assessing the trail width the heavy use along popular trails often leads to the establishment of a number of parallel trails which extend the total width of affected area beyond the original single trail. Likewise, in flat areas large hiker groups tend to spread out, disturbing much wider area of the ecosystem than just the trail itself. The disturbance tends to decrease with distance from the original main trail. The score calculation for the width indicator is therefore based on two measurements, i.e. the width of the main trail as well as the total width of the affected area. Hence, the following equation was used to derive the scores for the total trail width.

$$Total_{w_{score}} = \left(W_{trail} + \frac{W_{IZ}}{2}\right) \quad (1)$$

where W_{trail} is the width of the main trail, W_{IZ} is the width of the total impact zone related to the main trail and $Total_{w\_score}$ is the total score for the width indicator according to Table 1.

3.3. GIS analysis and statistical evaluation

Extracting physical properties from digital data requires less person time and money for field surveys. Large trail systems can thus easily be examined and monitored. Therefore, it was decided to appraise the use of a GIS for examining the spatial interrelationship between the measured trail condition in situ and physical properties obtained at specific trail locations obtained from secondary data. For that purpose, each measured sampling point was also assigned its GPS coordinates and was imported into a GIS together with the assessed condition class variables. Thus, each sampling point could be visualized according to its condition class within the spatial pattern of the whole trail system at each study site. Concentrations of sampling points with poor conditions become easily apparent. More importantly, the layer of condition class can be analyzed spatially against available geographical layers such as elevation, gradient, land cover, ecological sensitivity, etc., to investigate spatial relationships between

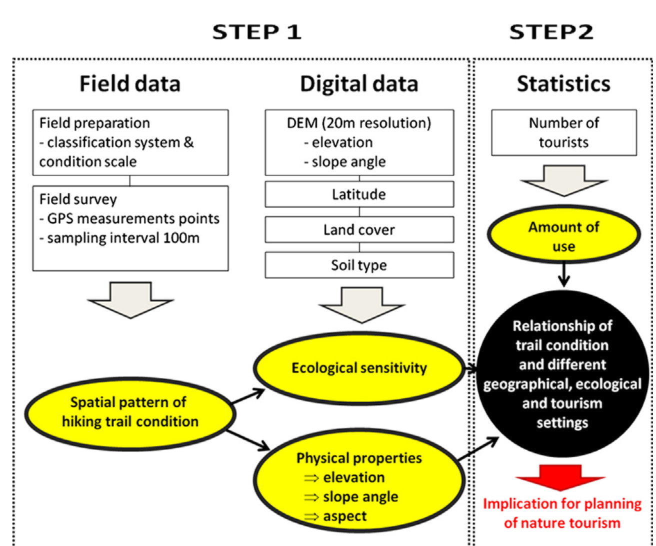

Fig. 2. Flow chart illustrating the relationship between the study's major steps of data collection and conceptual elements. The study is divided into two steps. This study presents step 1.

trail condition and local physical properties. In this paper condition class was analyzed against vegetation cover data obtained from a joint database on Icelandic land cover compiled by the Agricultural University of Iceland from an Icelandic farmland database and a land cover/land use map based on the European land cover database CORINE adapted for Icelandic conditions by the National Land Survey of Iceland (NLSI, 2009); soil type data based on Arnalds and Óskarsson (2009); elevation above sea level as well as gradient (degrees) derived from a digital elevation model (DEM) at a 20 by 20 m resolution obtained from the Icelandic geo-database IS50V3.1; and ecological sensitivity created from multi-criteria evaluation of the combined effect from slope, soil type and vegetation type. A flow chart of the working method and the GIS-analysis applied is presented in Fig. 2. To test the relationships between hiking trail condition class and each of the local physical variables a chi-square test (χ^2) of independence was applied.

4. Results

4.1. Hiking trail condition in Þórsmörk and Fjallabak Nature Reserve

The spatial patterns obtained for the calculated total condition scale classes clearly show that the frequency of points classified as being in *bad* or *very bad* condition is higher in Þórsmörk than in FNR (Fig. 3). Also, in Þórsmörk sampling points of bad conditions are much more clustered, thus forming long sections of the hiking trail (of 300 m to 1000 m) in bad and very bad condition.

Less than half (41%) of the hiking trails assessed within the Þórsmörk area are classified as being in good or very good condition. A total of 29% are in acceptable condition. Trails classified as bad or very bad amount to 30% and 12% respectively (see Fig. 4 for examples). The majority (61%) of the hiking trails assessed within FNR on the other hand are in good (27%) or very good (11%) condition, while less than 1% is in very bad condition. Thus the physical condition of the trails in Þórsmörk is noticeably worse than in FNR. As to be expected, the width of a trail's impact zone tends to expand greatly in flat, unvegetated or partially-vegetated areas. In such areas the width of the impact zone may reach over 50 m, often with no clear single path. This was particularly noticeable in the flat sections of the higher altitudes in the Landmannalaugar hiking trails system (Fig. 5). These wide, loosely distributed trails cause great damage to the patches of mossy vegetation which characterize the landscape at higher altitudes (Fig. 6). In such susceptible vegetation even a single step can have a severe impact, emphasizing the importance of tourism management.

4.2. Relationship between hiking trail condition and physical properties

4.2.1. Elevation

The trail sampling points assessed for FNR are located between 575 m a.s.l. and 1120 m a.s.l. with a mean value of 742 m a.s.l. In Þórsmörk the sampling points are between 198 m a.s.l and 800 m a.s.l., and the average elevation of the samples is 384 m a.s.l. The hiking trails are thus located at higher elevations in FNR compared to Þórsmörk. The results show a slight increase in the frequency of good condition classes (Cond_cl 0 and 1) at higher elevations in both study areas (Fig. 7). This observation may possibly be explained by the fact that fewer people hike the trails at higher elevations because it is more physically demanding and instead choose the easier and more accessible trails at lower elevations. This behavior likely applies to all day visitors, however so far no information on the number of tourists is available to support this hypothesis. However, all condition scales

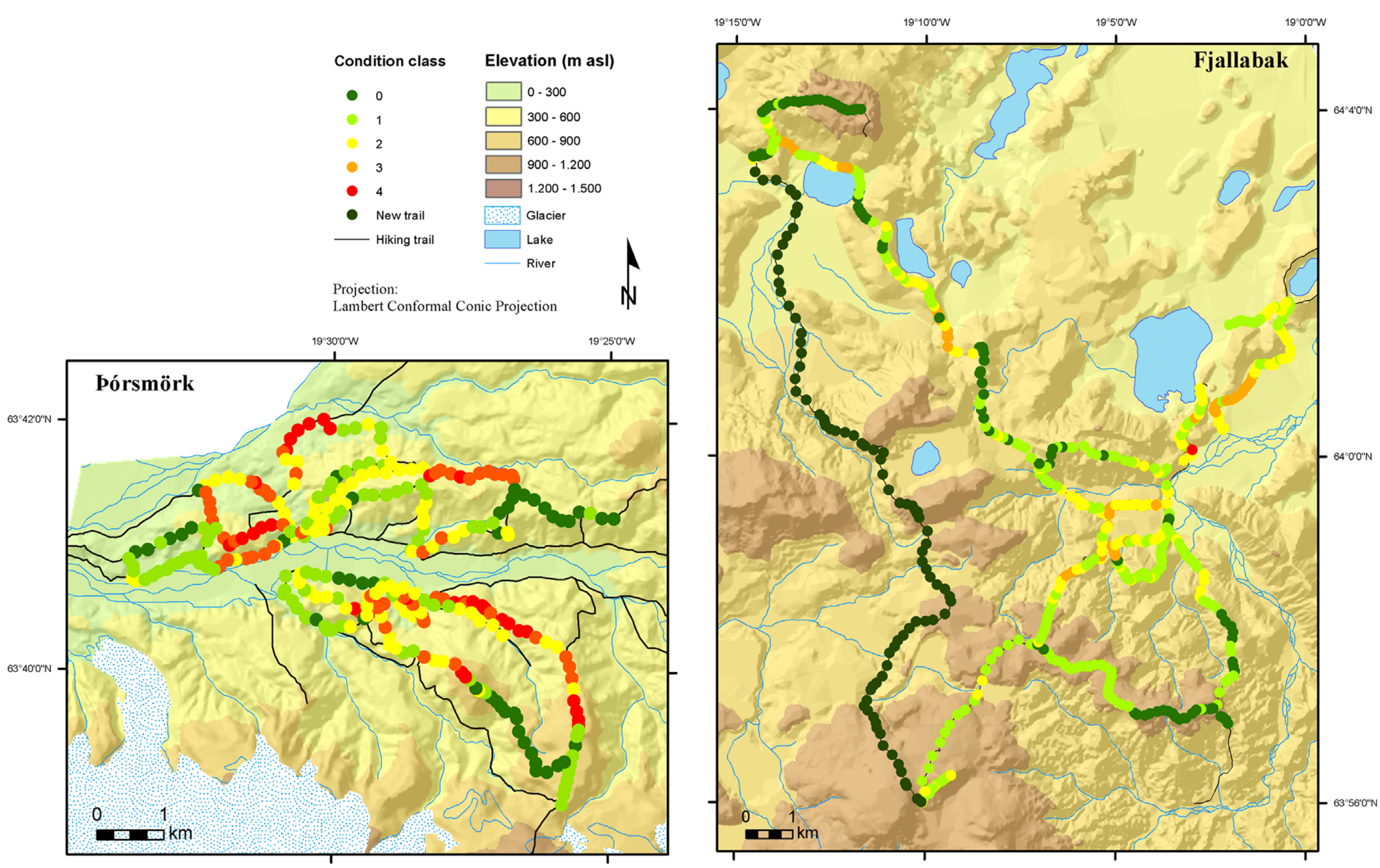

Fig. 3. The spatial pattern of the assessed hiking trail condition for the two study areas tested, Þórsmörk to the left ($n=293$) and Fjallabak Nature Reserve to the right ($n=524$).

Fig. 4. Examples of severe hiking trail degradation in the study areas (Photographs Rannveig Ólafsdóttir & Micael Runnström).

Fig. 5. Large impact zone as a result of a hiking trail on a flat unvegetated surface close to Landmannalaugar (Photograph Rannveig Ólafsdóttir).

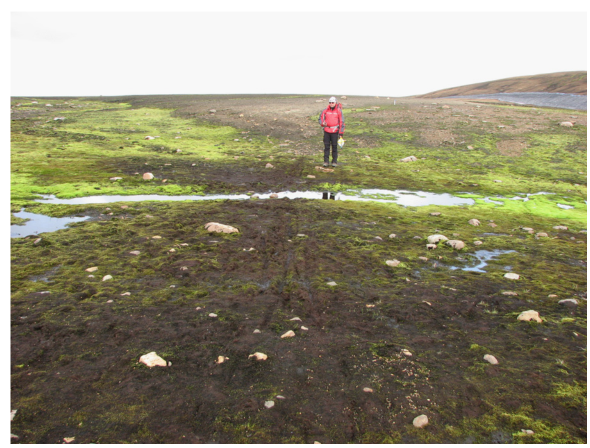

Fig. 6. Severe impact of a hiking trail traversing the patchy mossy vegetation that characterizes large areas of the Landmannalaugar hiking trail system (Photograph Rannveig Ólafsdóttir).

are represented in each elevation category and one can find both good and bad conditions at all elevations, except for very bad condition class (Cond_cl 4) at high elevations in FNR. Trail condition and elevation are statistically dependent in both study sites (Þórsmörk: $\chi^2 = 30{,}572$; with $p < 0.001$; FNR: $\chi^2 = 114{,}47$; with $p < 0.001$): more samples of good trail conditions (Cond_cl 0 and 1) occur in higher elevation and more samples than expected of severe trail conditions occur in lower elevation.

4.2.2. Gradient

The condition class analysis examined against gradient shows a clear relationship with gradient in the Þórsmörk area (Fig. 8). The higher the gradient, the more frequent the occurrence of bad conditions on the hiking trails. These variables are statistically dependent ($\chi^2 = 36.03$; with $p < 0.001$), possibly explained by the higher erodibility of the vegetation and soil by water at higher gradients caused by the higher velocity of running water due to gravitational forces as the gradient increases. In FNR the relationship is however not as clear as in Þórsmörk with condition class 3 (bad condition) slightly decreasing with increased gradient ($\chi^2 = 9.34$; $p = 0.155$). Part of an explanation to this might be that the whole trail system as such is much younger in FNR than in Þórsmörk. Hitherto, the majority of the visitors in FNR only stop for a day, and the large majority of hikers come to hike only one path, namely the path between Landmannalaugar and Þórsmörk.

4.2.3. Bio-physical properties

No clear relationship was observed between the hiking trail condition classes and the different bio-physical variables tested, namely soil type, vegetation cover and ecological sensitivity. When only looked at vegetated areas versus unvegetated areas (Fig. 9) no relationship is obtained in the Þórsmörk area ($\chi^2=5{,}553$; $p=0.235$), while at FNR a significant relationship is obtained ($\chi^2=66.04$; with $p<0.001$). Hence, more samples than expected are observed for severe trail conditions (Cond_cl 2, and Cond_cl 3) when vegetation is surrounding the trail.

4.2.4. Interrelations between severe trail condition and physical properties

When hiking trails in bad and very bad condition (Cond_cl 3 and 4) are combined a clearer relationship emerges with regards to ecological sensitivity, gradient and elevation (Fig. 10). The proportion of hiking trails in bad and very bad condition increases noticeably with an increase in ecological sensitivity at both study sites. With regards to gradient and elevation it is however noteworthy that the proportion of trails in bad and very bad condition increases with increased gradient and elevation in the Þórsmörk area, but decreases in FNR. Higher spatial resolution and better quality of digital data with regards to physical properties, still lacking in Iceland, might give improved relations when compared with data at hiking trail level.

5. Discussions and conclusions

5.1. Relationships between environmental condition and tourism in the Icelandic highlands

Increased tourism impact worldwide combined with tourists' growing environmental awareness has led to increased demands for sustainable planning and management of tourism, particularly in the world's most vulnerable areas (e.g. Monz, et al., 2010a, 2010b; Newsome, et al., 2013; Ólafsdóttir & Runnström, 2009;

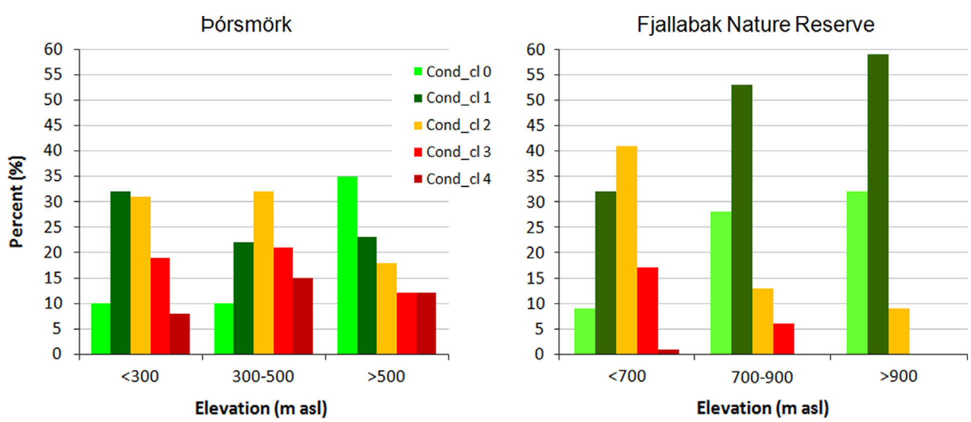

Fig. 7. Relationship of elevation and hiking trail condition in the study areas. The hiking trail condition classes are separated into three elevation categories, i.e. in Þórsmörk <300 ($n=109$), 300–500 ($n=127$), and >500 ($n=57$); and in FNR <700 ($n=280$), 700–900 ($n=133$), and >900 ($n=111$).

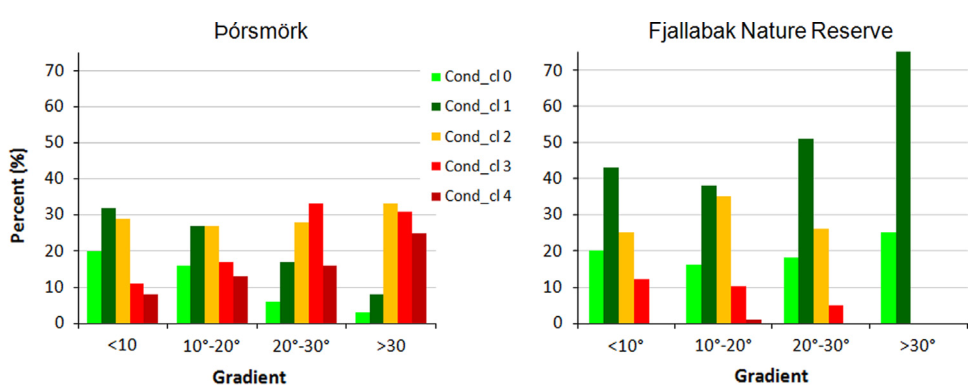

Fig. 8. Relationship of gradient and hiking trail condition in the study area. The hiking trail condition classes are divided into 4 gradient categories, i.e. in Þórsmörk $<10^\circ$ ($n=137$), 10°–20° ($n=70$), 20°–30° ($n=51$), and $>30^\circ$ ($n=35$); and in FNR $<10^\circ$ ($n=318$), 10°–20° ($n=159$), 20°–30° ($n=43$), and $>30^\circ$ ($n=4$).

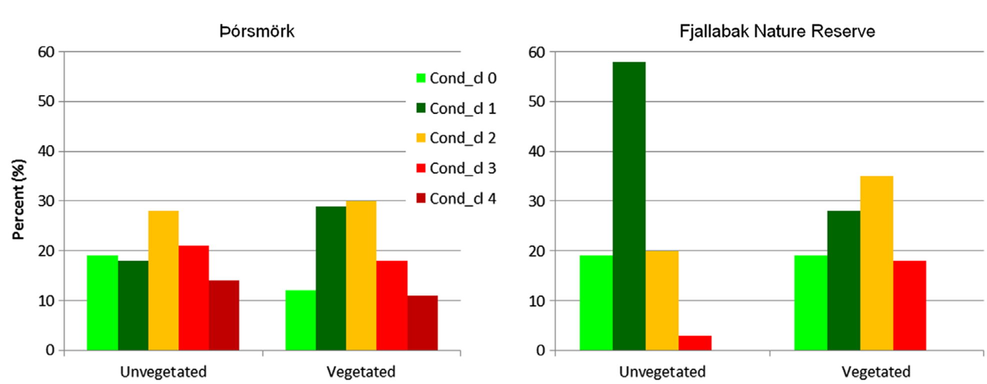

Fig. 9. Proportion of the different hiking trail conditions in vegetated vs. unvegetated areas in the respective study sites. Þórsmörk: Vegetated ($n=206$), Unvegetated ($n=87$). FNR: Vegetated ($n=252$), Unvegetated ($n=272$).

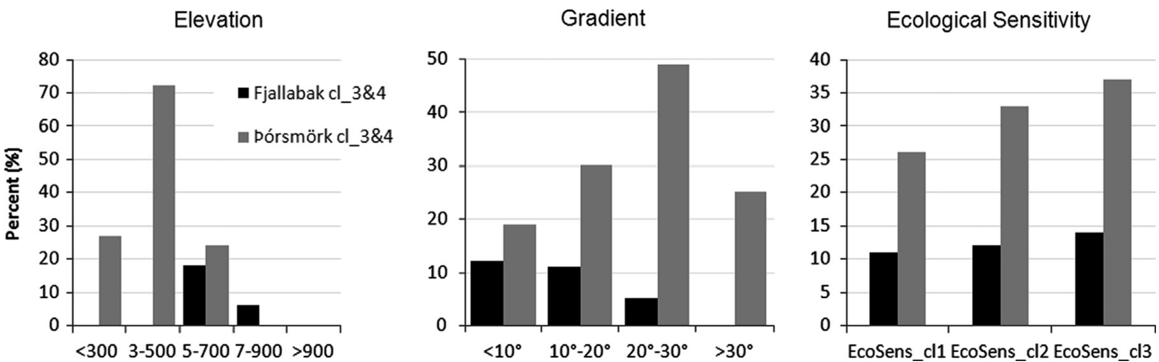

Fig. 10. Relationships between hiking trails in bad and very bad condition (i.e. condition class 3 and 4) by study area and (a) elevation, (b) gradient, and (c) ecological sensitivity.

2011). In Iceland tourism has been increasing at an exponential rate over the past decades. Subsequently environmental impacts on the country's natural resources have also increased. Hiking has for a long time been one of the most popular outdoor activities among Icelanders as well as international tourists visiting the Icelandic highlands. Despite an increasing interest in alternate outdoor activities, such as riding, biking, snowmobiling, etc., hiking still retains its popularity. Thus, the impact from tourist trampling is increasing proportionally with the increases in tourism. Forbes, et al. (2004) explain that in Arctic environments ecological changes are inevitable even with very low levels of visitor traffic. They report that reduction in species cover and density may occur at low trampling intensities, leading to decreased perceived environmental values to the hikers as a consequence of reduced visual quality. Our study reveals that within the two study sites in the southern Icelandic highlands severely deteriorated trail segments amount to more than 30%, and 10% of the respective sites' trail systems. Such figures demand action if one desires to ensure the sustainable use of these natural resources, especially since the observed trail deterioration usually is associated with severe soil erosion that may trigger subsequent land degradation impacting larger areas. This chain of events is supported by research on land degradation in Iceland (e.g. Greipsson, 2012; Haraldsson & Ólafsdóttir, 2003; Ólafsdóttir & Guðmundsson, 2002) emphasizing the country's delicate ecological balance. Hence, in the country's most vulnerable areas relatively minor damage to the vegetation cover is enough to expose the underlying soil bank to the active processes of wind and water erosion. Thus unsuitable environmental impact from tourism can easily trigger more severe land degradation, further stressing the critical importance of sustainable management of tourism in vulnerable arctic environments.

Our analysis of the relationship between the observed trail condition and local physical properties only produces significant relationships for elevation – in both study sites. Thus, the results provide interesting indications that the physical properties tested are of less importance with regards to hiking trail conditions, leaving the magnitude of trampling as the best indicator variable of trail conditions in the Icelandic highlands. This finding is in agreement with Nepal and Nepal's (2004) suggestion of a strong relationship between trail degradation and visitor use. However, based on a visual interpretation of their mapping they also indicate that physical properties are equally responsible for hiking trail degradation. Their observation coincides with the results in this study that in all cases bad trail condition are found on part of each trail, but not a whole trail, and that physical variables are related to the most severe trail conditions. Our findings demonstrate that trail conditions are based on a combination of trampling magnitude and local physical properties (Fig. 11). This finding is supported by Cole (2004) who concludes that the most

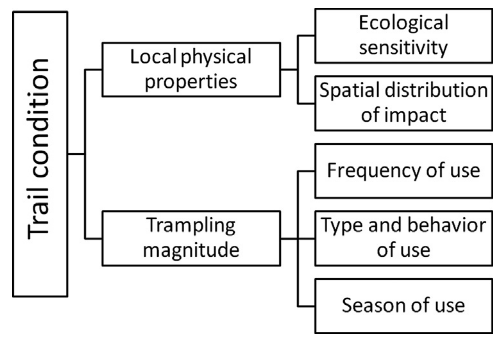

Fig. 11. Key factors influencing trail condition (modified from Cole, 2004).

influencing factors of trail condition are intensity of use and area of impact. Nevertheless, more precise spatial data on local physical properties would be needed to calibrate a more reliable model of the different factors influencing hiking trail condition in Iceland, and to understand their complex interrelationships. An average gradient for a certain area (e.g. 5×5 m^2) may be measured at each sampling point in field, but the procedure is both time consuming and would not be useful in identifying potentially susceptible areas as by using digital data layers of the local physical properties. A higher resolution DEM from which accumulations of surface water can be modeled might further aid in finding locations where bad trail conditions is likely to occur.

5.2. Management implications

The vulnerability of Iceland's natural resources is exaggerated by the country's geological origins and its location in the middle of the North Atlantic Ocean. The Icelandic highlands are also characterized by a short growing season and large parts of the highlands are located within the country's neo-volcanic zone, further intensifying its ecological vulnerability. It is important to keep this in mind when planning for the future of nature based tourism in the Icelandic highlands to avoid environmental impacts from tourism to cause such damage that the value for the purposes of tourism will be decreased.

Dynamic landscapes and diverse natural scenery have long been the major resource of the Icelandic tourism industry. The two case study sites surveyed here exemplify many of the most popular tourist spots in the Icelandic highlands. They serve as representative examples of spectacular but vulnerable natural resources attracting visitors in volcanic arctic environments. This vulnerability underpins the critical importance of well-defined planning and management of tourism in such environments in order to preserve the source of the original attraction. Managing vulnerable natural areas for tourism development without changing the tourists' experience remains a challenge which many strive towards, but few accomplish. In order to succeed, knowledge based on reliable data and research is fundamental, as has been stressed by numerous researches (e.g. McCool, Clark, & Stankey, 2007; Patterson, Niccolucci, & Marchettini, 2008). It is thus of vital importance that the selection of planning method should be based upon holistic land use planning for tourism that is based upon knowledge and understanding of the natural resources in question and a rational interaction between land use management and conservation. In Iceland such holistic planning is still lacking, as is comprehensive data on the environmental impact of tourism. In such a situation environmental attributes available from digital data can provide critical information about the various tourism resources. Integrating them in a GIS improved the visualization of spatial patterns and the analysis of the relationship between different environmental geo-biophysical variables.

The methodological approach in this study is based on using low-cost and easily applicable, but yet comprehensive tools to assess the condition of hiking trails in the Icelandic highlands. Such an approach allows for a holistic understanding of environmental conditions that is less time consuming and more cost effective than direct measurements in field. The results show that a visual assessment in the field based on a carefully prepared classification system of trail conditions, much larger trail systems can be effectively assessed and mapped. Visual interpretation of the spatial pattern of condition classes provides valuable information to managers about the location of degraded trails and problem areas. Likewise planners will be able to locate potential problem sites when designing new trails. Analysis of the field data against high resolution digital data of local physical properties further give planners indications of the most important variables related to hiking trail degradation.

Furthermore, when designing recreational hiking trails in the Icelandic highlands, special care should be taken when planning trails on slopes, especially in moss and moss-heath covered slopes. Wherever possible, planners should avoid steep slopes when designing new hiking trails. Overall, our study clearly indicates that the number of hikers is the major factor of trail deterioration. Therefore it is of fundamental importance to control the number and flow of visitors in the most vulnerable areas. Visitors can be managed by restrictions, or alternatively by informational signs targeting the environmental conscience of visitors by informing about the area's ecological vulnerability as well as the effects of their own trampling on such an ecosystem. It is also crucial to maintain hiking trails at all times so that it is more likely for hikers to stay on the trail and pre-empt the spreading of a larger impact zones. In the Icelandic highlands where the trails are usually marked with wooden poles, it is important that the distance between the poles is close enough so that the hikers can easily navigate from one pole to the next. This is especially vital in flat areas where trails tend to spread out and consequently quickly disturb a much larger area.

At present, many hiking trails in the Icelandic highlands are gradually becoming more popular for other types of outdoor recreation, for example mountain biking and mountain marathon races which have an even larger the environmental impact. Therefore even more emphasis needs to be put on the management of the trails. The condition scale based on the classification system developed in this study can be used to regularly monitor trail conditions and to record the changes in order to increase the understanding of the environmental responses to enhance the overall benefits of tourism. Analysis of the relationship between the monitoring scale of trail conditions, local bio-geophysical properties, and the concentration of hikers on different trails will further increase the holistic understanding needed for the management of nature based tourism in vulnerable ecosystem like the Icelandic highlands.

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