New approaches for wilderness perception mapping: a case study from Vatnajökull National Park, Iceland

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by

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Abstract

The Icelandic Central Highland is by many considered to be one of the last remaining wilderness areas in Europe. However, rapidly increasing tourism as well as the construction of hydro- and geothermal power production plants are causing increasing pressure on the highland. Knowledge about the location of remaining wilderness is therefore essential to avoid further declining of natural areas of this type in Iceland. This study examines the use of new data and methodology to map wilderness perception attributes in a Geographical Information System, using Vatnajökull National Park as a case study. Web-shared geotagged photographs taken by tourists are used to assess the opportunity for solitude; road appearance and traffic intensities are used to map apparent naturalness; and mobile phone coverage data to assess primitiveness. Viewshed analyses and remoteness models are furthermore used to complement the overall wilderness perception map. The results indicate that geotagged photos provide useful data as they show visitor patterns unlike any other type of data hitherto used for wilderness assessment. Traffic intensities and visibility of roads are further considered to provide a better estimation on the impact of roads on wilderness than solely using proximity to different road types. Mobile phone coverage data indicates areas of self-reliance in a wilderness environment. It is concluded that the new data types examined in this study add valuable information to previous wilderness mapping, providing more detail to areas of perceived solitude, naturalness, primitiveness, and remoteness, and are therefore of important use for management and planning purposes.

Key words: Wilderness mapping, wilderness perception, geotagged photos, GIS, Vatnajökull National Park, Iceland

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Table of Contents

List of figures

List of tables

1 Introduction

1.1 Mapping wilderness

Wilderness has worldwide received increased interest during the past century (e.g. Hendee, Stankey, & Lucas, 1990). Reasons for this interest are numerous, ranging from purely historical or theoretical perspectives, such as the evolution of wilderness perception (Nash, 1982; Turner, 1920) to highly applied matters concerning the protection and management of designated wilderness areas (Lesslie & Taylor, 1985; Manning & Lime, 2000). Nonetheless, Cole (2012) concludes that one of the main motivations for wilderness research is the perception that wilderness is becoming rare and at risk, and therefore needs research on how to protect and manage it. Carver, Tricker, & Landres (2013) are of the same opinion, and further stress that knowledge of the location and extent of wilderness is essential for its management. However, several scholars including for example Hendee et al. (1990) point out that the concept and definition of wilderness is highly debated. Authors, such as Blair, See, Carver, & Samson (2008) acknowledge this, and state that due to the highly personal nature of wilderness there is not one single definition that satisfies everyone. This fact has its implications for wilderness allocation and management, as agreement on a definition is a prerequisite to determine which areas to manage, as well as how to do so (Hendee et al., 1990).

Around the enactment of the Wilderness Act in 1964 in the USA, mostly matrixes based on fieldwork were used for making inventories of wilderness areas (Hendee et al., 1990). Since the 1980s, maps have increasingly been used to simplify the designation of wilderness (Lesslie & Taylor, 1985). Even though the idea of wilderness perception was widely supported by that time, wilderness maps were mainly based on objective geographical features such as proximity from anthropogenic features (Lesslie, Mackey, & Preece, 1988). Kliskey & Kearsley (1993) were one of the first to use Stankey's (1973) wilderness purism scale in response to the criticism of not using perception, thereby introducing wilderness perception mapping. Even though they still mostly applied anthropogenic proximity criteria, they did [try to] account for the different perception values of wilderness visitors.

As reviewed by Blair et al. (2008), one of the main challenges with wilderness perception mapping is how to map the character or attributes of wilderness quality. This can be partly attributed to the difficulty of quantifying individual perceptual experiences, but also to the availability of suitable data. This thesis focusses on the latter, and examines the use of new data for wilderness perception mapping or as proxies for such. More specifically, the use of geotagged photos will be examined to map solitude, one of the main attributes of wilderness (i.e. Ellison & Hatcher, 2007; Hammitt, 1994, 2012; Long, More, & Averill, 2007). Global System for Mobile Communications (GSM) coverage data will furthermore be used to map primitiveness, and road appearance and traffic intensities will be used to approximate the perception of roads in a wilderness area. Together with more conventional data describing the wilderness attributes remoteness and naturalness, this is likely to lead to the most extensive wilderness perception mapping in Iceland so far, using Vatnajökull National Park as a case study.

The Central Highland in Iceland, which Vatnajökull National Park constitutes a large part of, is considered to be one of the last remaining large wilderness areas in Europe (e.g. Ólafsdóttir & Runnström, 2011; Thórhallsdóttir, 2007). This has not gone unnoticed by tourists, and is expressed by a strong increase in visitors searching for a wilderness experience in the last few decades (Sæþórsdóttir, 2013). Besides tourism, Sæþórsdóttir (2012) points out that the Central Highland is increasingly being used for hydropower and geothermal power production. Sæþórsdóttir (2013) further states that these contrasting land uses are likely to lead to future conflicts, making careful planning essential if Iceland wants to further expand power production and at the same time keep wilderness tourism alive in the Central Highland. Knowledge of the Icelandic wilderness is therefore of great importance.

1.2 Research aims

The general aim of this study is threefold. Firstly to examine the use of web-based data for mapping perceived wilderness by using public web-shared geotagged photos as a proxy for identifying areas of solitude. Secondly, to assess the use of traffic intensities and road appearance as an indicator for apparent naturalness. Thirdly, to assess the use of mobile phone coverage data for wilderness primitiveness.

The following research questions are addressed:

1. Can web-based public geotagged photos be used to assess the wilderness attribute of solitude?

2. Can traffic intensity data and road types be used to map impact on the wilderness attribute of naturalness?

3. Is GSM coverage data usable as an indicator for the wilderness attribute of primitiveness?

4. What are the major differences between the wilderness perception mapping analysis from this study and wilderness maps based on the proximity of anthropogenic features as defined in the Icelandic law on Nature Conservation?

1.3 Structure of the thesis

The thesis starts with an introduction leading to the research aims, followed by a background chapter containing firstly a brief literature review about the history and concept of wilderness, followed by a review of wilderness mapping methods applied over the past decades. It then continues to describe public geotagged photos on photo sharing websites, and how they have been used in previous studies. The methodology chapter starts with a short overview of the general methodology that is used. It then describes how geotagged photos from Flickr and Panoramio are extracted, analysed and converted to a wilderness solitude map. Next is the description of the classification of roads, which is based on road appearance and car intensities, followed by the use of GSM coverage as a proxy for the wilderness attribute of primitiveness. It then continues to describe the construction of the wilderness perception map based on wilderness attributes naturalness, remoteness, primitiveness, and solitude. The perception map is then converted in different zones, and compared with the wilderness map based on Icelandic designated wilderness both quantitatively and spatially. The results chapter presents the mapping results and emphasises the general patterns that can be distinguished from those maps. It furthermore shows how wilderness is distributed spatially and quantitatively in Iceland, according to the results of this novel approach. In the final chapter the results are critically discussed and conclusions presented.

2 Background

2.1 The wilderness concept

2.1.1 A brief history of wilderness

Wilderness is an age-old concept. Through time, and in different cultures, the conception of what wilderness is has varied widely. For example in the English King James version of the bible from the eighteenth century, the word wilderness is used almost 300 times and mostly referred to as the opposite of civilization and paradise (King James Bible Online, 2014). Joel 2:3 provides a good case in point: *"A fire devoureth before them; and behind them a flame burneth: the land [is] as the Garden of Eden before them, and behind them a desolate wilderness; yea, and nothing shall escape them"*. This clearly shows that the Garden of Eden, as the original paradise, is a direct opposite of wilderness. In short, the general perception of wilderness was a negative one, a deserted or desolate place where you don't want to be (Cronon, 1996).

How different is the conception of wilderness since the end of the nineteenth century. Where it was first related to wasteland, it has now been replaced by one of value, something to appreciate, and protect. Why this (sudden) appreciation of land formerly seen as a barren environment? According to Cronon (1996), there are two main reasons: the sublime and the frontier. Sublime landscapes, in the eighteenth century described as vast and powerful, were places where one had the greatest chance of meeting God. Although God could show up anywhere, it was believed by romanticism that in landscapes where you feel small, insignificant and mortal, you have the highest chance of meeting God. Consequently, the first established national parks in the United States were sites that met with these perceptions (Cronon, 1996). The wild frontier in the New World was another reason for appreciating and protecting wilderness. In the earliest phase of the settlement of America, most of the land was in pristine condition, as the Indians did not alter the landscape to the same extent as the new settlers did (Marshall, 1930). Civilizing the frontier in the west became an important American icon. As the frontier gradually became more and more civilized, the idea to protect nature slowly gained attention. As described by Hendee et al. (1990), Catlin was one of the first to call for the protection of nature in the early 1800s, followed by Thoreau in 1858. The establishment of Yellowstone National Park in 1872 exemplifies the general acceptance of the idea that this American icon of the frontier should be protected and preserved for future generations (Hendee et al., 1990).

It may be concluded that the concept of wilderness has changed significantly over the past centuries. The worldwide establishment of protected areas shows the value that is given to nature and wilderness in present times - in particular those areas which have been classified as protected area category Ib ("wilderness area") according to the classification system developed by the International Union for the Conservation of Nature (IUCN) in the 1980s.

2.1.2 Defining wilderness

In recent literature there is, by and large, a consensus about the idea that wilderness is an highly subjective concept, and thus that the perception of wilderness can differ significantly from person to person (e.g. Dawson, Newman, & Watson, 1998; Hammitt & Madden, 1989; Kliskey & Kearsley, 1993; Kliskey, 1994a; Stankey, 1973). This essential subjectivity makes wilderness a highly debated concept, which in turn has led worldwide to the creation of numerous and quite diverse definitions (Cronon, 1996; Lupp, Höchtl, & Wende, 2011; Martin et al., 2008; Nash, 1982; Shultis, 1999). However, as has been pointed out by many (e.g. Hendee et al., 1990), in order to protect and manage wilderness areas it is still important to define what wilderness is as clearly as possible. As definitions are the foundation for wilderness mapping, a brief overview is given here below.

Nash (1982, p. 5), realizing the complexity of the concept, proposed the definition "*Wilderness is what men think it is*". Definitions of this sort - while not necessary wrong -downplay the physical (and thus objective) aspects of wilderness and, most importantly, the interaction between subjective perception and objective circumstances which together constitute the wilderness experience. They are thus obviously not a good starting point for wilderness management because, according to such conceptualizations, wilderness in essence can be everywhere and nowhere at the same time. One of the most prominent definitions of wilderness is probably the Wilderness Act of 1964 from the United States:

> *A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammelled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its*

> *primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.*

This definition clearly shows the importance both of objective (e.g. "untrammelled", "without permanent improvements or human habitation") and subjective characteristics (e.g. "primeval influence", "appears to have been affected") in the wilderness experiences, along with some characters which can be seen as belonging to both types or possibly neither (e.g. "solitude", "unconfined type of recreation"). The fact that it took eight years and 65 bills before agreement on a final version of the Wilderness Act was achieved emphasizes how delicate it was to come up with a definition that was acceptable for the majority in congress (Hendee et al., 1990). Many national and international wilderness definitions have since then been based on the wording of the Wilderness Act (Ólafsdóttir & Runnström, 2011), including the Icelandic definition.

Despite this, the debate about the existence of wilderness is still very much ongoing. Wohl (2013, p. 5), for example, defines wilderness as "*a region that people have never influenced*", and as she considers climate change to be a human induced phenomenon, she concludes that no region on earth is untouched, and thus that wilderness no longer exists. Since wilderness is a subjective concept, many definitions are based on cognitive dimensions. Hammitt (as cited in (Ellison & Hatcher, 2007, p. 2) defines wilderness as "*the environmental situation in which users have some control over the information they must process and the attention required of them to process it or "cognitive freedom"*". Another interesting citation in Ellison & Hatcher (2007, p. 2) is from Kaplan and Talbot. They describe it as "*dominance of the natural, absence of civilized resources, where nature is dealt with on its own terms and there is an absence of demands on one's behaviour that are artificially generated or human imposed*". These cognitive dimensions, also known as attributes of wilderness perception, will be elaborated on in the next section.

2.1.3 Attributes of wilderness perception

Solitude, following its mention in the Wilderness Act of 1964, is considered as one of the major attributes or characteristics of the wilderness experience (Ellison & Hatcher, 2007; Hammitt, 1994; Hollenhorst, Frank, & Watson, 1994; Long et al., 2007). Even though the first thought might be one of being alone, several studies have shown that most wilderness tourists are not single travellers when experiencing wilderness (Hammitt, 2012; Long et al., 2007). Hammitt (1994) concludes that wilderness solitude in practice is not so much about being totally on your own, but more about being away from social structures. This includes a temporary release from the pressures and stress of everyday life. He considers wilderness solitude to be more connected to privacy than the idea of being on your own.

Dawson et al. (1998) acknowledge that wilderness areas should provide the opportunity for solitude, and consider solitude and privacy to be the primary dimensions of wilderness experiences. In an attempt to improve the understanding of other potential dimensions, they conducted exploratory research in the Adirondack wilderness area in New York State, USA. Four focus groups were interviewed, namely recreation planners and managers, researchers and educators, members of the central New York Chapter of the Adirondack Mountain Club, and undergraduate and graduate students at the SUNY College of Environmental Science and Forestry. Their result was an extensive list of cognitive dimensions and attributes that potentially satisfy or dissatisfy recreational wilderness experiences. One of the listed attributes is *"to feel a sense of earlier and rugged time in history"* (p. 259), which coincides with the earlier mentioned idea of the frontier. There are also contradicting attributes on the list. Some see *"evidence of management activities"* (p. 259) as a dissatisfying attribute, while others indicate that *"a lack of adequate trail maintenance"* (p. 259) has a negative impact on their wilderness experience. This again shows the difficulty to define wilderness once and for all, and also the diversity of perception in wilderness experiences. This is supported by Johnson et al. (2005), stating that wilderness is not solely described by the opportunity of solitude. Instead of digging into the dimension of solitude, they assessed the concepts of overall *wilderness experience, naturalness, primitiveness* and *remoteness* using in-depth interviews. After extensive analysis of the collected data, they concluded that visitors are largely consistent in defining the four concepts. Naturalness was related with environment, recreation evidence, and ecological impact. Development impacts were associated with primitiveness, and remoteness was described by distance, accessibility, and the number of people. Wilderness was mainly described by the factors environment, social, personal, and development impacts. They concluded that the core meaning of the dimensions was generally consistent, even though there was a high level of variability within each of them.

That visitors should perceive dimensions of wilderness differently is in good accordance with the conceptual founding of the purism scale (Stankey, 1973). When managing protected areas, it is important to know what visitor tolerance limits and preferences are when it comes to core dimensions of wilderness such as solitude and remoteness (Elands, van Marwijk, Vistad, & Vorkinn, 2012). Stankey's (1973) purism scale divides wilderness users into four groups: Strong purists, moderate purists, neutralists, and non-purists. Each of these groups perceive wilderness differently. A non-purist, for example, can experience wilderness when surrounded by a low number of man-made structures, where a strong purist can only have a true wilderness experience when there is no trace of human interference or influence at all.

It may thus be concluded that wilderness is best assessed by combining physical conditions (e.g. absence of anthropogenic elements such as roads, houses and power lines; a certain minimum size), and perceptual qualities such as the opportunity for solitude.

2.1.4 Wilderness in Iceland

The notion to protect wilderness areas in Iceland originated relatively recently. The country's first legislative definition was set forward in 1999 in the Icelandic Law on Nature Conservation: *"Wilderness: an area of land at least 25 km2 in size, or in which it is possible to enjoy the solitude and nature without disturbance from man-made structures or the traffic of motorised vehicles on the ground, which is at least 5 km away from man-made structures or other evidence of technology, such as power lines, power stations, reservoirs and main roads, where no direct indications of human activity are visible and nature can develop without anthropogenic pressures"* (The Nature Conservation Act no. 44/1999). To date, however, only limited systematic assessment has been conducted to identify Icelandic wilderness (Ólafsdóttir & Runnström, 2011).

Vatnajökull National Park was formally established in 2008, based on Act no. 60/2007. It is the largest national park in Iceland, covering around 13.600 km^2 or roughly 13% of total land area of Iceland. The Act and subsequent regulation (no. 608/2008) required the park authorities to develop a concise management plan which should furthermore be based on accepted international standards, such as those developed by the IUCN. The management plan was completed in 2010 (accepted in 2011) and introduces, among other things, the concept of "wilderness zones" into protected area management in Iceland. These zones were based on a modified version of the 1999 wilderness definition but have not as yet been formally mapped out, so their boundaries remain unclear. Much of the critiques and debates concerning the management plan have furthermore related to issues of wilderness designation and wilderness management (Ólafsson, Árnason, Þórhallsdóttir, & Þórhallsdóttir, 2013).

The Icelandic tourism industry is largely based on the country's wilderness resources (Sæþórsdóttir, 2013). Hence increased tourism during the last decades has resulted in a significant increase in the number of yearly visitors to the Central Highland. However, increased tourism popularity comes at a cost, as today's purists experience the most popular destination in the Icelandic Highland as less wild than before (Sæþórsdóttir, 2013). Stronger management of wilderness areas is therefore necessary to protect the Icelandic wilderness from further decline.

2.2 Wilderness mapping

Numerous attempts have been undertaken to map wilderness worldwide. Hitherto, most are based on traditional definition using proximity analysis, while more recently more and more uses perception analysis (Carver et al., 2013; Flanagan & Anderson, 2008; Kliskey & Kearsley, 1993; Kliskey, 1994a; Ólafsdóttir & Runnström, 2011). As discussed by Higham & Kearsley (2001, p. 82), wilderness is a matter of *"personal cognition, emotion, values, and experiences"*. This subjectivity means that wilderness can be found in different places by different people. Empirical studies done for example by Johnson et al. (2005) attempt to dismantle the wilderness visitor experience, and therefore providing a better understanding of wilderness attributes such as solitude, remoteness, naturalness, and primitiveness. This knowledge can subsequently be used as a starting point to map wilderness.

As Ólafsdóttir & Runnström (2011) point out, most wilderness mapping studies assess the wilderness qualities of remoteness and naturalness. Other examples of used criteria are ruggedness, lack of human impact (Carver, Comber, McMorran, & Nutter, 2012), perception (Orsi, Geneletti, & Borsdorf, 2013), untrammelled quality, undeveloped quality, and solitude or primitive and unconfined quality

(Carver et al., 2013). Indicators to map these qualities vary, and seem to be interchangeable between qualities. Even though solitude and primitiveness are, together with naturalness and remoteness, often described as the main wilderness qualities (Johnson et al., 2005), they are not often used as main criteria. A potential reason might be the difficulty to find good indicators to map them.

As one of the first, Kliskey has undertaken various attempts to map wilderness based on purism scales in the 1990s (Kliskey & Kearsley, 1993; Kliskey, 1994a, 1994b). In his first attempt, together with Kearsley (Kliskey & Kearsley, 1993), the data used for the research was derived from a survey that asked respondents to classify the desirability of various items found in a wilderness setting. Examples were campsites, maintained tracks, commercial mining, solitude, and free from evidence of obvious human impact. Respondents could choose between strongly desirable, desirable, neutral, undesirable and strongly undesirable. Then they calculated for each item the purism score, which resulted in a table showing which item is acceptable to be found in a wilderness area for each purist group. Finally a GIS was used to map which areas would be considered as wilderness for the four purist groups.

Since then, an increasing number of studies were carried out attempting to map wilderness (Carver et al., 2012; Carver, Evans, & Fritz, 2002; Carver et al., 2013; Flanagan & Anderson, 2008; Orsi et al., 2013). Most recently, researchers have started to use web 2.0 applications, such as Flickr, Panoramio and Picasa, as a source of geographic information (Antoniou, Morley, & Haklay, 2010). Within the context of wilderness mapping, it seems to have only been used once to estimate visitor flows on walking trails (Orsi & Geneletti, 2013). As the amount of so called User Generated Spatial Content increased every second, it is just a matter of time before new methods will be developed that bring wilderness mapping to a new level.

Icelandic wilderness has been mapped by Ólafsdóttir & Runnström (2011), using the definition of the Act on Nature Conservation of 1999. Besides proximity from anthropogenic features, they further improve their results with a viewshed analysis that identified which features can be seen from any point based on a Digital Elevation Model (DEM).

2.3 New wilderness proxies

2.3.1 Photo sharing websites

Recently there has been a rapid change in the potential of data collection for mapping wilderness perception through the use of the World Wide Web (WWW). The WWW has evolved rapidly since it's arising in the beginning of the 1990's. In the beginning there were mainly static documents and pages that could be viewed by users. During the last decade, a significant change in both technology and its use occurred. Instead of browsing through static content, the user gained a central role by creating, sharing, collaborating and communicating content on the WWW (Antoniou et al., 2010; Díaz, Granell, Huerta, & Gould, 2012; Lee, Cai, & Lee, 2014). This new generation in the WWW is also known as Web 2.0 (Lee & Torpelund-Bruin, 2011). Typical Web 2.0 examples are Facebook, YouTube, Wikipedia, Twitter, Tumblr, and Flickr. As the content origins from its users, it is also known as User Generated Content (UGC).

Photo sharing websites are typical examples where users are the main generators of the content. Such websites have become increasingly popular in recent years. The most well-known examples are Flickr, Picasa, Instagram, and Panoramio (Zheng, Zha, & Chua, 2010). People seem to use such sites for different purposes, such as sharing photos with friends or family, to backup photos, or to just show off their best images to the rest of the world.

Browsing through the vast amount of photos is however not limited to the homepages of photo sharing websites. One of the most popular places to view Panoramio photos is Google Earth, where a selection of Panoramio photos is available as a layer. Only two years after its launch Panoramio was acquired by Google (Zielstra & Hochmair, 2013). Subsequently, Google has incorporated the Panoramio photo database in a number of other services, such as Google Maps.

The introduction of mobile devices, such as smartphones and tablets, further greatly influenced the development of photo sharing websites (Ardizzone, Di Miceli, La Cascia, & Mazzola, 2012). Being (almost) always connected to the internet, it becomes very easy to upload and share photos online. To support third party developers for creating applications, websites, and applications on mobile platforms such as Android and IOS, many of the photo sharing websites started to develop so called Application Programming Interfaces (API) (Díaz et al., 2012). These interfaces make it easier for third party developers to interact with the software or databases of the suppliers. In the case of photo sharing websites, API's have been developed to for example search, upload, comment and download photos. This also enabled major photo management and editing applications such as Lightroom, Aperture and Photoshop, to develop plugins where users can directly upload their content to their favourite sites.

A relatively new phenomenon is to pinpoint your photos to a location. This is commonly called geotagging (Zheng et al., 2010). Both desktop applications and websites create the possibility to add the location of the photo to the location where it has been taken. In recent years, especially in the more upscale market, it has almost become a standard that cameras are equipped with GPS functionality (Zielstra & Hochmair, 2013). When on, the camera will store the coordinates it received from the GPS in the metadata of the photo. The same applies for modern smartphones, which use GPS, WiFi, and GSM signals to locate the position of the phone, and therefore the location of a just taken picture. Applications that support viewing photos on a map, will read this location data, and place the photos automatically at the position where the image was taken. When uploading pictures to photo sharing websites, users can usually choose whether or not they want to include the location of their photos.

Photo sharing websites can be divided in two categories when it comes to its geographic characteristics, namely spatial explicit and spatial implicit (Antoniou et al., 2010). Spatial explicit means that the main aims of the website is to position the pictures on the Earth. Panoramio is an example of a spatial explicit website. For spatial implicit website´s, such as Flickr and Picasa, the main aim of the website is to let users manage and share their photos. The possibility of giving them a spatial location is not more than an option. Antoniou et al. (2010) concluded that spatial explicit photo-sharing websites have a better spatial accuracy than spatial implicit websites.

2.3.2 Geotagged photos

The enormous amount of UGC on photo sharing websites that has been created in the past decade has attracted the attention of many researchers (Antoniou et al., 2010; Zheng et al., 2010). The main reason is likely that this kind of data has never been available before. The fact that the data is freely available might also have helped. Not only did researchers study the phenomena of photo sharing websites, and more specifically geotagged photos, they also looked at the various applications.

Most of the applications of geotagged photos are within the tourism spectrum (Lee et al., 2014), although exceptions exists (Nakayama &

Sato, 2012). Most research seems to concentrate on three themes, namely hotspot and landmark identification, extracting travel routes, and generating travel recommendations (Sun, Fan, Bakillah, & Zipf, 2013).

Hotspot and landmark identification are probably the most returning theme within tourism related studies, as it is the foundation of more advanced research. It often involves some sort of clustering or aggregation to create something meaningful (Ardizzone et al., 2012; Feick & Robertson, 2014).

When popular landmarks are identified, an attempt is made to extract routes or trajectories between those landmarks (Jankowski, Andrienko, Andrienko, & Kisilevich, 2010). Temporal information, such as the date and time a picture was taken, is combined with the spatial locations of the photos from individual photographers.
The generation of travel recommendations is probably the most difficult theme (Lu, Wang, Yang, Pang, & Zhang, 2010). Okuyama & Yanai (2013) for example developed a travel planning system that generated travel routes based on a large number of geotagged photos. Instead of using a static set of locations, they handled them as a sequence of location points. Another interesting route based example comes from Sun et al., (2013). They used several UGC sites for their analysis (Openstreetmap, Tripadvisor and Flickr) to generate travel recommendations.

Within the above mentioned themes, the use of textual tags in combination with the locations often reoccurs. Yahoo, the owner of Flickr, carried out a study where they created a so called TagMap, visualizing the dominant tags on a map (Kennedy, Naaman, Ahern, Nair, & Rattenbury, 2007; Rattenbury & Naaman, 2009). A similar study has been done by Feick & Robertson (2014), where they explored textual tag frequencies on various spatial aggregation scales.

Even though studies (Antoniou et al., 2010; Zielstra & Hochmair, 2013) conclude that spatial explicit websites such as Panoramio have a better spatial quality, most studies seem to use Flickr as their data source (Crandall, Backstrom, Huttenlocher, & Kleinberg, 2009; Feick & Robertson, 2014; Jankowski et al., 2010; Kennedy et al., 2007; Lee et al., 2014). The most important reason is probably the additional metadata, especially textual tags and the date a photo was taken. This opens up the possibility to add a temporal dimension, needed for route related analysis. The great popularity of Flickr by photographers might be a second reason. If the time and date that a picture has been taken is of no significant importance, combining sources is also a possibility.

2.3.3 Geotagged photos for solitude mapping

Instead of mapping places with a high likelihood of solitude opportunities, it is easier to map places with a high possibility of meeting people. Unfortunately, precise data of people movements is scarce. Figures exist about overnight stays as well as the number of people visiting visitor centres, but these data are too general to map. On the other hand, public geotagged photographs on photo-sharing websites do give an indication where people go. Iceland has furthermore a few advantages that probably result in a better spatial distribution of the data. The lack of dense forests is one of them. As noted by Orsi & Geneletti (2013), limited views while walking or driving in dense forests withhold people from taking pictures. Iceland, on the contrary, has vast open landscapes that most people find very attractive, and are therefore frequently photographed. Another advantage is that roads are relatively quiet, making it easy to stop virtually anywhere along the road to take a picture. A brief look at the map of Iceland overlaid by geotagged pictures confirms this, as photo locations follow both the ring road and highland roads (Figure 5).

The aesthetic appreciation of the Central Highland is well illustrated by Sæþórsdóttir (2010), who analysed interviews and diaries about wilderness experiences. She concludes that tourists find the aesthetic experience the most profound attribute. Moreover, tourists *"praised the unspoiled spectacular landscape with its wide open views, as well as the diverseness and colorfulness of nature"* (Sæþórsdóttir, 2010, p. 343). As most tourists generally like to take pictures of beautiful things, the entire Highland is potentially interesting to take photos from.

This, together with the notion that the most visited places by tourists are also among the highest photographed (Crandall et al., 2009), it is safe to assume that places in the Highland that have not been photographed are less visited than highly photographed places. Places with little or no online evidence of photographic activity offer subsequently a higher chance for aloneness or solitude.

3 Study area

Vatnajökull National Park (VNP) in Iceland was selected as the study area for this research. The national park was established in 2008, and is currently the largest national park in Europe. The majority of the park land area (more than 50%) is covered by the Vatnajökull icecap. In recent years, the total size of the park has however increased significantly in non-glaciated areas, mostly in the southwest and north (Vatnajokulsthjodgardur, 2014). As most of the adjacent land in the western and northern regions is state owned, there are opportunities to further expand the park. Therefore the study area will be the park, and a wide buffer around it. A map of the study area is shown in Figure 1. Because the park covers such a large portion of the country, most of which is furthermore in natural or pristine condition, it would appear to be an ideal place to establish fairly large wilderness areas.

Parts of the Central Highland have become one of the most visited places in Iceland by both local population and foreign tourists (Sæþórsdóttir, 2010, 2013). Tourists are attracted to see and experience the relatively unspoiled landscapes that the highland has to offer. Popular activities include hiking, ice climbing, glacier walks and snowmobiling.

The Central Highland is not solely reserved for tourism only. The large icecaps, high amount of precipitation, and the mostly uninhabited character of the region also makes it an ideal place for hydropower. In the past decades many dams and power plants, both large and small, have been built. The Kárahnjúkar dam, constructed in 2008 just north of Vatnajökull National Park, was heavily criticized as it is located in the middle of the wilderness, and impacted downstream rivers and watersheds (Sæþórsdóttir, 2010; Thórhallsdóttir, 2007). Besides hydropower, Iceland’s position on the edge of two tectonic plates makes it highly suitable for geothermal energy production. Most of the geothermal power plants have so far been built in the lowlands. There are however plans to construct plants in the Central Highland, as some of the most geothermal active regions can be found there. The construction, the plants themselves, and all needed infrastructure such as roads and power lines can have an enormous impact on both the environment and the wilderness experience of visitors (Sæþórsdóttir, 2010).

The VNP management plan (2011) textually describes eight wilderness zones within the park. Even though VNP uses the international IUCN classes to define different protected areas, none of them has been categorised as a 1b wilderness area. Besides the very general textual description of the wilderness areas in the park, no maps exist that delineate the wilderness zones. This emphasises the need of wilderness mapping. The increasing popularity of the park for tourism further emphasises that need.

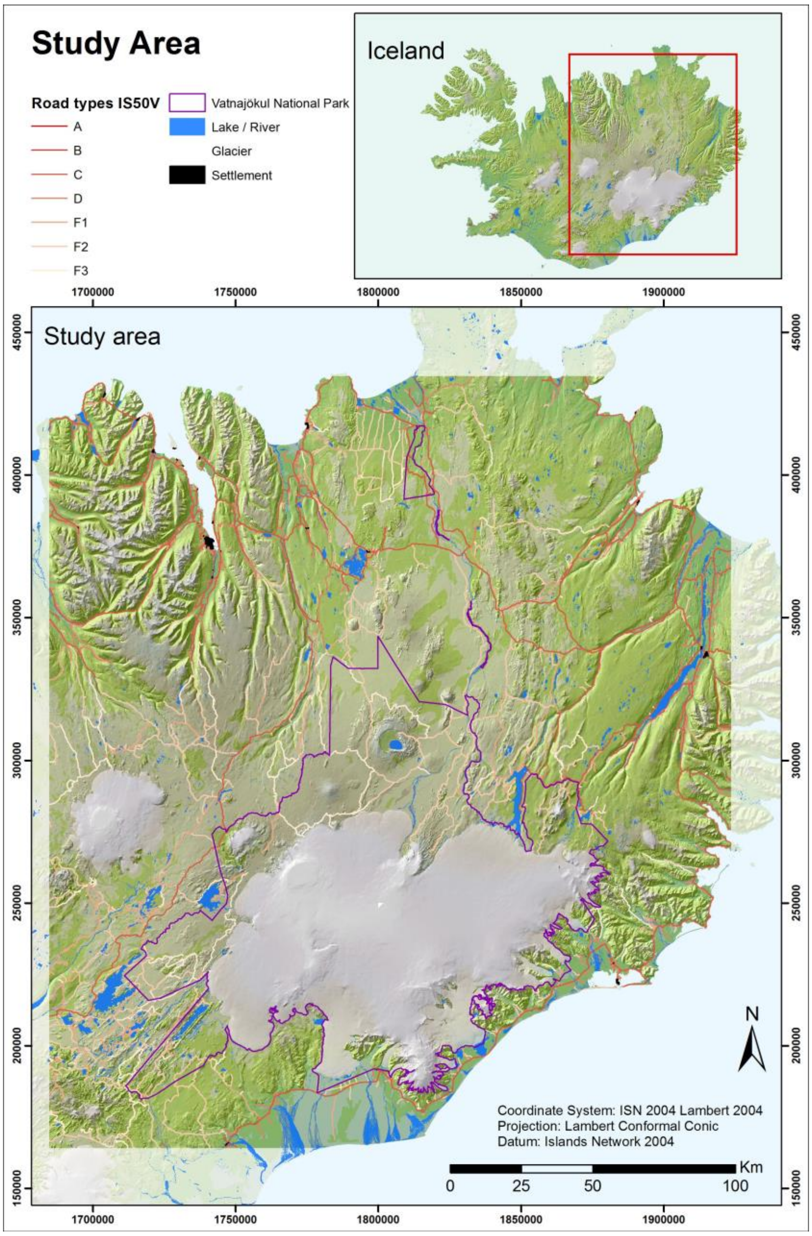

Figure 1. Map of study area

4 Data and methods

4.1 Methodological criteria

The wilderness attributes of naturalness, solitude, remoteness, and primitiveness were used as main criteria to fulfil the research aims, using both conventional and new data. Each of the four selected attributes has one or more indicators as shown in Figure 2. Flowchart presenting the research working procedures. In order to provide nuances between not wild and wild areas all indicators were mapped applying a fuzzy logic. According to Carver et al. (2013) fuzzy analysis may be used to map the wilderness continuum (Figure 3).

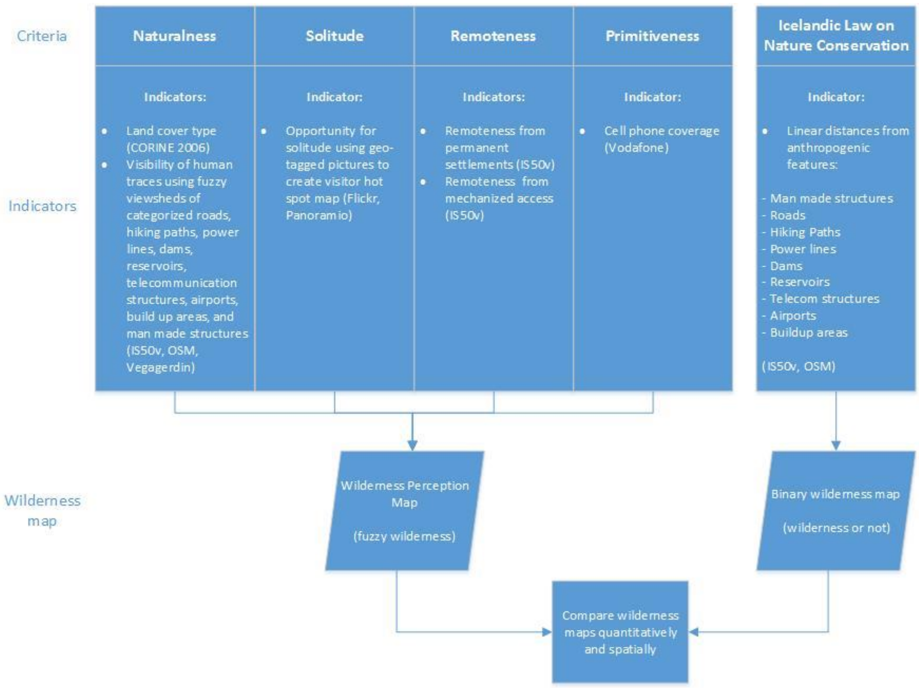

Figure 2. Flowchart presenting the research working procedures

4.2 Geotagged photographs

Coinciding with increased tourism worldwide, the number of photographs taken by tourists increases. As more and more tourists choose to distribute their photos on the WWW, they provide data that may be used to identify the most popular tourist destinations and routes. At the same time they provide data that represent the least visited tourists' sites. In this way this data provide a reasonable proxy for mapping areas of solitude.

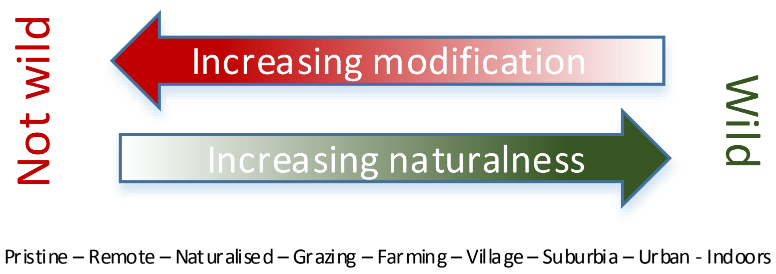

Figure 3. The wilderness continuum. Modified after Carver et al. (2013)

Geotagged photos by bounding boxes

The availability of programming interfaces from photo sharing websites makes it relatively simple to obtain a large number of photos from any preferred area. With previous experience in web programming language PHP, it was a logical decision to develop a PHP script that would collect all geotagged photos in the whole of Iceland.

Both Panoramio and Flickr provided the option to limit search results using certain parameters. Searching for images for a specific location was done by adding a so called bounding box to the search criteria. The bounding box consisted of two coordinates, bottom left and top right, describing the area of interest. As these are intensive queries for a database, and to ensure performance and stability of their service, the maximum amount of results for a 'geo query' is limited. Panoramio will return a maximum of 500 images for each request, where Flickr is limited to only 250 pictures. Both sites let the user know how many photos were found, and how many were returned. Initial estimates showed that the total amount of pictures for both sites would lie around 100.000 photos. This therefore called for an automated process to download the metadata of photos. In short, a script was developed that dynamically created requests to Flickr and Panoramio, based on thousands of bounding boxes covering entire country, and then parsed and stored the returned data in a PostgreSQL database. The actual pictures were not downloaded due to processing time and disk size limitations. Instead, the URL of thumbnail and medium size of the image was stored in the database. In this way it was still possible to view the picture when needed. The entire process will be described in more detail in the following paragraphs.

In order to download metadata of all publicly available photographs in Iceland in the most time efficient way, a strategy of multiple bounding box sizes was applied. Four grids of bounding boxes were created in ArcGIS with cell sizes of $25km^2$, $1km^2$, $62500m^2$, and $100m^2$, all of them covering all of Iceland. The 'Grid index Features' tool was used to create the grids. The Icelandic coastline map in the IS50V database from the National Land Survey of Iceland (LMI) was used as input to determine the extent of the grid. Since both Panoramio and Flickr require coordinates to be in latitude and longitude, the files were converted into WGS84 and the minimum X and minimum Y, representing the bottom left corner, and maximum X and maximum Y, representing the top right corner, were calculated. The attribute fields were calculated with Python, using the following formula like this for calculating the maximum Y column:

!shape.extent.YMax! Equation 1

The attribute tables were then exported as text file, containing an ID field and the four coordinate fields. A text editor was finally used to make sure that columns were comma separated and coordinates had points as decimal separator which was required for the script.
What the PHP script in essence did, was to read the entire text file of bounding boxes for a certain scale, and query the website for each of the bounding boxes. The query for Flickr was as followed:

```
http://api.flickr.com/services/rest/?method=flickr.photos.s
earch&api_key=0a3364846f4dd472608081f774391d70&min_taken_da
te=1970-1-1& accuracy=1&sort=date-taken-
desc&bbox=".$arr[1].",".$arr[2].",".$arr[3].",".$arr[4]."&e
xtras=date_taken,geo,tags,owner_name,url_m,views,url_t
```

where the `$arr[x]` are the coordinates that are dynamically adjusted according to the bounding boxes from the text file. Other parameters include a minimum date setting of 1-1-1970, accuracy =1 to include all photos disregarded their spatial accuracy. The end of the query stated a number of parameters that were asked to return for future analysis. The results for each query were directly stored in the database.

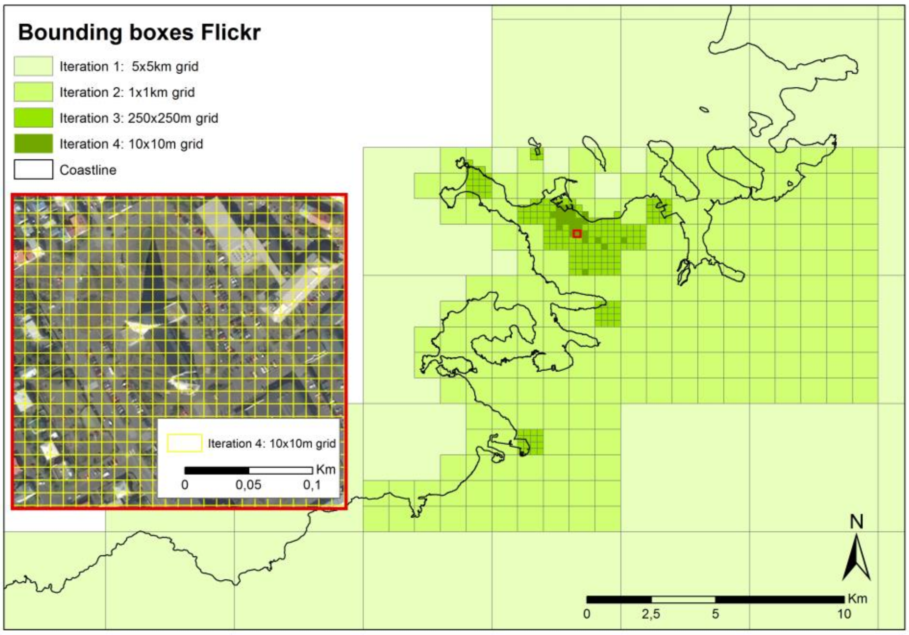

Figure 4. Bounding box iterations used to download metadata of Flickr photos from the Capital Area

The first iteration for both Flickr and Panoramio consisted of a grid containing 4611 bounding boxes of 25km^2 each, scanning the whole of Iceland for pictures. If more than the maximum number of allowed images were found within a bounding box, it was stored in the script. When all bounding boxes were queried, the script processed a query as output that could directly be used in ArcGIS to select all bounding boxes where more than the maximum downloadable amounts of pictures were found. Next, using a spatial selection, all bounding boxes of 1km^2 that were located within selected bounding boxes of 25km^2 were selected and used as second iteration. By this way, areas with a too high picture density in iteration 1 were split up into smaller areas to attempt again to download the metadata of all pictures. If for an area still more pictures were found than returned, it was again split up in smaller areas. Figure 4 shows the bounding boxes that were queried for Flickr in Reykjavik. At the end of each iteration the database was checked for duplicate pictures. There were two main reasons for the occurrences of duplicates. Firstly, it seemed that both databases sometimes returned a few duplicate pictures on the edge of two bounding boxes. Secondly, it was possible that pictures had already been downloaded in previous iterations covering the same area.

Flickr

Writing a script to download metadata of Flickr photographs was relatively straightforward. The API is well described, and a significant user community helped finding answers on most often asked questions. Initially there was a problem that it found more pictures than it actually returned. The reason turned out to be a missing parameter in the search string. When no accuracy was given, it only returned pictures with the highest accuracy level 16. shows all iterations that were needed to download all public geotagged pictures from the Flickr database. The metadata of in total 120787 unique photos were downloaded from the Flickr database. Iteration 4 was split up in four parts because of the large number of bounding boxes to process.
Table 2 describes the metadata that was stored from each image.

Table 1. Download iterations of Flickr images

Iteration	**Size of bb (m)**	**Nr. of bb**	**Found**	**Returned**	**Dupl.**	**Processing time (minutes)**
1	5000x5000	4611	131325	74731	4355	140
2	1000x1000	1721	77595	46426	21425	80
3	250x250	795	43156	30145	14042	43
4.1	10x10	2501	2289	2071	1127	102
4.2	10x10	2499	2395	1284	1258	96
4.3	10x10	9999	6440	6327	4487	350
4.4	10x10	14066	14911	13781	7291	450

Table 2. Metadata about Flickr images that was downloaded and stored in database

Column name	**Field type**
photo_id	Integer
photo_name	Text
owner_id	Text
owner_name	Text
url_thumbnail	Text
url_geoserver	Text
url_medium	Text
geometry	Geometry
longitude	Double
latitude	Double
place_id	Text
woeid	Text
tags	Text Array
accuracy	Integer
date_taken	Timestamp

Panoramio

The script for Panoramio was more or less similar to the one that was developed for Flickr. Less information was available from Panoramio pictures compared to Flickr. The two fields that were missed most were tags and the date that the picture was taken. Especially the date taken field could have been very useful for further analyses, such as seasonality and yearly growth.

Table 3 shows the iterations that were needed to extract metadata of all the Icelandic pictures from Panoramio. Only three iterations were needed because of the larger number of allowed downloads for each query. The metadata of in total of 92062 pictures were downloaded from the Panoramio database. Table 4 shows how the pictures were stored in the database.

Table 3. Download iterations of Panoramio images

Iteration	**Size of bb (m)**	**Number of bb**	**Returned**	**Duplicates**	**Processing time (minutes)**
1	5000x5000	4611	72174	4317	49
2	250x250	1721	38496	16384	90
3	10x10	6760	7830	5737	65

Table 4. Metadata from Panoramio images that was downloaded and stored in database

Column name	**Field type**
photo_id	Integer
photo_name	Text
owner_id	Text
url_thumbnail	Text
url_geoserver	Text
url_medium	Text
geometry	Geometry
longitude	Double
latitude	Double
date_uploaded	Text

Spatial quality

Zielstra & Hochmair (2013) assessed the positional accuracy of both Panoramio and Flickr. They concluded that the median error for Panoramio ranged between 0 and 24,5 meter, and for Flickr between 46 and 1606 meter. Okuyama & Yanai (2013) acknowledged this relatively high mean error, and only used Flickr images with an accuracy level of 11 and higher on a scale of 1 till 16 for their research. For this study all Panoramio pictures were used because of their good spatial accuracy. For Flickr, in accordance with Okuyama & Yanai (2013), only pictures with accuracy levels of 11 and higher were used. In total 51052 picture locations are used within the study area.

Converting photos into a solitude map

To convert the photo locations into something meaningful and useful, Kernel Density Estimation (KDE) was used. In short, KDE transforms point data into a smooth density surface using a search radius looking for points within a given distance. KDE is an often applied method for point datasets in various fields such as emergency response (Krisp & Špatenková, 2010), identifying biodiversity hotspots (Lyon, Cottrell, Siikamäki, & Van Marwijk, 2011), and visitor movement (Meijles, de Bakker, Groote, & Barske, 2013; Orellana, Bregt, Ligtenberg, & Wachowicz, 2012). Sugimoto (2011) demonstrated that it can also be used to map the density of photo locations.

One of the main concerns was that a single photographer could have taken multiple pictures at one location. A filter was applied to avoid this potential problem. Within areas of 250x250 meter, the number of unique photographers was counted using the summary statistics tool in ArcGIS. These values were then used as input for the KDE. To apply KDE a search radius, or sometimes called bandwidth, needs to be set. This parameter determines how far values are being spread out over de Euclidean space. Lyon et al. (2011) notes that this is an important parameter to set, as it strongly influences the smoothness of the surface. Factors to consider are the type of data, distribution of points, and the size of the study area. As no set rules exist, it was chosen to use the advised search radius by ArcGIS of 955 meter. ArcGIS uses a formula that takes into account the study area size and distribution of points. Grothe & Schaab (2009) point out that choosing a search radius is a heuristic process, and trial and error often leads to the best results. Multiple search radius values ranging between 250 and 5000 meter were therefore tested. After examination of the results it was concluded that the radius calculated by ArcGIS showed the best result as there is a balance between smoothness sufficient detail.

4.3 Traffic intensities and road appearance

Categorizing roads based on their appearance and amount of cars they serve is in accordance with Ólafsdóttir & Runnström (2011), who also classified roads based on their impact on the wilderness experience. Flanagan & Anderson (2008) conclude that the type of road surface influences the desirability in a wilderness environment. All purist groups in their study rated paved roads as undesirable. Gravel roads were defined as undesirable by moderate purists and strong purists. Only strong purists defined natural surface roads as undesirable. Besides roads, the noise produced by cars also has an impact on the wilderness experience. Iglesias Merchan, Diaz-Balteiro, & Soliño (2014) conclude that roads, even at a far distance, can have a negative influence on the nature experience. Benfield, Bell, Troup, & Soderstrom (2010) agree, and furthermore indicate that the impact is regardless of volume, meaning that the quantity of cars has a bigger influence than the volume they produce.

The Icelandic Road Authority, Vegagerdin, is responsible for the maintenance of many roads. They also register the exact number of passing cars on most of them. Table 5 shows daily averages of traffic by road type for the summer season (June – September). Summer season averages were used because most wilderness tourists visit the study area in this period. Car intensity averages corresponds mostly with the road types from IS50V. Therefore, the IS50V road types, which are mainly based on appearance, were taken as foundation for the classification. Road type C was subdivided into three classes to overcome the significant difference between the minimum and maximum amount of cars. Subdividing the F-roads based on car intensities was considered, as they have a relatively similar appearance and high diversity in intensities. It was discarded, however, because for many of the F-roads no intensity data were available. The final classification can be seen in Table 6, including the weights that were assigned to each of the classes. Weights were calculated based on the rank sum method, a common method to derive weights from ranked data (Malczewski, 1999).

Table 5. Daily traffic averages in summer season (June-September) by road type in study area

IS50V Road type	**Minimum**	**Maximum**	**Average**	**Km road**
A	7871	18017	12708	3,7
B	3276	4983	3990	7,9
C	11	12475	583	2731,9
D	12	215	47	830,1
F1	10	203	58	118,4
F2	3	234	32	862,7
F3	3	14	7	214,7

For each of the new road classes a viewshed analyses is performed, calculating from where roads are visible based on the topography.

These are then multiplied by a Euclidean distance raster to introduce fuzziness. More information about viewshed modelling and the use of Euclidean distance rasters to can be found under 4.5.2.

Table 6. Road classification and weights based on appearance and traffic intensities

Class	Road type	Weight
1	A roads	0,2
2	B roads	0,178
3	C roads > 500 cars	0,156
4	C roads without measurement	0,133
5	C roads < 500 cars	0,111
6	D roads	0,089
7	F1 roads	0,067
8	F2 roads	0,044
9	F3 roads	0,022

4.4 Cell phone coverage

As discussed by both Sæþórsdóttir (2010) and Johnson et al. (2005), primitiveness is a part of the wilderness experience, expressed in attributes as simplicity, lack of technology, and self-reliance. Nowadays, many people are highly dependent or even addicted to their cell phones. Subsequently, the lack of cell phone reception will enhance the wilderness experience. Without the possibility to reach out for help, the need for self-reliance significantly increases. Wilderness purists experience cell phone coverage as a negative thing (Boller, Hunziker, Conedera, Elsasser, & Krebs, 2010). Holden (2004) studied the use and knowledge about the availability of satellite phones in wilderness camps for children. He concluded that knowledge about the phone had a negative influence on the wilderness experience.

To use this perception about cell phones in wilderness environments, GSM coverage data from Vodafone was used. Siminn was also asked for their coverage data, but unfortunately did not respond to the request. The data was classified based on reception levels, where 1 is equal to good reception, and 4 to no reception at all. This coincides with primitiveness levels. Without reception, it is impossible to reach out for help, resulting in a high level of primitiveness. With very limited connection it might be possible to make a phone call, but using the internet to check on Google Maps how far away the next hut is, is not possible. With full coverage, offering the possibility to check maps, the weather forecast, and upload pictures to social media, the level of primitiveness is very low.

4.5 Wilderness mapping

4.5.1 Spatial Multi criteria evaluation

Spatial Multi Criteria Evaluation (SMCE) is a powerful and often used tool to map wilderness (Carver et al., 2012, 2013; Ólafsdóttir & Runnström, 2011; Orsi et al., 2013). Multiple input rasters are combined, resulting in a map showing the suitability or quality of the concerning study. There are a number of important considerations when applying this methodology. First of all, all combined datasets should have the same cell size. In this study, a cell size of 20 m is used. This is the same cell size as the DEM, which is an important and often used dataset as input for multiple analysis. Most accuracies of input datasets are also within 20 m, which makes this the most logical choice. The input datasets and their accuracies can be seen in Table 7. The DEM was furthermore used as extend and mask for all analysis, to ensure that all output maps cover exactly the same area.

Table 7. Input datasets for wilderness perception map

Name dataset	Source	Accuracy (m)
Roads	IS50V	5
Hiking paths	OSM, Hiking maps	Unknown
Telecommunication structures	IS50V	2-10
Power lines	IS50V	10
Settlements	IS50V	10
Man-made structures	IS50V, OSM	1-10
Hydrological dam	OSM	Unknown
Reservoir	IS50V	1
Airports	IS50V	20
Lakes	IS50V	1-50
Rivers	IS50V	1-50
DEM	LMI	Unknown
Corine2006	European Environmental Agency	25
Road intensity	Vegagerdin	5
Geotagged photo’s	Panoramio, Flickr	0-24 Panoramio, 46-1606 Flickr
Cell phone coverage	Vodafone	Unknown

The possibility to weigh criteria is a powerful option within SMCE. Based on for example interviews, surveys, or management policies, different weights can be assigned to criteria. To combine multiple criteria maps, it is essential that they are comparable with each other. Remoteness is for example expressed in travel time in hours with values ranging from 0 till more than 16 hours. Primitiveness, on the other hand, has values ranging from 1 till 4 indicating reception levels. To overcome this difference in value ranges and what they mean, maps are normalized. This means that the values of all criteria maps are transformed into values ranging between 0 and 1, but at the same time maintaining their original spread of values. Now all criteria range from low to high on a common scale. When normalized, they can be combined using equal or adjusted weights, and result in a final suitability or quality map.

4.5.2 Naturalness

The wilderness attribute of naturalness was included to cover how natural areas are perceived. This was done with two maps. Firstly, land cover was assessed on its naturalness, and secondly viewsheds from anthropogenic features were developed to analyse how free areas were from man-made structures.

Land cover

Land cover was assessed on its naturalness using the CORINE land cover database from 2006. CORINE, which stands for Coordination of Information on the Environment, is a European wide land cover database that is managed by the European Environmental Agency. How natural a land cover type is was based on the classification from Paracchini & Capitani (2011). They created a map of Europe showing the naturalness. All land cover classes were distributed over seven classes, ranging from not natural to very natural.

Apparent naturalness based on viewsheds

Apparent naturalness is often considered as one of the most important attributes of the wilderness experience **(**Carver et al., 2012). Seeing traces of human existence in the form of buildings, roads, power lines are considered to degrade wilderness. As discussed by Ólafsdóttir & Runnström (2011), Iceland's topography plays an important role in the visibility of features in the landscape. Even though anthropogenic features might be close, they could easily be hidden by a hill. It is therefore better to analyse what is actually visible in the landscape instead of calculating proximity values from anthropogenic features. Visibility of features in the landscape can be calculated in a GIS using viewshed analysis. A digital elevation model (DEM) describing the topography and vector data of the analysed anthropogenic features are used as input. A DEM is usually a raster with cell values describing the altitude above sea level. The size of the raster cells greatly influences the accuracy of the viewshed analysis. For this study a DEM with a cell size of 20 m was used.

Various parameters can be set to optimize the viewshed analysis. First of all, the height of the observer should be set. According to Dagbjartsson, Þórsson, & Pálsson (2000) the average height of Icelandic women is 1,706 m and 1,806 m for men. The observer height was therefore set at the average: 1,75 m. Then there are two parameters to be set for the anthropogenic features. The first parameter is the height of features. Sander & Manson (2007) conclude that the use and accuracy of the objects height is of significant influence on the accuracy of the final viewshed. Unfortunately no height information was available in the used datasets. One generalized estimated height for features was not applied because of the high variability of heights within the same feature types. In case feature heights become available in the future they can be used to improve the viewsheds. The second parameter for the features is the maximum distance a feature can be seen from. As discussed by Ogburn (2006), the maximum distance is mainly determined by the limits of human vision, environmental limits, and properties of objects and their surroundings. Ogburn (2006) used a common rule to calculate the maximum visible distance of an object, which is based on the limitations of the human eye and the size of the object. He states that objects are visible if the distance is not more than 3440 times its size. A house of for example four meters in diameter would therefore be visible at a maximum distance of 13,76 km. To apply this rule, information about the size of objects is required, which was not available unfortunately. It was therefore necessary to use other sources for determining the maximum distance. Ólafsdóttir & Runnström (2011) for example used a distance of 10 km for most features. Carver et al. (2013) and Carver et al. (2012) used distances between 15 km and 30 km, based on best practises and actual feature size. To be on the conservative side, it was decided to use 15 km for smaller objects and 25 km for large objects. If information about the size of objects becomes available in the future this can be used to calculate the maximum visible distance for individual objects.

As ArcGIS only uses points and vertexes as input for the viewshed tool, it was necessary to convert polygon features to points. Furthermore, the geometry of a few features were simplified for processing time reasons. Table 8 describes the settings that were used for the various features.

Table 8. Features and accompanying settings that are used for viewshed analyses

Feature	**Maximum distance (km)**	**Simplification (m)**	**Geometry type**
Buildings	15		Polygon
Telecommunication structures	15		Point
Power lines	15		Polyline
Roads	15	5	Polyline
Hiking paths	15	5	Polyline
Airports	15		Polygon
Reservoir	25	5	Polygon
Hydrological dam	25		Polygon
Settlements	25		Polygon

To accommodate for variability in atmospheric conditions and the fact that objects closer are more likely to be observed than objects further away, fuzziness for each of the viewsheds was introduced. This was realized by multiplying the binary viewshed with a euclidean distance raster. Areas defined as not visible in the viewshed were assigned the same value as the maximum distance (no negative impact on wilderness). Viewsheds of all features were then normalized to values between 0 and 1 in order to be able to compare them. Finally, the viewsheds were combined with equal weights given to all features as no data was available to weigh them individually.

4.5.3 Remoteness

Remoteness is considered as one of the main attributes of wilderness (Johnson et al., 2005). As discussed by Ólafsdóttir & Runnström (2011), remoteness is often described by the indicators remoteness from permanent settlement and remoteness from mechanized access. Both indicators were mapped for this study.

Remoteness from permanent settlement describes how remote areas in the study area are related to places of permanent habitation. Most people live and stay in residential areas. The longer it takes to get from the point of origin to the destination, the more remote a place is perceived to be (Johnson et al., 2005). Remoteness from permanent settlement has been used several times in wilderness studies, for example by Ólafsdóttir & Runnström (2011) and Carver et al. (2002). Linear distance from settlements is a common way to map it.

Remoteness from mechanized access describes the minimum walking time that is required to reach an area from the nearest access point that can be reached by mechanized transport. In the 1980s remoteness from mechanized access was mapped using distances from roads, like was done by Lesslie et al. (1988). More recently, advanced GIS analysis are applied to calculate hiking times, taking into account hiking speed, topography, and land cover (Carver et al., 2012, 2013; Comber et al., 2010; Orsi et al., 2013).

The path distance tool in ArcGIS is used to map both remoteness indicators. Various inputs are necessary to generate the remoteness maps. First of all, the source from which to start calculating the remoteness from needs to be defined. For remoteness from mechanized access the road network dataset from IS50V was used. Settlements were used as input for remoteness from permanent settlement. Furthermore, the tool uses a DEM to calculate true distances taking into account the topography of the area. As hiking on upward and steep downhill slopes is physically more challenging and therefore more time-consuming, Tobler’s hiking function was used to account for this (Tobler, 1993). The last input is a cost raster, which is a combination of barriers such as lakes and wide rivers, and features limiting walking speed like streams and glaciers. As there was no land cover dataset available for Iceland with matching hiking speeds, it was decided to only include the most influencing features of which references were found in literature. Table 9 shows which settings were used.

Table 9. Factors and barriers for the cost layer for modelling remoteness

Feature	**Factor**	**Source/Comment**
Lakes	Barrier	(Carver et al., 2012)
Wide rivers as polygons	Barrier	(Carver et al., 2012)
Slope > 45	Barrier	(Carver et al., 2012)
Hiking paths	1	(Tobler, 1993)
General off-trail hiking	0.6	(Tobler, 1993)
Small rivers	0.2	(Richards-Rissetto & Landau, 2014; White & Barber, 2012)
Glaciers	0.5	(White & Barber, 2012)
Roads	6-18	Only used for remoteness from permanent settlement

Lakes, wide rivers that were represented as polygons in the dataset, and slopes of more than 45 degrees were set as barriers. For general off-trail hiking, Tobler's (1993) suggestion to use a factor of 3/5 (0.6) was used, meaning a decrease in walking speed of 40%. Hiking paths were therefore set as 1 (no change). Small rivers and glaciers received according to literature a factor of 0.2 and 0.5. More detailed factors about for example rivers (Carver et al., 2012; Doherty, Guo, Doke, & Ferguson, 2014), hiking trails (Doherty et al., 2014) and land cover (Doherty et al., 2014; White & Barber, 2012) exist, but could not be used with the available data for the study area. An attempt was made to create a stream order using hydrology tools in

ArcGIS, as was done by Doherty et al. (2014). The resulting locations of streams were very inaccurate compared with rivers and streams from IS50V, and therefore not used. Roads are finally added to the cost raster of remoteness from permanent settlement to provide a better estimation how remote locations are if people make use of motorized transport to travel from settlements to the wilderness areas. The cost factor for roads varies based on driving speeds for the particular road, ranging from 30 km/h on highland roads to 90 km/h on the main roads. Thus, a travel model is created indicating the minimum time needed to travel from settlements to every random location in the study area, allowing both travel by car and by foot. Finally, the output rasters of both remoteness indicators are combined with equal weights.

4.5.4 Opportunity for solitude

For the wilderness attribute of solitude, the dataset described in section 4.2 is used.

4.5.5 Primitiveness

For primitiveness, the created GSM coverage dataset described in section 4.4 is used.

4.5.6 Creating the wilderness perception map

One of the strengths of SMCE is the possibility to assign weights to criteria and indicators. Certain criteria might have a larger impact, or should be given more importance based on (public) opinions or management policies. Comber et al. (2010) clearly demonstrate that different classification methods and weightings can significantly chance the final result. For this study no expert opinions or management policies were available to directly use as input. Weights have therefore been set to be as objective as possible by giving all criteria and indicators equal weights. The wilderness perception map therefore presents by no means the only true wilderness. It can only be used as a baseline to compare with future maps based on real weights. Table 10 shows the weights that were assigned to the criteria and indicators.

Table 10. Weights assigned to the criteria and indicators

Criteria	**Weight Criteria (%)**	**Indicator**	**Weight indicator (%)**
Naturalness	25	Naturalness of land cover	50
		Visibility of human impact	50
Remoteness	25	Remoteness from mechanised access	50
		Remoteness from permanent settlement	50
Solitude	25	Photographer density	100
Primitiveness	25	Cell phone coverage	100

The SMCE analyses where the criteria and indicators are combined is done in the Integrated Land and Water Information System (ILWIS). ILWIS is particularly strong in designing SMCE criteria trees, normalizing criteria, and assigning weights.

The result is a wilderness perception map ranging from not wild to very wild, and everything in between.

4.5.7 Wilderness zones

For management purposes, it is desirable to classify the map into wilderness qualities with clear boundaries. The wilderness perception map created under 4.5.6 is therefore classified in nine classes, using the Jenks Natural Breaks method. This classification method is also used by the Scottish Natural Heritage (2013) to map wildness and wild land in Scotland. In short, data is grouped in classes with the aim to reduce variance within classes, and to maximise variance between classes. Various wilderness qualities should therefore be grouped in different classes. After discussion with S. Carver (personal communication, 21 May 2014) it was decided to use one more class compared to the 8 classes that were used by the Scottish Natural Heritage. This extra class was introduced because Iceland has significantly more wilderness than Scotland. The three highest classes 7 till 9 were defined as high wildness, and classes 5 and 6 as low wildness. The purpose of this classifications is to demonstrate a methodology that can be used to classify fuzzy wilderness.

4.6 Wilderness mapping according to Icelandic law on Nature Conservation

In order to assess the new methods and data that were presented in this study, wilderness was also mapped using proximity analyses based on the Icelandic Law on Nature Conservation. Even though Icelandic wilderness has been mapped before by Ólafsdóttir &

Runnström (2011), it was decided to do it again in this study for two main reasons. Firstly, the used database has (most likely) been updated in recent years. This could lead to inconsistencies. Secondly, the applied resolution is different in this study, what could lead to difficulties when overlaying results.

In Table 11 the datasets are shown that were used to create the wilderness map according to the Icelandic Nature Conservation Act.

Table 11. Input data for wilderness map based on Icelandic Law on Nature Conservation

Dataset	**Source**	**Accuracy (m)**	**Distance (km)**
Roads	IS50V	5	5
Hiking paths	OSM, Hiking maps	Unknown	5
Telecommunication structures	IS50V	2-10	5
Power lines	IS50V	1-10	5
Settlements	IS50V	1-10	5
Man-made structures	IS50V, OSM	1-10	5
Hydrological dam	OSM	Unknown	5
Reservoir	IS50V	1	5
Airports	IS50V	20	5

ArcGIS was used to create Euclidean Distance rasters from all datasets in Table 11. The rasters were imported in ILWIS and inserted in a criteria tree as a constraint. A constraint is used for binary indicators, where something is true or false. For each of the indicators the values from 0 to 5 km were set to 0 (false), and from 5 km till the maximum value as 1 (true). All indicators combined resulted in a binary map with values of 0 representing no wilderness, and 1 representing wilderness.

4.7 Comparing and quantifying wilderness

In order to compare the two wilderness maps, i.e. the one based on perception and the one based on proximity analyses using parameters according to the Icelandic Law on Nature Conservation, the perception map was reclassified as described in 4.5.7. The three highest classes were considered as wilderness, as they represent high wilderness qualities. Both wilderness maps were then converted to polygons, and areas of each polygon was calculated. According to the Icelandic Law on Nature Conservation, a wilderness area should have the size of at least 25km^2. Wilderness areas that do not met this criteria were therefore considered as not being designated wilderness. Now the total area of wilderness inside and outside VNP could be calculated.

The maps were furthermore compared in a spatial way by overlaying them. Four classes were created from the overlay, namely areas that were assigned as wilderness in both maps, only in the perception map, only in the Nature Conservation map, or not at all.

Finally, the areas of different wilderness classes of the perception map were calculated within and outside VNP. This gave an idea of the amount of wilderness left in both analyses.

5 Results

5.1 Geotagged photographs

The results show that most photographs that tourists share on the world wide web are taken on the most popular tourists sites within the study area (Figure 5).

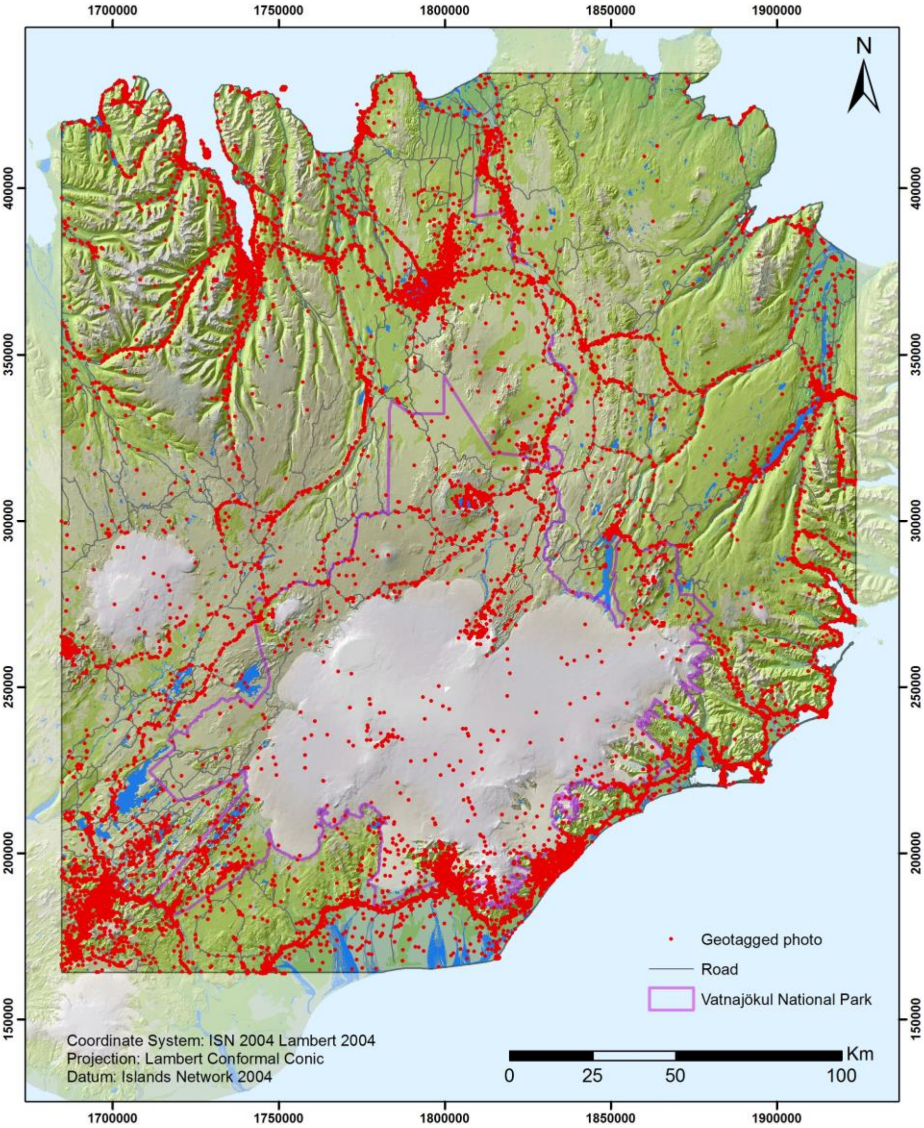

Figure 5. Spatial distribution of geotagged photographs within the study area

The results further show that most of the photos are taken along the roads. Hence the pattern largely reflects the Icelandic road network. It may however be estimated that areas with no or few photos are areas with less access and therefore less visitors. Thus the pattern provides a fairly good indication of areas of solitude (Figure 6). Few photos densities spots differ from the overall road network appearance. Those are popular hiking routs. One of them is the popular hiking route "Laugavegur, and is represented as a high density area in the south west of the study area.

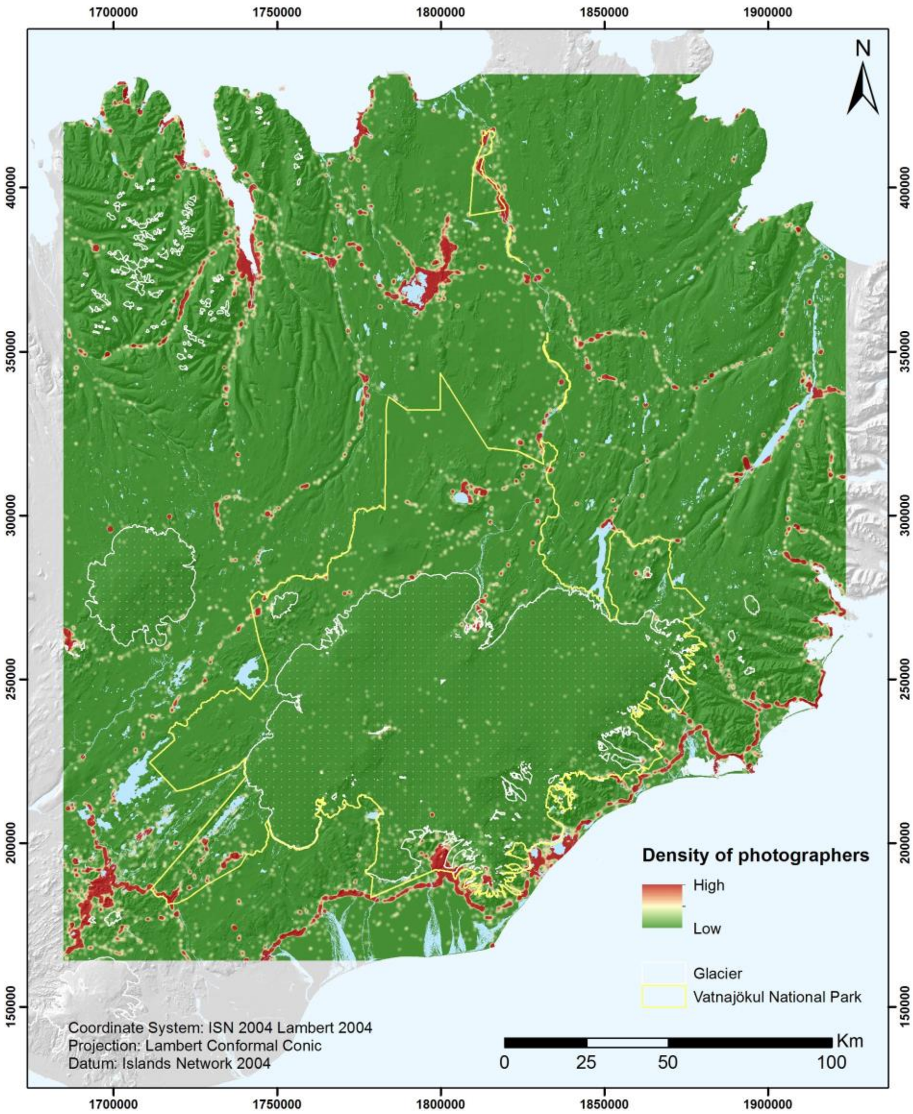

Figure 6. Map of photographer density based on KDE

5.2 Impact of roads based on appearance and traffic intensity

Figure 7 shows the impact of roads on the wilderness experience based on their visibility, appearance and traffic. Locations close to paved roads with much traffic produce the highest impact. The surrounding topography, which is calculated by the viewshed analyses, can however somewhat mitigate impacts under preferable conditions. A good example is just west of Akureyri, where the ring road is located in a relatively steep valley. Even though relatively close to the road, the impact is fairly limited. Most of the F-roads in the highlands seem to generate a relatively low impact. This is in accordance with the assigned weights to the highland roads based on the limited disturbance of these in general natural surface roads with (very) limited traffic.

5.3 GSM coverage as input for primitiveness

GSM coverage in the Icelandic highlands varies from good reception close to the telecommunication structures to areas with no reception at all (Figure 8). This has implications for the level of self-reliance when traveling in the highlands, and therefore might offer a higher perception of primitiveness. Red areas on the map represent areas without cell phone coverage, and thus higher levels of self-reliance. Especially the Vatnajökull glacier stands out in this respect. The mountains close to Akureyri in the north west of the study area also have limited reception levels. Most of the main tourist locations have good reception. An exception to this seems to be Askja, which has no coverage. In general most of the highlands have at least limited cell phone coverage according to the model, but whether that is in reality enough to make a phone call when in need is still questionable.

5.4 Remoteness

The criterion of remoteness is subdivided in two indicators: Remoteness from mechanised access (Figure 9), and remoteness from permanent settlement (Figure 10). Remoteness levels increase when moving away from roads and settlements. The Vatnajökull icecap is in both cases the most remote place within the study area. The main reasons for this are the absence of roads and the relatively high effort and therefore time it takes to hike up to the icecap. The shape of mountains and ridges can be distinguished in many places. This is the result of the cost layer, and more specifically Tobler’s hiking function. Steep slopes cause a significant decrease in hiking speed, and therefore a rapid increase in remoteness. On Figure 10, which shows remoteness from permanent settlement, roads are identifiable. The low resistance for roads in the cost layer results in relatively low travel times around roads compared to their surroundings. Remoteness from permanent settlement is furthermore higher than remoteness from mechanised access. This is correct, as the travel time to get from the nearest permanent settlement to that same road is added to the total travel time, and thus leads to an increase in remoteness.

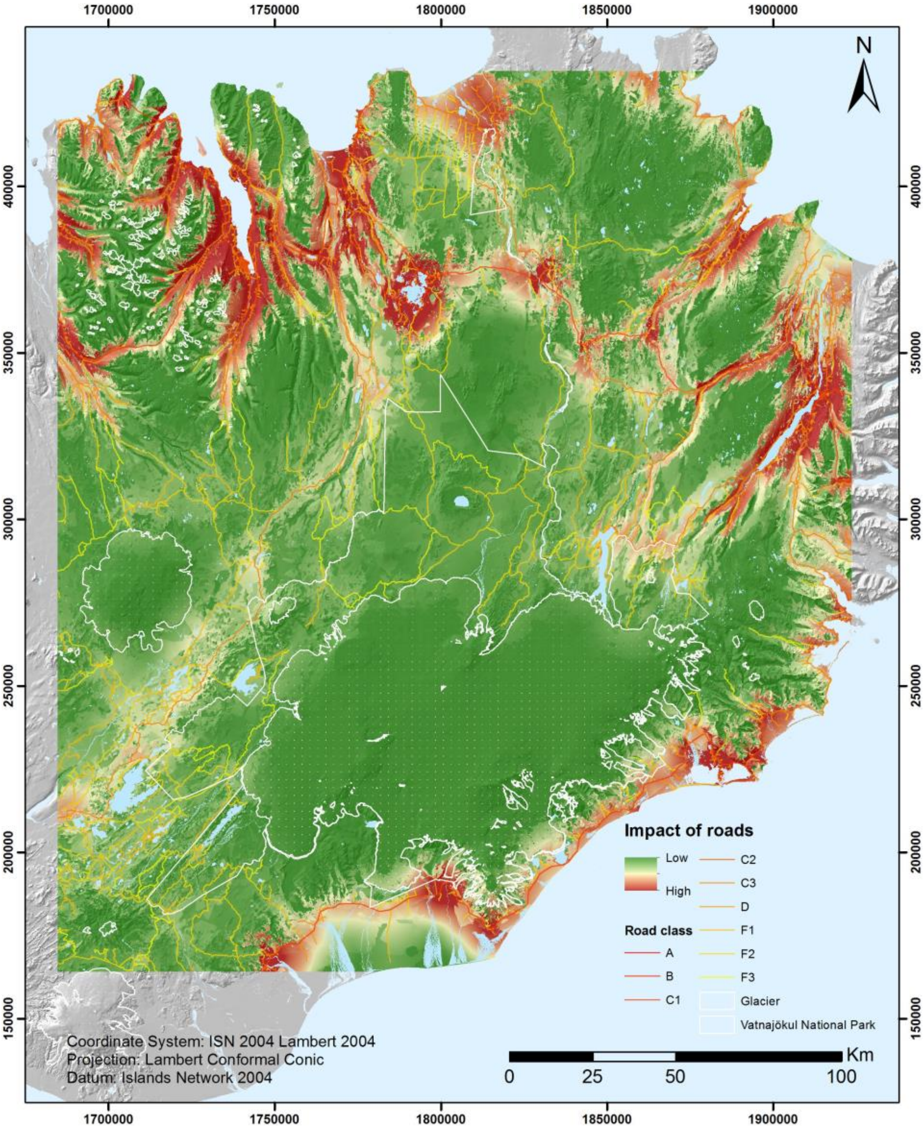

Figure 7. Impact of roads on apparent naturalness based on road appearance, visibility, and traffic intensities

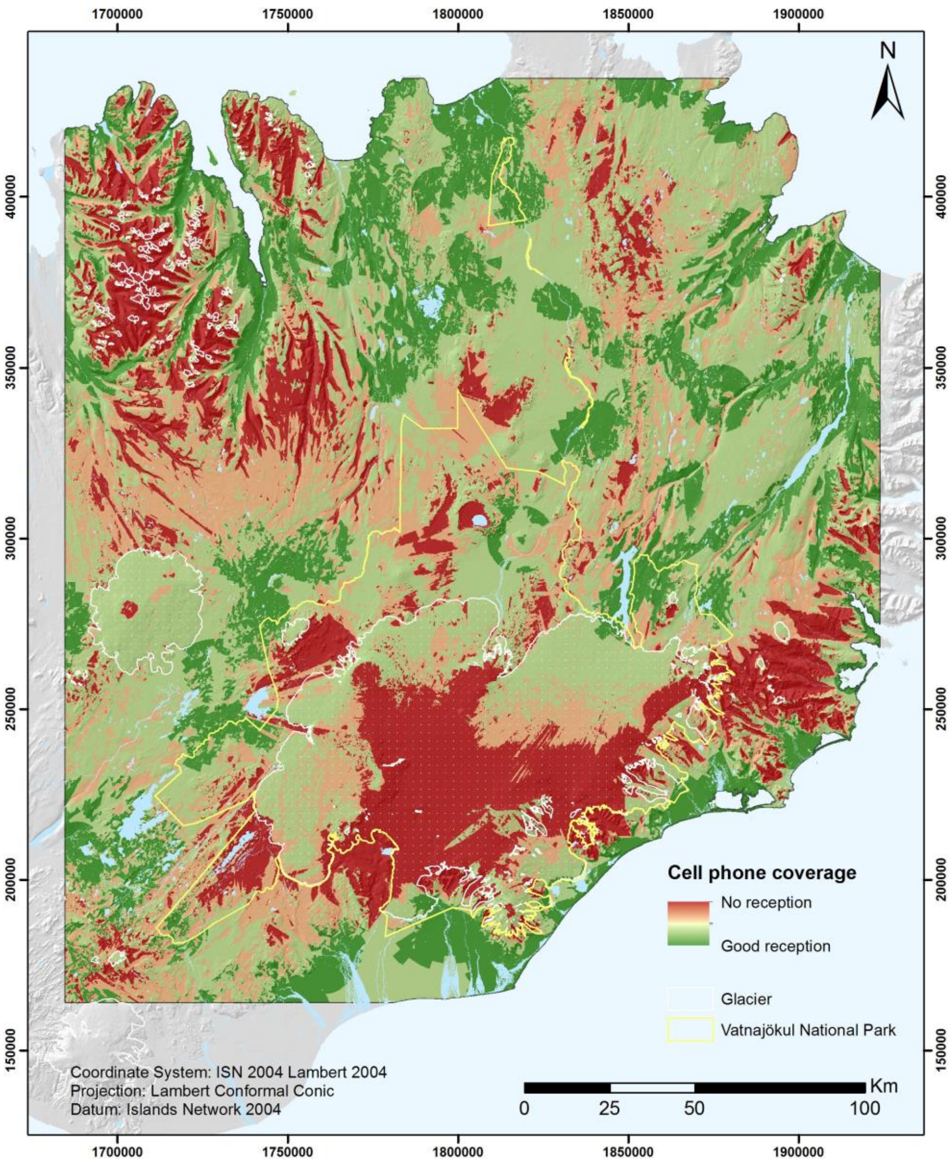

Figure 8. Cell phone coverage indicating level of primitiveness

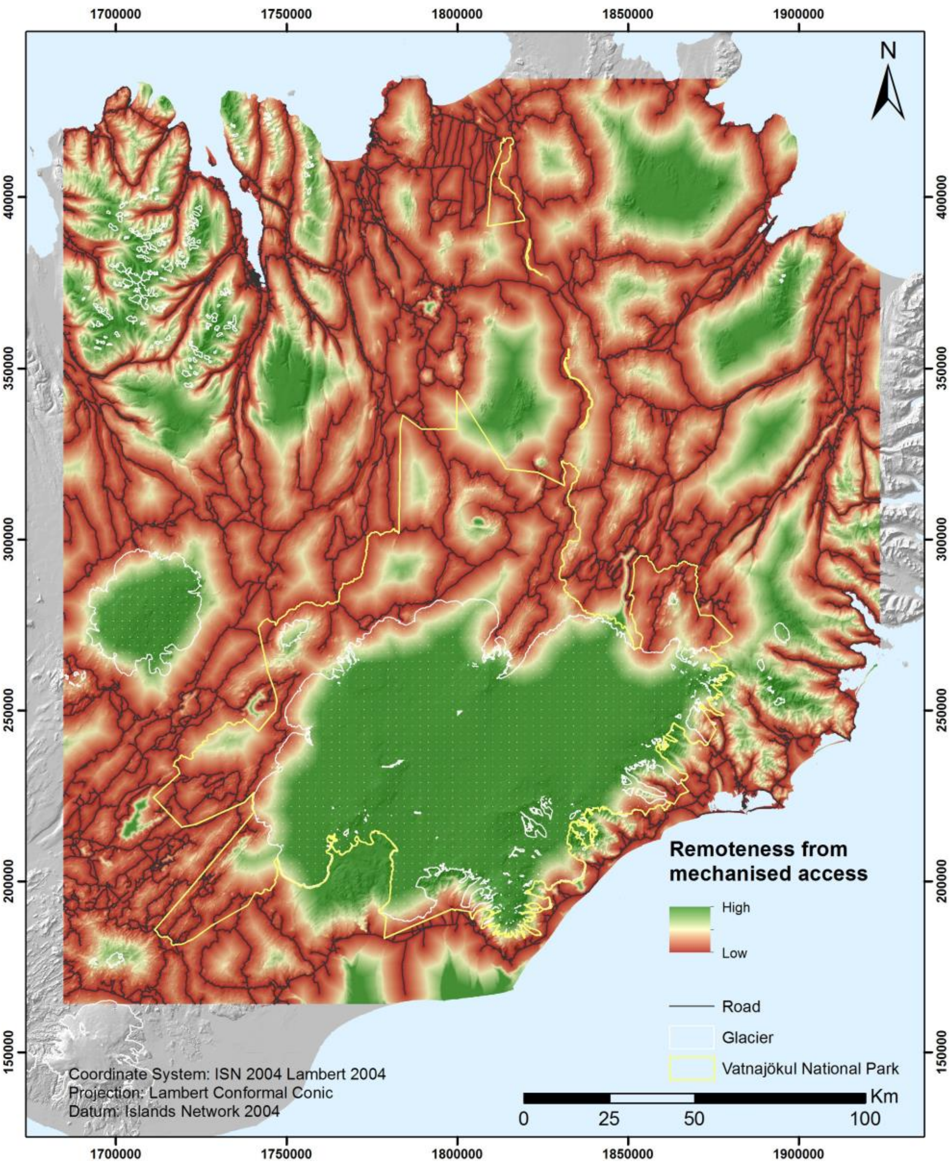

Figure 9. Remoteness from mechanised access

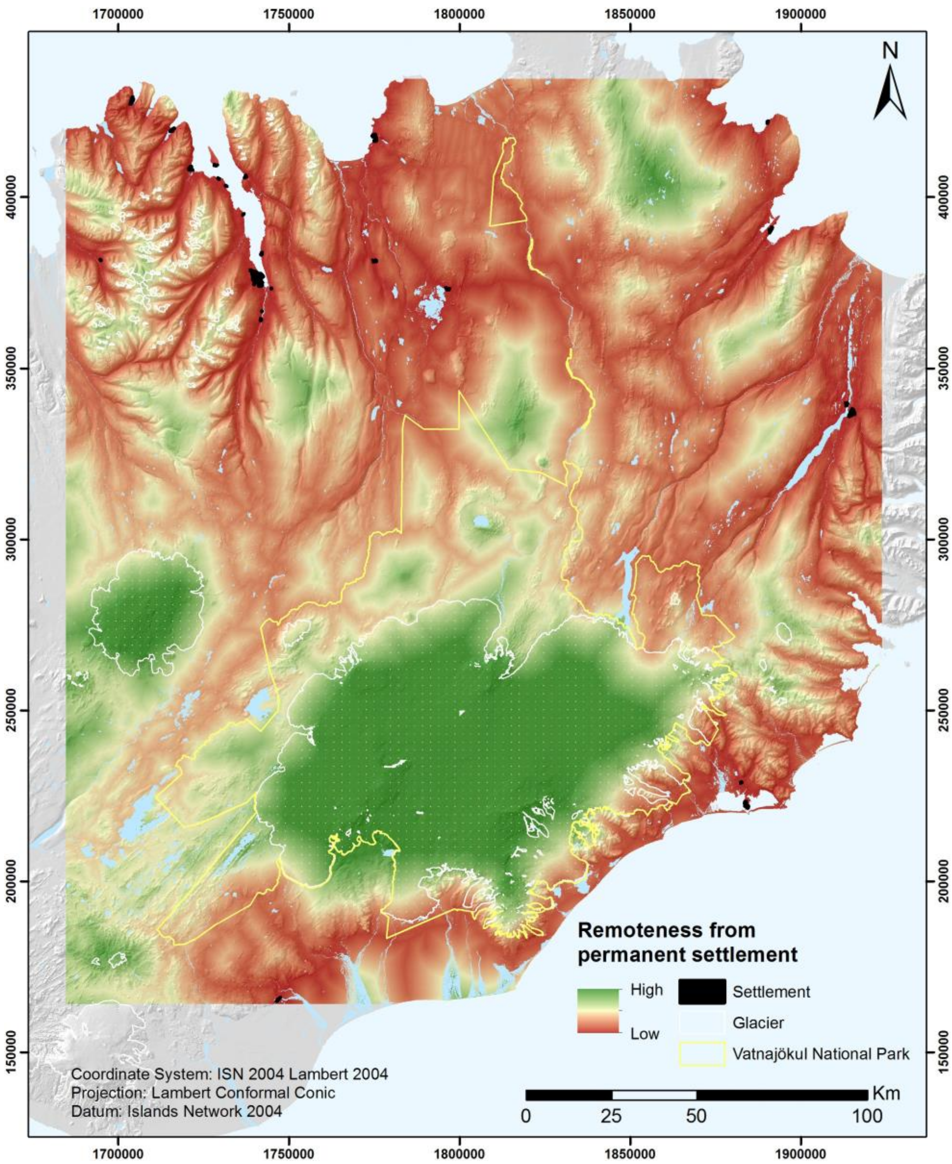

Figure 10. Remoteness from permanent settlement

5.5 Naturalness

The naturalness map based on CORINE land cover is shown in Figure 11. Most of the Highland received the highest level of naturalness, with as main land cover classes "Glaciers and perpetual snow" and "Bare rocks". However, considerable areas north of the Vatnajökull glacier got the second highest value in naturalness. The concerning land cover classes are "beaches, dunes, sands", "sparsely vegetated areas", and "Moors and heathland". Areas of low naturalness are mostly located close to inhabited places.

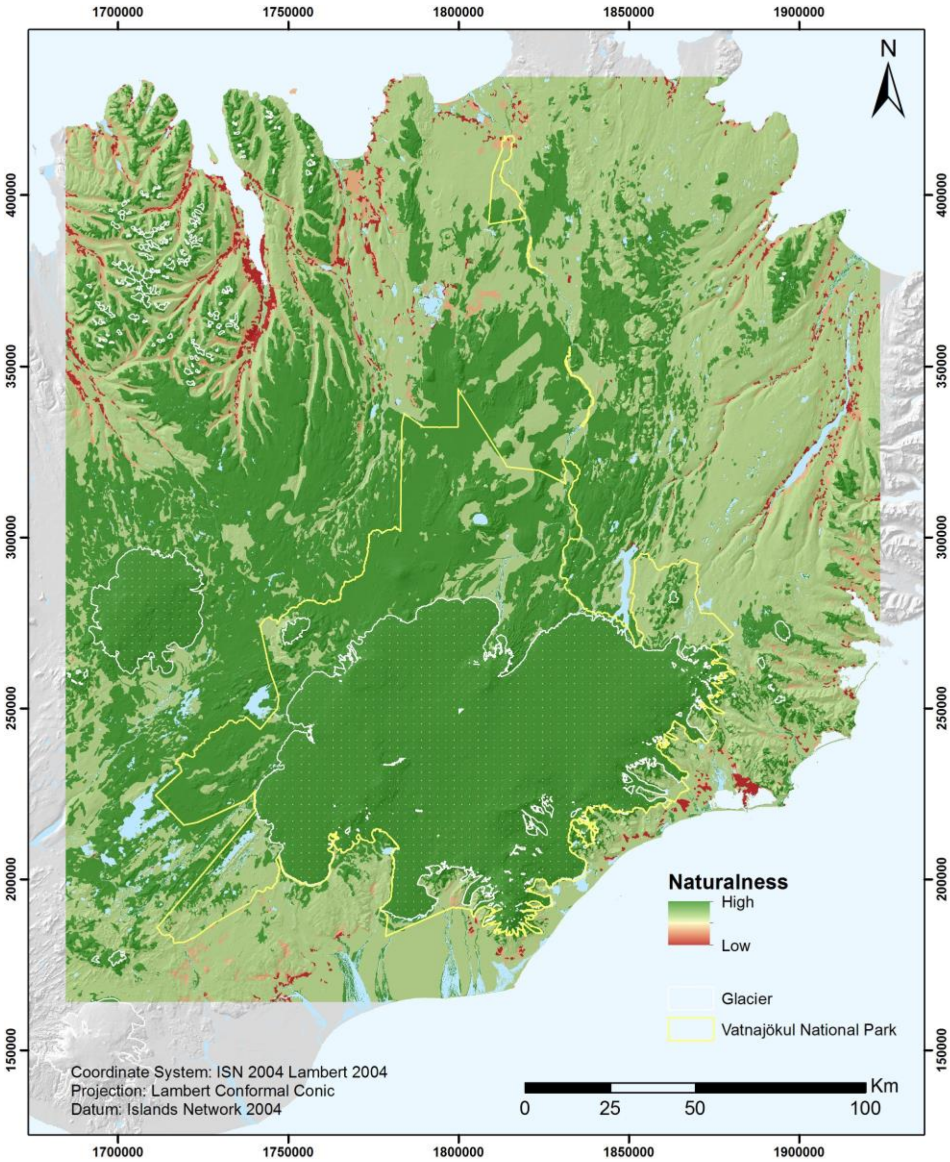

Figure 11. Naturalness based on CORINE land cover

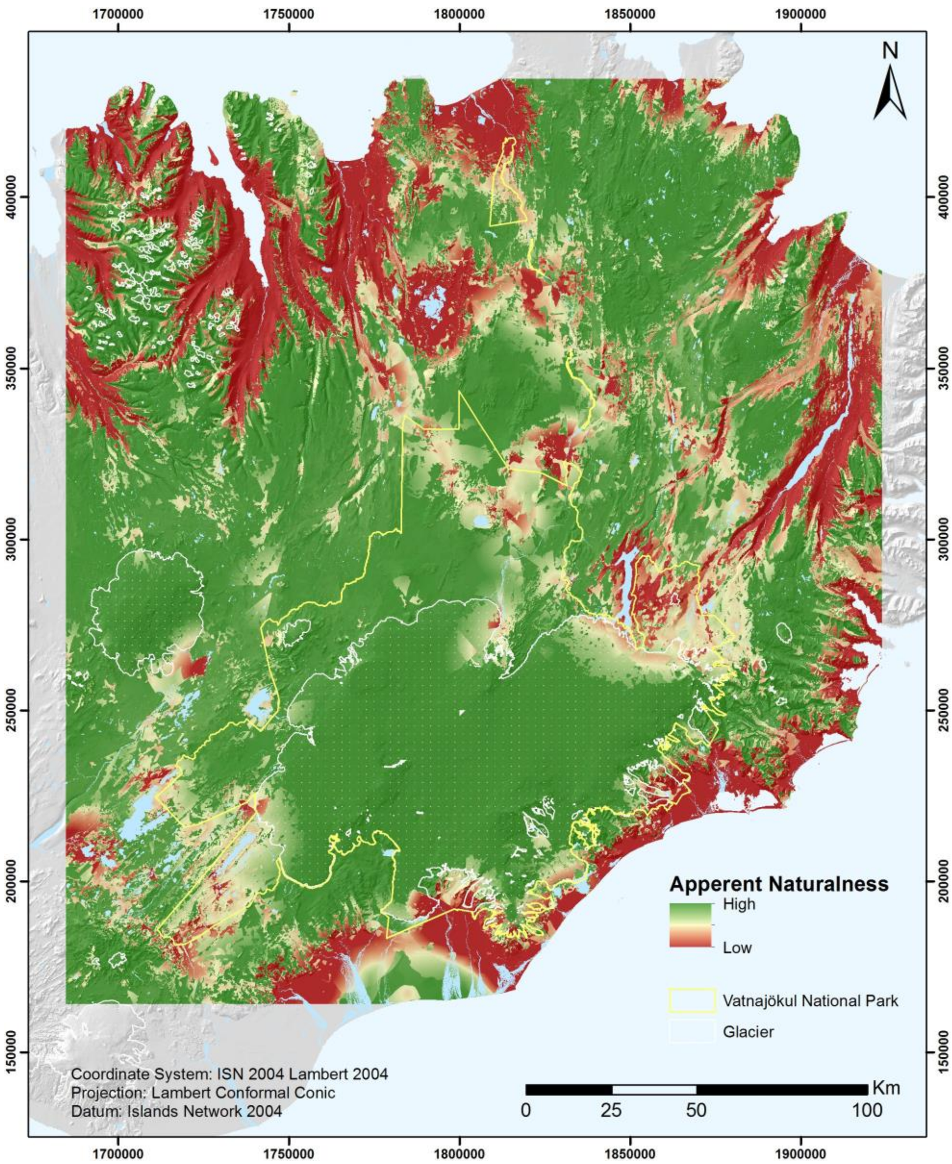

Figure 12. Apparent naturalness based on combined viewshed analysis of nine types of anthropogenic features

Figure 12 shows the apparent naturalness based on the combination of nine viewshed analyses of anthropogenic features. Apparent naturalness is degraded by two reasons, namely the number of (different types of) visible anthropogenic features, and the distance between feature and the viewpoint. Apparent naturalness is low in many of the coastal areas where most anthropogenic objects are located. It is furthermore interesting to see the impact that the hydrological dam and accompanying reservoir have on the naturalness in the north eastern part of VNP. The combination of paved roads, three dams, some structures, and the reservoir create an area of relatively low naturalness that expands well onto the Vatnajökull glacier.

5.6 The wilderness perception map

The combined wilderness perception map based on opportunity for solitude, naturalness, remoteness, and primitiveness is visualised in Figure 13. The entire wilderness continuum is represented, from not wild in mostly inhabited areas to very wild in the middle of the Vatnajökull glacier. The main highland roads can be distinguished, which is a combination of relatively low values in solitude, apparent naturalness and remoteness from mechanised access. The influence of primitiveness (GSM coverage) can also be seen in a few places. The most prominent location is in the north east of the study area, where a round light red circle is visible caused by high cell phone reception levels.

5.7 Wilderness zones

Figure 14 shows the result of the classification of wilderness in three zones using Jenks Natural Breaks classification method. Most of the highlands are classified as low or high wilderness. The Vatnajökull glacier with adjacent areas is the largest continuous area of high wilderness quality with an area of in total 8021 km^2. The distribution of wilderness zones in VNP, the VNP management zones, and the total study area can be seen in Table 12.

Table 12. Area of wilderness zones in study area and VNP

Wilderness zone	**VNP**		**VNP North**		**VNP East**		**VNP South**		**VNP West**		**Study area**	
	km²	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
High	9453	68	2275	58	1658	57	2912	83	2608	73	22888	41
Low	3774	27	1495	38	996	35	402	11	881	24	20849	37
No wilderness	720	5	168	4	234	8	221	6	96	3	12025	22

More than 2/3 of VNP is classified as high wilderness quality, and only 5% as not wild. Most of the highest wilderness qualities are found on the icecap. There are a few areas besides the icecap that are also classified as high wilderness. The largest is the area known as Vonarskarð, located North West of the glacier. In most directions there seem to be areas with high wilderness qualities that might be worthwhile additions to VNP.

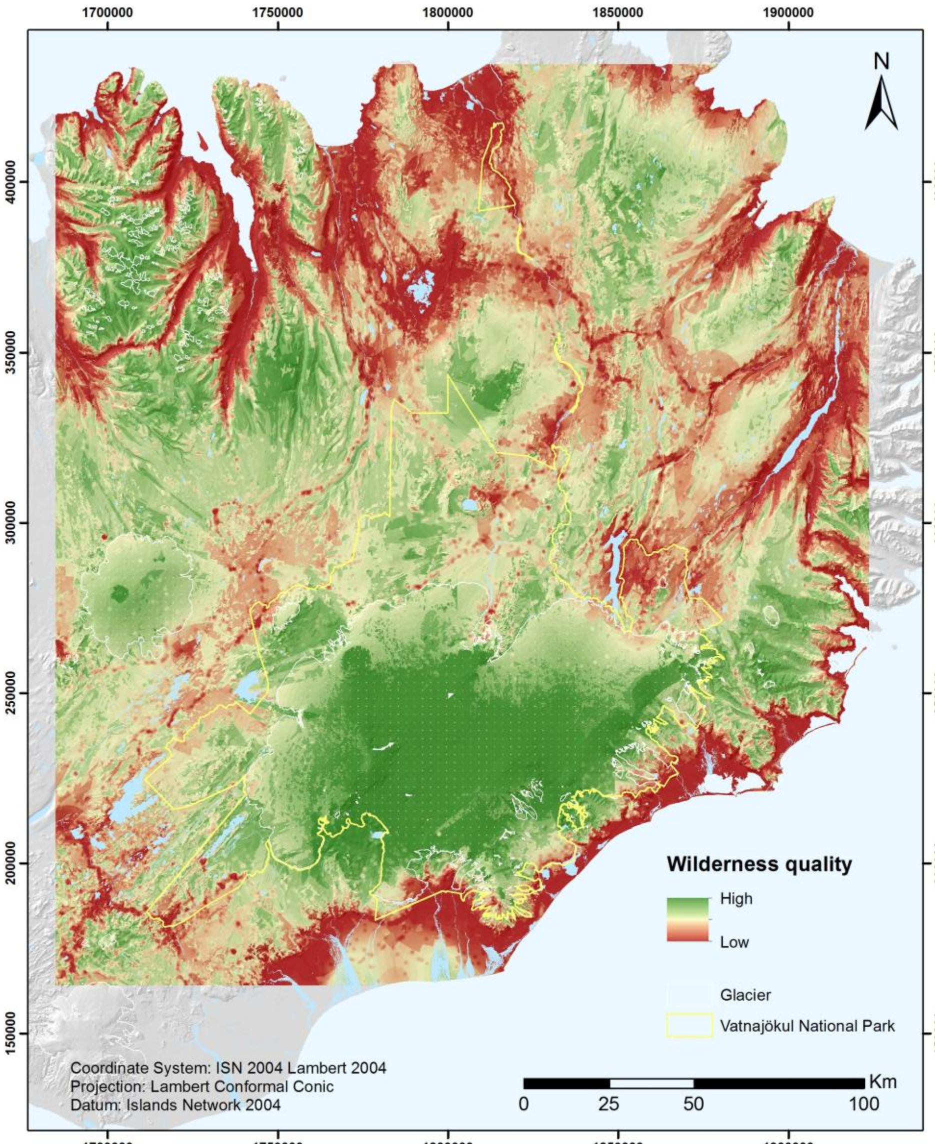

Figure 13. Criteria of solitude, naturalness, remoteness and primitiveness combined in one wilderness perception map using equal weights

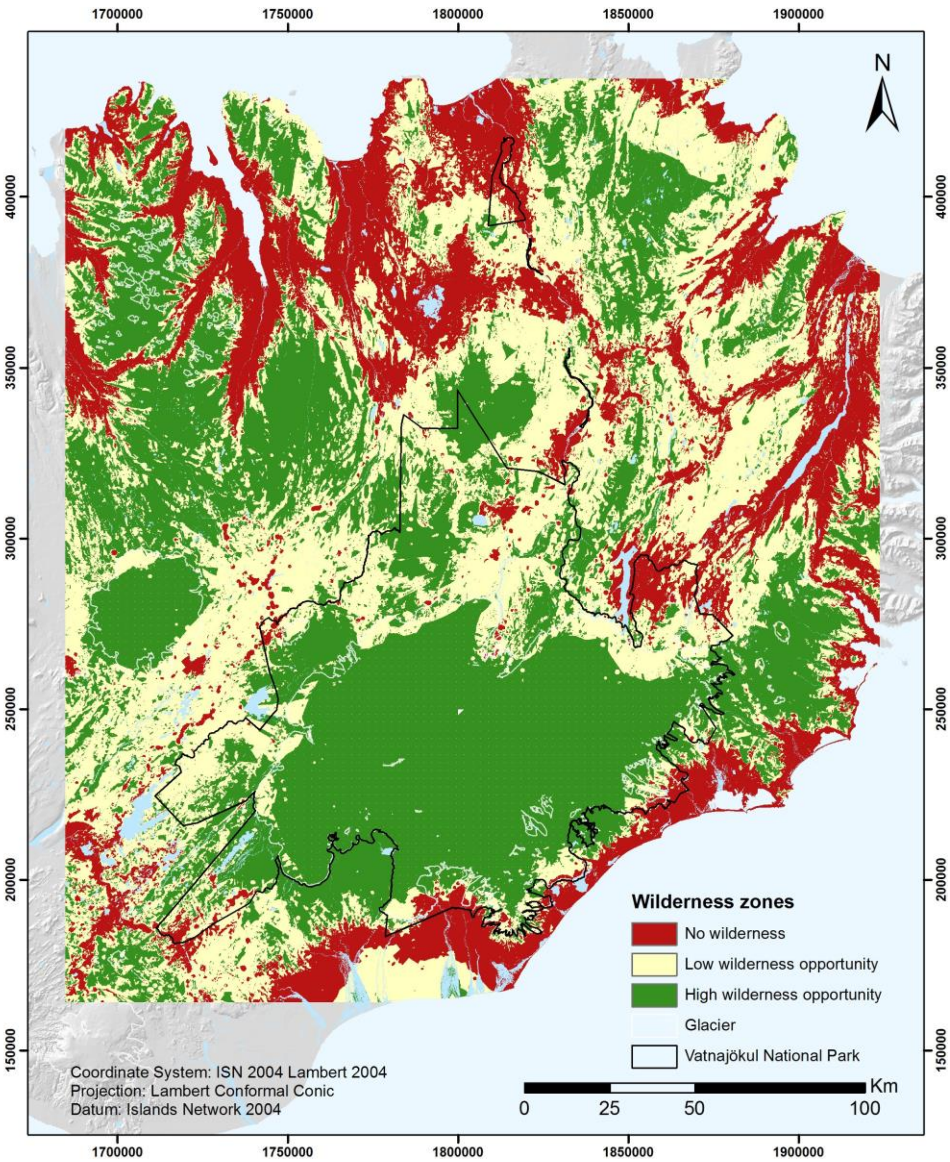

Figure 14. Wilderness classified in three zones using Jenks Natural Breaks

5.8 Wilderness map Law on Nature Conservation

Figure 15 shows the wilderness map based on criteria of the Icelandic Law on Nature Conservation. It is characterised by sharp boundaries defining if an area is wilderness or not. The number and visibility of anthropogenic features has no influence on the classification of wilderness. Most of the Vatnajökull icecap is classified as wilderness due to the lack of anthropogenic features. Just north and south of VNP are considerable wilderness areas that could potentially be interesting to add to the national park based on this result.

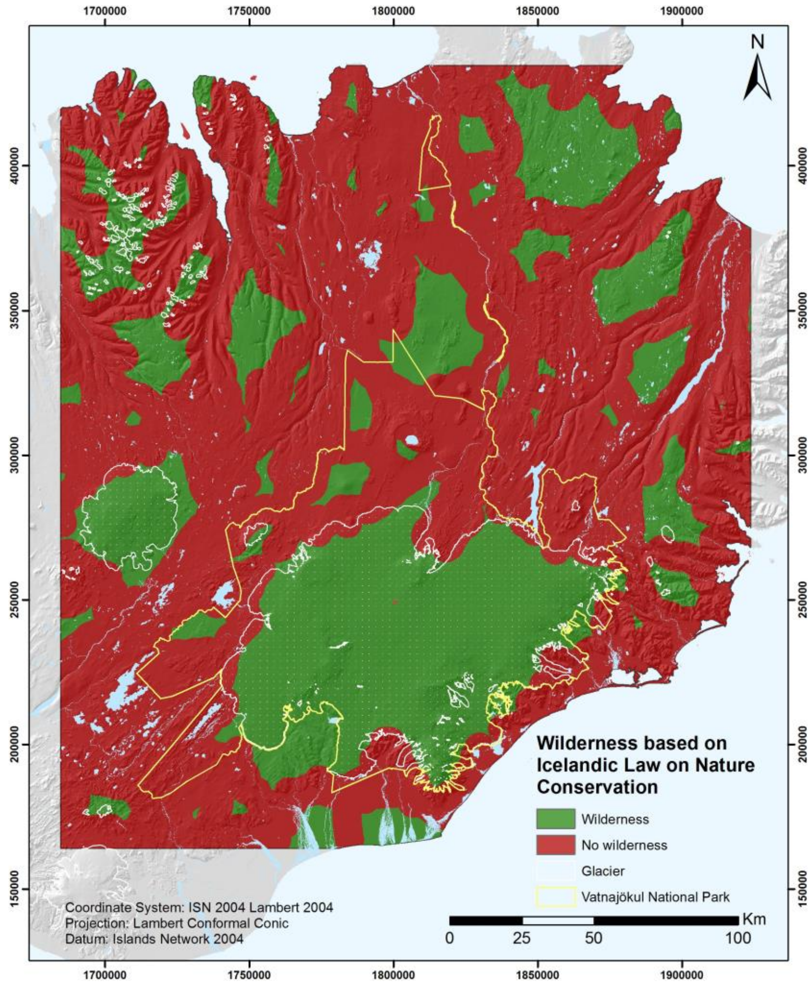

Figure 15. Wilderness based on Icelandic Law on Nature Conservation, characterised by sharp boundaries and binary classification wilderness or no wilderness

5.9 Comparison of wilderness maps

The classified wilderness perception map and the map based on the Icelandic Law on Nature Conservation are compared by area size in Table 13. In all sections more wilderness is found in the wilderness perception map.

Table 13. Comparison of wilderness areas between perception map and Law on Nature Conservation map

Wilderness map	**VNP**		**VNP North**		**VNP East**		**VNP South**		**VNP West**		**Study area**	
	km²	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
Perception map												
Wilderness	9453	68	2275	58	1658	57	2912	82	2608	73	22888	41
No wilderness	4495	32	1665	42	1230	43	623	18	977	27	32876	59
Law on Nature Conservation												
Wilderness	7916	57	1715	44	1475	51	2844	80	1882	52	16551	30
No wilderness	6032	43	2225	56	1413	49	691	20	1703	48	39220	70

In Figure 16 the maps are compared using a spatial overlay method. Four different classes are defined: areas that both maps defined as wilderness, only by the perception map, only by Law on Nature Conservation, or not wild in both. The largest common area that is defined as wilderness is the Vatnajökull icecap. Especially in the north east of the study area are considerable areas defined as wilderness by the Law on Nature Conservation and not in the perception map. The main reason seems to be the relatively good GSM coverage in these areas, as the other criteria show relatively high wilderness quality values.

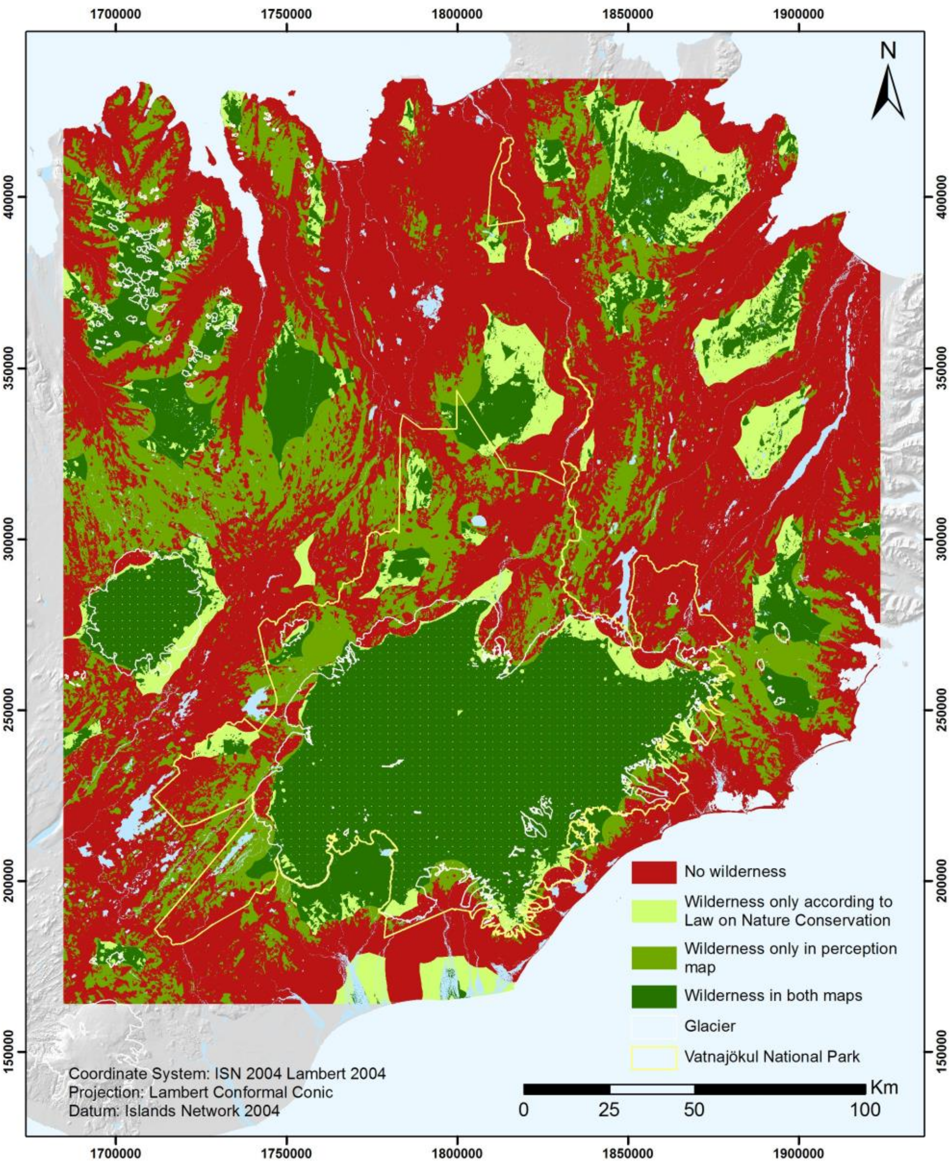

Figure 16. Spatial comparison of wilderness maps

6 Discussion and Conclusions

6.1 Geotagged pictures

The use of geotagged photos for mapping solitude, and in research in general, is still in its infancy. Difficulties with for example processing, analysing, and interpreting should therefore be expected, as best practises and methods are still being developed (Zheng et al., 2010). In this study some of the current limitations were encountered. One of the most prominent concerns is the spatial accuracy of the pictures. As discussed by Zielstra & Hochmair (2013), spatial accuracy varies between photos. Based on visual analyses, a few reasons could be identified. Firstly, the user has mistaken the location on the map when selecting the location where the picture was taken. To illustrate, a picture of lake Víti (which is a lake close to Askja) was pin pointed at an on the satellite image similar looking lake on top of Trölladyngja volcano. Secondly, instead of selecting the location where the photo was taken, the location of the photographed subject is selected. This is a common problem with mountains and glaciers, and potentially resulting in a significant error as mountains can be seen from far away. Thirdly, people seem to sometimes deliberately misplace the location of their picture to an area with less pictures, as was mentioned before by Zielstra & Hochmair (2013). This was only found in areas with extremely high picture densities however, such as the famous waterfalls and geothermal areas. Besides spatial accuracy there are a few more limitations with the use of geotagged pictures. As concluded by Hollenstein & Purves (2010), the Flickr and Panoramio communities should not be considered to be representative of society as a whole. Not all tourists take photos, and an even smaller part also decides to upload them to photo sharing websites. A potential source of information are the tags that can be added in Flickr. To investigate the perception of the word ‘wilderness’ under the Flickr users, metadata of all pictures containing the tag wilderness was downloaded. The result shown in Figure 17 demonstrates that pictures with the tag ‘wilderness’ don’t seem to be usable as a direct input for mapping solitude. It does however provide information about what people perceive as wilderness, and at which locations.

Despite the limitations that geotagged pictures currently have, they did provide valuable information about visitor patterns unlike any other type of data hitherto used for wilderness assessment. Orsi & Geneletti (2013) agree, and state that geotagged pictures are suitable for mapping solitude in an extended area as better information is often not available. By taking the number of photographers in an area instead of all available photos, it was avoided that areas were overestimated because one person uploaded multiple photos at one location. The high picture density on the ring road furthermore shows that Iceland is worth photographing virtually everywhere. This is important as this indicates that there is a relationship between the presence of people and the availability of geotagged photos. The added value of a solitude map based on photographer densities is furthermore demonstrated in the final wilderness perception map. The high presence of people makes areas not wild, while they might have been classified as low wilderness based on the other three criteria.

New applications will be possible when the amount of available geotagged pictures has further increased. One example would be to analyse seasonality of wilderness tourism. In this study all pictures from the past years have been used, but within the next few years the dataset will be of sufficient size to create solitude maps by season or month. Figure 18 shows the seasonality in Iceland based on the current dataset. It clearly demonstrates that the Central Highland is much more visited during the summer months.

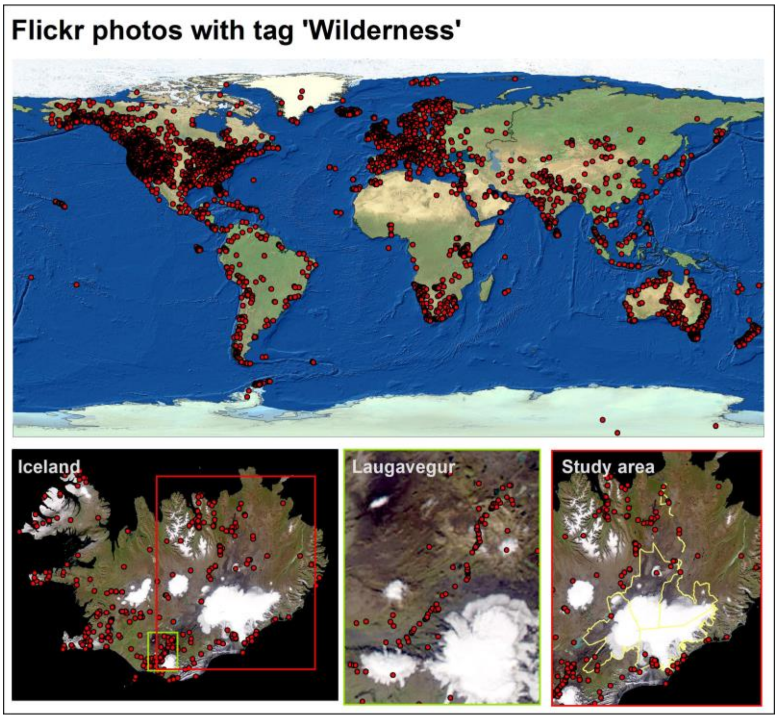

Figure 17. Locations of geotagged photos that were tagged as wilderness by Flickr users

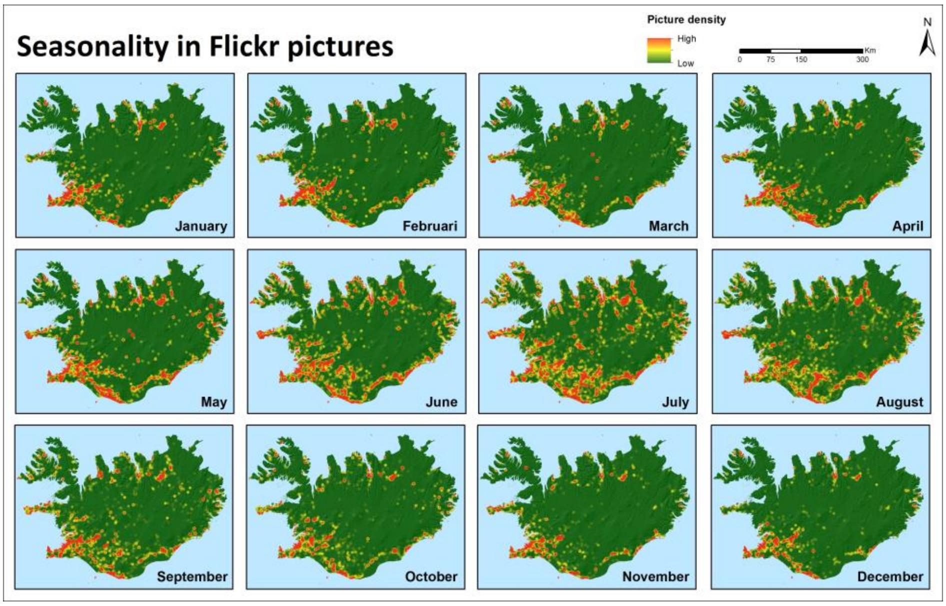

Figure 18. Map showing the use of geotagged photos from Flickr for seasonality analyses

6.2 Road appearance and traffic intensities to map impact on wilderness

The diversity in appearance and traffic intensities of Icelandic roads is enormous. The impact that roads have on the wilderness experience therefore varies widely. Lesslie et al. (1988), who conducted one of the first wilderness mapping studies, classified roads based on their use when mapping Australian wilderness. Ólafsdóttir & Runnström (2011) used a similar approach, and classified Icelandic roads in two classes with different linear distances to assess road disturbance. Daily traffic averages of Icelandic road types however indicate that an increase in classes might further approach the impact they cause. The methodology applied in this study combined the appearance (size, surface type), traffic intensities, visibility, and distance from roads. This approach is considered to provide a better estimation of the impact of roads on the wilderness experience than solely using proximity to different road types, as visibility and sound makes higher disturbance factor to tourists. Flanagan & Anderson (2008) confirm that road appearance has a significant influence on the impact a road has, and mapped perceived wilderness accordingly. Iglesias Merchan et al. (2014) empirically studied the annoyance levels from various sounds in a natural landscape, and concluded that passing cars have a negative impact on the nature experience.

The rank sum method was used to assign weights to the road classes. Malczewski (1999) notes that it has its limitation, as it is an estimation without theoretical background. It can also be difficult to apply with very large datasets or when data is lacking a clear order. The road types and traffic intensities show a clear order in both appearance and use. That the used weights have their influence on the map showing the impact of roads, is obvious. Most of the F roads in the highlands have a low impact on the wilderness experience. In contrast, paved and relatively heavily used roads cause high impacts. However, empirical research is necessary to confirm that the applied method is in accordance with the perception of wilderness tourists, and to better estimate the perceived differences of Icelandic roads.

6.3 GSM coverage data as wilderness primitiveness proxy

The lack of GSM coverage contributes to the level of self-reliance in a wilderness environment, and therefore to the level of primitiveness. This makes it a potentially interesting indicator for wilderness mapping studies. Research on cell phone coverage on the wilderness experience is however scarce. One of the few studies is a visitor survey conducted by Boller et al. (2010) in the Swiss Alps. Results indicated that purists dislike cell phone coverage. The opinion of other wilderness visitor groups was not given.

Previous use of cell phone coverage in wilderness mapping studies has not been found. One of the main reasons is likely the lack of data availability. Coverage data is valuable information, and therefore not distributed easily. The limited availability of scientific proof that cell phone coverage influences the wilderness experience might also contribute.

This study demonstrated how cell phone coverage can be used as input for wilderness perception mapping. As it was assigned the same weight as other wilderness attributes, it had a significant influence on the final wilderness perception map in a number of areas. If this impact is valid is questionable, especially as the actual level of connectivity is not known. It is therefore suggested to use empirical research to further improve the knowledge with regards to this indicator before applying it in planning and management applications.

6.4 Wilderness perception mapping

Over the past decades methodologies in wilderness mapping evolved from simple linear distance calculations from anthropogenic features (Lesslie et al., 1988) to advanced calculations using viewshed analyses, fuzzy rules, and hiking models to estimate remoteness (Carver et al., 2012, 2013; Comber et al., 2010). However, the data that is being used has mainly stayed the same. This study examined the use of new datasets and methods to further improve the mapping of wilderness perception. This is important as Sæþórsdóttir (2012, 2013) points out that the Icelandic highlands are under high pressure from rapidly increasing tourism and development plans for hydro- and geothermal power production in the highlands.

Mapping wilderness based on perception, and using a gradual scale for wilderness quality, has several advantages over mapping wilderness based on proximity from anthropogenic features. As discussed by Carver et al. (2012), mapping wilderness based on the wilderness continuum concept, using wilderness attributes as a starting point, results in more reliable maps than maps created by simple linear distance calculations from anthropogenic features. The latter is usually too generalised and therefore might miss critical patterns and variability that could be essential for planning and management purposes. Moreover, the use of weights for criteria and indicators provides the possibility to incorporate public opinions, policies, or management priorities. Not only is the final wilderness map is useful, but also the intermediate results of the criteria and indicators. The photographer density map can for example be used for seasonality analyses, and the map showing apparent naturalness can be used to analyse the impact of infrastructure on the wilderness quality. Travel time by foot and mechanised transport furthermore seems to be a better estimation of remoteness then calculating linear distances from roads.

There are multiple potential management applications imaginable for the perception map. Non purists and neutralists could for example be triggered to visit areas with sufficient wilderness quality, but also have easy access, that are managed well, and that are capable of handling intensive use. Another powerful application is to estimate the impact of planned hydro- or geothermal power plants on the wilderness quality. The impact that a dam and all accompanying infrastructure for hydropower production can have on the wilderness quality is demonstrated with the Kárahnjúkar project. Figure 12 shows that wilderness quality around the dam is significant lowered. As demonstrated by Carver et al. (2013), input data can be updated with future plans, and the impact is directly visualised. Some of above applications are possible using solely proximity to from anthropogenic features, but would miss the nuance that is so important for planning and management purposes.

The wilderness perception map presented in this study, that was produced by combining the wilderness attributes of solitude, naturalness, remoteness, and primitiveness, is here only produced to illustrate the methodology. As equal weights were applied to all indicators and criteria, and new methods and data need empirical research, no absolute conclusions can be drawn from the map. The same applies for the derived statistics, comparison of the two wilderness maps, and the classifying of wilderness zones. The general methodology for zoning is shown as it can be useful for management purposes. It can for example be used to identify the core wilderness areas that should absolutely be protected. Defining thresholds where wilderness starts is difficult however. Carver et al. (2012) used expert opinions together with fuzzy logic, and Orsi et al. (2013) based their thresholds on unsupervised classification. All methods however contain a certain amount of subjectivity.

6.5 Recommendations

There are a few possible options to address the spatial quality concerns of geotagged pictures. The dataset could for example be improved by manually checking every single photo by someone with knowledge about the area, and relocate or discard it in case the position is incorrect. For a study area the size of VNP this seems impossible. Another possibility could be to relate the title, tags and position. If the coordinates of a picture with a certain title are not within a predefined range of the known position of the photographed object, it could be rejected or relocated. In this study, Flickr and Panoramio pictures were combined into one dataset to create a dataset of sufficient size for the density mapping. This might have introduced some bias. Time will however solve this problem, as the database of geotagged pictures increases rapidly. For the years 2011 till 2013, the metadata of respectively 11216, 18555, and 51937 photos was downloaded from Flickr. If this trend continues in the coming years, only one source is sufficient. It is therefore recommended to update the database of geotagged pictures when analyses are done.

It is furthermore suggested to do empirical research on the impact of Icelandic roads on the wilderness experience. Visitors of the highlands could for example be interviewed at various locations, and specifically asked if and then where they were bothered by the sight and sounds of roads. Another method might be a survey showing pictures of Icelandic roads in their surroundings, and ask how desirable or undesirable they may be. This information could then be used to assess the applied method in this study.

With regards to the used viewshed analyses, a few recommendations are made. The maximum distances of 15 km and 25 km that were used in this study, are based on previous literature. It could be worthwhile to examine the viewshed map in the field to determine if features are indeed visible. Viewsheds were furthermore combined based on equal weights. The number of different visible feature types (houses, roads, power lines) at one location therefore determines the impact on apparent naturalness. To illustrate, a location with 30 houses close to each other has less impact than one house and a road. A good example in the map showing apparent naturalness is a location north east of Askja, just outside the borders of VNP. The combination of three buildings, a hiking path, a highland road, and a small airport result in a very high impact. To avoid this overestimation of impact, it would be better to count the absolute number of visible objects. Unfortunately this is not possible in ArcGIS as viewsheds are generted based on points only. Line features such as roads are split up in vertexes, and each vertex is counted as a separate feature (road). It is therefore recommended to use more advanced software such as the voxel-based viewshed model used by Carver et al. (2012). Expert opinions or survey could finally be used to assign weights to the different types of objects to further improve the analyses as is suggested by Carver et al. (2012). A small hiking path now received the same weight as a hydropower dam, which is something most people won’t agree with.

As the results of the naturalness classification based on the CORINE land cover database are questionable, it is recommended to see if other land cover datasets are more suitable to assess naturalness. The classification of naturalness could also be revised to better suit the Icelandic landscape.

Future studies could furthermore try to incorporate seasonality in the analyses. In the winter season the wilderness is most likely considerably larger due to inaccessibility by snow. Traffic intensities and visitor density maps based on geotagged photos seem to be very useful as data source.

Finally it is recommended to use expert opinions, input from park managers, and policies to define weighs for indicators and criteria in the perception map. Equal weights were applied in this study as no reliable input was available. Comber et al. (2010) demonstrated that weights have a significant influence on results. The wilderness perception map presented in this study can therefore only be used as a baseline to compare different opinions, and illustrate how different wilderness maps can be compared. However, even when weights have been assigned, it is still only an estimation of selected aspects of wilderness quality (Carver et al., 2013).

6.6 Concluding remarks

The results indicate that publicly available geotagged photographs are useful data for assessing perceived solitude, as the derived density map shows visitor patterns unlike any other type of data hitherto used for wilderness assessment.

Traffic intensities and visibility of roads are further considered to provide a better estimation of the impact of roads on wilderness than solely using proximity to different road types, as visibility and sound makes higher disturbance factor to tourists.

GSM coverage data identifies areas of self-reliance in a wilderness environment, which is considered as an indicator for wilderness primitiveness. More research is needed however on the impact of the availability of cell phone coverage on the wilderness experience.

It is concluded that the new data types examined in this study add valuable information to previous wilderness mapping. They provide a higher precision to areas of perceived solitude, naturalness, primitiveness, and remoteness, and therefore of important use for management and planning purposes.

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Appendix: PHP script for downloading metadata of Flickr photos

```
<?php
#set long execution time to prevent script from stopping before being
finished
ini_set('max_execution_time',64000000000000);
header("Content-Type:text/html");
echo '<?xml version="1.0" encoding="utf-8"?>';
$total_found = 0;
$total_parsed = 0;
$to_many_in_bounding_box = "";
$search_string_arcgis = "";

?>
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en"
lang="en">
  <head>
    <meta http-equiv="Content-Type"
content="text/html;charset=utf-8" />
    <title>flickr_search.php</title>
  </head>
  <body>
<?php

        # Connecting, selecting database
   $dbconn = pg_connect("host=localhost dbname=geo_pictures
user=postgres password=xxxxx")
    or die('Could not connect: ' . pg_last_error());

    # load bounding boxes from text file
        $lines = file('bb_flickr.txt', FILE_IGNORE_NEW_LINES);

    # search for pictures within each bounding box that was read from
the text file
        foreach ($lines as $value) {
                do_search($value);
        }
        echo "<br><br>Finished with all bounding boxes!";
        echo "<br>Total pictures found: ". $total_found;
```

```
        echo "<br>Total pictures parsed: ". $total_parsed;

        $to_many_in_bounding_box = str_replace(",", ";",
$to_many_in_bounding_box);
        $to_many_in_bounding_box = str_replace(".", ",",
$to_many_in_bounding_box);
        $to_many_in_bounding_box = str_replace(",", ".",
$to_many_in_bounding_box);
        echo "<br>Bounding boxes with too many pictures: ".
$to_many_in_bounding_box;
        echo "<br>Query for arcgis: ".$search_string_arcgis;

        pg_close($dbconn);


# uses libcurl to return the response body of a GET request on $url
function getResource($url){
  $chandle = curl_init();
  curl_setopt($chandle, CURLOPT_URL, $url);
  curl_setopt($chandle, CURLOPT_RETURNTRANSFER, 1);
  $result = curl_exec($chandle);
  curl_close($chandle);

  return $result;
}

function do_search($value) {

        global $total_found;
        global $total_parsed;
        global $to_many_in_bounding_box;
        global $search_string_arcgis;

        # strip bounding box for url
        $arr = explode(",",$value);
        $boundingbox_id = $arr[0];
        $xmin = $arr[1];
        $ymin = $arr[2];
        $xmax = $arr[3];
        $ymax = $arr[4];

        # flickr key
        $api_key = "0a3364846f4dd472608081f774391d70";

        # dynamic url. Uses bounding boxes from text file
```

```
	$url =
"http://api.flickr.com/services/rest/?method=flickr.photos.search&api
_key=xxxxxxxxxxxxx&min_taken_date=1970-1-
1&accuracy=1&sort=date-taken-
desc&bbox=".$arr[1].",".$arr[2].",".$arr[3].",".$arr[4]."&extras=date
_taken,geo,tags,owner_name,url_m,views,url_t";

	$feed = getResource($url);
	$xml = simplexml_load_string($feed);

	#check for empty xml. If empty, try again
	if (($xml->photos['total']) == '') {
		echo "<b>empty xml!!</b>";
		$feed = getResource($url);
		$xml = simplexml_load_string($feed);
	}
	if (($xml->photos['total']) == '') {
		echo "<b>again empty xml!!</b>";
		$feed = getResource($url);
		$xml = simplexml_load_string($feed);
	}

	# print number of pictures within bounding box, and warn if
total is more than 250 (maximum flickr will return with bounding box
request)
	if (($xml->photos['total']) > 250) {
		echo "Bounding box to search for: " . $value . "<br>";
		echo "WARNING!! Number of photo's found is: {$xml-
>photos['total']}<br>";
	}	else {
		echo "Bounding box to search for: " . $value . "<br>";
		echo "Total number of photos found: {$xml-
>photos['total']}<br>";
	}

	$total_found = ($total_found + ($xml->photos['total']));

	# Some checks to alert for missing pictures
	if ((count($xml->photos->photo)) > 250) {
		echo "<b>Warning!! Number of pictures in response: "
.count($xml->photos->photo)."</b><br>";
	} else {
		echo "Number of pictures in response: " .count($xml-
>photos->photo)."<br>";
	}
```

```
	$total_parsed = ($total_parsed + (intval(count($xml->photos->photo))));
	echo "Total pictures so far: ". $total_parsed ."<br><br>";

	# Add current bounding box to list in case there are more than 250 photos found
	if (($xml->photos['total']) > 250) {
		$to_many_in_bounding_box = $to_many_in_bounding_box ."<br>". $value;
		$search_string_arcgis = $search_string_arcgis ."\"PageNumber\" = ".$boundingbox_id." OR ";
	}

	# Parses returning xml from Flickr, stores it in local variables and stores them in postgres DB
	foreach ($xml->photos->photo as $photo) {
	  $title = str_replace("'", "", $photo['title']);
     $photo_id = $photo['id'];
	  $owner_id = $photo['owner'];
	  $owner_name = str_replace("'", "", $photo['ownername']);
	  $url_thumbnail = $photo['url_t'];
	  $url_geoserver = substr(($photo['url_t']),7,-4);
	  $url_medium = $photo['url_m'];
	  $latitude = $photo['latitude'];
	  $longitude = $photo['longitude'];
	  $place_id = $photo['place_id'];
	  $woeid = $photo['woeid'];
	  $tags = $photo['tags'];
	  $tags = str_replace("'", "", $tags);
	  $tags = str_replace("{", "", $tags);
	  $tags = str_replace("}", "", $tags);
     $tags = "{".preg_replace('/\s+/',',',$tags) ."}";
	  $accuracy = $photo['accuracy'];
	  $date_taken = $photo['datetaken'];

	  if (substr($date_taken, 5, 2) == "00") {
		$date_taken = substr_replace($date_taken,"06",5,2);
	  }
	  if (substr($date_taken, 8, 2) == "00") {
		$date_taken = substr_replace($date_taken,"15",8,2);
	  }

	  # store pictures in Postgres database
```

```
        $result = pg_query("INSERT INTO flickr(   photo_id,
photo_name,   owner_id,   owner_name,   url_thumbnail,
url_geoserver,   url_medium,
geometry,   longitude,   latitude,   place_id,   woeid,   tags,
accuracy,   date_taken)
                                                        VALUES('$photo_i
d',   '$title', '$owner_id', '$owner_name', '$url_thumbnail',
'$url_geoserver', '$url_medium',
ST_GeomFromText('POINT($longitude $latitude)',4326), '$longitude',
'$latitude', '$place_id', '$woeid', '$tags','$accuracy',
'$date_taken');");
            if (!$result) {
                die('Could not insert row: ' . pg_last_error());
            }

            # dump the result object
            var_dump($result);

        }
        echo "<br><br>---------------------------------------------------
-----------<br>";
}

?>
  </body>
</html>
```