IDENTIFICATION OF AREAS FOR FORESTRY AT THE REGIONAL PLANNING LEVEL IN ICELAND: EXAMINATION OF A LAND-USE ASSESSMENT METHOD

by

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Abstract

The subject of this research project is the development and initial test of one potential land-use assessment method for Iceland, intended to aid the selection of areas for a given land-use (forestry in this instance) based on the natural attributes of land only. The method evaluates land for a given land-use and is designed for the regional planning level in Iceland and intended to be relatively quick and easy to apply. The main features of the method are the use of expert evaluation, the division of natural variables or factors into categories, and the use of a common grade scale for all land-uses. The method consists of six steps: 1) creation of cells, 2) mapping of current land-use and natural factors, 3) cell grading (based on expert assigned grades), 4) weight derivation (by experts) and calculation of weighted grades, 5) calculation of overall grades by summing weighted grades, and 6) comparison of grades for different land-uses and comparison to current land-use. The overall result is a map showing the cells most suitable for forestry.

The method was tested for the municipality of Skaftárhreppur in Iceland. The test included an evaluation of the stability of the method and of the method results, which were evaluated by examining their concurrence with current forests and by a comparison with a direct expert evaluation of the test area. The method results indicated that agriculture and forestry could co-exist in the study area. Overall, while certain improvements are needed, the proposed method renders results of sufficient quality to merit its further use as it meets the objectives set out in the beginning.

Dedication

Bræður mínir

Sigurður (16.03.1966 – 08.12.1997)

Gunnar (27.04.1970 – 05.07.1998)

Alltaf með mér

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Glossary

This glossary contains the English translation of all Icelandic institutions and publications mentioned in the main text and the list of references.

Alþingi:	Icelandic Parliament
Búvísindi:	Icelandic Agricultural Sciences
Bændasamtök Íslands:	The Farmers Association of Iceland
Embætti Veiðimálastjóra:	Directorate of Freshwater Fisheries
Ferðafélag Íslands:	Iceland Touring Association
Ferðamálaráð Íslands:	Iceland Tourist Board
Fiskifélag Íslands:	Icelandic Fisheries Society*
Hafrannsóknarstofnun:	Marine Research Institute
Hagstofa Íslands:	Statistics Iceland
Hið íslenska náttúrufræðifélag	Natural History Society of Iceland
Hið íslenska þjóðvinafélag:	Icelandic Society of Friends of the Nation*
Iðnaðarráðuneyti:	Ministry of Industry
Íslenskar landbúnaðarrannsóknir	Icelandic Agricultural Research*
Landgræðsla ríkisins:	Soil Conservation Service
Landbúnaðarháskólinn á Hvanneyri:	Hvanneyri Agricultural University
Landbúnaðarráðuneyti:	Ministry of Agriculture
Landmælingar Íslands:	National Land Survey of Iceland
Landsvirkjun:	The National Power Company
Landvernd:	National Association for the Protection of the Icelandic Environment
Náttúrufræðistofnun Íslands:	Icelandic Institute of Natural History

Náttúruvernd ríkisins:	Nature Conservation Agency
Norræna ráðherranefndin:	Nordic Council of Ministers
Ofanflóðanefnd:	Committee on landslides and avalanches*
Orkustofnun:	National Energy Authority
Rannsóknarstofnun landbúnaðarins:	Agricultural Research Institute
Samband íslenskra sveitarfélaga:	The Association of Local Authorities in Iceland
Siglingastofnun Íslands:	Icelandic Maritime Administration
Skógrækt ríkisins:	Iceland Forestry Service
Skógræktarfélag Íslands:	The Icelandic Forestry Association
Skógræktarritið:	Icelandic Forestry – The Journal of the Icelandic Forestry Association
Sögufélag:	Historical Society*
Umhverfisráðuneyti:	Ministry for the Environment
Veðurstofa Íslands:	Iceland Meteorological Office
Vegagerðin:	National Road Authority
Veiðimálastofnun:	Institute of Freshwater Fisheries
Verkefnisstjórn Rammaáætlunar um nýtingu vatnsafls og jarðvarma	Steering Committee for the Master Plan for Hydro and Geothermal Energy Resources in Iceland

* Direct translation, as no official translation was found.

Chapter 1
Introduction

The subject of this research project is the development and initial test of one potential land-use assessment method for Iceland. The intent of the method is to aid the selection of areas for a given land-use based on the specific natural attributes of land in Iceland, but excluding economic and social attributes in this initial examination. The method is intended as a tool for the general land-use planning process in Iceland and although the focus for this project is on forestry, the method is not intended for forestry specifically, but it can be used to compare several land-uses. The method is designed for the regional planning level, which in Iceland corresponds to maps in a scale of 1:50,000 and the general land-use types employed at that level (i.e. general agriculture rather than different types of agriculture). The results of the method are intended as one tool in land-use planning, not as the ultimate decision basis.

As no general land-use assessment method has been applied in Iceland before, this initial examination is kept simple and only two potential land-uses are examined: agriculture and forestry. Obviously there are many other potential land-uses, both extensive (e.g. nature conservation) and intensive (e.g. industry), but it was deemed important to test such a more formal assessment approach in a relatively simple manner. In addition, agriculture and forestry essentially rely on the same natural attributes (they are both dependent upon vegetation growth) and can thus be treated in a similar manner. Some other land-uses operate on a different scale and may operate alongside several land-uses. Tourism, for example, can function quite well together with both forestry and agriculture and should therefore not be included in this context, as it is not mutually exclusive from either forestry or agriculture.

The need for a land-use assessment method that can identify areas suitable for forestry has historical roots. When Iceland was settled in the 9th century AD, forests covered an estimated quarter of the country (Blöndal and Gunnarsson, 1999). In the centuries following the settlement, great deforestation took place, so that at the turn of the 20th century, when the first serious attempts at reforestation began, the forests had declined by around 95% (Skógrækt ríkisins, 2000 a). Currently, extensive plans for reforestation are underway, and it is quite likely that forestry will be a much more significant part of future regional planning processes.

A combination of various natural and human factors contributed to the heavy deforestation (Skógrækt ríkisins, 2000 a). The natural factors include the northerly geographic location of Iceland (around 65°N), which places the country at the northern margin of the Northern Forest Zone (Sigurgeirsson and Kristjánsdóttir, 1995). Geologically speaking, Iceland is a young country and therefore relatively active geomorphologically, with extensive erosion by glaciers, rivers and the ocean. Iceland has also numerous volcanoes, with over 150 volcanic eruptions since settlement, some of which have resulted in heavy ash-fall. Historically, some of these eruptions were felt on an international or global scale, e.g. the eruption at Laki in 1783 (Blöndal and Gunnarsson, 1999; Skógrækt ríkisins, 2000 a). This activity, coupled with the relatively small size of the country

(103,000 km^2), means that Icelandic nature is very vulnerable. From the time of settlement, the country has also been exposed to climate change, resulting in cold spells, starting in the 13th century and lasting more or less until the end of the 19th century (Skógrækt ríkisins, 2000 a). The impacts of settlement were both direct and indirect. The settlers used the trees for construction and fuel, and large areas of forests were burned to create agricultural land, mostly grazing land. Grazing then prevented regeneration of the forests, with the result that untouched examples of the original forests do not exist. At the start of the 20th century, birch woods existed as scattered remnants covering around 1% of Iceland's area (Bjarnason, 1977; Blöndal and Gunnarsson, 1999).

In 1907, Alþingi (the Icelandic Parliament) passed forestry and soil conservation laws, creating Skógrækt ríkisins (Iceland Forestry Service) (Skógrækt ríkisins, 2000 b). Alþingi passed the current forestry law in 1955 (Lög um skógrækt nr. 3/1955). According to the law, the purpose of Skógrækt ríkisins is to 1) protect forests and forest remnants, 2) increase the extent of forests, and 3) advise on forestry issues (research and education). This law also states that land reclamation should lead to the establishment of woodlands where possible (Skógrækt ríkisins, 2000 b). Another important law affecting land-use was the law on Héraðsskógar, passed in 1991, which addresses the region of Hérað specifically. The aim of the law is to protect the forests that exist in Hérað and stimulate the growth of *nytjaskógar* ('utility-forests'). The law stipulates a plan, covering 40 years and a 15,000-hectare area (Lög um Héraðsskóga nr. 32/1991). Alþingi passed a similar law for the region of Suðurland in 1997, creating the Suðurlandsskógar project (Lög um Suðurlandsskóga nr. 93/1997). In 1999 Alþingi passed a law on regional forestry plans. The law stipulates that at least 5% of the low-elevation area of each region must be devoted to forestry (Lög um landshlutabundin skógræktarverkefni nr. 57/1999).

These laws of the 1990's will result in a dramatic increase in the area devoted to forestry. Already there are those voicing concerns about the impact this reforestation will have on other land-uses and how it will affect the landscape. This concern has led to some demands for a more comprehensive consideration and inclusion of forestry into land-use and land conservation planning, especially considering the long-term nature of forestry (Landvernd, 2000; Sigurðsson, 2000). Such a consideration of forestry calls for some method to aid in making a rational decision on land-use planning; a method that is both feasible given Icelandic circumstances and relatively simple to apply, so it does not require too many additional resources for the planning process.

A land evaluation method suited to Icelandic circumstances requires special consideration, because the island's nature is in many respects unique (Schutzbach, 1985). Iceland is one of few examples of a mid-oceanic ridge 'reaching surface', which, coupled with the presence of a mantle plume ('hot spot') under the country, results in a unique geology and some uncommon plant species (Einarsson, 1994; Bernes, 1996; Plummer and McGeary, 1996). Geologically speaking, Iceland is a young country and is as a result very geomorphologically active (in a geological time frame) compared to most other countries (Einarsson, 1994). Iceland also has a comparatively warm climate for its latitude, largely due to the warm Gulf ocean stream and the small size of the country, which makes a maritime climate predominant throughout the island (Bernes, 1996). The country is also a rather isolated island, which means the introduction of new flora and fauna by natural processes is rather limited, resulting in a relatively non-diverse wildlife (Hersteinsson and Sigbjarnarson, 1993; Bernes, 1996). In addition, Iceland lies between two continents and has wildlife species originating in both, resulting in a somewhat unusual wildlife composition (Steindórsson, 1964; Bárðarson, 1986). Consequently, most land-use assessment methods developed in other parts of the world require a number of modifications to fit Icelandic circumstances and, equally, any method developed specifically for Icelandic circumstances cannot be employed unaltered in other parts of the world. Thus, a new land-use assessment method geared towards Iceland, based on recognized principles from land evaluation methods developed in other countries, is required. The initial idea of developing such a method came up during a field trip by members of Skógrækt ríkisins in September 1996. One of the members, Gunnar Freysteinsson, took it upon himself to develop the idea further, with additional input from Freysteinn Sigurðsson, geologist at Orkustofnun (National Energy Authority). As the project had no specific funds set aside for it, both worked on it alongside their full-time jobs. In 1998, Gunnar had plans to enter a Ph.D. program and focus on the project, but unfortunately the project came to an abrupt stop in July 1998, when Gunnar died in a car accident.

Chapter 2
Literature review

The goal of the project is to develop and test one potential land-use assessment method, which will assist in evaluating an area's potential for a given land-use. In order to achieve this goal, at least three main challenges need to be overcome. The first challenge is to establish a relationship between natural variables and various land-uses. The second challenge is to compare different land-uses. The third challenge is to categorize natural and land-use data (both of which are spatial data). All of these challenges are to some extent interlinked, particularly the first two, which can be combined within the single concept of land evaluation. The following review begins by examining relevant previous research regarding land evaluation and then summarizes the literature on the analysis of spatial data.

Land evaluation

Land evaluation aims to answer the following question: what land-use is best suited for a given area of land? The evaluation is thus a process of assessing land performance for specific purposes, because different kinds of land-use have different requirements (Dent and Young, 1981; FAO, 1993). Land evaluation generally involves carrying out surveys and studies of the various aspects of land (e.g. land forms, soils and vegetation) in order to identify and compare various land-uses based on the objective of the evaluation (FAO, 1993; FAO et al, 1997). Land evaluation is thus an integral part of land-use planning, which is the systematic assessment of land potential, land-use alternatives and socio-economic conditions in order to provide appropriate and adequate land for different uses (Leung, 1989; FAO, 1993). The assessment of land potential requires information about the fitness of land for different land-uses, i.e. land suitability or land capability (Steiner, 1983; Leung, 1989). While both terms are generally used, there is no general agreement on their exact definition. Some view capability as the inherent capacity of land to perform at a given level for a land-use, i.e. the fitness of a given area of land to sustain a defined use, while some view suitability as the fitness of a given area of land for a specific land-use (FAO, 1976; Hammond and Walker, 1984). Others view suitability as applying to a tightly defined land-use (e.g. carrot growing) and capability as applying to a broad land-use type (e.g. agriculture or forestry) (McRae and Burnham, 1981; Nortcliff, 1988). The two terms are, however, frequently used interchangeably (Hammond and Walker, 1984). For the remainder of this paper, suitability will be applied to a specific use, while capability will be applied to the broad use concept. The term fitness is adopted to cover the general concept of the potential of land for different land-uses (i.e. both suitability and capability).

Many different systems for analyzing land fitness exist (Steiner, 1983; Davidson, 1992). The systems can be divided into major types according to whether they are qualitative or quantitative, and whether they refer to current or potential fitness (Dent and Young, 1981; McRae and Burnham, 1981). Qualitative systems are general appraisals normally based on the natural variables of land, sometimes with supplementary economic data. A disadvantage of qualitative assessments is that they are inherently subjective, although at least the subjectivity is obvious and not hidden. In addition, some maintain that land evaluation results are valid if they reflect the evaluator's best judgement (McRae and Burnham, 1981; Wandahwa and van Ranst, 1996). Quantitative systems are appraisals, which provide quantitative estimates of production or other expected benefits, frequently using socio-economic data (Dent and Young, 1981; McRae and Burnham, 1981). In both qualitative and quantitative systems, the important natural variables are identified and the systems constructed such that these variables either define categories (category systems) or are combined mathematically to produce an index (parametric systems) (McRae and Burnham, 1981). Category systems group variables into a small number of discrete ranked categories, frequently based on those properties that impose permanent limitations on the range of suitable land-uses. Parametric systems use a continuous scale of assessment, either by grading land according to likely output or benefits or by combining the various natural variables (parameters) that are believed to influence the fitness in a mathematical formula. Both types of systems have their advantages and disadvantages. A division into few ranked categories is easily understood and flexible, relatively easily applied, and useful even in the context of limited data, which has led to wide use of category systems. Some disadvantages are that category systems are inherently subjective, the division into few categories can be too coarse, and interactions between different natural variables are difficult to take into account. The advantages of parametric systems are that they are easy to apply consistently, are attractively simple and quantitative, accurate and specific. Parametric systems are considered less subjective than category systems, however, in many cases parametric systems are mathematical expressions of subjective opinions. The systems take into account combined effects of various factors and are easily adapted; if following a set formula gives absurdly wrong evaluations, the systems are easily modified by altering the choice of factors, their weighting, or the mathematical operation. This adaptability is also the greatest weakness of parametric systems, as it means that the systems can be designed and modified to give the 'right' answer (McRae and Burnham, 1981).

Although varied in structure, most, if not all, fitness systems share some basic principles or concepts. Firstly, land fitness is assessed for given land-uses (McRae and Burnham, 1981). Secondly, the land under consideration is initially characterized in terms of its natural variables and then evaluated for land-use fitness (Davidson, 1992). Thirdly, evaluation involves a comparison of two or more kinds of land-use (FAO, 1976). Fourthly, a common feature of many fitness methods is their reliance upon expert judgment (Banai-Kashani, 1989).

The oldest and most established capability system is the US Soil Conservation Service's (SCS) capability classification. The SCS classification is based on standard soil surveys and focuses on agriculture, although the information has been used for other land-uses as well. In general, the classification is based on grouping soils according to their limitations. The classification has three levels: the capability class, subclass and unit. The class indicates the scale of limitations (few limitations to very severe limitations), the subclass indicates the type of limitation within one class (erosion, water, soil type, climate) and the units are further distinctions within the subclasses (Steiner, 1983). A variety of other methods use the SCS classification as a blueprint, including the US Department of Agriculture (USDA) method, the Canada Land Inventory (CLI) and the British Land Use Capability Classification. The USDA method employs essentially the same structure, with minor modifications (Steiner, 1983; Davidson, 1992). The CLI is similar to both American systems. A main difference is that the CLI extends the method to land-uses other than agriculture, i.e. forestry, recreation and wildlife (Davidson, 1992). Yet another similar method is the British Land Use Capability Classification. This method employs seven classes, but the classes are more precisely defined with limiting values for particular properties specified (Ministry of Agriculture, Fisheries and Food, 1974; Davidson, 1992). Apart from the general structure, all of these methods depend heavily on soil information and are, with the exception of the CLI, geared towards agriculture in the first place. An Icelandic method using the same structure exists, with some modifications for Icelandic conditions. This method, which is exclusively focused on agriculture, has five classes and five subclasses denoting limits (wetness, soil limits, slope, soil erosion and climate) and has not been extensively tested or applied since its development (Guðmundsson, 1990).

The framework for land evaluation developed by FAO (1976) for assessing suitability of land for a specific use is a widely used evaluation method, particularly in less developed countries (Nortcliff, 1988; Wandahwa and van Ranst, 1996). The FAO framework is based on expert knowledge and consists of a set of principles and concepts to guide the construction of local, regional or national evaluation systems. The framework sets out a number of principles, basic concepts, the structure of suitability classification and the procedures necessary to carry out a land suitability evaluation (FAO, 1976). The land-uses subject to land evaluation may be major kinds of land-use (e.g. irrigated agriculture or forestry) or land utilization types, which is a concept at the core of the framework. Land utilization types consist of a set of technical specifications for a crop or a number of crops in a given physical, economic, and social setting (FAO, 1976; Nortcliff, 1988). The framework has the same categories for all classifications. Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land-use. There are four categories of decreasing generalization. The first is Land Suitability Orders, which indicates whether land is suitable or not. Within Orders, the second category of Land Suitability Classes reflects the degree of suitability. The number of Classes is not specified, but a maximum of five is recommended (FAO, 1976; Bydekerke et al, 1998). The third category is Land Suitability Subclass, which reflects the main kinds of limitations. The purpose of the classification decrees the number of Subclasses and the limitations chosen. The fourth category is Land Suitability Units, which are subdivisions of a Subclass. The Units differ from each other in their production characteristics or in minor aspects of their management requirements (FAO, 1976).

A very influential method is the University of Pennsylvania or McHarg (1969) method (Steiner, 1983). In general, the method consists of identifying natural processes as representing values, which can then be ranked. The method defines the best areas of a potential land-use to be at the convergence of most of the favourable factors for the land-use in the absence of most detrimental factors. The method can be applied both to specific land-uses (suitability) or broader land-uses (capability), and can be divided into seven steps:

1. Identify land-uses and define the needs for each use.
2. Relate land-use needs to natural factors.
3. Relate specific mapped phenomena to land-use needs.
4. Map concurrences of desired phenomena and formulate rules of combination to express a gradient of suitability.
5. Identify the constraints between land-uses and biophysical processes.
6. Overlay maps of constraints and opportunities, and develop a map of intrinsic suitabilities for a land-use through rules of combination.
7. Develop a composite map of the highest suitabilities of the various land-uses.

(McHarg, 1969; Steiner, 1983).

Whatever method of fitness assessment is selected, the objective of it must always be kept in mind. Fitness assessment is a means to an end and the ultimate aim is to provide an input to the overall planning discussion (FAO et al, 1997; Young, 1998). An overall assessment calls for a multipurpose grading scheme (Davidson, 1992).

Analysis of spatial data

The process of transferring the complexity of the real world into a more comprehensible set of spatial data has been a long-time challenge for science. Real world phenomena can be conceptualized in a variety of ways; they can be thought of as points or lines, or areas of various shapes and sizes (polygons). The conceptualization of a natural phenomenon depends largely on what aspect of it is deemed important, e.g. its size or location. The most common conceptualization for land-use and natural resources is the one of area (sometimes referred to as polygons, regions or zones). The area unit can be natural entities like lakes or islands, or human constructs such as census and postal zones (Laurini and Thompson, 1992).

One of the major decisions when mapping either land-use or natural resources is whether to use regular (geometric) or irregular area units (polygons). Because natural phenomena are rarely regular in shape, polygons are able to represent natural phenomena more accurately, as they can show curved lines. The creation of polygons may, however, be based on doubtful assumptions about their boundaries, or involve lengthy and cumbersome computations if units are overlaid (Steiner, 1983; Tomlin, 1990; Verburg et al, 1999). While using polygons has advantages in terms of efficiency of storage and ease of display, a grid system is easier to work with in modeling situations (Countryman and Sofranko, 1982). Regular units (rasters) have the advantage of simplicity, both for recording data and for comparisons, especially overlay. Despite this simplicity, rasters can incorporate complex attributes, depending on the scale (size) of the raster (Tomlin, 1990; Laurini and Thompson, 1992; Verburg et al, 1999). The main disadvantage is that details can be missed unless the raster is very small, which requires more data collection (Steiner, 1983). Of regular units, the square figure (usually in the form of a cell in a grid) dominates the world of spatial analysis. The square has simple and valuable conditions of equality of sides; it can be broken into smaller units or aggregated into larger units of the same shape. The square can handle both location (geographic or arbitrary) and the attributes of the location. The attributes can be quite complex, because there is a choice of assigning single or multiple values to each cell (Laurini and Thompson, 1992; Verburg et al, 1999; Fotheringham et al, 2000). Many operations, logical or arithmetic, are quite straightforward when working with squares and in fact one of the simplest methods of storing, manipulating and presenting spatial data is to allocate the data to the cells of a predetermined grid (McRae and Burnham, 1981). That said the square has some drawbacks. The square does not capture point or line features well, although that depends partially on the resolution (the size of the grid-cell/square in relation to the size of the object being mapped). Attempts have been made to address this drawback with particular coding techniques. The accuracy of location is also dependent on the size of the grid-cell. Overall, however, the square has many advantages compared to its limitations, which has resulted in the square having a long history of use (Laurini and Thompson, 1992; Verburg et al, 1999; Fotheringham et al, 2000).

Chapter 3
Project methodology

The aim of the project under discussion is to develop and examine one potential method to help select areas for a given land-use in Iceland, in this instance forestry. The method should be applicable to all of Iceland. The country is quite small in size (103,000 km^2) and the natural variation between regions is no greater than the variation within regions, and consequently it is assumed that the general assessment is the same for the entire country, e.g. grasslands will be very good for agriculture in all parts of the country.

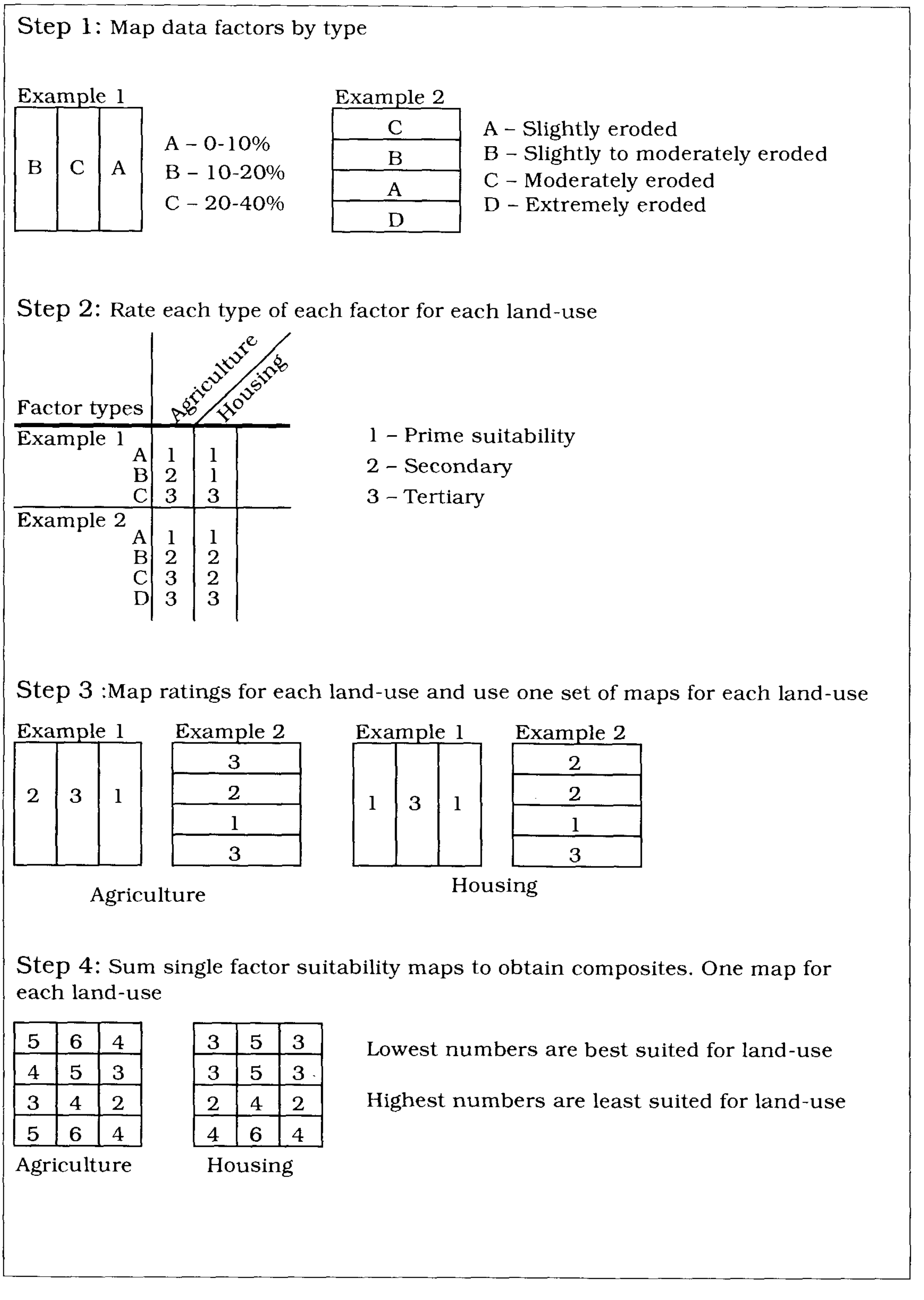
The method should produce results that are guiding, rather than deciding. To be useful, the method should be relatively easy and quick to use, as well as transparent and comprehensible for laypersons. It must thus be comparatively simple in construction and rely on equipment, technology and information available to those organizations and companies in Iceland involved in planning land-use.

Several principles obtained from the literature act as guidelines to achieving those aims. Firstly, the method must make good use of existing methods and sources of data (FAO et al, 1997). Fitness assessments have hardly been used in Iceland and thus no method geared toward the specific Icelandic circumstances exists. A capability method for nature conservation is currently in development, which is similar in structure to the method tested in this project (Verkefnisstjórn Rammaáætlunar um nýtingu vatnsafls og jarðvarma, 2002). Secondly, expert knowledge can compensate for limited data, as local experts can provide sufficiently reliable information, avoiding the need for time-consuming and costly research (McRae and Burnham, 1981; Bojórques-Tapia et al, 1994). Thirdly, the information base for the method must be in a form user-friendly for non-specialists outside the planning or earth science professions, i.e. the method should be expressed in a largely non-technical language (Arnot and Grant, 1981). Fourthly, all natural variables should be weighted for each land-use, to indicate their relative value (FAO et al, 1997). Fifthly, fitness assessments provide general indications of overall patterns of fitness, rather than precise representations. For larger scales, such as the regional scale, even very large cells can yield meaningful insights (Lyle, 1985). Sixthly, the structure of the data for different land-uses must allow for a comparison between uses, based on some common measure of performance (Johnson and Cramb, 1994). Lastly, while data accuracy and reliability is essential, other considerations, such as timeliness and cost-effectiveness, also come into play, so the use of patchy or less than perfect data should not be considered an inherent problem with the method, but rather a reflection of the real situation facing land-use planners (FAO et al, 1997; Selman, 2000).

Method structure

In accordance with the guidelines and the stated aims, the structure of the proposed method is largely based on the McHarg (1969) method, with some modifications drawn from other methods (Figure 1 provides a simplified illustration of the McHarg method). Several reasons for choosing this method over the US Soil Conservation Service's (SCS) method or any of its derivatives, or the popular FAO framework, can be listed. Firstly, the proposed method is designed for the regional planning level in Iceland, where only broad land-use types are used (e.g. general agriculture, rather than specific agriculture such as potato growing), i.e. the focus is on capability rather than suitability, which in effect rules out the FAO framework. Secondly, a basis for the SCS method is a correlation between inputs and products for different types of soils. The unfortunate fact is, that Icelandic soils are unique (which means that soil information from neighbouring countries is only partially transferable) and have not been exhaustively studied to date (Helgason, 1990). Although the relationship between certain inputs (mainly nutrients) and products is generally known, the impacts of many other factors remain uncertain. As some soil classification issues are not resolved yet, there is currently neither any information directly correlating different soil types with output nor accepted methods for evaluating soils for various uses in place (Guðmundsson and Sigvaldason, 2000; Rannsóknarstofnun landbúnaðarins, 2000; Guðmundsson, 2003). In addition, all of the methods (except the Canada Land Inventory) are essentially structured for agriculture only. Thirdly, evaluations in the SCS derivatives all consist of estimating limitations. When estimating fitness for a relatively new type of land-use (as forestry is in Iceland) emphasizing limitations rather than positive potential can be discouraging to potential users (McRae and Burnham, 1981). The McHarg method allows for emphasizing positive features rather than negative features.

Figure 3-1 The McHarg method



(Adapted from Steiner, 1983)

The major modification to the McHarg method introduced in this project is the use of weights for each natural factor and land-use, in accordance with the fourth principle identified previously. The weighting structure is based on the weighted-factors method, where each factor is assigned a grade, which is multiplied by the weight of that factor, and the results of the multiplications are added to determine a composite grade (Banai-Kashani, 1989). This structure has three main advantages. Firstly, the relative importance of different natural factors for each land-use can be considered, as not all factors are equally important for different land-uses. Secondly, since the outcome is a weighted grade, using a different number of natural factors for different land-uses (factors may not be relevant to all land-uses) is no problem, as the range of the composite grade remains the same for all land-uses. Without weightings, land-uses with many relevant natural factors would have a relatively higher composite score, than those with fewer relevant factors. Lastly, the calculations are very simple and thus easily applied and understood. In addition, the introduction of weights mirrors the many applications of land evaluation for more specific purposes, i.e. evaluation of land suitability (see e.g. Steiner et al, 2000; Store and Kangas, 2001; Deng et al, 2002; Kalogirou, 2002; Ceballos-Silva and López-Blanco, 2003).

A fixed grid cell system is chosen as a basis for two main reasons. Firstly, using a predetermined grid is one of the simplest methods of storing and overlaying spatial data, especially in modeling situations (McRae and Burnham, 1981). Secondly, the use of irregular units (polygons) essentially requires a digitizer and a geographic information system (GIS) (Countryman and Sofranko, 1982). Not all of the potential users of the method in Iceland have a GIS. Grid cells allow for manually storing data in a table format, which enables the use of generally available programs, such as Microsoft® Excel©. For potential users with access to a GIS it is a simple matter to switch over to polygons, if the conclusion of the research project is that the method is usable.

To provide a common measure of fitness the same basic grade scale is used for the different land-uses. The grade scale is divided into classes, which denote how suitable a given natural factor is for a given land-use. The grade scale has five classes: very bad, bad, medium, good and very good, each with a fixed grade value (see Table 3-1).

Table 3-1 Grade classes

Grade	Class	Description
X	Excluded	Natural attributes in this grade class are totally unsuitable (excluding) for the given land-use
1	Very bad	Natural attributes in this grade class are highly unsuitable (very limiting) for the given land-use
3	Bad	Natural attributes in this grade class are rather unsuitable (rather limiting) for the given land-use
10	Medium	Natural attributes in this grade class are somewhat suitable (with limitations) for the given land-use
30	Good	Natural attributes in this grade class are rather suitable (not very limiting) for the given land-use
100	Very good	Natural attributes in this grade class are very suitable (hardly limiting) for the given land-use

The main reason for opting for five classes is that the use of five classes of some form is quite common in fitness assessments (e.g. FAO, 1976; Shields et al, 1986; Cocklin et al, 1990; Littleboy et al, 1996; Bastian, 2000). In addition, factors that are excluding (completely unsuitable) for a given land-use are marked specifically. Excluding factors essentially introduce a threshold value, i.e. cells containing an excluding factor are utterly unable to support the specified land-use, irrespective of the land-use potential of the cells' other natural factors. One excluding factor thus automatically removes a cell from further consideration.

Many options exist for assigning a range of values to a grade, with a range from 0-10 or 0-100 being quite common (McRae and Burnham, 1981; FAO et al, 1997). There are also many possibilities for the division of a selected range (see e.g. Store and Kangas, 2001; Deng et al, 2002; Kalogirou, 2002). A range of 0-100 is selected here, because it allows for a broader range of values and thus more distinction. In addition, it is a range that most people are quite familiar with, and thus easy for people to comprehend and apply. The full range has non-linear increments, based on $\left(\sqrt[4]{100}\right)^n$, for n=0,1,2,3,4, with the corresponding values rounded to the nearest whole number (except for n=3, which was rounded down to 30, rather than 32), giving the range of values seen in Table 3-1. This division is chosen for several reasons. A non-linear scale emphasizes the difference between classes more and reduces the potential of many low scores summing up to a high score. In addition, a ministry appointed task force within Iðnaðarráðuneyti (Ministry of Industry) and Umhverfisráðuneyti (Ministry for the Environment) employs a non-linear scale for a similar method for nature conservation currently in development (Verkefnisstjórn Rammaáætlunar um nýtingu vatnsafls og jarðvarma, 2002). The chosen scale is logarithmic, consisting of a simple mathematical formula, and is believed to have sufficient difference in grades between classes to reduce the possibility of many low scores accumulating to a high score. The scale also places proportionally greater emphasis on better grade classes, in accordance with the intention to focus on the most favourable areas for each land-use. Many different land-uses compete for a limited amount of land, and it makes therefore sense to identify and assign the most favourable area for a given land-use.

The method consists of six main steps (see Figure 3-2). Firstly, a superimposition of a grid on the area under study divides the area into cells, each of which has a specific reference number in the grid, e.g. 1-1 (column 1, row 1), 1-2 (column 1, row 2), 2-1 (column 2, row 1) etc. Secondly, the natural factors and current land-uses are mapped for each cell. Thirdly, each cell is graded, based on the natural factors, for each land-use. Some natural factors exclude particular land-uses, e.g. glaciers exclude forestry. For each land-use, cells containing excluding natural factors should be determined at the outset, to ease the continuing process (fewer cells need to be considered). Fourthly, experts in a given land-use assign each natural factor a weight based on the estimated importance of each factor for that particular land-use. A weighted grade is calculated for each cell by multiplying the grade with the corresponding factor weight. Fifthly, the weighted grades for the natural factors are summed for each cell and a combined grade for a particular land-use for each cell is calculated. Sixthly, the grades for different land-uses are compared to identify the land-use with the highest grade for each cell. Cells that have the highest grade for the land-use under consideration (forestry in this project) are identified and compared to current land-use, to determine which cells contain land-uses that are incompatible with, or can exclude, the land-use under consideration. The result is a map (or table) showing the areas (cells) most suitable for the given land-use. This result is then available for decision-making. Overall, the main features of the proposed method are the use of expert judgement (to compensate for lack of data) and the application of weights (relevance) to natural factors for different land-uses.

As was mentioned in the Introduction, this trial run of the proposed method only considers two land-uses, agriculture and forestry. These two land-uses, along with conservation and tourism, are the most frequent land-uses in Iceland and therefore the land-uses most likely to benefit from fitness assessments at this scale. Other land-uses, such as industry, archaeological or cultural sites generally cover much smaller areas (in Iceland at least), i.e. they are normally point features at the regional scale of analysis and thus become more important at a smaller scale (i.e. municipal plan). Conservation is excluded because a system for estimating conservation capability is in development. As the structure of the conservation system is somewhat similar to the proposed method, the incorporation of the completed conservation system into the method should be relatively simple. Tourism is another important land-use in Iceland, but defining its suitability parameters (e.g. distinctiveness and uniqueness) was too complex and too heterogeneous for inclusion in this project. In addition, tourism operates on a different scale than forestry and agriculture and is not mutually exclusive from forestry and agriculture.

Figure 3-2 The method

Step 1: Cell creation

Step 2: Map data

Example 1 - Exposition

A	C
C	B

A – Very shady
B – Shady
C – Medium

Example 2 – Land texture

A	A
B	C

A – Rocks
B - Lava
C - Sands

Step 3: Grade cells for each land-use based on grade table

Variable	Forestry	Agriculture
Exposition		
A	3	3
B	3	10
C	10	30
Land texture		
A	Excluding	Excluding
B	10	10
C	3	3

Forestry

Example 1

3	10
10	3

Example 2

X	X
10	3

Agriculture

Example 1

3	30
30	10

Example 2

X	X
10	3

Step 4: Assign weights

	Forestry	Agriculture
Exposition	0.60	0.65
Land texture	0.40	0.35

Forestry

Example 1

1.8	6.0
6.0	1.8

Example 2

X	X
4.0	1.2

Agriculture

Example 1

1.95	19.5
19.5	6.5

Example 2

X	X
3.5	1.05

Step 5: Sum grades

Forestry

X	X
10.0	3.0

Agriculture

X	X
23.0	7.55

Step 6: Compare grades

As only two land-uses are considered in this pilot project, the study does not need to be concerned about a complete coverage of the study area, i.e. obviously some sites will suit neither of the two land-uses, but could be highly fit for other land-uses not considered.

Implicit to the method is the assumption that the land-uses are distinct, i.e. that no interaction occurs between them, which is clearly not the case unless land-uses are wholly incompatible, which forestry and agriculture are not. Two main interactions are possible between these land-uses. First, forests can act as windbreaks for fields close by, leading to higher temperatures and thus improved growing conditions for crops. Such an interaction is very difficult to measure as it depends largely on local conditions (e.g. main wind direction, wind force, the orientation and shape of both forest and fields) and is thus nearly impossible to include with any accuracy at the regional scale in question here. Second, either land-use could attract in wildlife species that could harm the other land-use. This interaction, however, is bound to be very limited. Both agricultural areas and forests are generally clearly demarcated in Iceland because fields are usually fenced so that livestock (sheep) can roam around freely. The only true forest species in Iceland are some bird species, which pose little, if any, threat to crops. The only large grazing animals are reindeer in the eastern highlands, which rarely venture down into populated areas and are then hindered by fences from entering fields. Species known to pose risks to crops (e.g. geese and swans) are indifferent to forests. Overall, in the case of forestry and agriculture, the interaction between the land-uses is considered sufficiently limited to warrant the assumption that the land-uses are distinct.

The prime directive for selecting both land-use categories and natural factors is that both must make sense for Icelandic conditions. As mentioned in the Introduction, Icelandic nature is rather unique and many concepts used in land evaluation in other countries do not apply. A case in point is exposition (shade). In Iceland, the northerly latitude means that sunlight is a limiting factor for many plants and thus south-facing slopes (which generally receive more sunlight) can be more favourable for plants. In some other countries, northerly exposures are more favourable for vegetation because they provide less direct sunlight and cooler temperatures, which can be beneficial in hot climates (Hickey and Jankowski, 1997). In addition, as the proposed method applies to Iceland, all the documents used in the process are in Icelandic. Icelandic terms sometimes have no direct equivalent in English and this paper thus does not entirely accurately reflect them. An example is the use of 'gravel plain' for the term *eyrar*, for lack of a better word. The term gravel plain can mean different things, but *eyrar* clearly refers to variously sized islets in rivers or riverbanks, with little or no vegetation and consisting mostly of sand and gravel, which are flooded with varying frequency. This language difference should be kept in mind.

Land-use categories

The land-use categories incorporate the most dominant or relevant land-uses in Iceland. The categories reflect land-uses used in published regional plans, which are largely conventional. The first category is agriculture. Agriculture in Iceland consists of roughly four types: grass cultivation ('traditional' or mixed farming, including dairy farming), intensive cultivation (horticulture, grains, poultry etc.), sheep farming, and horse farming (both horse and sheep farming are dependent on extensive grazing pastures). Agriculture in Iceland is fairly land consuming (most of it is extensive rather than intensive, thanks to the prevalence of horses and sheep) and very important for certain regions (Jónsson and Magnússon, 1997; Runólfsson, 2003). The actual fitness assessment uses the general category of agriculture, as the choice between different types of agriculture would be made on a smaller scale (site or municipal plans). The general understanding of agriculture for the overall category is more traditional agriculture (grass cultivation + horse/sheep + small scale intensive agriculture). The second category is archaeology and cultural heritage. This land-use rarely covers extensive areas but the areas it does cover are very important, as the land-use can impose limits on other land-uses, or even exclude other uses altogether (Cocklin et al, 1990). The third category is forestry. Forestry in Iceland consists of five types: mixed forestry (forests used for recreation and as windbreaks), timber forestry (mostly coniferous species), soil conservation forestry, nature conservation forestry (mainly conservation of birch forest remnants) and land improvement forestry (e.g. water and vegetation protection) (Blöndal, 1987; Lúðvíksson, 1987). As already mentioned, forestry is gaining in both spatial extent and social importance across the country. The actual fitness assessment uses the general category of forestry, as the choice between different types of forestry would be made on a smaller scale (site plans). In addition, as is the case for agriculture, information on different types of forestry at specific locations is not readily available. The fourth category is industry (large scale), which in Iceland consists mainly of (a few) plants and factories, geothermal fields (used for electricity and heating), and hydropower production (including reservoirs) (Jónsson and Magnússon, 1997). The fifth category is mines and quarries for minerals and construction materials. Comparatively speaking mines and quarries are not always large in Iceland, but they can have a great impact on the environment and exclude other land-uses (Embætti Veiðimálastjóra et al, 2002). The sixth category is nature conservation. Nature conservation can potentially cover extensive areas and is thus a very important land-use. The choice of areas in the past has not been very systematic, but an evaluation method for conservation is currently in development (as mentioned previously). The seventh category is summer cottages. A decline in agriculture over the last few decades (which released land), along with increased car ownership and road improvements, has considerably increased the number of summer cottages (Jónsson and Magnússon, 1997). The eighth category is tourism, which is very important, as it is the second largest foreign currency earner in Iceland (Ferðamálaráð Íslands, 2001). Originally, the fitness assessment included this category along with agriculture and forestry, but tourism was later dropped, as it was deemed too heterogeneous for a single assessment (i.e. the requirements for different kinds of tourism were considered to be too diverse). In addition, the relatively limited research on tourism in Iceland also reduces the reliability of any assessment. The ninth category is built-up areas, i.e. what is referred to in Iceland as *þéttbýli*, literally, 'dense settlement'. The official definition of *þéttbýli* is a cluster of houses populated by more than 50 people where the distance between houses usually does not exceed 200 m (Skipulagsreglugerð nr. 400/1998). This land-use is particularly important in some parts of the country, where not all the land is suitable for towns or cities (e.g. due to avalanche or earthquake risks) (Ofanflóðanefnd, 2002). The tenth category is water protection. This land-use is very important in some regions of the country, and worldwide the supply of good quality water resources is increasing in importance (Miller, 1996).

Natural factor categories

The selection of natural data for land evaluation follows two rationales. First, the data should as much as possible be objective measurements and, second, the data should be as independent of time as possible, i.e. be expected to hold true for many years (Hammond and Walker, 1984). The land resource (natural) data required for land evaluation in general is information on climate, landforms and soils, land cover, vegetation and water features (Nortcliff, 1988; Marsh, 1998; FAO and UNEP, 1999). With reference to this list, the method includes ten natural variables: elevation, landscape, land texture, temperature, precipitation, exposition, hydrological regime, soil type and soil cover, and vegetation. This list does not contain the only possible variables, but these variables cover most of the important natural aspects that need to be considered for various land-uses. The only major omission is, perhaps, information on winds. This variable was excluded because local conditions (e.g. landforms) highly influence winds, making their representation with any accuracy or reality at the large scale employed here difficult. In addition, because local conditions so influence winds, extrapolating from measurement points with any accuracy is very difficult. Consequently, reliable wind data is largely limited to meteorological stations and their surroundings, which are rare in most parts of Iceland and the coverage of reliable wind data is thus somewhat limited.

Existing data influences the definition of the natural factors, i.e. the factors are partially defined so the required information can be relatively easily derived from available information. The rationale for the class division of each factor is based on social and/or natural properties of the factor in questions as they relate to the situation in Iceland (see discussion of each factor) and how clearly decisive and distinguishing between the largest number of different land-use categories the properties are.

The elevation factor has five classes: 0-200 m, 200-400 m, 400-700 m, 700-1000 m, and >1000 m. Very few permanent residences in Iceland are located above 200 m and the 200 m boundary thus marks the limit of permanently populated areas (Jónsson, no date). This lowest range thus contains practically all the intensive agriculture, as well as the majority of industry. The 400 m boundary essentially represents the limit of the forest range. Some small forest patches exist above 400 m in ideal locations, but large and/or thriving forests do not exist far above 400 m (Sigurðsson, 1990; Ragnarsson, 1999). In addition, most *afréttir* (municipally controlled common grazing grounds) are also above 400 m (Maronsson, 2002). The 700 m boundary constitutes the limit of continuously vegetated areas (Þorsteinsson, 1972). Most *afréttir* do not extend much above this elevation, due to lack of sufficient vegetation for grazing animals. The 1000 m boundary sets the limit of large vegetated areas. Elevations above 1000 m are a largely inorganic wilderness (only around 40 species of plants have been found above 1000 m), frequently experiencing considerable precipitation (Steindórsson, 1964).

The landscape factor has five classes: mountains and ridges, canyons and gullies, hills and hummocks, plains and glaciers. The glaciers are a specific class due to their movement and the rapid alteration of their surface. Glaciers still classify as a landscape factor rather than a hydrological regime factor because they are a very important part of the landscape in Iceland due to their size and extent (they cover about 10% of the country). The landscape factor considers two aspects, landform and elevation (which distinguishes between mountains/ridges, hills/hummocks, and plains). Two complementary methods determine the elevation boundary between different classes. The first method entails examining place names and the corresponding elevation of the location. Mountains and ridges in Iceland frequently include words such as *fjall*, *fell* and *hryggur* in their names. Hills and hummocks include words such as *hæð*, *ás*, and *hóll*. The second method relies on the general perception of what constitutes a mountain and what a hill, by asking a person to think of a particular natural feature and determine which it is, mountain or hill. The elevation of the location in question is noted and this is repeated for other locations, to determine the approximate elevation boundary. Based on these two methods, the boundary between plains and hills/hummocks is at 20 m and the boundary between hills/hummocks and mountains/ridges at 100 m.

These boundaries also take into consideration the fact that the boundaries have to be discernible on the scale of the base map available (1:50,000 with 20 m intervals).

The land texture factor has five classes: rocks and debris, lava fields, gravel plains, sands and thick soil. The classes represent the most common types of land cover in Iceland, as well as being easily distinguishable from each other. In addition, the classes are largely discernible on basic topographic maps.

The temperature factor applies to mean summer temperatures only (June-August), because the summer temperature effectively controls vegetation growth and thus affects the land-uses most dependant upon natural fitness. The factor has five classes: 0-3°C, 3-6°C, 6-8°C, 8-10°C, and 10-12°C. Grass does not grow at all below 3°C, which obviously has great implications for agriculture (Þorvaldsson, 1996). The 6°C boundary effectively sets the limit for the growth of birch in any form (which is the native climax species in Iceland) and grass also begins to grow well when the temperature exceeds 6°C (Friðriksson and Sigurðsson, 1983; Blöndal, 2002). Areas with temperatures below 8°C are generally unsuitable for forestry, although local conditions can mitigate the low temperature (Ragnarsson, 1990). The 10°C boundary is a slightly more arbitrary choice, although above 10°C most vegetation grows at considerable rates. The upper limit, 12°C, is the maximum mean summer temperature expected in Iceland. No place in Iceland ever recorded a mean summer temperature above 12°C, until the summer of

2003, which had temperatures 1-2°C above the average (Einarsson, 1976; Einarsson, 1989, Veðurstofan, 2003).

The precipitation factor applies to annual precipitation. It has four classes: 0-600 mm, 600-1200 mm, 1200-2000 mm and >2000 mm. Areas with precipitation less than 600 mm are the dry areas of Iceland, nonetheless they can be extensively vegetated in sheltered locations. Their botanical composition, however, differs from wetter areas, with grasses relatively dominant compared to mosses. The 600-1200 mm range represents a common precipitation range for populated areas (Einarsson, 1976; Einarsson 1989). In the 1200-2000 mm range mosses and other humidity-seeking plants become very noticeable. This precipitation range is common for the lower highlands and *byggðafjöll* ('settlement mountains') (Einarsson, 1976). In areas with precipitation exceeding 2000 mm, grass growth decreases and mosses begin to predominate.

The exposition factor has five classes: very shady, shady, medium, sunny, and very sunny. Determining exposition exactly is a very complex process, as it includes the consideration of many variables, such as the slope of the surface the sun is shining on, neighbouring landforms (which can block the sun), time of year and the time of day. Obviously, an exact determination would require extensive calculations and modeling and is thus not feasible for this project. Instead, exposition classes are developed, based on basic topographic information, to provide a sufficient estimate, rather than an exact value. A detailed description of the development of the classes is in Appendix 1. The definition of each exposition class involves a combination of the slope angle and orientation. The very shady class has northerly slopes with a slope angle of less than 10°. The shady class has east and west facing slopes with a slope angle of less than 10° and northerly slopes with a slope angle between 10° and 35°. The medium class has southerly slopes with a slope angle of less than 10°, east/west-facing slopes with slope angles between 10° and 35°, and northerly slopes with a slope angle exceeding 35°. The sunny class has southerly slopes between 10° and 35°, and east/west facing slopes with a slope angle over 35°. The very sunny class has southerly slopes with a slope angle over 35°.

The hydrological regime factor has three main classes: bedrock permeability, rivers and streams, and lakes and ponds. The bedrock permeability is further divided into four classes: very impermeable, rather impermeable, permeable and very permeable. These classes are the ones devised and used by Orkustofnun, which is the data provider for this information (Sigurðsson and Ingimarsson, 1990).

The soil factor has two main classes: soil type and soil cover (erosion). The soil type has six classes: brown andosol, organic andosol/histosol, vitric/gravelly andosol/regosols, leptosols, sandy andosols and leptosol/sandy andosol complex. This typology was developed by Rannsóknarstofnun landbúnaðarins (Agricultural Research Institute), which also provides the data for this factor. The soil cover has also six classes: no erosion, little erosion, slight erosion, considerable erosion, severe erosion, and extremely severe erosion. These classes also come from Rannsóknarstofnun landbúnaðarins.

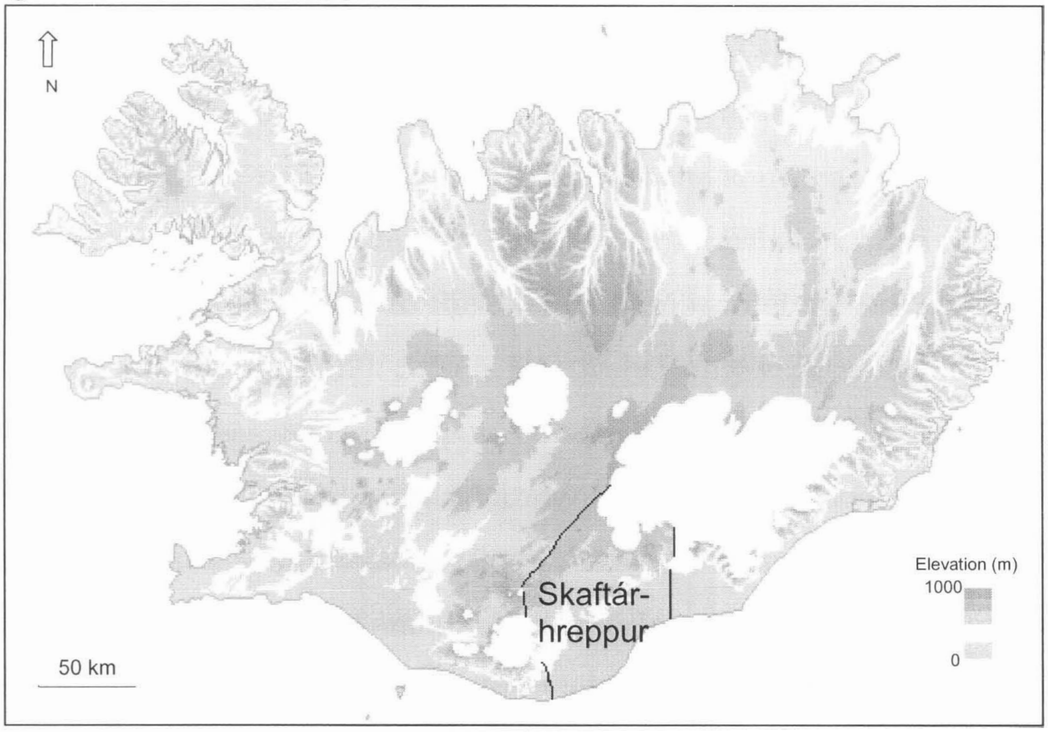
The vegetation factor has five classes: forests, wetlands, grasslands, moss and shrub heath and marginal vegetation. Forests, particularly birch forests, represent the climax stage of vegetation in Iceland and include areas of tall shrubs (what is called *kjarr* in Icelandic) (Blöndal, 1987). Wetlands include bogs and marshes, and usually have high groundwater levels. A simple popular definition of wetlands in Iceland is that one's shoes get wet when walking across them. Grasslands are dry land, dominated by grass, which grazing mostly maintains. Moss and shrub heaths are poorer dry land, where dwarf shrubs and mosses become more prominent. Marginal vegetation refers to areas with scant vegetation, which is common in mountains and on gravelly or sandy low-lying areas. These classes represent a simplification of the vegetation classes used by Náttúrufræðistofnun Íslands (Icelandic Institute of Natural History), which provides most of the data.

Chapter 4
The study area

The test run of the method uses the municipality of Skaftárhreppur, named after the river Skaftá, as a study area (see Figure 4-1). The size of Skaftárhreppur is around 6800 km^2 and it is one of the most naturally diverse areas of Iceland, thus providing a good testing ground for the proposed method. The region has about 600 inhabitants, most of which are employed in agriculture. Tourism is also a growing industry, centred on the region's only town, Kirkjubæjarklaustur (population around 150). The region is noted in Iceland for a comparatively good climate, with mild winters and warm and sunny summers (Magnússon et al, 1983; Kirkjubæjarstofa 2001). Jökulhlaups (glacial bursts) and volcanic eruptions have shaped the landscape of the region. Eruptions include the famed Skaftáreldar in 1783, which produced one of the biggest lava flows in recorded history anywhere on earth, named Eldhraun. Skaftárhreppur is also close to the volcano Katla, which erupts approximately twice per century, as well as numerous other active volcanoes (Jósepsson and Steindórsson, 1981; Magnússon et al, 1983; Kirkjubæjarstofa 2001).

The settlements in the region traditionally consist of six areas: Landbrot, Meðalland, Síða, Fljótshverfi, Álftaver, and Skaftártunga, each of which has its own natural characteristics although Fljótshverfi and Síða are quite similar (Magnússon et al, 1983; Jónsson and Sigmundsson, 1997).

Figure 4-1 Skaftárhreppur



(Landmælingar Íslands, 2003. By general permission)

The area of Landbrot applies to the settlements on the eastern fringe of Eldhraun. The land there is dry, with extensive wetlands beyond the lava. Until the construction of drainage canals at the turn of the 20th century, only small parcels of land were suitable for fields. Most fields are still small, but the farmers there share extensive *afréttir* (common grazing grounds) in the mountains. Erosion and sand drifts (mainly from the east) are a recurring problem in the area (Jósepsson et al, 1982; Magnússon et al, 1983; Jónsson and Sigmundsson, 1997). The area of Meðalland lies on the south side of Eldhraun, on a strip of vegetated sand between the lava and the ocean, and is one of the flattest and lowest areas of Iceland. The area has two major natural threats; sand drifts in the east and erosion due to floods and jökulhlaups in the west.

Historically, the area had extensive wetlands, but drainage has eradicated large parts of them (Jósepsson et al, 1982; Magnússon et al, 1983). The areas of Síða and Fljótshverfi apply to the settlements positioned at the roots of the mountains in the southeastern part of Skaftárhreppur and are divided by the river Hverfisfljót, with Síða to the west of it and Fljótshverfi to the east (Magnússon et al, 1983; Jónsson and Sigmundsson, 1997). Síða is relatively richly vegetated, while Fljótshverfi is less vegetated, particularly in its southern part which has extensive areas covered by sand and/or lava (Magnússon et al, 1983; Jósepsson and Steindórsson, 1984). Álftaver lies to the west of the river Kúðafljót and a series of small hills (pseudo-craters), which have historically provided protection from jökulhlaups resulting from eruptions in Katla, form its margin on the north side. The area has extensive wetlands and good grazing grounds. The main threats to Álftaver are sand drifts and erosion due to the nearby rivers (Jósepsson and Steindórsson, 1984). The rivers Hólmsá and Skaftá form the margin of Skaftártunga, which is shaped like a wide, but shallow, valley. The area is relatively well vegetated, with large wooded areas and good grazing grounds (Jósepsson and Steindórsson, 1983; Magnússon et al, 1983).

Chapter 5
Application

Chapter 3 contained a description of the general structure of the proposed method. This chapter will provide a more detailed discussion of the application of the method, including the specific measures required for the study area. The discussion follows the steps in the method, beginning with a description of the structure of the grid-cell system and the land-use and natural factor categories. A discussion on the selection of the expert participants will follow and the results of the participant assessments will conclude this chapter.

Grid-cell system

Basic topographic maps formed the basis of the grid-cell system (see Appendix 2 for a list of the maps used). The maps are on a scale of 1:50,000 and were created from aerial photographs and based on a Transverse Mercator projection with an UTM reference net and a numbered geographical grid. To simplify the labelling of the grid cells for the project, the marked geographical grid on the maps formed the base for the grid cells, with each grid unit on the map divided into four equal-sized cells, resulting in cells 0.25 km^2 in size (0.5 by 0.5 km). This resolution is believed to be sufficiently small to capture the features relevant at the scale in question (1:50,000) and provide identified areas of a feasible and usable size, while keeping the number of cells manageable. A smaller resolution would quickly multiply the number of cells, which could pose calculation problems, while a larger resolution could prove too coarse to be useful. In addition, as the natural data maps were in a range of scales (both larger and smaller than 1:50,000) this cell size was considered a good compromise size. This cell size did result in some overlap between natural factor classes for some cells (i.e. cells did not always contain one factor class only), which is practically inevitable when using a fixed grid. For most factors, however, the overlap was minimal, applying to an estimated 5-10% of the cells, with an estimated maximum of 15% for the elevation, which had the largest number of overlap cells.

To keep matters simple, the numbering of the grid units formed the base for the numbering of the grid-cells. Unfortunately, the marked grid is not the same for all the maps. Maps depicting areas west of approximately 18°W have a grid of UTM Zone 27, while maps east of 18°W have a grid of UTM Zone 28, and the numbering of units on the base maps is therefore not sequential. Consequently, there is a jump in the numbering of the grid-cells, leading to an apparent gap in the grid-cell system, while it is in actual fact continuous. Cells straddling the border, i.e. that are partially on a map with a Zone 27 grid and partially on a Zone 28 grid map, were assigned to the map containing half or more of the cell. The grid-cell reference numbers were entered into a Microsoft® Excel© worksheet to form a data entry matrix, used for all subsequent data entering and grade calculations.

The administrative boundaries on the base maps formed the basis for the borders of the study area. The size of the study area is quite a bit smaller than the size of Skaftárhreppur proper as the study area does not include all glaciated areas.

Land-use categories

The availability of land-use information, i.e. whether or not maps containing the information existed, was a major consideration for all land-use categories, as the method is based on area coverage. All land-use information was entered manually. The archaeology and cultural heritage category includes four categories: 1) areas or places protected by the law on *þjóðminjar* (national heritage) (Þjóðminjalög nr. 107/2001), 2) deserted farms (houses), 3) sheepfolds or ruins, and 4) churches and graveyards. Only land labelled on the base maps as *ræktað land* (land in production) or land with farmhouses on them, was included for the agriculture category, which definitely underestimates the actual area of land used for farming, as it does not contain most of the summer grazing grounds. However, as no map depicting the grazing grounds was found (and probably does not exist), they were excluded. The grazing grounds do not involve any investment by any of the farmers in the area, as most of them are commons. In addition, the use of many of the traditional grounds is declining, due to a general decline in agriculture and increased environmental concerns, but many grounds are located at higher elevations, where the natural environment is less resilient. For the forestry category the information on forestry sites comes from maps from the Suðurlandsskógar project. The maps are from forestry site plans for each individual farm participating in the Suðurlandsskógar project and denote designated forestry areas. Not all these areas have been planted with trees yet, but as they have been set aside for forestry they are included in this category. Some data gaps exist, as site plans do not exist for all the farms involved, and some planting takes place apart from the Suðurlandsskógar project. Information on these additional projects is, however, not easily available. For the mines and quarries category, only mines sufficiently large to merit labelling on the base maps were included. There might be other quarries in the region, as Vegagerðin (National Road Authority) frequently tries to use suitable deposits nearby when constructing roads. However, these quarries would be quite small and therefore largely insignificant at the scale employed here (Embætti Veiðimálastjóra et al, 2002). The nature conservation category includes three types of conservation: 1) areas protected by the law on nature conservation (Lög um náttúruvernd nr. 44/1999), 2) areas on *Náttúruminjaskrá* (Nature conservation register), and 3) conservation areas under *Svæðisskipulag Miðhálendis Íslands* (Regional plan for the Central Highland of Iceland). The information on nature conservation came from a map from Landmótun, which is a landscape architecture office hired by the municipal council of Skaftárhreppur to make a plan for the area. Umhverfisráðherra (Minister for the Environment) confirmed the plan in March 2003 (Umhverfisráðuneyti, 2003). Landmótun also provided the location for the summer cottage category. Only areas or places with man-made constructions (cabins, airports or landing strips, roads and tracks) are included in the tourism category. All cells containing one of these features were included even if they did not cover the entire cells as it is assumed that although the feature itself might not cover an entire cell, areas immediately adjacent to the man-made structures are also being used. The base maps, as well as information from Landmótun provided this information. Identifying the actual areas that tourists use is somewhat difficult, as no specific research or mapping of this has been done, although some of the most popular locations (e.g. the fissure of Eldgjá, the crater row Lakagígar, and the rock formations at Dverghamrar) are known. The fairest assumption would be that tourists probably travel throughout the area to some extent, depending on accessibility and the type of tourists. The only place that falls under the definition of *þéttbýli* (built-up or urban area), is the town of Kirkjubæjarklaustur. Neither large-scale industry nor water conservation areas exist in the region.

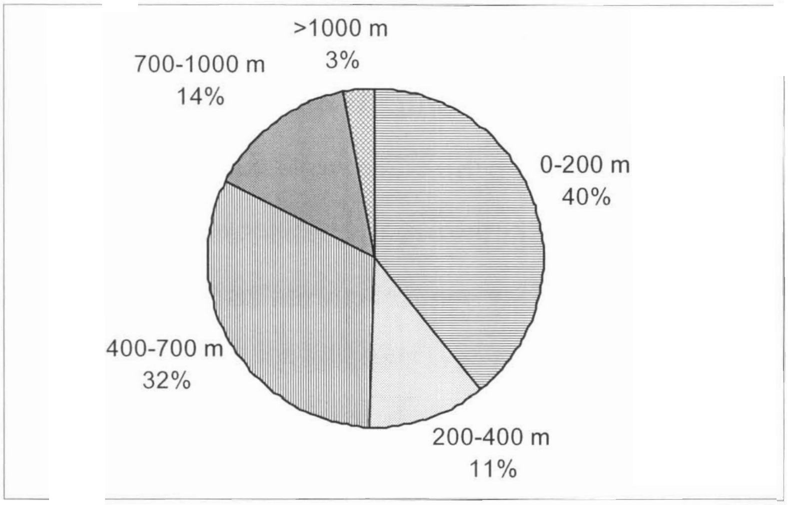
Natural factor categories

The mapping of all the natural information was manual, i.e. the natural factor was visually determined from the relevant data maps for each cell and entered in the data table manually. Where there were known errors in the data maps, corrections were made (based on personal observation and information from people familiar with the area).

The assignment of a natural factor class to cell followed a majority rule, i.e. a cell was assigned the class covering 50% or more of the cell. If no class covered more than 50% (e.g. steep slopes ranging over three or more elevation classes), a dominance rule was followed, i.e. the elevation class covering the largest part of the cell was assigned to the cell.

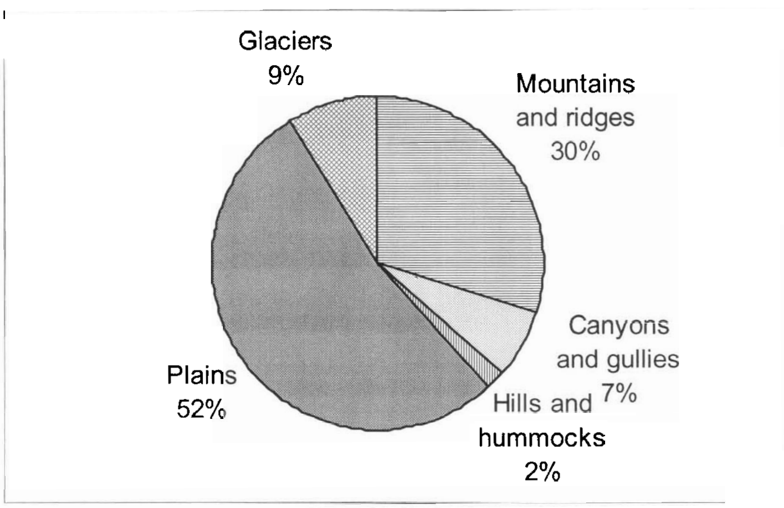
The base maps provided the elevation information. Figure 5-1 shows the proportion of each elevation class for the study area.

Figure 5-1 Elevation distribution



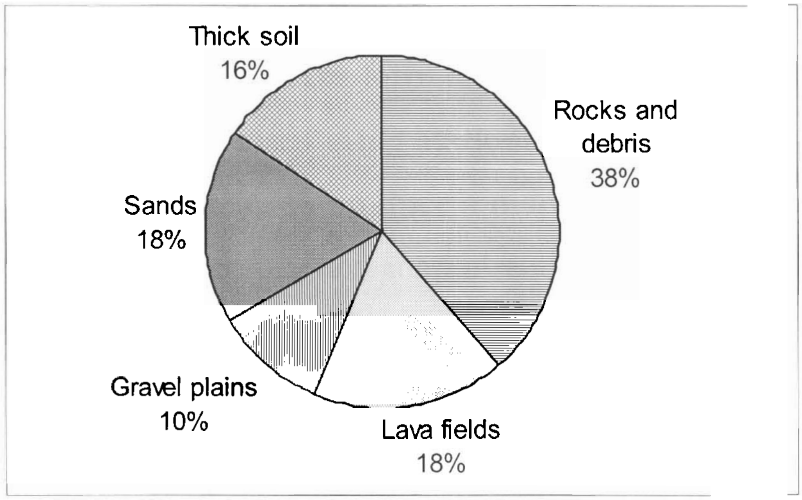
The base maps provided the landscape information. The assignment considered surrounding cells, e.g. cells containing small level areas on top of mountains classified as mountains, even though the cell considered in isolation could classify as a plain. Figure 5-2 shows the proportion of each landscape class for the study area.

Figure 5-2 Landscape distribution



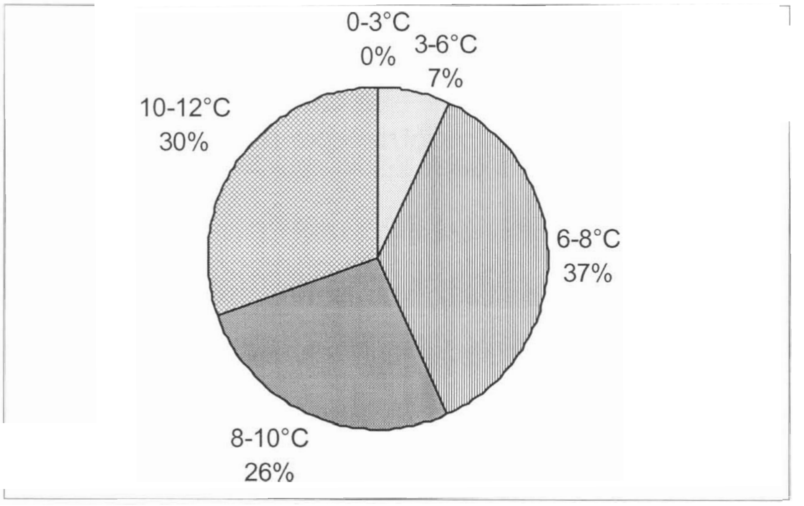
The base maps provided land texture information.. Lava and sands are marked specifically on the base maps. The rock and debris class included all bare mountainous areas, as well as areas labelled as distorted surfaces, gravel and moraines on the base maps. The gravel plains class included all gravel surfaces in and on rivers, as the class is called "*eyrar*" in Icelandic (see previous discussion on translation considerations). The thick soil class included all vegetated areas (cultivated fields, scrubs, woodlands) on the base maps. Personal knowledge of the study area also supplemented this category. Figure 5-3 shows the proportion of each land texture class for the study area.

Figure 5-3 Land texture distribution



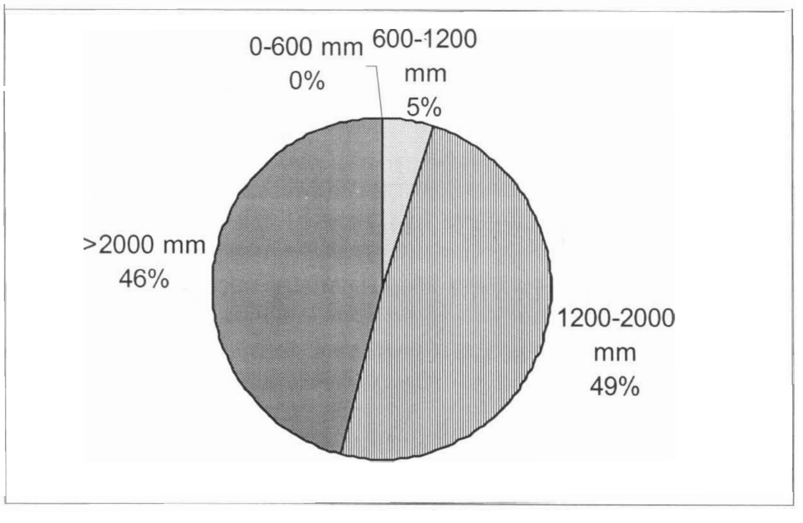
Veðurstofa Íslands (Iceland Meteorological Office) provided the temperature information, which consisted of monthly averages for the summer months (June, July, and August) from the meteorological monitoring stations in Skaftárhreppur. This information was used to produce a temperature map of the area (see Appendix 3). Figure 5-4 shows the proportion of each temperature class for the study area.

Figure 5-4 Temperature distribution



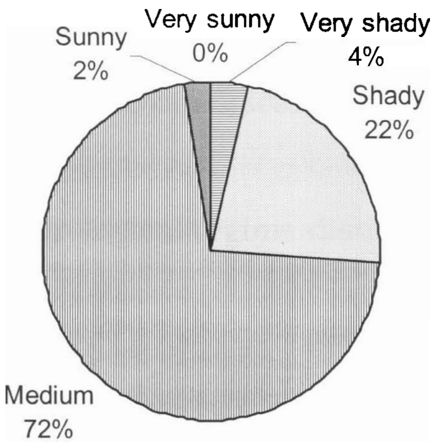
A precipitation map of Skaftárhreppur from Orkustofnun (National Energy Authority), based on data from Veðurstofa Íslands, provided the precipitation information. Normally Veðurstofa Íslands would provide this information in the form of a data series from individual meteorological monitoring stations, which would then have to be processed further to produce a map of the precipitation. In this case, however, a precipitation map already existed due to hydrological research done in Skaftárhreppur. Figure 5-5 shows the proportion of each precipitation class for the study area.

Figure 5-5 Precipitation distribution



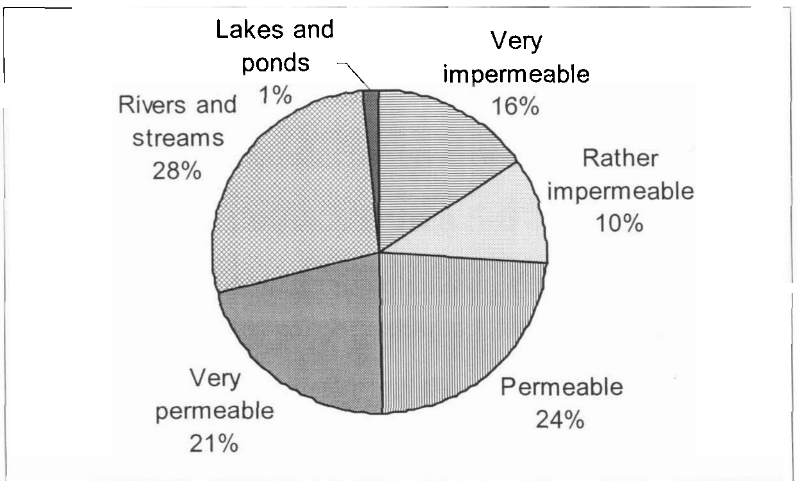
The base maps provided the exposition information, which followed the same majority and dominance rules as elevation. Figure 5-6 shows the proportion of each exposition class for the study area.

Figure 5-6 Exposition distribution



The data for the hydrological regime came from three sources. A permeability map from Orkustofnun, supplemented by a geological map of the area, provided the permeability information. The base maps provided information on rivers, streams, ponds, and lakes. Strictly speaking, only rivers and streams meeting a dominance rule (i.e. more than 50% cell cover) should have been included. However, few (if any) rivers in Iceland are over 250 m wide (half the cell width), which would mean that this category would hardly ever register, although rivers and streams are a very common feature in Iceland in general and in Skaftárhreppur in particular. Consequently, cells *containing* rivers or streams were mapped, which introduces a certain error into the areal representation, as the rivers and streams can actually cover a minor part of each cell, but it was deemed necessary to capture the presence of rivers and streams. This source of error must be borne in mind at later stages. Only rivers/streams running through the entire cell (i.e. flowing in and out) were included. In addition, only continually flowing rivers were included, i.e. intermittent streams were not included. For the lakes and ponds a dominance rule was followed, i.e. only lakes and ponds covering more than 50% of a cell were mapped. Figure 5-7 shows the proportion of each hydrological regime class for the study area.

Figure 5-7 Hydrological regime distribution



The soil type and soil cover factors posed certain difficulties, particularly the soil type. The classes used in the forms handed to the participants were taken from the official website of the Icelandic soil project at Rannsóknarstofnun landbúnaðarins (RALA) in the spring of 2001 (Rannsóknarstofnun landbúnaðarins, 2000). The data on both soil type and cover came from printouts from RALA in the summer of 2001. Unfortunately, the soil type classes on the printouts did not totally match the classes employed on the forms, i.e. the soil classification had changed somewhat between the preparation of the forms and the printouts, so that the printouts actually contained fewer classes than the forms. This necessitated joining two of the classes employed on the forms together when mapping the data. Although the printout of the soil cover had the same number of classes as the form, the printout actually displayed combined classes (e.g. instead of displaying areas with no erosion and little erosion separately, the printout displayed them together as areas with no and/or little erosion). This fluctuation in classes is because no official soil classification system exists in Iceland, for two main reasons. Firstly, because Icelandic soils are so unique they do not comply with other (foreign) classification systems without some modifications and secondly, holistic and systematic research of Icelandic soils has not been undertaken until recently (Rannsóknarstofnun landbúnaðarins, 2000). Figures 5-8 and 5-9 show the proportions of each soil type and soil cover class, respectively, for the study area.

Figure 5-8 Soil type distribution

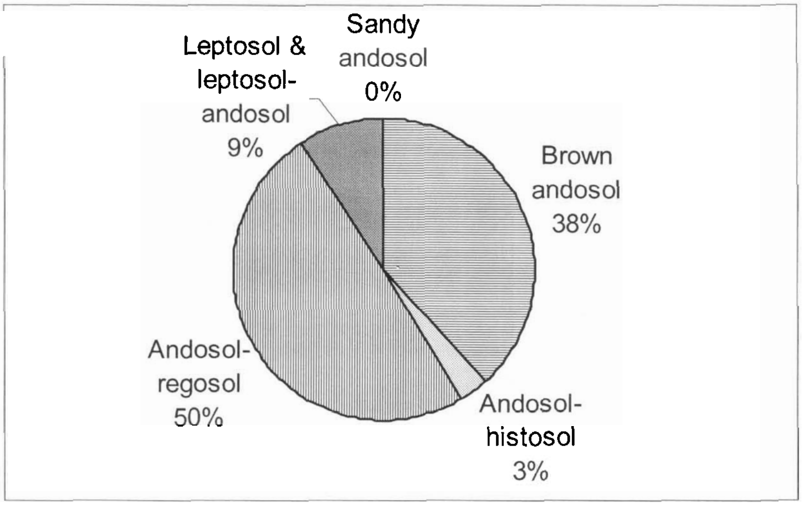
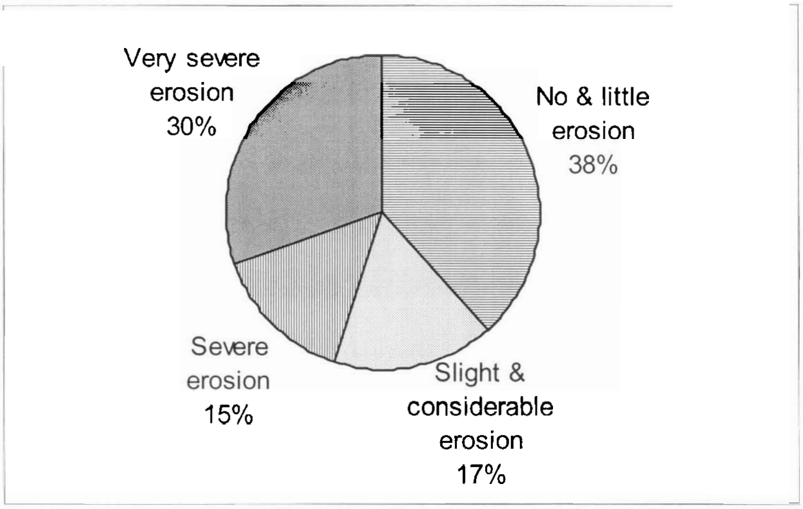
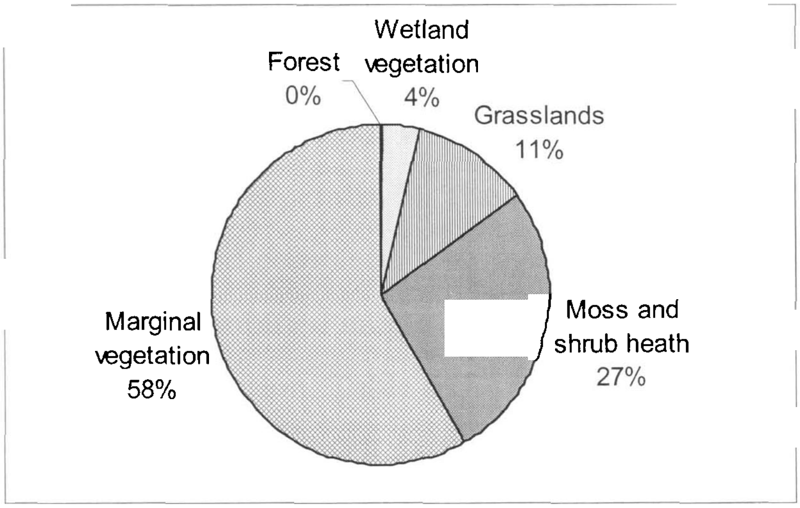


Figure 5-9 Soil cover distribution



The vegetation information came from three sources. Printouts from Náttúrufræðistofnun Íslands (Icelandic Institute of Natural History) provided part of the information. Those printouts only covered part of the study area. The base topographic maps on a scale of 1:50,000, as well as topographic maps on a scale of 1:100,000 provided the information for the remaining areas. These topographic maps contained sufficient information on the scale in question (regional plan, with five general vegetation categories). If the method is developed further for other scales specific vegetation maps (more detailed vegetation categories) will be necessary. Figure 5-10 shows the proportion of each vegetation class for the study area.

Figure 5-10 Vegetation distribution



Selection of participants

Expert knowledge was required for two study components, for assigning grades to all natural factor classes for a given land-use and for assessing the relative importance (weight) of each natural factor for a given land-use. Participants were identified by initially contacting key contacts in the community (e.g. members of relevant land-use organizations, university teachers, members of local authorities) to suggest the most suitable participants for the study. This approach proved useful, as it identified the most suitable participants for each land-use (i.e. participants suggested by more than one contact). A drawback to the approach was that it proved fairly time consuming, but this is a minor drawback as finding potential participants needs only to be done once (as each participant makes an assessment only once). A list of the participants is in Appendix 4.

Expert evaluation

The participants assigned grades to the natural factor classes. To do so, the participants filled out a simple form, which listed all the classes and the grades (see Appendix 5). The form was designed to be easy to understand and complete. The answers from all the participants produced a combined single grade for each class for both the land-uses under consideration. Table 5-1 shows the combined grade (Applied) for each factor class, as well as the assigned grades for each factor class. The table demonstrates that a unanimous grade assignment only exists for a few classes, in most cases there is some variation in the assignment.

Table 5-1 Grades

Natural factor	Agriculture		Forestry	
	Applied	Assigned values	Applied	Assigned values
Elevation:				
0-200 m	100	100,100,100,100	100	30,100,100
200-400 m	30	10,30,30,100	10	3,10,10
400-700 m	3	3,3,3,10	1	X,1,1
700-1000 m	X	X,X,1,3	X	X,X,X
>1000 m	1	X,X,1,1	X	X,X,X
Landscape:				
Mountains and ridges	10	3,10,10,10	3	3,3,10
Canyons and gullies	3	1,3,3,30	10	1,10,100
Hills and hummocks	30	10,30,30,100	10	3,10,10
Plains	100	30,100,100,100	10	1,10,30
Glaciers	X	X,X,X,1	X	X,X,X
Land texture:				
Rocks and debris	1	1,1,1,3	3	1,3,3
Lava fields	1	1,1,3,10	1	1,1,10
Gravel plains	3	3,3,3,10	10	10,10,10
Sands	3	1,3,3,100	3	1,3,30

Natural factor	Agriculture		Forestry	
	Applied	Assigned values	Applied	Assigned values
Thick soil	100	100,100,100,100	30	30,30,100
Temperature:				
0-3°C	X	X,X,X,3	X	X,X,X
3-6°C	1	1,1,1,10	X	X,X,1
6-8°C	3	3,3,10,30	1	1,1,10
8-10°C	100	10,30,100,100	10	3,10,100
10-12°C	100	30,100,100,100	100	30,100,100
Precipitation:				
0-600 mm	1	1,1,1,10	3	3,3,10
600-1200 mm	100	30,30,100,100	30	30,30,100
1200-2000 mm	30	10,30,30,100	30	30,30,100
>2000 mm	3	3,3,10,100	30	10,30,30
Light exposition:				
Very shady	1	1,1,1,3	10	10,10,10
Shady	3	3,3,3,3	10	10,10,30
Medium	30	10,10,30,30	30	10,30,30
Sunny	100	100,100,100,100	30	30,30,100
Very sunny	100	10,30,100,100	30	30,30,100
Hydrological regime:				
Bedrock permeability:				
Very impermeable	30	10,30,30,100	30	1,30,30
Rather impermeable	100	30,100,100,100	10	3,10,30
Permeable	10	10,10,10,30	10	3,10,30
Very permeable	3	3,3,3,3	3	3,3,30
Rivers and streams	30	3,10,30,100	X	X,X,X
Lakes and ponds	30	3,10,30,30	X	X,X,X
Soil type:				
Brown andosol	100	30,100,100,100	30	30,30,100
Organic andosol/histosol	100	30,100,100,100	30	30,30,100
Vitric/gravelly andosol-regosol	30	3,30,30,100	10	10,10,10
Leptosol – leptosol/sandy andosol complex*	3	1,1,3,3,3,3,3,10	3	1,1,3,3,3,3
Sandy andosol	30	10,10,30,30	10	10,10,30
Soil cover (soil erosion)				
No/little erosion*	100	30,30,100,100,	30	10,30,30,30,

Natural factor	Agriculture		Forestry	
	Applied	Assigned values	Applied	Assigned values
		100,100,100, 100		100,100
Slight/considerable erosion*	10	3,3,3,10,10,10, 10,30	10	3,3,10,10,30,30
Severe erosion	1	X,1,1,3	3	1,3,3
Very severe erosion	1	X,X,11	1	1,1,3
Vegetation:				
Forest	30	30,30,30,100	100	30,100,100
Wetland vegetation	30	10,30,30,100	3	1,3,10
Grasslands	100	100,100,100, 100	10	3,10,10
Moss and shrub heath	10	10,10,10,30	10	10,10,10
Marginal vegetation	3	1,1,3,3	3	3,3,10

*: Joined class, see previous discussion on factor, X: Excluded

A majority rule was followed where the assignment was not unanimous, i.e. the grade that most participants selected was assigned to a class. The median grade was selected when no majority emerged (i.e. in case of ties). In case of a majority tie (i.e. two grades received the same number of assignments) the land-use was given preference and the class was assigned the higher grade. Admittedly, in such a situation assigning the lower grade to a class would be more a conservative choice. However, discussions with the participants demonstrated that in general the participants had a tendency to be very cautious in their assignments and in some cases almost loath to assigning a good or very good grade. This is a well know phenomenon in Iceland. Later developments have often shown experts (particularly forestry experts) to be conservative in their assessments (Blöndal and Gunnarsson, 1999). Therefore, it was deemed reasonable to assign the higher grades. Admittedly, this is a personal preference, as there are solid arguments for both assigning the lower and the higher grade. A special case in this instance, however, is the excluded class. Different assignments to other grade classes affect the relative potential of land. An assignment to the excluded class, however, removes a cell from further consideration and this step should not be taken unless there is a clear majority on this, i.e. unless it is absolutely certain that a specific attribute excludes a given land-use.

The participants filled out a simple form (see Appendix 6) in order to estimate the weight of each natural factor for a given land-use. For this estimation, the participants simply assigned weights directly. Many different ways exist for deriving such weights, most of them far more sophisticated than the direct assessment employed here. A drawback of most of these methods is that they are far more complicated, sometimes requiring considerable calculations; therefore they are considered less transparent than direct estimation. The number of factors involved (ten) can pose a certain challenge here, as research has shown that most people are not good at dealing with more than seven factors (±2) simultaneously (Banai-Kashani, 1989). However, given that the scale employed here (0-100%) is one that most people are quite familiar with, it was believed that the number of factors would not pose too much of a difficulty. In addition, direct assessment is one of the most straightforward and simple ways of doing so, and requires no special knowledge on behalf of the interviewer or the participant, which is important as one of the main objectives of the method is to keep the method relatively simple and easy to execute. The answers from all the participants produced a single weight for each natural factor for a given land-use (see the column Applied in Table 5-2). The median value was used for this. Although the mean is the more common measure used for calculating such central values, it is not the most suitable measure in this case, as the distribution of the weight values was skewed, in which case the median is better. In addition, extreme values influence the mean more than the median, which can produce erroneous values for relatively small datasets such as is the case here (Barber, 1988). As the sum of the medians for the ten factors did not equal 100 exactly, the medians had to be standardized (by calculating the difference between the sum and 100, and dividing the difference among the factors). Consequently, the applied weight value is in all cases slightly higher than the median. Table 5-2 shows the single weight (Applied), as well as the minimum (Min) and maximum (Max) weight assigned to each factor, which can give an indication of the variation in weight assignment. Standard deviation indicates how typical the average value is of a whole distribution, but in this case, the standard deviation is not the best indication of the variation, because of the skewed distribution already mentioned above (Barber, 1988).

Table 5-2 Weights

Natural factor	Weight					
	Agriculture			Forestry		
	Applied	Min	Max	Applied	Min	Max
Elevation	0.103	0.00	0.15	0.210	0.15	0.30
Landscape	0.103	0.00	0.10	0.060	0.05	0.10
Land texture	0.103	0.05	0.20	0.110	0.00	0.10
Temperature	0.123	0.05	0.20	0.110	0.05	0.15
Precipitation	0.053	0.05	0.10	0.110	0.00	0.15
Light exposition	0.053	0.00	0.15	0.060	0.00	0.15
Hydrological regime	0.053	0.05	0.10	0.060	0.05	0.15
Soil type	0.153	0.10	0.15	0.110	0.05	0.20
Soil cover	0.153	0.08	0.15	0.110	0.05	0.15
Vegetation	0.103	0.05	0.15	0.060	0.05	0.15

Once both grades and weights had been determined, a combined sum for each cell for both forestry and agriculture was calculated (as shown in Figure 3-2). First, grades were calculated for each cell using the values in Table 5-1 and the base information, yielding ten data tables of grades (one for each natural factor) for each land-use. Figures 5-11 and 5-12 show the distribution of the grades for each factor for both agriculture and forestry. The grade distributions for the two land-uses are rather different, with a comparatively wider range of grade classes covered in each factor for agriculture and more factors with higher grades for agriculture, particularly the very good grade. This difference is logical, as there are greater limits to the growth of trees that form the base for forestry than to the growth of grass and most crops grown in Iceland. After all data tables of grades had been calculated, the grades in each table were multiplied by the corresponding natural factor weight shown in Table 5-2, yielding ten tables of weighted grades, one for each land-use. Finally, the ten weighted grade tables were summed, yielding two data tables, one for agriculture and one for forestry, containing the combined fitness grade for each cell.

Figure 5-11 Grade distribution for each factor for agriculture

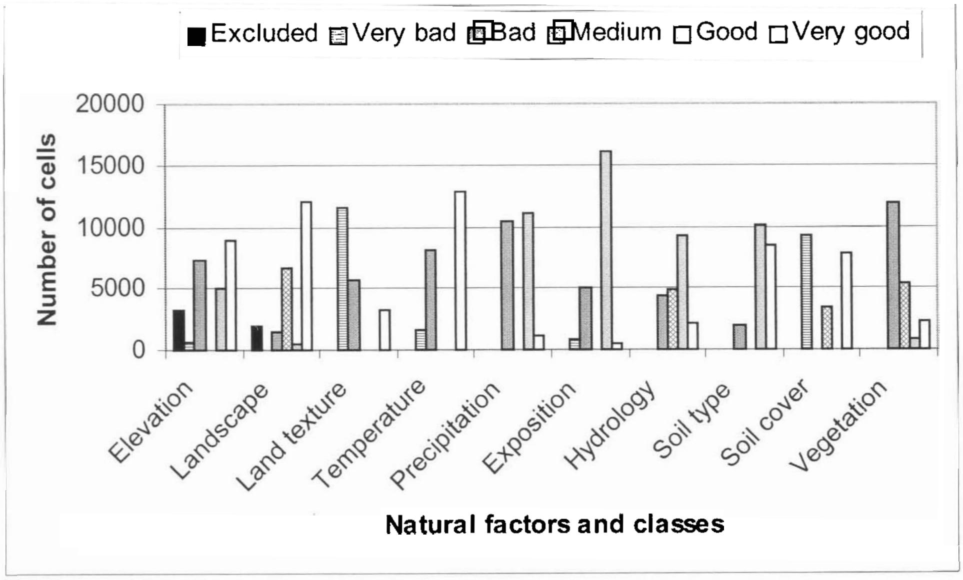
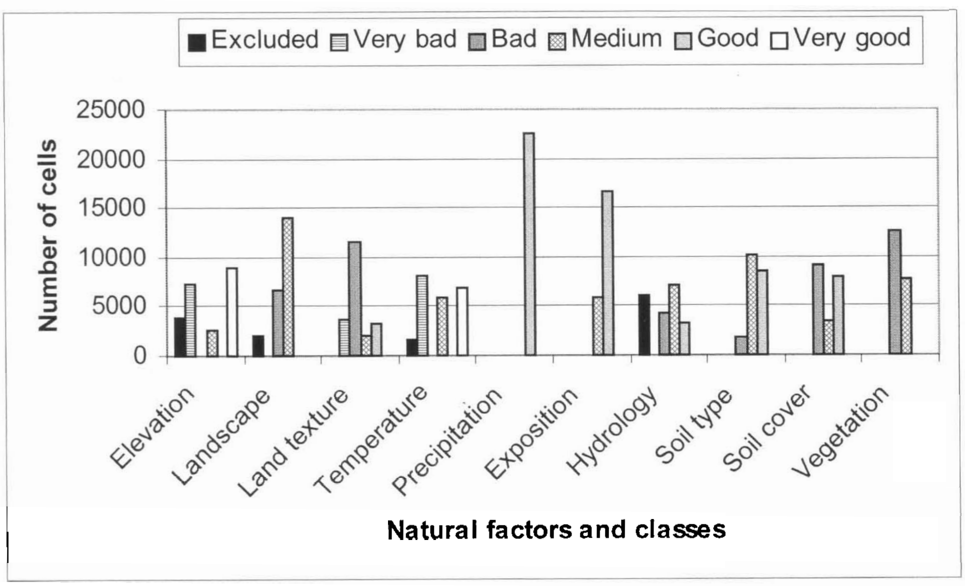


Figure 5-12 Grade distribution for each factor for forestry



Once the fitness grade had been calculated for both forestry and agriculture, the two tables were compared to identify cells deemed better for forestry. The comparison involved two steps. First was the identification of valid cells, i.e. cells not containing excluding properties for forestry. Next was the comparison of the grades of valid cells for the two land-uses and identification of cells that had a higher grade for forestry than for agriculture. The comparison consisted of a simple rule: grade for forestry > grade for agriculture. If the forestry grade for a given cell was higher than the agriculture grade, the cell was marked as a 'forestry cell', irrespective of the grade difference between the two land-uses. Those cells were then compared to the current land-use, to determine if the current land-use excluded forestry (e.g. historical remnants protected by law). The end result from the process was a fitness map documenting areas that are fitter for forestry, in comparison to agriculture.

Chapter 6
Results

Only a small portion of the study area emerged as fitter for forestry than for agriculture based on the method. Of the 22,647 cells in the entire study area, only 230 cells (around 1%) had higher grades for forestry than agriculture (see Figure 6-1). The exclusion of cells that contain non-compatible land-uses or restrictions on land-use (e.g. archaeological sites) reduces the number of forestry cells to 136 (0.6%) (see Figure 6-2).

Figure 6-1 Direct comparison between agriculture and forestry

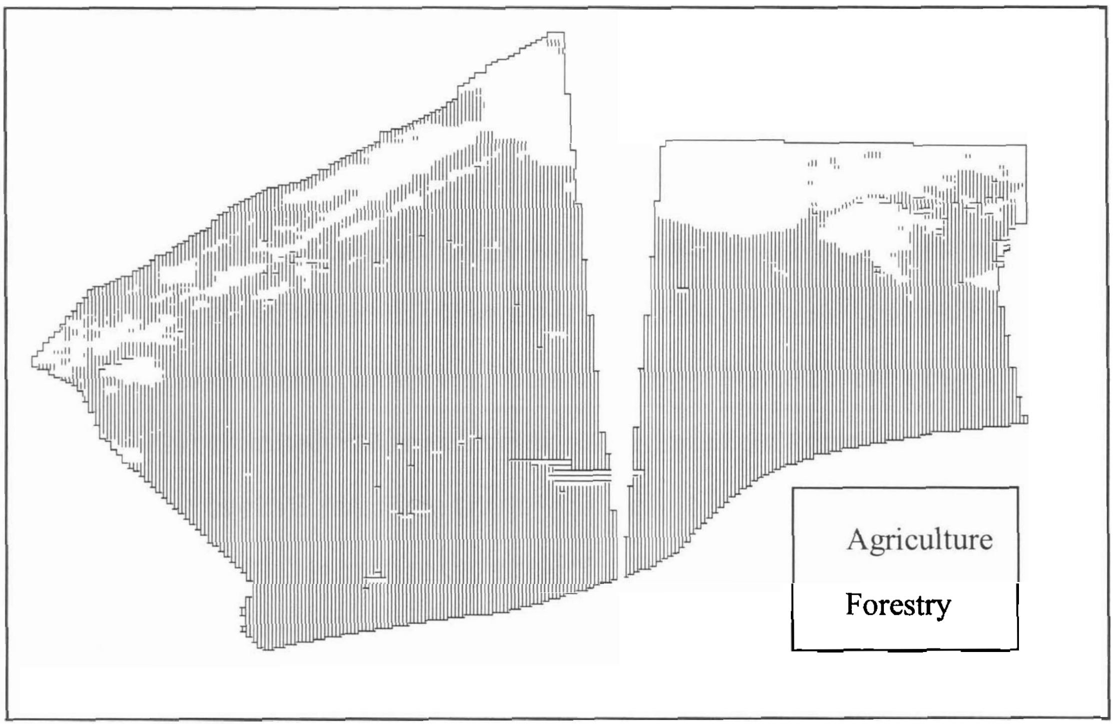
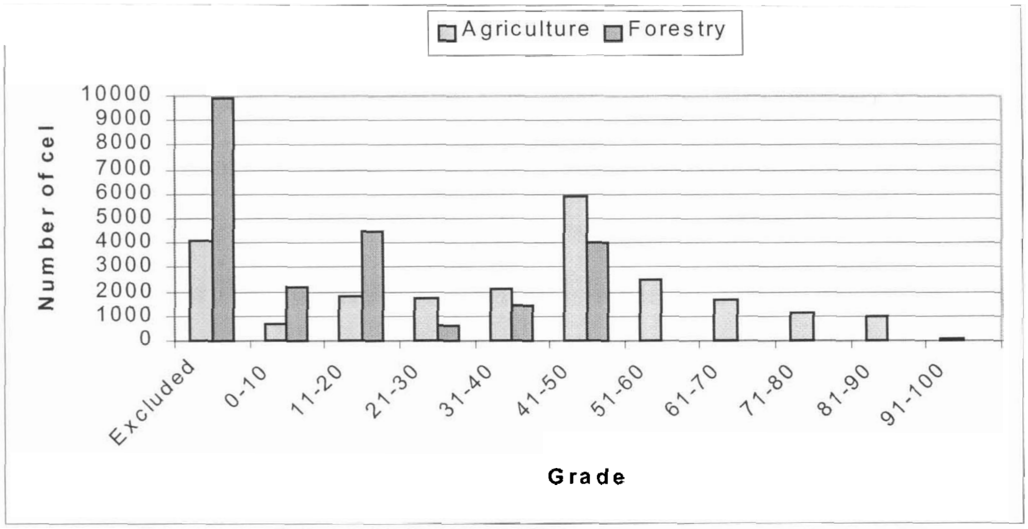


Figure 6-2 Non-excluded forestry areas

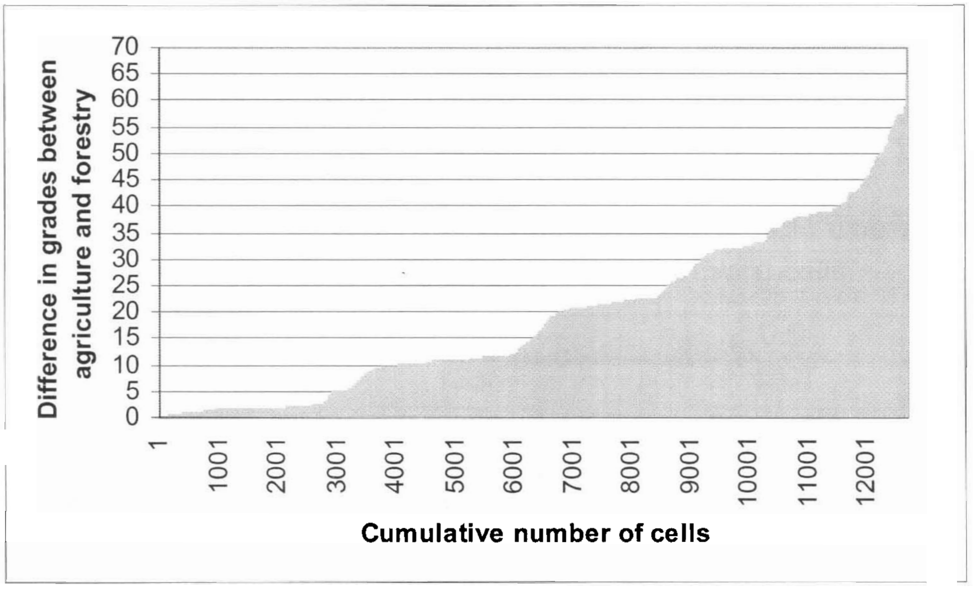
Of those 136 cells, 129 are highly fit, i.e. have grades higher than 30 (good grade class), while the remaining 7 cells all have grades below 10 (medium grade class). However, many of the 136 cells are single, isolated sites, which obviously reduces their usefulness as sites for actual forestry. The overall result is thus that only a tiny portion of the study area (around 0.6%) is naturally fitter for forestry than agriculture. This superiority of agriculture is logical, as trees generally require better growing conditions than grass, on which the mixed farming traditionally practiced in Iceland is based. It is thus expected that agriculture will generally receive higher grades, which it does (see Table 6-3 for the distribution of grades for agriculture and forestry).

Figure 6-3 Grade distribution for agriculture and forestry



This superiority of agriculture does not mean, however, that forestry is not a feasible land-use in the study area, as the method neither considers economic nor social factors. Even though agriculture might be a better option based on natural attributes the economic return from forestry might be higher, thus making forestry more desirable (this is not necessarily the case, however). In addition, changes in agriculture (a decline in traditional agriculture, and increasing specialization and diversity) have increased interest in forestry among many farmers. Consequently, some farmers might place more importance on forestry although many will, of course, not. The sheer dominance of agriculture in fitness also indicates that natural fitness is a much more limiting factor for forestry than for agriculture in the study area. Valid cells (i.e. cells that have no excluding attributes) are 12,696 for forestry (56% of study area) compared to 18,546 (82%) for agriculture. Only 5440 valid forestry cells (24%) have grades above 30, while 14,338 (63%) valid agriculture cells have grades above 30. Therefore, even if far more cells than the 136 identified by the method were assigned to forestry, there would still be large tracts of suitable land available for agriculture. Even if *all* good forestry cells (grades > 30) were assigned to forestry, there would still be around 8900 *good* agriculture cells left (around 39% of the area). This discussion, however, should not be taken as a sign that such an assignment is recommended in any way. It is merely meant to emphasize the point that the method does not provide absolute answers or decisions regarding land-use, but is only intended as one tool among several. The choice between the two land-uses will ultimately be based on other considerations as well. It must also be borne in mind that the simple comparison rule used in this study does not consider the difference in grades between agriculture and forestry, i.e. a cell is assigned the land-use with the higher grade, irrespective of the magnitude of difference. An examination of the difference in grades for valid cells shows that the maximum difference is around 64, but the minimal difference is only 0.009, which is clearly negligible (see Figure 6-4).

Figure 6-4 Difference in grades between agriculture and forestry



To determine whether the difference in grades between the two land-uses is really significant requires calculating some measure of how accurate each grade is (i.e. how great is the expected variation in each grade). Such a calculation requires examining the variation in the factors contributing to each grade, i.e. the assignment to a class and the factor weights. This calculation, however, is computationally very complex, as there are two land-uses, each involving ten factors, having a total of 52 classes, ten factor weights, and 12,696 cells (number of cells with valid grades for both land-uses) to consider. Consequently, a much simpler approach was employed to determine if the grade difference was discernible (i.e. there *is* a meaningful difference in the grades) or negligible (the difference is so small that there is no clear difference in the natural fitness for either land-use). The approach was to compare a fixed percentage 'uncertainty' to the difference in grades between the two land-uses by calculating whether the percentage variation is smaller (and thus discernible) or greater (and thus negligible) than the grade difference for each cell. This comparison included several different percentages and an examination of their effect on the number of cells with a negligible grade difference (see Table 6-1).

Table 6-1 Negligible grade difference for varying % of uncertainty

% of uncertainty	Number of cells	% of valid cells
1	74	0.6
3	1756	13.8
5	2092	16.5
10	2826	22.3
15	4262	33.6
30	6830	53.0

Greater uncertainty in the overall grade for each land-use increases the number of cells with a negligible difference considerably. A limited uncertainty (1%) has minimal effect, but assuming a 30% uncertainty in the grades means that there is no discernible difference between agriculture and forestry for over half the valid cells and even a 15% uncertainty reduces the number of valid cells by a third. The impact on those cells with higher grades for forestry is even greater. A 1% uncertainty means that 44 cells (of 230) have a negligible difference, while a 30% uncertainty results in 229 cells with a negligible difference. In other words, with a 30% uncertainty only one cell has a discernibly higher grade for forestry than agriculture. The level of uncertainty thus greatly influences the assignment of cells between agriculture and forestry. The level of uncertainty that eventually is deemed acceptable is largely a matter of debate. The only way to determine the uncertainty with any degree of confidence is by examining the variation in the assignment to a class and the factor weights, which, as already mentioned, requires immense calculations. The exact uncertainty is perhaps not the main issue. Although the inclusion of uncertainty reduces the ability of the proposed method to distinguish between sites for agriculture and forestry (because there are more sites that do not have a clear difference in the natural fitness for the two land-uses), it does not necessarily reduce the usefulness of the method to the same extent. The mere fact that many cells have potentially 'equal' fitness value for agriculture and forestry is also useful information. If neither agriculture nor forestry has a clear natural advantage for a given tract of land, land-use planners can, in any case, choose which land-use to assign to it based solely on other considerations (e.g. economic or policyrelated). After all, choosing between land-uses requires consideration of more than just natural fitness. As long as land-use planners consider the uncertainty in some way (e.g. by choosing a given level or comparing different levels) and realise the impact it has, this uncertainty need not be an insurmountable drawback.

The grades for agriculture and forestry were examined in one further way, by examining the distribution of non-weighted forestry grades for different non-weighted agriculture grades, i.e. how often the grades for forestry correspond to the grades for agriculture. A reciprocal examination is also possible, i.e. examining how often agriculture corresponds to forestry. Table 6-2 shows the percentage correspondence in grades between the two land-uses.

Table 6-2 Correspondence of non-weighted cell grades

		Forestry				
		Very low grade	Low grade	Medium grade	Good grade	Very good grade
Agriculture	Very low grade	14.94%	45.08%	13.43%	26.53%	0%
	Low grade	25.57%	45.67%	9.65%	17.11%	0%
	Medium grade	0%	34.23%	65.77%	0%	0%
	Good grade	0%	2.32%	27.04%	70.51%	0.13%
	Very good grade	0%	0%	43.79%	27.20%	29.02%

If forestry corresponded perfectly to agriculture, then the values should all be concentrated in the centre diagonal line of the table. As can be seen in Table 6-2, that pattern definitely exists, but with significant aberrations. The correspondence between medium and good grades (10 and 30) is fairly high (70.5% of cells that have a good grade for agriculture also have a good grade for forestry and 65.8% of cells that have a medium grade for agriculture also have a medium grade for forestry). The correspondence in other grades is less pronounced (e.g. only around 15% of the cells with a very low grade for agriculture also have a very low grade for forestry).

It is also possible to calculate the bivariate correlations between cell grades for each variable for agriculture and forestry. Table 6-3 shows these correlations. The centre diagonal line of the table thus displays the correlation in grades between corresponding natural factors for both of the land-uses, e.g. the correlation between land texture grades for agriculture and for forestry. The correlation between the grades of individual natural factors varies enormously, ranging from a very low correlation between the grades for precipitation for agriculture and land texture for forestry, to a near perfect correlation between soil type for both land-uses. The correlation is generally high between corresponding natural factors (e.g. land texture for both), although there are notable exceptions (e.g. a rather low correlation between vegetation, soil cover, and hydrological regime for the two land-uses).

Table 6-3 Correlation between non-weighted cell grades

		Forestry									
		Land texture	Exposition	Vegetation	Temperature	Soil cover	Soil type	Elevation	Landscape	Precipitation	Hydrological regime
Agriculture	Land texture	0.99	-0.05	0.16	0.03	0.31	0.43	0.05	-0.08	NaN	0.25
	Exposition	-0.04	0.78	-0.05	0.17	-0.04	-0.13	0.20	0.26	NaN	-0.12
	Vegetation	0.62	-0.02	0.29	0.09	0.29	0.36	0.18	-0.05	NaN	0.14
	Temperature	0.28	0.25	0.13	0.57	0.16	0.08	0.66	0.31	NaN	-0.15
	Soil cover	0.09	0.07	0.07	0.14	0.21	0.11	0.14	0.05	NaN	-0.04
	Soil type	0.45	-0.26	0.10	-0.17	0.42	1.00	-0.21	-0.38	NaN	0.42
	Elevation	0.08	0.35	0.06	0.80	-0.05	-0.17	0.99	0.51	NaN	-0.32
	Landscape	0.00	0.49	-0.02	0.58	-0.08	-0.39	0.61	0.88	NaN	-0.63
	Precipitation	0.00	0.27	-0.07	0.55	-0.11	-0.20	0.46	0.43	NaN	-0.35
	Hydrological regime	0.26	-0.28	0.01	-0.40	0.14	0.36	-0.46	-0.38	NaN	0.26

NaN: Not a number, due to the fact that precipitation is a constant for forestry

Because both agriculture and forestry are vegetation-based, the same growth factors largely influence both land-uses and, consequently, there will be a considerable correlation between the two land-uses. If the correlations were near to perfect, these relationships would certainly undermine the method objective. Overall, the combined raw correlation between agriculture and forestry is 0.5304. As expected, there is a positive correlation between agriculture and forestry, but it is not so great as to render comparison between the land-uses futile. The moderate correlation implies that there will be a variation in the grades for the two land-uses and, consequently, some areas will clearly be more preferable for one land-use than the other. In addition, the correlation itself can provide potentially useful information. For a really high correlation (and a more constant difference between agriculture and forestry grades), other considerations (e.g. economical or political) would need to become critical for the decision process. In addition, the method proposed here is not intended to actually make decisions, but merely as a decision-aid. In addition, a correlation between these two particular land-uses is not specific to the method; it will be a potential issue to any assessment method used.

A significant bivariate correlation between the grades for different natural factors for each land-use also exists, with correlation for agriculture up to around 73% (see Table 6-4) and correlation for forestry up to around 80% (see Table 6-5). Table 6-5 does not display precipitation, because the grade for the different precipitation classes present in the study area is the same for forestry, i.e. the precipitation is essentially a constant.

Table 6-4 Correlation for non-weighted cell grades for agriculture

	Land texture	Exposition	Vegetation	Temperature	Soil cover	Soil type	Elevation	Landscape	Precipitation	Hydrological regime
Land texture	1.00	-0.04	0.64	0.28	0.11	0.45	0.09	-0.09	0.19*	-0.01
Exposition	-0.04	1.00	-0.02	0.12	0.04	-0.13	0.19	0.23	-0.14	0.12
Vegetation	0.64	-0.02	1.00	0.26	0.24	0.39	0.14	-0.07	0.06*	0.01
Temperature	0.28	0.12	0.26	1.00	0.07	0.07	0.73	0.35	-0.11	0.15
Soil cover	0.11	0.04	0.24	0.07	1.00	0.11	0.12	0.04	-0.08	0.14
Soil type	0.45	-0.13	0.39	0.07	0.11	1.00	-0.17	-0.40	0.30	-0.22
Elevation	0.09	0.19	0.14	0.73	0.12	-0.17	1.00	0.56	-0.36	0.38
Landscape	-0.09	0.23	-0.07	0.35	0.04	-0.40	0.56	1.00	-0.34	0.45
Precipitation	0.19*	-0.14	0.06*	-0.11	-0.08	0.30	-0.36	-0.34	1.00	-0.25
Hydrological regime	-0.01	0.12	0.01	0.15	0.14	-0.22	0.39	0.45	-0.25	1.00

All correlations are significant at the 0.01 level (2-tailed) except *

Table 6-5 Correlation for non-weighted cell grades for forestry

	Land texture	Exposition	Vegetation	Temperature	Soil cover	Soil type	Elevation	Landscape	Hydrological regime
Land texture	1.00	-0.07	0.13	0.00	0.29	0.45	0.03	-0.11	0.28
Exposition	-0.07	1.00	-0.05*	0.32	-0.06	-0.26	0.36	0.45	-0.32
Vegetation	0.13	-0.05*	1.00	0.00	0.28	0.10	0.04	-0.04	-0.07
Temperature	0.01	0.32	0.00	1.00	-0.03	-0.17	0.81	0.52	-0.36
Soil cover	0.29	-0.06	0.28	-0.03	1.00	0.43	-0.08	-0.09	0.04
Soil type	0.45	-0.26	0.10	-0.17	0.43	1.00	-0.21	-0.38	0.42
Elevation	0.03	0.36	0.04	0.81	-0.08	-0.21	1.00	0.54	-0.35
Landscape	-0.11	0.45	-0.03	0.52	-0.09	-0.38	0.54	1.00	-0.59
Hydrological regime	0.28	-0.32	-0.07	-0.36	0.04	0.42	-0.35	-0.59	1.00

All correlations are significant at the 0.01 level (2-tailed) except *

A considerable correlation exists between the different natural factors for both agriculture and forestry, particularly between elevation and temperature, and to a lesser degree between elevation and landscape. This correlation to a certain extent mirrors the correlation for the 'raw' or base (i.e. non-graded) data (see Table 6-6).

Table 6-6 Correlation for base data

	Land texture	Exposition	Vegetation	Temperature	Soil cover	Soil type	Elevation	Landscape	Precipitation	Hydrological regime
Land texture	1.00	0.24	0.62	0.50	0.59	0.65	0.50	0.61	0.36	0.60
Exposition	0.24	1.00	0.13	0.19	0.16	0.18	0.19	0.26	0.18	0.34
Vegetation	0.62	0.13	1.00	0.37	0.57	0.62	0.37	0.47	0.16	0.49
Temperature	0.50	0.19	0.37	1.00	0.38	0.38	0.65	0.45	0.43	0.42
Soil cover	0.59	0.18	0.57	0.38	1.00	0.63	0.38	0.49	0.22	0.52
Soil type	0.65	0.18	0.62	0.38	0.63	1.00	0.38	0.51	0.25	0.56
Elevation	0.50	0.19	0.37	0.65	0.38	0.38	1.00	0.46	0.39	0.44
Landscape	0.61	0.26	0.47	0.45	0.49	0.51	0.46	1.00	0.37	0.59
Precipitation	0.36	0.18	0.16	0.43	0.22	0.25	0.39	0.37	1.00	0.36
Hydrological regime	0.60	0.35	0.49	0.42	0.52	0.56	0.44	0.59	0.36	1.00

In general, the correlation between individual factors is as expected for the base data; a considerable correlation exists between elevation and temperature, soil type and soil cover, and between land texture and vegetation. The maximum correlation for the base data is 0.65, which is lower than the maximum correlation for the non-weighted cells for both agriculture and forestry, even though the base data correlation is generally higher and more even overall. A notable exception is the exposition factor, which has a fairly low correlation with most other factors, a pattern which the expert assignment (i.e. the correlation for the non-weighted grades) mirrors. Soil type and soil cover also tend to have quite similar correlations to other factors for the base data, a pattern which is not preserved in the expert assignment. It is not to be expected, however, that the expert assignment (Tables 6-4 and 6-5) preserves the pattern for the base data, as the expert assignment 'transforms' the base data, by giving each cell a value and there is no guarantee that the values of different factor classes correspond exactly to their natural distribution.

The correlation between factors raises two issues. First, a considerable correlation between factors can mean that those factors are 'double counted', i.e. they have a proportionally greater impact than other less correlated factors. Second, highly correlated factors could potentially be represented by only one of them, i.e. the number of factors could potentially be reduced. However, such a reduction in the number of factors could mean a certain loss of information, as the factors are rarely (if ever) fully interchangeable, i.e. a high correlation does not necessarily mean that one factor is usable as a proxy for another.

Stability of method

The two variables used to calculate the weighted grade (the assigned grade and the weight) determine the weighted grade for each cell. The stability of the proposed method thus depends on how sensitive these two variables are to changes, i.e. whether a small change in either leads to a great change in the overall results. The extreme values from the grade and weight assessment (i.e. the highest and lowest assessments for each) were used to test the sensitivity of the method, as these values indicate the potential variability in the two variables. To determine easily the potential change in the overall result (i.e. the number of highly fit cells for both agriculture and forestry) the resultant grades were categorized into the five grade classes: very bad, bad, medium, good and very good. To create a range of grades for each class (instead of the original single value), the boundaries of the classes were set geometrically between the original grades. For example, the grade for the very bad class was $\sqrt[4]{100}^{0}$ and the bad class $\sqrt[4]{100}^{1}$, so the boundary between the two classes is at $\sqrt[4]{100}^{0.5}$ (approximately 1.8) and overall grades ranging from 0 to 1.8 were thus categorized as very bad, overall grades ranging from 1.8 to 5.6 ($\sqrt[4]{100}^{1.5}$) were categorized as bad, etc.

Grades

The most 'pessimistic' and 'optimistic' given assignments for each natural factor were used to test the assignment of natural factors to a grade class (i.e. a factor was assigned the lowest and the highest grade class from the assessments). The overall grades were then recalculated using these values to determine the effect on the grade distribution (see Figures 6-5 and 6-6).

Figure 6-5 Different class assignments for agriculture

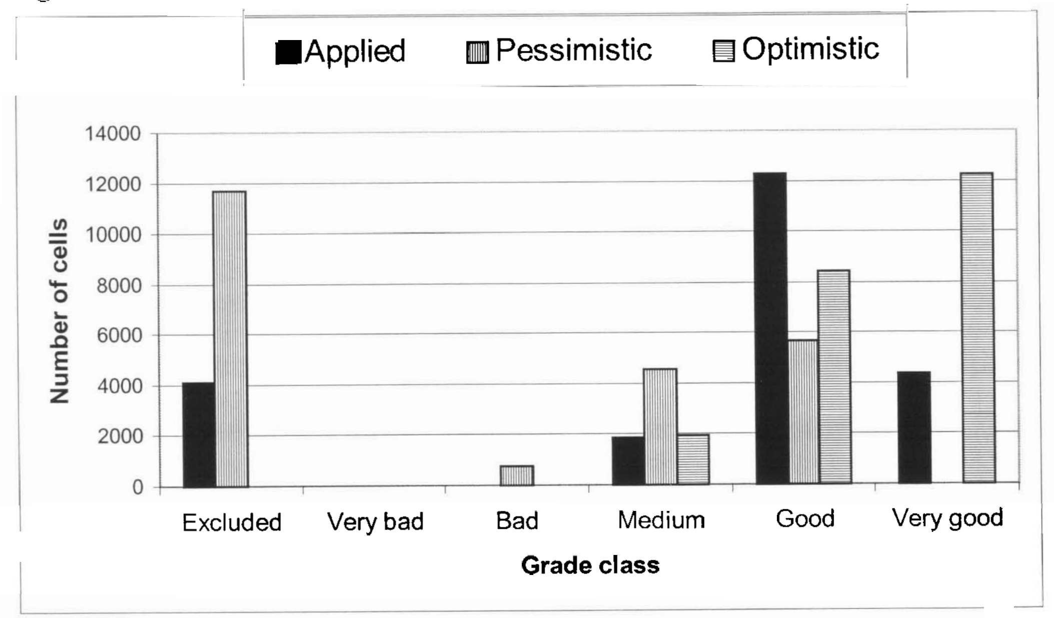
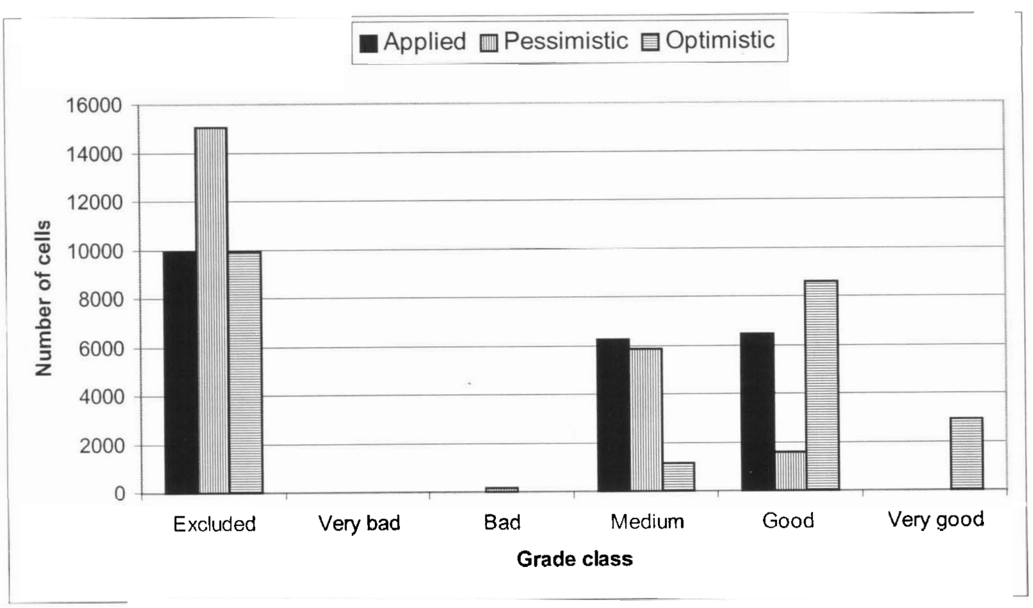
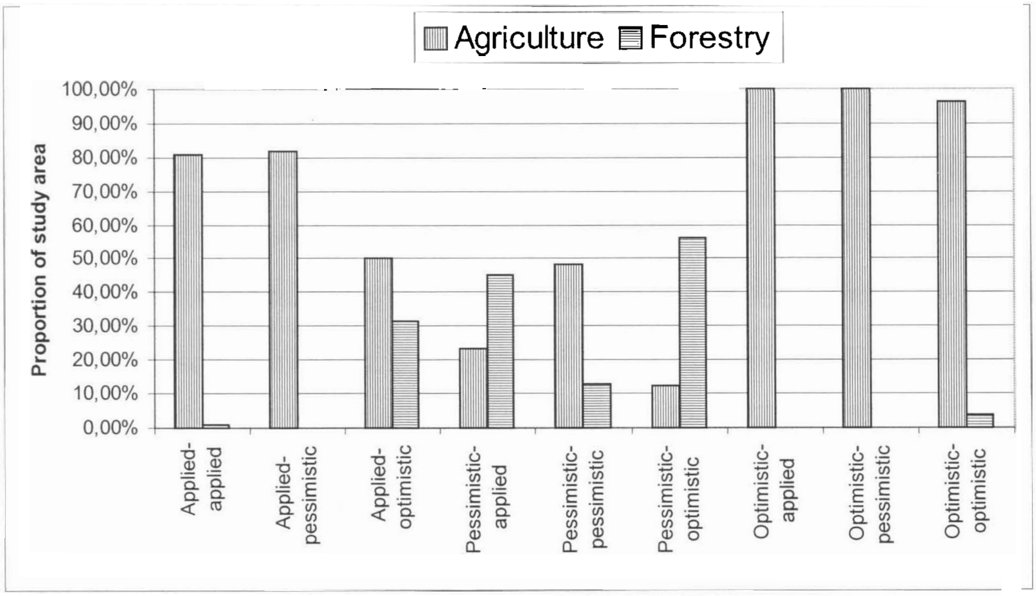


Figure 6-6 Different class assignments for forestry



The different class assignment leads to a different grade distribution for both agriculture and forestry. The pessimistic assignment results in a similar pattern of change for both land-uses, with a decrease in the number of fit cells, and a corresponding increase in the number of unfit and excluded cells (i.e. cells that have excluding attributes). The optimistic assignment leads to a more divergent pattern of change for the two land-uses, although there is a general trend of more cells with higher grades for both. The main difference is the number of excluded cells, which are eliminated in the case of agriculture but remain about the same for forestry. In general, the two assignments have an expected effect, with the pessimistic assignment decreasing the number of fit cells and the optimistic assignment increasing the number. Although the different class assignments result in different grade distributions for both agriculture and forestry, the similar pattern of change for the two land-uses means that the overall result remains basically the same, i.e. only a small part of the study area comes out as more suitable for forestry than agriculture (see Figure 6-7). The only way for the number of forestry cells to be close to, or larger than, agriculture cells, is to either use the optimistic assignment for forestry only or the pessimistic assignment for agriculture only, neither of which is very likely to be the case.

Figure 6-7 Comparative results of different class assignments



In addition, three alternative grade scales were tested, two evenly spaced scales and one logarithmic scale, similar to the applied scale (see Table 6-7). The resultant grades were categorized into the five grade classes, the same way as for the different assignments, using the grade values from the alternative grade scales.

Table 6-7 Alternative grade scales

	Grade		
Class	Scale 1	Scale 2	Scale 3
Very bad	0	20	$\sqrt[5]{100}$ 2.51
Bad	25	40	$\sqrt[4]{100}$ 3.16
Medium	50	60	$\sqrt[3]{100}$ 4.64
Good	75	80	$\sqrt[2]{100} = 10$
Very good	100	100	$\sqrt[1]{100} = 100$

The different scales resulted in a different grade distribution for both agriculture and forestry (see Figures 6-8 and 6-9).

Figure 6-8 Different scales for agriculture

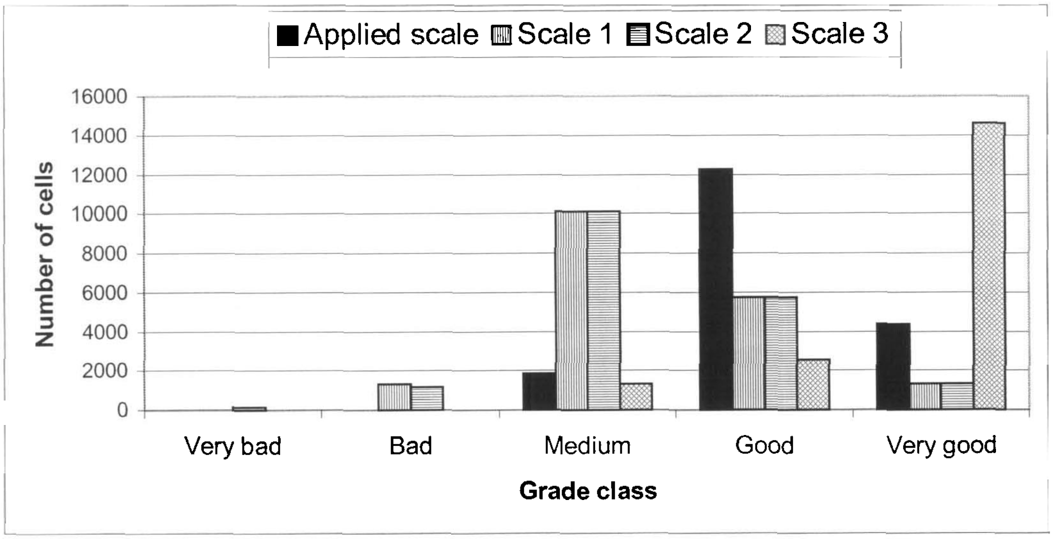
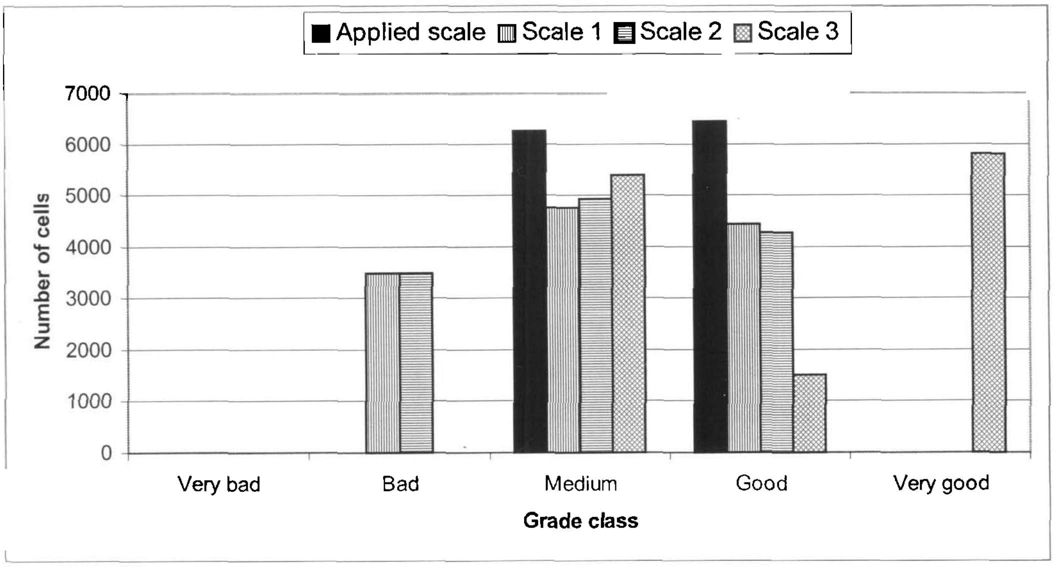
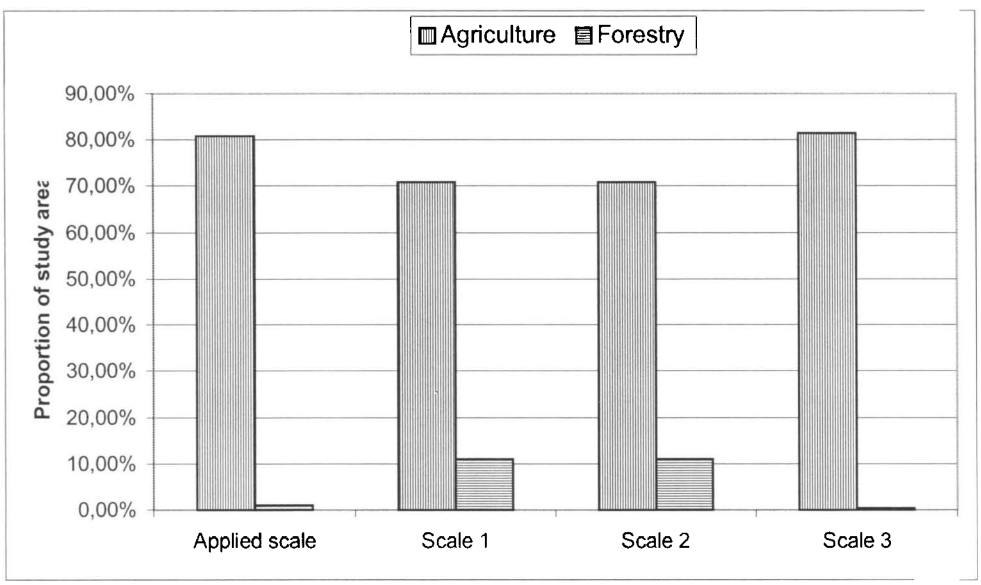


Figure 6-9 Different scales for forestry



The two evenly spaced grade scales (scales 1 and 2) result in similar patters of change for both agriculture and forestry, with a much more even distribution. This result makes sense as the evenly spaced scales emphasize the difference between the classes less. The pattern of change is also somewhat similar for the two land-uses for the alternative logarithmic scale, with a similar number of cells in the medium class, a decrease in the good class and a great increase in the number of cells with a very good grade. This change is as expected, as the very good class covers the largest range of grades (i.e. covers the largest part of the range between 0 and 100). For the logarithmic scale, cells more suitable for forestry than agriculture are only a fraction of the study area (around 1%), while with the evenly spaced scales forestry cells reach around 10% (see Figure 6-10). The overall result remains similar, despite the different grade distributions resulting from the three alternative scales; agriculture still dominates forestry, although the dominance is much less pronounced for the evenly spaced scales.

Figure 6-10 Comparative result of different scales



Weights

Four alternative weight values were tested: 1) minimum value (from weight estimates, equalized to sum to 100%), 2) maximum values (from weight estimates, equalized to sum to 100%), 3) calculated mean (instead of median), and 4) equal weight (same weight for all ten natural factors). The same categorization into grade classes was used as for the different class assignment.

The alternative weights resulted in different grade distributions for both agriculture and forestry (see Figures 6-11 and 6-12). The different weights produced a quite similar pattern of change for both land-uses; changing the weights resulted in only minor changes in the grade distribution. These results are largely due to the number of factors. All ten natural factors receive some weight (i.e. none are deemed entirely superfluous) for both land-uses. Assigning 100% among that many factors means that the possible range of values for each factor is much less than would have been the case for fewer factors, as there is less potential for large differences in weights between the factors.

Figure 6-11 Different weights for agriculture

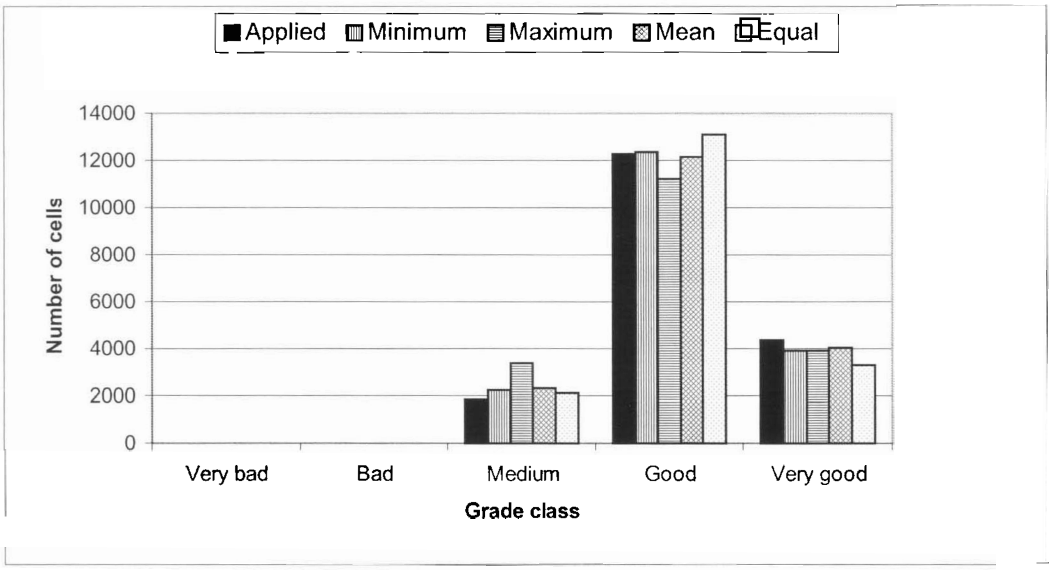
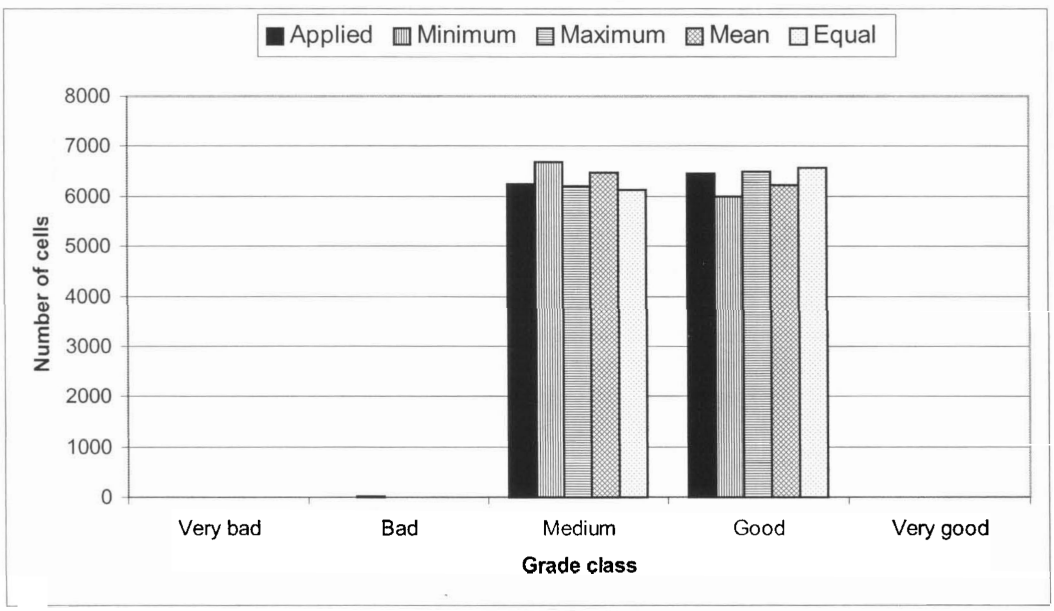
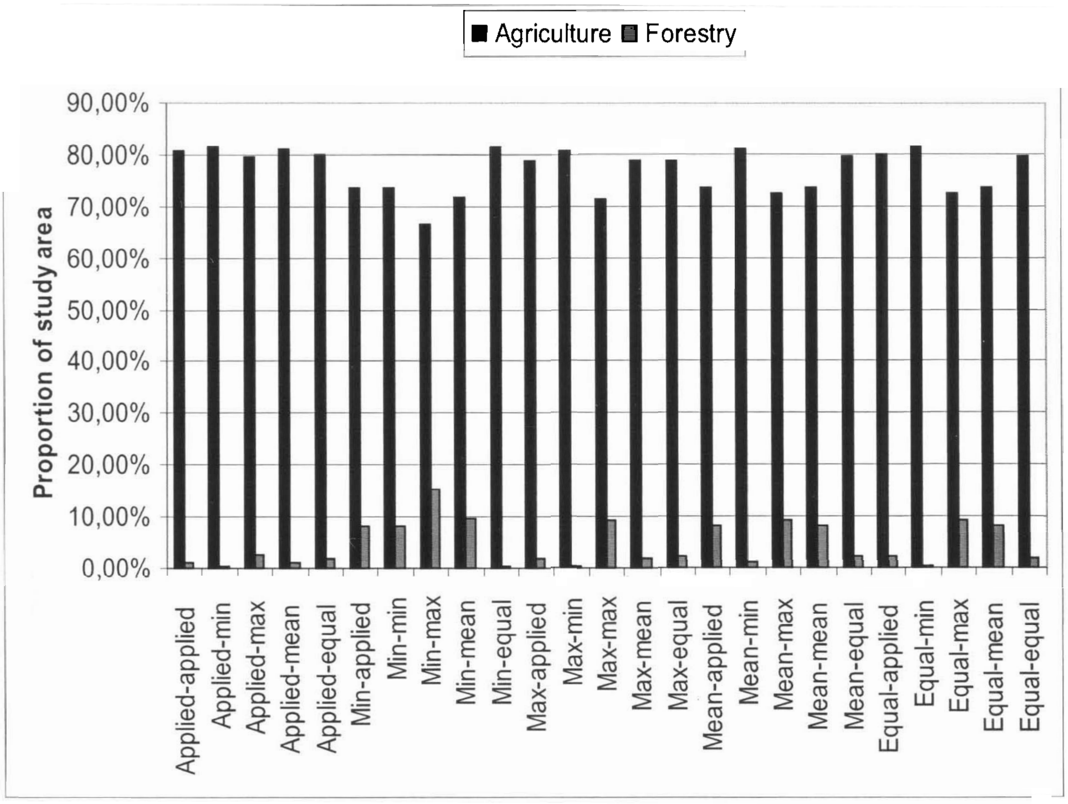


Figure 6-12 Different weights for forestry



Because the change in grade distribution is for the most part minor, relatively little change in overall results is expected. The different weights generally improve the situation for forestry, but agriculture continues to be the preferred option for the vast majority of the study area in all cases. The only way to significantly change the ratio between agriculture and forestry, is to use the minimum weights for agriculture only or maximum weights for forestry only (see Figure 6-13)

Figure 6-13 Comparative result of different weights



Conclusion

Different class assignments, different grade scales, or different weights produce different grade distributions, for both agriculture and forestry. Overall, however, agriculture continues to dominate forestry, although the level of dominance changes. An evenly spaced scale or the minimum, maximum or mean weights improve the fitness index in favour of forestry, which in these cases increases from around 1% of the test area (for the applied values) to between 8-10%. To alter the overall result requires favouring forestry by using the pessimistic assignment for agriculture. Theoretically, an undervaluation of the class assignments for forestry and an overvaluation for agriculture (or vice versa) is possible, but such a consistent bias is unlikely. The different class assignments have a greater effect on the grade distributions and the overall result than the different grade scales and weights, as the different class assignments are the only values capable of making forestry suitable in more cells than agriculture, by using the pessimistic assignment for agriculture and either the applied or optimistic assignment for forestry. However, neither scenario is particularly likely as there is no evidence to that effect and therefore the method appears to be relatively stable overall.

Validation of the method

How well the results of the method represent reality, i.e. whether the method really does identify the fittest areas for forestry, determines the usefulness of the method, and there are many approaches possible to determine this. The most reliable approach would be to test the areas, i.e. plant trees in areas identified as fit and unfit and check whether the resultant tree growth matches the fitness assessment. An obvious drawback to this approach is that it takes several decades to reach a conclusion. Another approach is to undertake spot checks, select a sample of cells and compare their fitness grade to their natural state, i.e. check whether a cell rated as suitable for forestry actually contains a forest. The usefulness of this is somewhat limited, as many historical and social factors have shaped the current landscape, eliminating a direct relationship between the natural potential of a given area and its natural state (Runólfsson, 2003). This lack of a direct relationship is particularly true for forests. The proposed method will *never* predict the historical forest range in Iceland, nor will any other method, because current conditions are different from historical conditions. The maximum historical forest range existed when the country was unpopulated. The approximate overall extent of forested areas before settlement has been ascertained (about 25% of the country) but their exact boundaries are unknown and cannot be determined with any accuracy. As mentioned in the Introduction, land-clearing, grazing and other uses of forests following settlement both reduced the size of forests and impeded their regeneration. The country also experienced a number of cold climate spells. The forest reduction also led to greater erosion, so areas that historically could sustain forests simply may not have the soil for it anymore. Many factors other than just natural factors influenced the historical forest range, which is therefore not a proxy for present potential. Checking whether areas forested today are identified as fit for forestry is still useful, as they should be if the method works. A relatively simple approach is to examine the results to see whether they make any sense based on personal/expert knowledge of the study area, e.g. are areas that are obviously unsuitable for forestry (e.g. glaciers) identified as fit for forestry. A reverse approach is also possible, i.e. getting a forestry expert with personal knowledge of the study area to assess the area and identify the most suitable forestry sites, and see how well this assessment corresponds with the method results. The validation was a combination of two of the validation approaches mentioned above. A check was made to determine whether current forests coincided with sites identified as fit for forestry, and the method results were compared with a direct expert assessment of the entire study area.

Concurrence with current forests

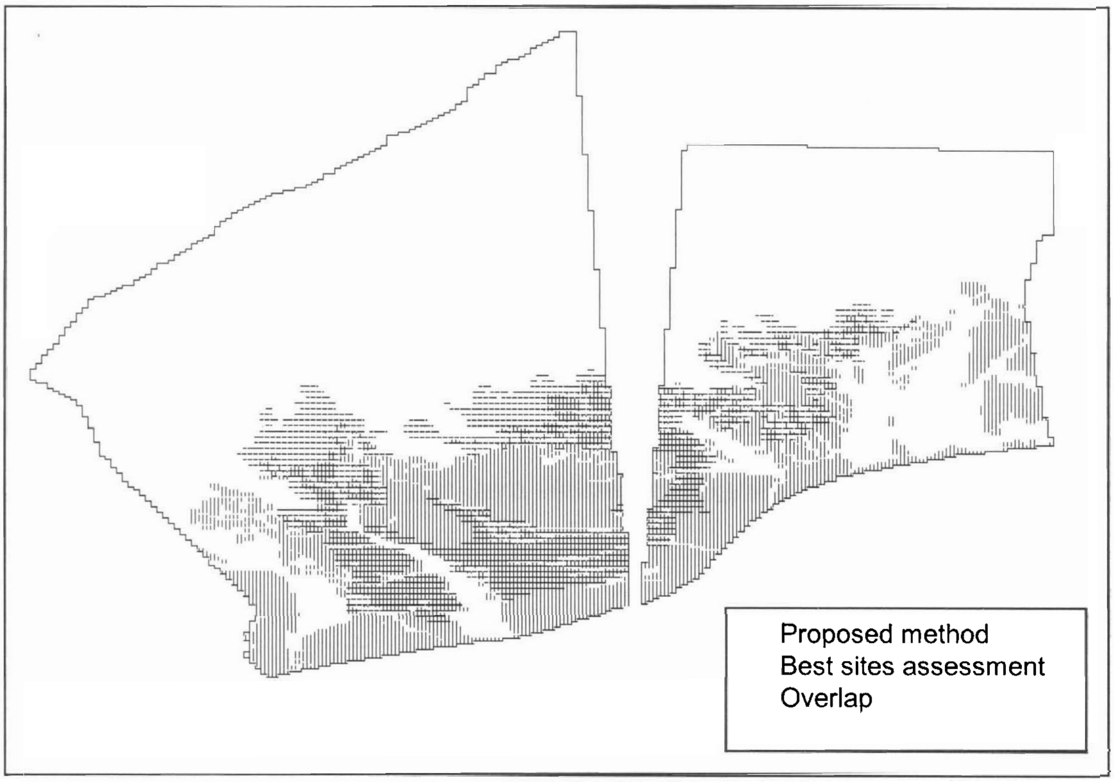
In the study area 57 cells are currently forested and the method excluded 24 of those. This exclusion is not as detrimental to the method's credibility as it might appear initially. In all cases, the exclusion was caused by the rivers and streams category. As previously mentioned (see discussion on hydrological regime in Chapter 5), the rivers and stream category introduces a certain error in areal representation, as rivers and streams may cover a minor part of each cell, with the majority part being dry ground (and thus capable of being forested). The exclusion is thus due to a known bias in the method and in addition, as there is a growing tendency to avoid planting trees too close to water features, this bias need not be all bad. For the remaining cells the grades ranged from just under 20 to around 45, which means that all the cells would fall under the medium or higher grade classes. The method's concurrence with current forests is thus acceptable.

Comparison with direct expert assessment

A forestry consultant, with good knowledge of the study area, assessed the area directly, i.e. identified on a map the 'best' forestry sites. The assessment identified 3363 cells (around 15% of the study area). These 'best sites' were compared with two model scenarios: 1) areas that received a higher grade than 30 (good grade class+) for forestry (i.e. those areas identified as forestry sites by the method), and 2) the areas identified as fit for forestry from the comparison with agriculture.

Cells with grades above 30 for forestry number 5440 (around 24%), which means that compared to the best sites assessment the proposed method 'overestimates' the number of good forestry cells (see Figure 6-14). Most of the 'overestimated' cells (around 93%) fall under two land texture classes: lava fields and sands. Neither class was categorized as excluding in the class assignment (although both received low grades), but lava fields and sands are largely excluded from the best sites assessment. The lava fields included in the best sites assessment are relatively flat and well vegetated, and hence more passable. The lava fields not included the best sites assessment are generally rougher and in places practically impassable for both vehicles and pedestrians. A similar situation applies to the sands. Sands included in the best sites assessment are generally more vegetated than those that were not included. This difference in lava fields and sands does not show up on the base maps used for mapping the land texture information and consequently the method does not differentiate between the different lava fields or sands. The 'overestimation' is thus to some extent due to the limitations of the information available from the base maps.

Figure 6-14 Comparison with best site assessment



The overlap between the proposed method and the best sites assessment is only 1782 cells or 53% of the best sites assessment, which means that the method 'misses' almost half the cells. As mentioned above, a major reason for this is the rivers and streams category, which leads to a certain underestimation of cells by the method, as cells containing rivers or streams are excluded, although large parts of them might be suitable ground. Using the same exclusion on the best sites assessment (i.e. removing cells containing rivers or streams) reduces the number of best sites by about a third, from 3363 cells down to 2336 cells. The number of overlap cells remains the same, meaning that the overlap now accounts for 76.3% of the best sites assessment, with 554 cells 'missed'. Of those 554 cells, 33 fall under the lakes and ponds category, and should therefore be excluded. The remaining 521 cells have grades ranging from just below 30 (e.g. 29.92) down to around 10 (medium grade class+). The proposed method thus does not identify those cells as good, like the best sites assessment does, however, the method identifies them as viable forestry sites, so the 'miss' is not complete.

Comparing the 136 cells deemed better for forestry than agriculture with the best sites resulted in an overlap of only 8 cells, or 5.9% of the forestry cells. As was the case for the good forestry cells, most of the remaining cells fall under the lava fields and sands categories, or 89% in this case.

Direct comparison of the best sites assessment and the proposed method results yields only average results. A closer examination of the comparison results shows that in most cases there are some reasons why the best sites assessment and the method results do not overlap more than they do, e.g. a bias due to the hydrological regime category. Overall, the comparison demonstrates that some improvements are required for the method, but there is sufficient overlap to indicate that the method has its merits.

Chapter 7
Discussion

The application of the proposed method was a continuous learning process, as the application was primarily intended to be a trial run of the method. Inevitably, some problems surfaced, a few unforeseen and a few to some extent expected. For the duration of the project the various participants gave several valuable observations and comments. All of the problems that arose, the observations received, and the actual tasks performed during the application of the method provided useful lessons for potential further developments. Following is a discussion of the main issues that arose during the application of the method.

Number of experts

Iceland is a country with a comparatively small population and therefore the number of people in any given field of work is comparatively small. Consequently, the number of suitable participants for the project was somewhat limited; there simply are not that many people with a sufficiently comprehensive knowledge of each land-use and not all of those people may be willing or able to participate in such a project, although there was only one outright refusal. The initial stages of the project demonstrated that this could particularly be a problem for relatively new land-uses, such as tourism (academic research of tourism is a rather novel discipline in Iceland), as well as for land-uses that are comparatively small in scale, such as forestry. For relatively long-established disciplines, such as agriculture, this was less of a problem.

The small number of available experts is admittedly an inherent weakness of the method, as it somewhat undermines the reliability of both the grade class assignments and the weight estimates, because both will inevitably be based on a limited number of expert opinions, giving each expert a comparatively greater weight, i.e. one, two or a few 'deviants' can 'bias' the assignments. This weakness is not, however, exclusive to the proposed method. The limited number of available experts will pose difficulties for almost any potential land-use assessment method employed in Iceland. Because many direct relationships between inputs and outputs (e.g. X type of soil produces Y amount of trees, which constitute Z fitness for forestry) simply are not known in Iceland, almost all assessment methods rely on expert judgment to some extent, be it for ranking different land-use options or variables, determining limitations, or directly assessing land units or natural attributes.

Novelty of approach

The most frequent comments from participants pertained to the proposed method itself; many of the participants found the process of assigning grades and weights initially somewhat daunting. The most common reason for their hesitancy was that the participants had never thought about the various natural factors in this way before, i.e. for many participants the method represented a completely new approach. In particular, many participants were more accustomed to considering the different natural factors in a general qualitative combination, rather than considering the individual effect of single factors quantitatively. This was particularly the case for elevation and temperature, between which there is a considerable known correlation, but also to some extent for temperature and precipitation, which appear to be frequently considered jointly with winds as 'weather'.

Specific land-use requirements

Several participants found some of the natural factor classes somewhat irrelevant to their land-use, and missed more relevant classes, e.g. a landscape class characterizing the bottom of slopes (hills/mountains), which is an important feature for forestry. Further developments of the proposed method should take all comments into account, but bear in mind that the classes for each factor apply to all land-uses under consideration, i.e. each factor must have the same classes for all the land-uses, which the factor is relevant for. The classes' design has to have some relevance to many land-uses, rather than be tailor-made to any single land-use, and too much specification for one land-use might make a class less relevant for another land-use. As the classification is intended for all possible land-uses, it is almost given that the classification will not fit any of them perfectly.

Knowledge of natural factors

During the project, it became clear that individual participants were more familiar with some natural factors than others. This was particularly the case with soil type and permeability, but some of the participants appeared to have limited knowledge of the properties of the different soil types and relied more on the labels of the permeability classes (very impermeable to very permeable) rather than the actual permeability values (in m/s) behind them. As far as the soil type is concerned this can be explained by the fact that soil science is a relatively young academic discipline in Iceland. Classification and other research of Icelandic soils is still ongoing, and consequently more in the domain of soil scientists, rather than part of the general knowledge of natural resource managers. A similar situation applies to permeability, which has not received much attention outside the circle of people researching it, probably because it has so far only been employed for very specific uses, such as hydrological modelling. In both cases, the fact that neither factor is particularly visible (i.e. applies to essentially subterranean properties) probably plays a part. Discussions with some of the participants also left the impression that they might have a tendency to 'undervalue' less familiar factors by giving them relatively low weights, which may introduce a certain bias, as some factors can thus get lower weights than they should have, i.e. the weighting might not accurately reflect the factor's actual importance. On the other hand, it could be argued that it is preferable that the participants do not assign great weight to those factors they are less familiar with and thus less sure of the impact of.

Data entering

Manually entering the natural data into the data table was more time consuming than expected. This was partially due to a lack of experience with handling large amounts of data and partially due to the nature of the original information, which was available only in a variety of scales and projections. Nevertheless, manual entering is still a feasible option for the proposed method, as the size of the study area is at the upper limit of regional plans in Iceland. Most potential future uses of the method would thus apply to smaller areas, involving less data and consequently less time. More automated measures, such as a geographical information system (GIS), could also possibly reduce the time required, although the different scales and projections of the original information could then pose certain difficulties. In addition, the costs of establishing a GIS to manage the natural attribute data on a large scale can be considerable.

Base data

The data is somewhat patchy for some of the natural factor categories, i.e. maps showing the specific categories for a given area are not always available. In some instances, combining information from more than one source (as was the case for vegetation) can solve this, particularly when employing broad natural factor categories, requiring less specific information, as is the case here. In other instances, there are gaps in the data, either because a certain natural factor has not been researched fully or because the research has not been applied to the entire study area (e.g. the lack of meteorological stations in the highland part of Skaftárhreppur). Expert knowledge of the area or extrapolation of the existing data can complement deficiencies. The scale employed matters in this context, however. At a broad scale such an approach may be adequate, but for larger scales (smaller areal units), where more precise information is required, the availability of suitable data can become a problem. One specific data problem is changing base data, exemplified by the fluctuation in classification of soils, which is due to the relative novelty of systematic soil research in Iceland. The proposed method can only provide as good an indication of potential land-use sites as the base data allow and changes in available base data might require changes in the natural factor definitions employed in the method. The main issue for the method, as far as data is concerned, is that improvements in data quality and availability are bound to improve the results of the method.

Grade assignment

There is no one 'right' or universally accepted format for assigning grades for the fitness of a land for a given land-use. The choice of the McHarg method, with its inherent assumption of additive grades, will be questioned by some, who might argue that it is more reasonable to focus on the limitations for each land-use, i.e. use the lowest grade for each factor as the total grade of a cell. The lowest grade approach does have some advantages. It is very simple in execution, because it eliminates the consideration of weights and all further calculations, as only the identification of the lowest assigned grade for each cell is required. The lowest grade approach also minimizes the possibility of several low grades adding together to make a good grade. It does, however, have some disadvantages as well. The lowest grade approach inherently focuses on limitations, which can be discouraging to potential users of a given tract of land, and this was one argument in favour of an additive grade approach, as it emphasizes the positive potential more. The grade scale used can also reduce the chance that several low grades add up to a good total grade, by emphasizing the difference between grade classes, such that a few high factor grades are essential to obtain a good overall grade. The number and choice of factors also influence the lowest grade approach much more, i.e. ten factors might have one factor with a low grade (poor factor) and thus yield a total low grade, whereas the use of five factors, which happened not to include the poor factor, would yield a higher total grade. In addition, it is debatable whether a low grade for one factor really means that the potential for a given land-use is low, i.e. does one low factor effectively overrule or negate nine (possibly) high factors? The argument can be made that as long as there is some land-use potential (i.e. a factor does not make a given land-use impossible), many good (positive) factors should count in the overall grade. In most cases the poor factor does not affect the potential of the other factors, and the good factors can to some extent compensate for the poor factor. Additive grading allows for that while a lowest grade approach does not. A lowest grade approach implicitly assumes that one low grade factor effectively nullifies all the others, which is not necessarily the case unless the factor is excluding (makes the land-use impossible), an option that is included in the proposed method. In addition, the elimination of weights is not necessarily a goal in itself. Although the solicitation of weights has certain philosophical and methodological issues, it is nevertheless important to consider the relative importance of different natural variables for each land-use. The fact that not all factors are equally important for different land-uses is generally acknowledged and therefore the importance of weighing the relative value of natural variables for each land-use is a recognized principle.

Recommendations

Based on the experience gained from the test application of the proposed method some modifications of the method are suggested and some further developments recommended.

Participants

The small number of experts in each field will always limit the number of available experts. Nonetheless, further attempts should be made to seek more participants, in order to increase the reliability of both the grade class assignment and the weight estimation. Some of the participants were hesitant to participate at first, as they were not entirely certain of the merits of the method, as land-use assessment has hardly been employed in Iceland and the method thus represents a novel approach. The application of the method described in this paper has yielded testable results, which will hopefully make people more willing to participate in the future. In addition, some people will probably be more willing to participate if people or agencies in an official or semi-official position undertake the method, i.e. it is not a project by a student. It could also possibly help to emphasize that all participants are given a choice on how they would like to be referred to (by name, as a representative of their organization, where the organization is named, or as a respondent) and thus need not have their name publicly linked to the application of the method, which is a concern in as relatively small a community as the land-use expert community in Iceland. On the other hand, allowing the experts to remain anonymous does, in some respect, undermine the method as the credibility of the results largely hinges on knowing that the experts actually *are* experts. In as small an expert community as in Iceland, however, the option of anonymity appears to be a necessary evil as some experts might not be willing to participate otherwise.

Natural factor classes

Some of the natural factor classes were less precise than desired, i.e. potentially confusing, or less useful than desired, due to a lack of experience with them (e.g. permeability). Future applications thus require some changes to clarify matters. Firstly, the land texture factor needs two changes. The *urð og grjót* (rock and debris) class should be renamed *grýtt land* (rocky ground) and the *þykkur jarðvegur* (thick soil) class should be renamed *gróið land* (vegetated ground), as it describes better the surface image of the ground and thus the phenomena that the class is mapped by. Secondly, the *ár og lækir* (rivers and streams) class needs modification, to ameliorate the bias it currently introduces. A potential way of doing so is to divide the class into two classes. The first class would be *ár og lækir – þekja* (rivers and streams – cover), applying to cells that do have rivers or streams covering more than 50% of a cell, either in a single (very wide) channel, or with many channels (e.g. a braided river). The second class would be *ár og lækir – tilvist* (rivers and streams – occurrence), denoting cells that contain rivers or streams, but where the rivers and streams are only a small part of the cell area. Thirdly, the permeability class could be 're-scaled' to make it more comprehensible, as the small values resulting from the m/s scale appear to be difficult for people to comprehend. A relatively simple conversion would be to m/day, which would translate the values into the millimetre to metre range, which most people are more familiar with. The permeability classes could also consist of other, perhaps more comprehensible, values. For example, a typical velocity of the groundwater (*V*) for each permeability class could be calculated, by using Darcy's Law:

$$V = k \cdot i$$

where *k* is the coefficient for hydraulic conductivity (i.e. the permeability) and *i* is a pressure gradient (Plummer and McGeary, 1996). By using a typical value of the active porosity (the percentage of a rock's volume that is openings, capable of holding and carrying water) and the typical velocity, a real velocity for each permeability class can be calculated, i.e. the approximate amount of water that flows through the rock for a given period of time (e.g. m/day or cm/day). Each permeability class can also contain a typical infiltration rate (the percentage of precipitation that percolates down to the groundwater). Both the real velocity and the infiltration rate could be tested, along with the permeability, to determine whether people found them more comprehensible to use. The real velocity and the infiltration rate would, however, only be typical values, and thus ignore any temporal or areal variation in the actual values (whereas the permeability itself is an actual value). Fourthly, little can be done about the difficulty some participants had with the soil type factor, as it cannot be re-scaled, re-classified or re-calculated. The best option is perhaps to provide each participant with some information on the different soil types and their properties, at least until soil science becomes a more established discipline in Iceland and the different soil types generally better known.

Natural factors

Reducing the number of natural factors would be a good idea for several reasons. First, fewer factors would likely be easier for the participants to deal with. Second, fewer factors allow for a greater range of weight values, i.e. assigning a 100% weight among fewer factors allows for potentially greater distinction between the factors. Third, the correlation between certain factors indicates that some factors could possibly be eliminated. This applies particularly to elevation and temperature, which are highly correlated. Temperature is one of the most important natural factors in Iceland, especially for forestry, where temperature is the major limiting factor, and a case can thus be made for dropping the elevation factor. A drawback to this, though, is the fact that temperature data are less accurate, particularly for the interior (highland) part of the country, where the lack of meteorological stations necessitates more data manipulation. In addition, many people within the land-use sectors, particularly agriculture, are quite used to employing elevation in their own semi-empirical land assessment because elevation is visible and accurate elevation maps are more available than temperature maps. As temperature also has a known relationship with elevation, a case can also be made for eliminating the temperature factor. Temperature is, however, also dependent upon other factors than elevation, such as distance from the ocean. The base temperature is also different between different parts of Iceland, i.e. the 0-200 m range does not have the same average summer temperature for all parts of the country, and elevation is thus not a full proxy for temperature. Temperature and elevation are thus not fully interchangeable and vary in importance for different land-uses so there are advantages and drawbacks to eliminating either of them. Similar concerns apply to other highly correlated factors, they are not fully interchangeable.

Later applications of the method can potentially drop natural factors that consistently receive a low weight, keeping in mind that factors might obtain higher weights in other parts of the country, or for other land-uses. Repeated tests of the method would provide insights if these concerns matter. A factor getting a low weight for all parts of the country and all land-uses can clearly be dropped. If a factor has a consistently low weight for one land-use, but not others, then the factor can potentially be dropped for that one land-use and retained for the others, i.e. assigned a built-in 0% weight for the one land-use. This initial run of the method suggests hydrological regime, exposition and landscape as potential dropouts. In addition to the relatively low weight, the hydrological regime factor also proved a little bit problematic for the participants, as many of them were not very familiar with the permeability aspect of it, which could have led to its low weight. A simplification for future applications could be to eliminate the permeability aspect, particularly as permeability is indirectly reflected in other factors, such as vegetation, soil type and soil cover. The landscape factor could include the water features aspect (rivers, lakes etc.). However, no decisions should be made until the method has been tested for land-uses besides agriculture and forestry, as permeability may be important for other extensive land-uses (e.g. water conservation). The same caution applies to exposition, landscape, and indeed any other natural factor; they should not be dropped until they have been tested for multiple land-uses. The relatively low weights for exposition might in part stem from its presentation, but some participants apparently found the detailed specification of slope orientation and angle (intended to clarify) somewhat confusing. Removing these technical descriptions from the forms used and employing the class names only (i.e. very shady, shady, medium etc.) might ameliorate the confusion. The detailed information could still be available for those participants that wished to view it.

Grade form

This is a minor point, but on the grade form (see Appendix 5) the excluded class should be moved to the left of the very bad class, such that the order of classes is: excluded, very bad, bad, medium, good, and very good. It is a more logical position for it, as it essentially represents a grade 'below' the very bad grade.

Cell location

As mentioned already in Chapter 6, some of the suitable forestry sites identified were scattered single cells, which obviously reduces their usefulness. Future applications of the proposed method should include some method of considering the location of cells, i.e. the properties of surrounding cells. The simplest approach would be to review the map with this in mind. Isolated cells deemed good for a given land-use (good cells) could then be re-evaluated in some way, either by excluding them from further consideration or applying some form of a 'reduction-grade' to them. Although an argument could be made that an isolated good cell surrounded by poor cells is not going to be a good place for the given land-use, the fact remains that it could still be possible to sustain the land-use there, especially as the size of the cells (0.25 km^2) is such that they still represent a feasible site (in Iceland at least) for some land-uses (e.g. forestry). Excluding the cells is thus too drastic a decision and it seems more reasonable to apply a reduction-grade. The reduction could be by multiplication with a single fixed reduction factor (value <1) or by using some threshold values based on the number of adjoining good cells, such that single cells get a great reduction, clusters of a few cells get a smaller reduction and numerous adjoining good cells get little or no reduction. More complicated methods to consider cell location are of course possible, particularly if a geographical information system is employed, but such systems can facilitate the input, processing, display and output of spatial data (Theocharopoulos et al, 1995). Whatever means of considering cell location is chosen, the choice must be based on solid arguments and with input from experts in each land-use, as different land-uses may have different requirements in this respect. An isolated site might have a limited effect on one land-use, but be a major consideration for another.

Weight solicitation

Participants assigned weights directly in this project. Such a direct assessment is simple, requiring no special knowledge from either the interviewer or the participant (the person providing the assessment). Such a simple method of weight derivation has, however, some drawbacks. Assessments can become more complicated when many factors are involved (there are limits on how many factors people can consider simultaneously), which can limit the number of variables possible to use. In addition, direct estimation does not allow for consistency checks of the weight values or some evaluation of the reliability of the assessments, as some more sophisticated methods do. A drawback of more sophisticated approaches is that they are more complicated for respondents and may be less transparent. Nevertheless, future applications of the proposed method should test more sophisticated estimation methods.

Other types of fitness

The proposed method only values natural fitness. Even if a certain site emerges with a high natural fitness for a certain land-use, another land-use could still be assigned to it, based on other factors under consideration (e.g. the relative size of potential areas for each land-use), economic considerations (one land-use yields more profits than another) or simply on political preferences for a given land-use. In the end, the choice between different land-uses always remains a managerial or political decision. Considering economic and social fitness could extend the usefulness of the method. In addition, managerial action can influence the natural fitness, i.e. the method only evaluates current fitness, not fitness potential. Enough time, funds and other inputs such as fertilizer, can turn sands into grassland, grassland into forests, divert rivers or eliminate sheep grazing. All of these actions, along with a multitude of others, could make sites currently ill fitted for a given land-use more fit in the future, and therefore future applications of the method should include the concept of economic fitness. Further developments should also include a consideration of fitness potential, not just current fitness. Finally, the method also needs to be broadened to include other land-uses besides agriculture and forestry to be of really good and comprehensive use in the future.

Conclusions

This initial examination of the proposed method suggests that the method, when fully developed, has the potential to identify and evaluate possible sites for a given land-use, or at least the two land-uses considered so far. As there is no universally accepted method of land-use assessment, aspects of the method are of course open for debate. Certain modifications are required and the method admittedly has drawbacks.

The basic structure of the method (additive scoring with weighted variables) will raise questions, although it is supported by solid arguments. Admittedly, additive scoring has the potential of allowing low scores to add up to a decent score, which can yield misleading results, but a grade scale and a weighting procedure can reduce this potential (for a weighted average, many low scores are bound to lead to a lower overall score). In addition, some more fundamental concerns exist concerning the grade assessment and weight derivation of the method. These issues are the same, however, for any assessment method used. Fitness of land for a given land-use is fundamentally a human concept, not a natural entity, and thus has no direct measure, like e.g. soil depth or temperature. Any land-use assessment method will always have some issues in this regard as all methods involve some human (expert) valuation or opinion and where there are opinions, there are bound to be differences of opinion.

Specific aspects of the method are also debatable. The small number of available experts in Iceland is an inherent weakness of the method, as it somewhat undermines the reliability of the assessments. However, evaluation by experts is a more fundamental problem for land evaluation in general and therefore poses challenges for other assessment methods as well. The types of variables selected vary from assessment to assessment and also provides room for debate. In this case, participants indicated that the variables chosen did cover the most important aspects and there were no major omissions. Participants were also less familiar with some variables than others (e.g. permeability), which can undermine the reliability of the assessment of those variables. The concern about lack of familiarity is easily rectifiable in later applications, either by re-defining the variables or simply dropping them. The method only considers natural fitness, i.e. it does not address the economic, social and political aspects of land-use, which must also be considered during actual land-use decisions, neither does the method consider potential fitness, but it was also not the intent to do so in this initial examination of the method.

In addition, limiting factors, such as natural hazards (which are a major concern in the study area) also influence land-use decisions. The exact timing, extent, or probability of natural hazards are, unfortunately, difficult to predict accurately, as previous occurrences at best provide indications of potential effects. Given their inherent uncertainty, it was beyond the scope of this test application to include natural hazards in the test.

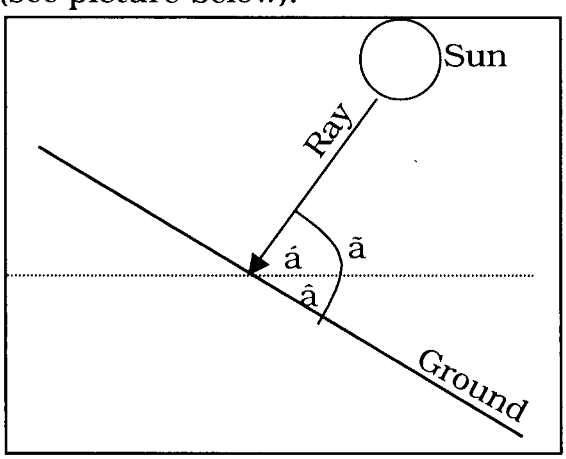
Even if the results of the proposed method are not perfect, the application of the method (and indeed most land-use assessment methods) yields definite benefits. First, the method compiles relevant natural information systematically and in one place. An overview of the natural conditions of a given area thus no longer requires consulting many different agencies, which saves both time and effort. Second, the application of the method also provides an overview of the availability of natural data and their quality, and can thus highlight gaps and further data collection and research needs. Third, going through the process induces people from different land-use sectors to consider different land-use options together, rather than just focus on 'their' land-use. The process thus encourages participants to adopt a broader point of view and can hopefully lead to more understanding and less friction between members of different land-use sectors. In addition, land-use assessment can provide a more objective assessment of the extent of land available for different land-uses and can potentially demonstrate that it is possible to find sites for most, if not all, prospective land-uses. Assigning a given land-use to a site for which it is much fitter for than another land-use clearly makes sense.

The proposed method delivered results of sufficient quality to merit further tests. It certainly meets the objectives defined at the beginning of this project, to design a method that is relatively quick to develop and easy to apply. Admittedly, some improvements are required. Where the data is adequate, the method (with modifications) can be useful for assessing the comparative fitness of a given area of land for different land-uses and can thus facilitate decision-making. It must be born in mind, however, that the method only values natural fitness, so it needs expanding with measures of economic and social fitness to be of even greater use. Incorporating economic and social factors, in a comparable format, should therefore be the next major step when developing the method further. Further developments should also consider additional land-uses, as this initial examination only includes agriculture and forestry, and obviously sites that are naturally poorly suited to either may be highly fit for other possible land-uses (e.g. industry, tourism, or conservation). Adjusting the method for different scales, e.g. the municipal plan scale, is also an important possible further development, as it could be useful for planning purposes to have a consistent assessment method (i.e. similarly structured) for all levels of planning. In addition, further consideration of limits to land-use, e.g. natural hazards, are needed, although it can be difficult to include this with any accuracy in the method.

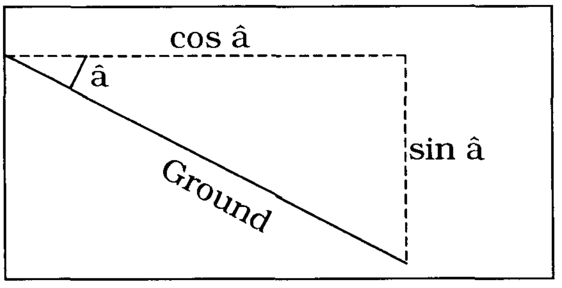
Even when fully developed, the method will only be one aid for making land-use decisions, not be *the* basis for making those decisions, as land-use decisions involve a multitude of factors not easily categorized or quantified and thus incorporated into a more complete land-use assessment method. The method can help to provide one comparatively objective basis for decision-making, which would otherwise not be available, and can therefore potentially offset the risks associated with subjective, changeable and arbitrary decisions. The method can therefore facilitate decision-making, but it only provides a piece of the overall picture. Finally, it should be reiterated that land evaluation methods have so far hardly been used in Iceland and the method thus represents only the initial steps towards a more comprehensive basis for planning in Iceland and should be judged as such. The proposed method is not the only or necessarily the best assessment method possible for Iceland, it is merely one possible land-evaluation tool which appears to have its merits.

Appendix 1
Exposition

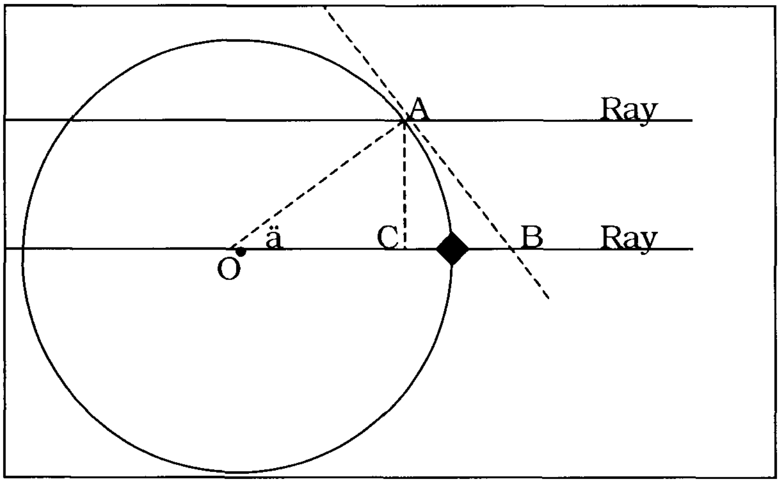
Accurate determination of sun exposition includes consideration of radiation angles, atmospheric conditions and surface conditions (Ahrens, 1994). Such calculations are clearly beyond the scope of this project but simpler approaches suitable to the project were not found and therefore an approach, based on relatively simple trigonometry and information on sunshine in Iceland, was devised. The sunshine information comes from two Icelandic almanacs (Fiskifélag Íslands, 2000; Halldórsson, 2000) and the mathematical information is from Gellert et al (1967). The development of the exposition classes described here includes numerous simplifications and assumptions. To start with, sunshine is visualized as a bundle of rays hitting the ground. The rays radiate from the sun under a certain angle over the horizon, defined as the sun altitude angle (á), and hit the ground, which can be sloping. The slope angle (â) is the inclination of the ground towards the sun. The angle that the rays hit the ground under, the sun radiation angle (ã), is thus a composite of á and â (see picture below).



The inclining ground (the slope plane) can be divided into a horizontal and vertical component, perpendicular to one another. The horizontal component of the plane corresponds to *cos* â and the vertical component of the plane to *sin* â (see picture below).



The sunrays hit these two planes under the sun altitude angle (á). Since the sun altitude angle is not always perpendicular to these planes, the sunshine on the horizontal plane is *sin* á and on the vertical plane likewise *sin* (90- á) = *cos* á. The sunshine on the horizontal plane is the same for all planes (all slopes) for the same sun altitude, irrespective of the orientation of the plane. However, the sunshine on the vertical plane changes according to its orientation, with less sunshine the further away the plane is from being straight towards the sunrays. The difference between the orientation of the slope angle and the direction of the sunrays is the angle ä in the picture below.



The circle represents the orientation of the slope relative to the sunrays (only the vertical component is considered). At the diamond the slope is perpendicular to the sunrays and therefore ä=0. The angle ä affects the sunshine on the slope plane as follows. For a given level of sunshine (equal to the distance between the two sunrays in the picture above) a slope plane perpendicular to the sunrays receives sunshine corresponding to the line AC (between points A and C). The tangent at point A demonstrates the orientation of a slope plane deviating at angle ä from being perpendicular to the sunrays. This slope plane receives less sunshine (for a given level of sunshine) than a perpendicular slope plane, because the same level of sunshine is spread over a larger plane, the line AB (between points A and B). The sunshine for the deviating slope plane is the ratio between AC and AB, which is also the cosine of the angle CAB. A triangle has angles equalling 180°. Consequently, the OBA angle (at point B) equals 180-BOA (which is ä)-OAB (which by the definition of a tangent must be 90°), so OBA becomes 180- ä –90= 90- ä. Likewise, the CAB angle equals 180-BCA (which is 90°)-CBA (which is the same angle as OBA), so CAB becomes 180-90-(90- ä)= ä. Consequently, the sunshine on the vertical component is correlated to *cos* ä.

The sunshine for the total plane is the sum of the sunshine on the horizontal and vertical components. This sunshine formula is:

sin á * *cos* â + *cos* á * *sin* â * *cos* ä;

where *sin* á is the sunshine on the horizontal component of the plane, *cos* â is the horizontal component of the plane, cos á is the sunshine on the vertical component of the plane, *sin* â is the vertical component of the plane, and *cos* ä is an adjustment for the orientation of the slope. This formula can be simplified for those extreme instances when the slope plane faces the sun directly or is inclined directly away from the sun. In the first instance, ä=0° and thus *cos* ä =1, which simplifies to:

sin á * *cos* â + *cos* á * *sin* â = *sin* (á + â)

In the second instance ä=180° and thus *cos* ä =-1, which simplifies the formula to:

á * *cos* â - *cos* á * *sin* â = *sin* (á – â)

A sun radiation index is defined as *sin* ã. The sun radiation angle (ã) has a range of values from 0° to 90°. Consequently, the radiation index has a range of values from 0 to 1. This index range is classified by choosing the values of 0.1, 0.3 and 1.0 (to reflect little, medium and great sun radiation). The boundaries between the classes are then geometrically derived, so that the boundary between the little and medium radiation are the square root of the multiple of 0.1 x 0.3. The result is 0.17, which corresponds to *sin* 10°. The same calculation for the medium and great radiation yields an angle of 33°, which is rounded up to 35°. For the summer months of June to August (the months most important for vegetation growth) there is on average daylight for 18 hours of the day, with the sun altitude angle ranging from 0° to an average maximum of about 45° for those 18 hours. For a fixed sun radiation angle (e.g. 10° or 35°) â is a function of á. When the sun is just rising or setting, the sun altitude angle is 0, so ã= â+*0*, which simplifies to ã= â and the slope angle between the different classes becomes 10° and 35°. For all times between sunrise and sunset the sun altitude angle varies over the day and consequently, it is impossible to denote a specific slope angle (â), which gives the same sun radiation angle (as â =*f*(á*)*, for a fixed ã). To complicate matters further, this relationship technically only holds for ground directly facing the sun. Land leaning at any angle away from the orientation of the sunshine (e.g. northerly and westerly slopes when the sun shines from an easterly direction) only receives a fraction of the sun radiation. In addition, the length of time that the sun shines on a given piece of land varies with the slope orientation, with southerly facing slopes generally receiving sunshine longer than northerly facing slopes. To be able to use slope angles to denote classes, á=*0* is used as a reference and thus ã = â and the slope angle boundaries become 10° and 35°. The different sun altitude angle for different orientations is considered by using the orientation of the slope.

The sunshine for a given slope (â) and given slope orientation is calculated using the sunshine formula. This calculation is made for different times of the day, as the sun altitude angle (á) varies from sunrise to sunset. These calculations include a number of simplifications in order to make the calculations less extensive. Firstly, to limit the number (and thus the complexity) of calculations the day is divided into 3-hour (3 am, 6 am, 9 am, etc.) intervals and the average (over the three summer months) sun altitude angle at each interval is found, giving á=0° at 3 am, á=22° at 6 am, á=39° at 9 am, etc. Secondly, the average of *sin* â for each slope class is determined and the corresponding â value used as the slope class average (5° for the 0-10° class, 22° for the 10-35° class, and 51° for the >35° class). Thirdly, the calculations are made only for the major slope orientations (north, northeast, east, southeast, south, southwest, west, northwest). The calculations consisted of filling in the following table and then summing the values for each slope class and orientation over the day to derive the composite values.

	N			NE			Etc.
	0-10°	10-35°	>35°	0-10°	10-35°	>35°	
3:00 AM							
6:00 AM							
9:00 AM							
Etc.							

Based on these composite values, the slope classes and the four major orientations (north, south, east, west) were assigned to the exposition classes (very shady, shady, medium, sunny, very sunny).

Appendix 2
Maps

All the base maps used are in a scale of 1:50,000 and prepared and published by the Defense Mapping Agency Hydrographic/Topographic Center, Washington D.C. in cooperation with Landmælingar Íslands (National Land Survey of Iceland). The maps used are:

1911 I Mýrnatangi

1911 IV Kötlutangi

1912 I Geirlandshraun

1912 II Eldhraun

1912 III Höfðabrekkujökull

1912 IV Hábarmur

1913 I Tungnaárjökull

1913 II Lakagígar

1913 III Snjóalda

2012 I Skeiðarársandur

2012 III Mávabót

2012 IV Brunahraun

2013 II Skeiðarárjökull

2013 III Síðujökull

Maps in a scale of 1:100,000 are used to supplement the information contained on the base maps. These maps are all published by Landmælingar Íslands. The maps are:

Blað 67 Langisjór

Blað 68 Skaftártunga

Blað 69 Hjörleifshöfði

Blað 77 Lómagnúpur

Blað 78 Kirkjubæjarklaustur

In addition, a geological map of the southern part of Iceland is also used for supplementary information. The map is in a scale of 1:250,000 and is published by Náttúrufræðistofnun and Landmælingar Íslands. The map is:

Sheet 6 Miðsuðurland

Appendix 3
Temperature

The conversion of the temperature information into a temperature map involved a number of steps. First, the average summer temperature for each of the meteorological stations was calculated from the monthly averages. Second, this average was then converted to temperature at sea-level, using the elevation of the meteorological stations and the general relationship between elevation and temperature, i.e. that temperature drops by 0.6°C for every 100 m increase in elevation during summer (Einarsson, 1976). Third, lines were drawn between the three stations (forming a triangle). Then the temperature difference and the distance between the stations were calculated and a base temperature gradient marked on each line between the stations, giving isolines within the triangle. These lines were then extended directly, considering the coastline, to the borders of the area. All the meteorological stations are located in the southern, lower elevation part of the area and consequently there is no information on which to base the isolines in the northern part of the area. Therefore, the same base temperature was assigned to the entire area beyond the most northern isoline. Fourth, in Iceland temperature increases generally by 2.5°C for every 100 km inland during summer (Einarsson, 1976). This relationship was used to calculate and draw isolines of 0.1°C increase in temperature on the base map. This information was then used with the base temperature to calculate the base sea-level temperature for each cell (i.e. base temperature + increase inland = base sea-level temperature). Fifth, the average elevation of each cell was estimated from the base maps, mostly to the nearest 20 m, but to the nearest 10 m where there were 10 m contour intervals on the map. This information was then used to calculate the change in temperature attributable to elevation, using the general relationship between elevation and temperature already mentioned. This information was then used to calculate the normal temperature for each cell (i.e. base sea-level temperature – elevation change = normal temperature).

Appendix 4
List of participants

Note: many participants requested anonymity and are thus only listed as a respondent.

Arnór Snorrason, Rannsóknarstöð skógræktar (Iceland Forest Research)

Björn B. Jónsson, Suðurlandsskógar

Borgþór Magnússon, Náttúrufræðistofnun Íslands

Jón Helgason, former Minister of Agriculture, former president of Búnaðarfélag Íslands (The Icelandic Agriculture Society*)

Ólafur R. Dýrmundsson, Bændasamtök Íslands

Sólrún Ólafsdóttir, farmer, Kirkjubæjarklaustri II

Respondent, Búnaðarsamband Suðurlands

Respondent

Respondent

Respondent

Respondent

Respondent

Respondent

Respondent

Respondent

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* Direct translation, as no official translation was found

Appendix 5

Grade form

	Very bad	Bad	Medium	Good	Very good	Excluding
levation (above sea level)						
0-200 m						
200-400 m						
400-700 m						
700-1000 m						
> 1000 m						
andscape						
Mountains and ridges						
Canyons and gullies						
Hills and hummocks						
Plains						
Glaciers						
and texture						
Rocks and debris						
Lava fields						
Gravel plains						
Sands						
Thick soil						
emperatue						
0-3°C						
3-6°C						
6-8°C						
8-10°C						
10-12°						
recipitation						
0-600 mm						
600-1200 mm						
1200-2000 mm						
>2000 mm						
ight exposition						
Very shady (N 0-10°)						
Shady (A/V 0-10°, N 10-35°)						
Medium (S 0-10°, A/V 10-35°, N > 35°)						
Sunny (S 10-35°, A/V > 35°)						
Very sunny (S > 35°)						

Hydrological regime						
Bedrock permeability						
Very impermeable ($10^{-8} - 10^{-5}$ m/s)						
Rather impermeable ($10^{-6} - 10^{-3}$ m/s)						
Permeable ($10^{-4} - 10^{-1}$ m/s)						
Very permeable ($>10^{-3}$ m/s)						
Rivers and streams						
Lakes and ponds						
Soil						
Soil type						
Brown andosol						
Organic andosol/histosol						
Vitric/gravelly andosol-regosol						
Leptosol						
Sandy andosol						
Leptosol/sandy andosol complex						
Soil cover (soil erosion)						
No erosion						
Little erosion						
Slight erosion						
Considerable erosion						
Severe erosion						
Very severe erosion						
Vegetation						
Forest						
Wetland vegetation						
Grasslands						
Moss and shrub heath						
Marginal vegetation						

Note that the actual form handed out to the participants was in Icelandic.

Appendix 6
Weight form

THE WEIGHT OF DIFFERENT NATURAL FACTORS

Please assign weight to the following natural factors based on their importance for a given land use (see below) in Skaftárhreppur.
Please assign the weight in increments of 5% (5%, 10%, 15% etc.), if any natural factor is thought to weigh less than 5%, assign it 0%.

Please make sure that the sum of the weights is 100%.

	Weight (%)
Elevation (above sea level)	______
Landscape	______
Land texture	______
Temperature	______
Precipitation	______
Light exposition	______
Hydrological regime	______
Soil type	______
Soil coverage (soil erosion)	______
Vegetation	______
Sum:	______ % (100%?)

Note that the actual form handed out to the participants was in Icelandic.

Appendix 7
Ethics approval

SIMON FRASER UNIVERSITY

OFFICE OF RESEARCH ETHICS

BURNABY, BRITISH COLUMBIA
CANADA V5A 1S6
Telephone: 604-291-3447
FAX: 604-268-6785

May 1, 2003

Ms. Ragnihildur Freysteinsdottir
Graduate Student
Resource and Environmental Management
Simon Fraser University

Dear Ms. Freysteinsdottir:

Re: Identification of Areas for Forestry at the regional planning Level in Iceland

The above-titled ethics application has been granted approval by the Simon Fraser Research Ethics Board, at its meeting on April 28, 2003 in accordance with Policy R 20.01, "Ethics Review of Research Involving Human Subjects".

Sincerely,

Dr. Hal Weinberg, Director
Office of Research Ethics

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