SOIL EROSION IN ICELAND

Olafur Arnalds, Elin Fjola Þorarinsdottir, Sigmar Metusalemsson, Asgeir Jonsson, Einar Gretarsson og Arnor Arnason

Soil Conservation Service
Agricultural Research Institute
February 2001

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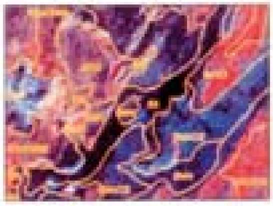

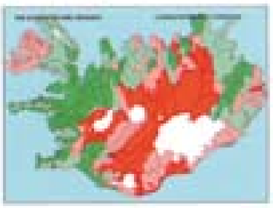

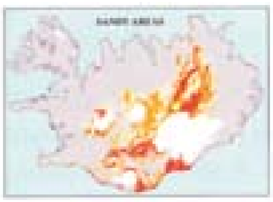

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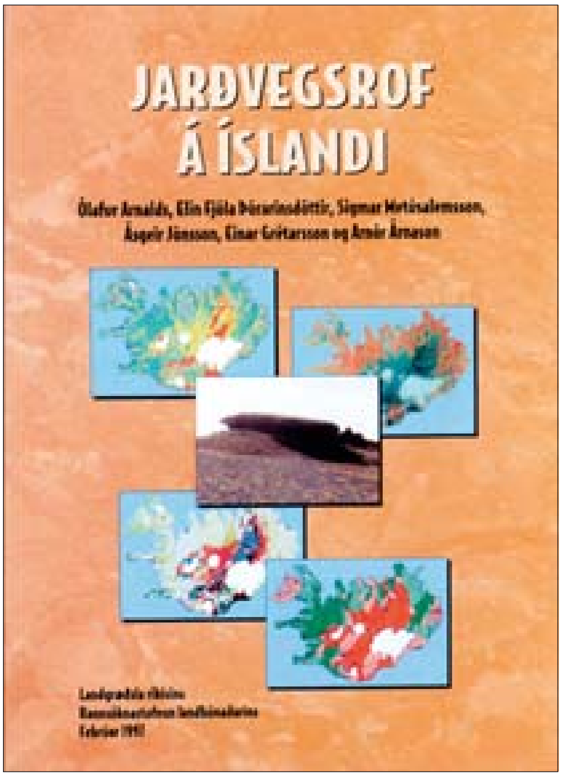
PREFACE



This publication describes the results of a national erosion assessment in Iceland. It was originally published in Icelandic, and is a result of the combined efforts of two institutes: the Agricultural Research Institute (RALA) and the Soil Conservation Service (LR). The Icelandic publication received wide attention in Iceland. It demonstrated the poor status of Icelandic ecosystems, and contained clear and detailed information about the type and severity of erosion in all local communities. It also contained detailed information on the grazing commons in Iceland. The assessment results have become the foundation for soil conservation planning and hence an important document for sustainable land use in Iceland. The project received the Nordic Nature and Environmental Award in 1998.

There has been considerable foreign interest in the methods used by the national erosion assessment program, and in the programs results. The Nordic award and the international interest prompted ideas to translate the publication into foreign languages. It has therefore now been translated into Danish and German, as well as English. The Danish and German versions will be made available on the Internet (www.rala.is/desert).

The format follows the original layout – the Icelandic text is simply replaced with foreign text. It can be argued that it would have been more ideal to produce a completely new book - a publication more suited to the foreign reader. Doing so, however, would have both positive and negative aspects. Perhaps the most important factor would be that costs for such a publication would have been prohibitive. Another problem with writing a new publication is that it would involve intensive work by the people (already too few in number) who are active in soil erosion research in Iceland. A notable drawback to the direct translation published herein is the large number of place names familiar to most Icelanders and cited in the book. The foreign reader may have difficulty locating these names. However, we have made an effort to reduce these instances or to help the reader locate the areas on maps.

Publishing the original Icelandic book in foreign languages does have some important benefits. It shows how a complete survey of erosion in Iceland is demonstrated to the Icelandic public, land users, administrators and lawmakers. It also retains information valuable to the many scientists who visit Iceland and want more detailed information than can be given in a more general publication. These scientists include a number of university groups that visit the country each year.

It should be pointed out that some of the research described in this book has been published, or is being published, in foreign journals, and these are cited at the end of the next chapter: ‘Background’.

The book was translated into English by Robert Melk, with additional review by Thorgeir Lawrence. The English translation was proof-read by the English Language Center in Reykjavik. Colette Bürling translated the book into German, with additional help and review from Halldór Kjartansson. The Danish translation was done by Michael Dal, with additions from Henry E. Jensen.

Guðrun Palsdottir and Elin Asgeirsdottir managed the translation and publication of the English, Danish and German version of this book.

BACKGROUND

Iceland

The barren surfaces and active soil erosion in Iceland often surprise visitors. Erosion is one of the most active geomorphic processes shaping the surface of the country. Severe land degradation has damaged Icelandic ecosystems to a large extent, resulting in loss of woodlands and creating vast deserts.

Iceland is a 103,000-km^2 island in the North Atlantic Ocean, situated between 63° and 66° north. The country is warmed by the Gulf Stream, and the climate is described as maritime cold-temperate to sub-arctic, with annual rainfall ranging from 500 mm north of Vatnajokull glacier, to over 2000 mm in South Iceland. Iceland's ecosystems are influenced by volcanic eruptions, and volcanic ash deposits are widespread. The island is mountainous with lowland areas along the coastline and river plains. The current population is close to 280,000 people.

The soils that form in volcanic deposits are called Andosols and are unique in character. Short reviews about Icelandic soils were recently published by Arnalds (1999a, 1999b). Andosols are often sensitive to disturbance because they lack a layer of silicate clay minerals.

Environmental Change

Fertile brown Andosols once covered most of Iceland, along with lush vegetation such as birch and willow woodlands. Iceland was settled about 1125 years ago by Vikings, who brought in domestic animals. The environmental change since man came to Iceland is staggering. Desert surfaces with limited vegetation now cover the largest part of the country. It is often difficult for the foreign traveller (and many Icelanders) to realize the scope of this tremendous change. And it can be difficult to explain the term "reclamation" to a foreigner who is used to a fully vegetated environment.

The evidence for this environmental change includes historical records, sagas, annals, old farm surveys, old topographical terms and place names, relict areas and current vegetation remnants, pollen analyses and soils buried under desert sand. More detailed accounts of this change were given by A. Arnalds (1988) and O. Arnalds (1999a, 2000a). Also see bibliography at www.rala.is/desert.

Conservation and Restoration

Icelanders have long realized the poor status of their ecosystems. Advancing sand that buried and destroyed valuable farmland in the south resulted in the establishment of a government agency in 1907 with the purpose of halting soil erosion: the Icelandic Soil Conservation Service (LR). It may be the oldest operating soil conservation agency in the world. At the same time, a foundation was laid for the Icelandic Forest Service with the initial aim of saving the last remaining tall-growing birch-stands.

The Icelandic government, farmers, non-governmental organizations (NGO's) and the general public are fighting the degradation of Icelandic ecosystems. About 15% of all Icelandic farmers are participating in organized reclamation work in co-operation

with LR. Special afforestation projects are funded by the government to increase the tree cover of Iceland and to establish future timber industry. Moreover, the most valuable native tree-stands are protected under the care of the Forest Service.

Iceland has a long tradition of volunteer work in reclamation and forestry by NGO's and charity organizations. One of the first environmental movements in Iceland is the Icelandic Forestry Association, which was founded in 1930. It is currently an alliance of 57 district societies with approximately 7000 members.

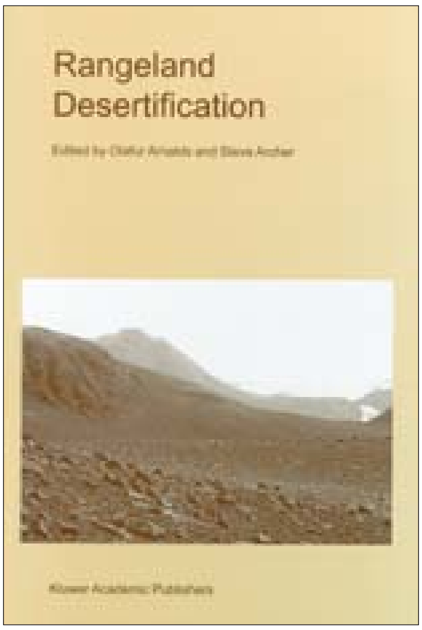
During the last decades, public awareness of the poor state of the Icelandic ecosystems has been raised considerably. "Land reclamation" and "forestry" are words that now resound in the soul of the Icelander. The country is determined to find a secure path to the road of sustainable land use and the restoration of lost ecological treasures.

The National Assessment Erosion Assessment Program

The Soil Erosion Assessment Program was initiated in 1990, after the first classification of soil erosion forms had been developed in co-operation with Larry Wilding and Tom Hallmark at Texas A&M University. The program was completed with the Icelandic version of this book and an international workshop in Iceland in 1997 (see www.rala.is/rade). Most of the fieldwork was carried out during the summers of 1991-1995. During the peak of the summer, up to four teams operated at the same time, each consisting of two persons. The data was processed and the database developed during the winter months.

Another program has recently been initiated based on the experience gained over the past 10 years at RALA and LR. Called Nytjaland ("land that is used"), it is aimed at creating a geographical database for land resources of all farms in Iceland. This database is important in relation to the certification of sustainable land use, which is planned to become a partial prerequisite for government subsidies for sheep production in 2003.

The methods developed for the erosion assessment, and the results, are now an important part of the making of long-term soil conservation strategies. The results have also influenced the development of new laws for soil conservation in Iceland.



International Workshop on Rangeland Desertification

An international workshop on rangeland desertification was held in Iceland in relation to the completion of the national erosion assessment program. Over 80 participants from more than 40 countries or international agencies partici-

Foreign desertification scientists in a recently formed Icelandic desert.

pated. Iceland provides a unique environment to investigate desertification processes because of the severe degradation and active erosion processes. Two publications have been printed as a result of the workshop: Rangeland Desertification, published by Kluwer Academic Publishers, and Case Studies of Rangeland Desertification. Proceedings from an International Workshop in Iceland, published as a RALA Report (see www.rala.is/rade). Both publications were edited by Ólafur Arnalds and Steve Archer.

Some Further Reading in English Related to this Publication

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1. INTRODUCTION

1.1 Erosive Forces and the Soil

Soil erosion has set its mark on Iceland's ecosystem ever since the last ice-age glaciers receded and vegetation re-established itself. Soil formation began in the glacial moraines that appeared as glaciers receded. As vegetation gained a firmer footing and soil organisms developed, the soil began to acquire the characteristics needed for a fertile resource. These characteristics enable the soil to store rainwater, where it becomes available to vegetation along with necessary nutrients. Soil is not only minerals and water – it is a living resource, a vital link in the chain that maintains the earth's ecosystem. Soil takes a long time to become fertile, and is therefore a non-renewable resource when compared to man's short lifespan.

When land is barren, wind and water attack its surface with impunity, but almost no erosion occurs when it is covered with vegetation. Soil formation is in constant conflict with the forces of erosion, until erosion finally levels the landscape: mountains become plains. Such conflicts can span millions of years. Under natural conditions, soil formation is rapid enough to counterbalance erosion, thereby allowing the soil to maintain its fertility and support a continuous vegetation cover.

Soil is fundamental to producing food for mankind. The history of civilization is in many ways also the history of soil resources: civilizations are nourished by that which the earth provides, and decline if natural resources are severely depleted. After man began using the land and ploughing it to grow crops, the equilibrium fluctuated between the forces of erosion and those of soil formation.

Soil erosion changes the appearance of the land, and can transform fertile areas into barren wastelands. Loss of soil is one of the most serious problems now facing mankind; it leads to famine, migration, and even war between nations, and this has been true since the beginning of civilization. Today, it is estimated that the livelihood of 900 million people is threatened due to soil erosion (UNEP, 1991).

An Icelandic glacier.

Degradation of Iceland's natural vegetative cover, together with soil erosion, began with the country's settlement around 1100 years ago, although the forces of erosion had already had ample assistance from various volcanic and glacial events. The story of the land includes reminders of natural resources now long gone, similar to changes ongoing in the world today that constrain man's ability to survive. It is believed that the soil and vegetation in Iceland today is but a fraction of what it was when the country was originally settled (Hákon Bjarnason, 1942; Sigurður Þórarinsson, 1961; Sturla Friðriksson, 1963; Ingvi Þorsteinsson, 1978; Andrés Arnalds, 1998).

It is considered probable that degradation in land quality was the main instigator of events during the Sturlungur Age, which ended

An old farm in East Iceland. Soils and vegetation have been greatly affected by land use since settlement 1100 years ago.

with Iceland losing its independence (Guttormur Sigbjarnarson, 1969). Fate led matters to the point where an international agreement was concluded on June 17, 1994, the 50th anniversary of Iceland's independence: the Convention to Combat Desertification. The United Nations has now dedicated that day to the struggle against desertification.

During this century, Icelanders have argued fiercely about the nature and causes of soil erosion. The utilization and depletion of forestlands, along with livestock grazing, are considered the main causes underlying vegetation loss and increased soil erosion. This has, among other things, influenced the views of Icelanders towards traditional sheep farming.

Opinion polls have shown that most Icelanders believe that soil erosion and the depletion of vegetation are the nation's most severe environmental problems. Yet despite general recognition of the problem, and vigorous soil reclamation efforts, a comprehensive survey of soil erosion for Iceland did not exist.

1.2 Mapping of Erosion in Iceland

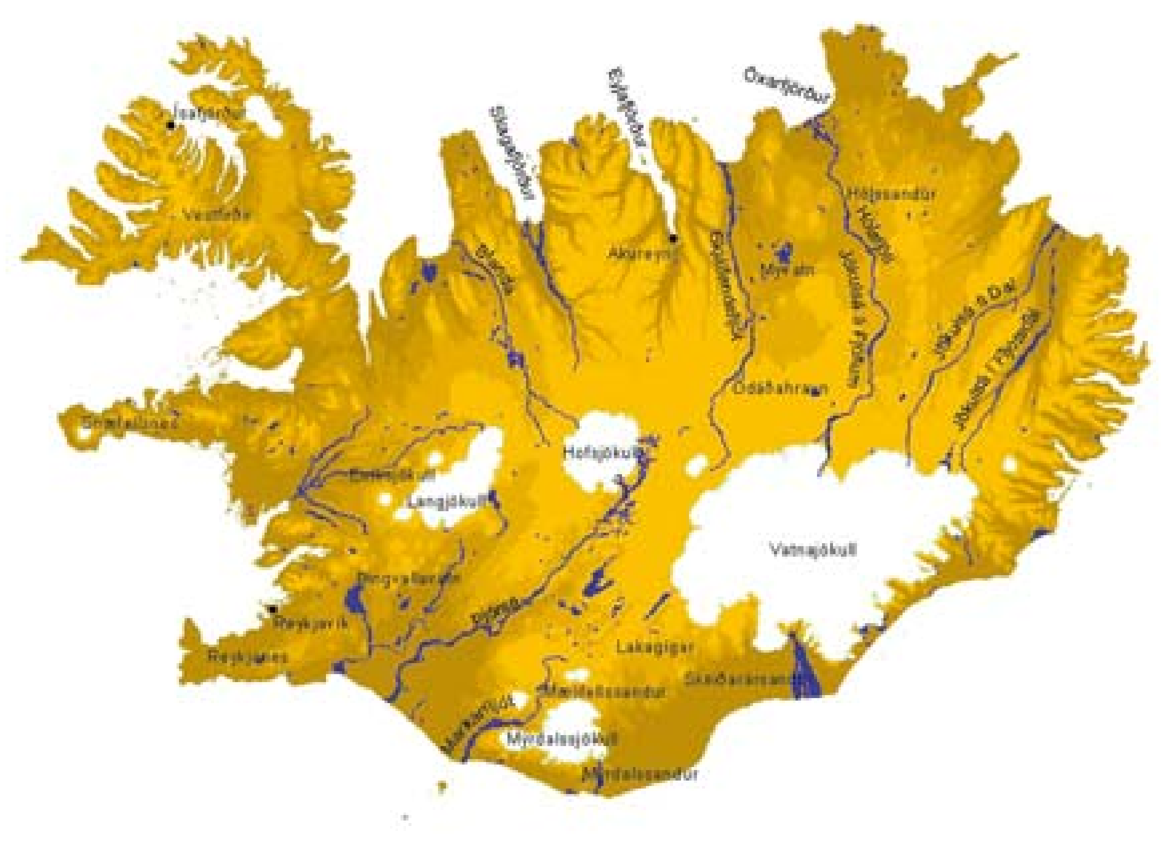
In 1991 the Agricultural Research Institute (Rannsóknastofnun landbúnaðarins, RALA) and the State Soil Conservation Service (Landgræðsla Ríkisins, LR) embarked upon a cooperative research project to develop methods for mapping soil erosion. It was funded by the *Agricultural Productivity Fund* and the *National Research Council,* together with special funding from RALA and LR.

In addition to developing suitable methods for mapping soil erosion, the project also focused on collecting data concerning soil erosion throughout Iceland. The project was in part based on experience gained by RALA during an assessment of grazing tolerances of rangelands. The classification system for erosion was developed in association with Texas A&M University in the USA, in the wake of a research project sponsored by the *Icelandic Science Foundation.* Numerous methods of mapping were evaluated, while information was also collected on the rate of erosion. Mapping began in earnest in the summer of 1993. Developments in the field of information technology were an important factor throughout the project. Erosion mapping for the whole of the country was almost complete after the summer of 1995.

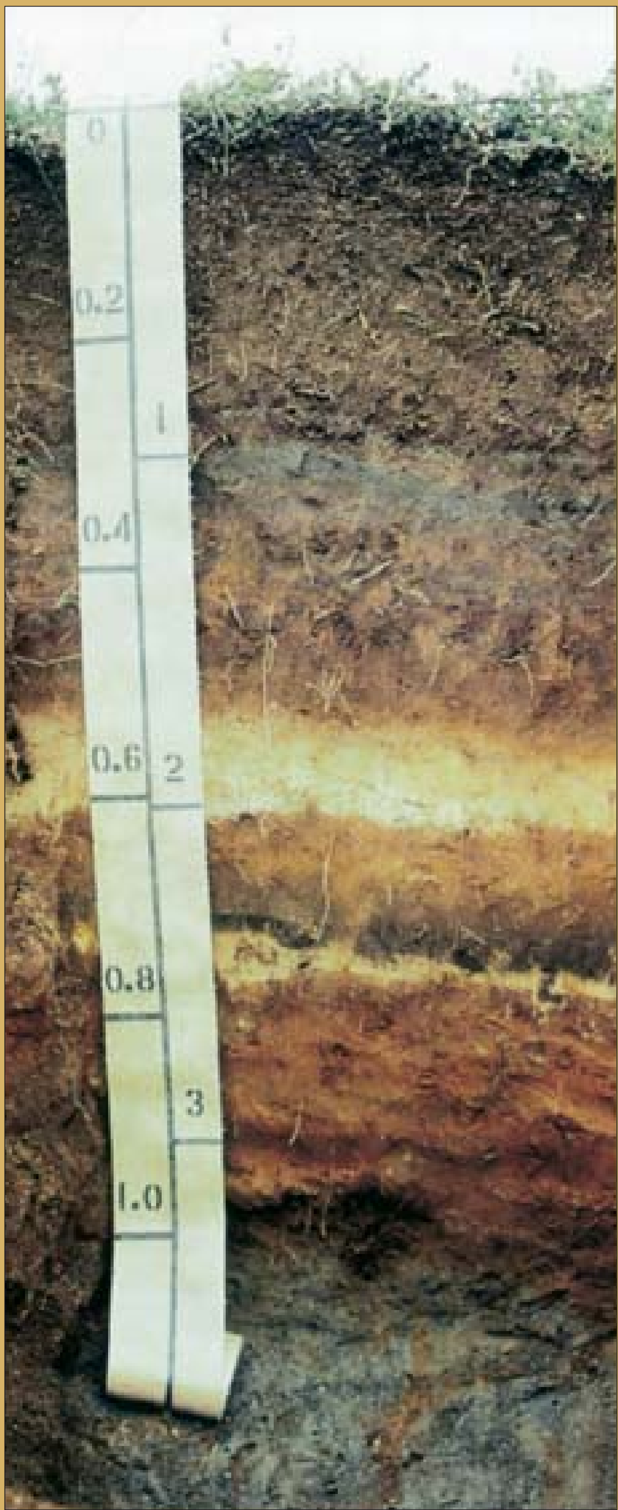
The project organizers believe that the database on erosion can change the general attitude to soil erosion so that good land will be properly valued, while providing for skilled assessment of land where erosion is considered serious. Planning by LR will in the future be based on this database, especially for determining project priorities. It is the hope of the project partners that in the near future a clear, overall land utilization policy for grazing will be formulated, based on the results described here.

It is important that all information collected is made accessible. RALA and LR have placed emphasis on local dissemination of the results of the mapping in each district. In addition, local residents are encouraged to take a greater initiative in ensuring that grazing is limited to continuously vegetated areas, where minimal soil erosion has occurred, leaving eroding areas and deserts untouched.

A homepage operated by RALA and LR and can be found at: *http://www.rala. is/desert.* The RALA/LR database not only contains information on soil erosion, but also on rangeland boundaries, vegetation, etc., which are important factors to be considered when planning land utilization. These information resources form the basis for continued work towards ensuring that agriculture reconciles aims for environmentally friendly production with sustainable land utilization.



This report describes the project and methods developed for mapping soil erosion. It provides the first comprehensive survey of soil erosion in Iceland. Tabulated data are included for the country as a whole, for individual districts, for rural counties and communities, and for the various communal grazing areas. Finally, the conclusions are discussed and recommendations made regarding future utilization of land for grazing.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2. SOIL EROSION AND SOIL CONSERVATION

2.1 Soil Erosion and History

Societies are founded on the earth's resources. The well-being of mankind depends on them, and as history shows, civilizations wither when the earth is incapable of providing enough.

Soil erosion has shadowed man from the time he began cultivating the land. Land preservation and soil erosion are often mentioned in ancient Greek and Roman writings, such as in works by Solon and Plato (see for e.g., Rubio, 1995). Soil erosion at home may be one reason why Phoenicians, Greeks, Carpathians, and Romans expanded their empires by founding new colonies in search of more fertile land (Hillel, 1991). But where there were once thriving nations along the southern rim of the Mediterranean, today there is barrenness. Libya is an example: it was called the Breadbasket of the Roman Empire. These empires collapsed when they became dependent on distant and unreliable sources of supplies.

Looking even further back in history, many powerful nations appeared around the Mediterranean Sea, and along the fertile river areas that are now Iraq and Iran. All these civilizations died out, in part because they either took too much from the land, or irrigation water became contaminated due to over-exploitation, as with the Tigris, Euphrates and Nile Rivers (see Hillel, 1994). The role of atmospheric changes in this development is unclear. The soil and irrigation water may also have become saline, which to some degree can be traced to extended drought brought about by atmospheric changes (Issar, 1995). Atmospheric changes may, however, have resulted from changes in vegetation cover over large areas in the wake of erosion. Those interested in examining the role of soil in the history of civilization, including ancient times, have many sources to choose from, including an article by Björn Sigurbjörnsson (1994), Rubio (1995) and Hillel's book about the Rivers of Eden: The Struggle for Water and the Quest for Peace in the Middle East (1994).

Civilizations are founded on natural resources. Fertile soils are needed to support the nations.

2.2 Terminology

"Soil erosion" is the term most often used when discussing the degradation of Iceland's ecosystems. It generally applies to the destruction of vegetated areas and soil erosion.

"Soil degradation" is a relatively broad concept that includes soil erosion, salinization and other processes that can alter soil characteristics, which can then greatly impair the growth potential of vegetation. “Soil erosion” is a narrower concept, defined as “detachment and removal of surface material, which results in poorer soil, inhibits or could inhibit the growth of vegetation or prevents vegetation from establishing on the soil surface.” This definition includes the removal of surface soil, its transport and deposition, and therefore differs from the definition of many geologists, who often see erosion as detachment.

It should be stressed that soil is an ecosystem, an organic world that is a link in the nutrient cycle. It takes a long time to form and can become fertile and rich in life – as in undervegetated land, or sparse and barren of life – as in a desert. This world takes a long time to recover if its resources are diminished or lost because of soil erosion.

Soil erosion is considered to be both *natural erosion* and *accelerated erosion*. It is a normal characteristic of nature to level out the land’s surface – this is natural erosion. Accelerated erosion is soil erosion resulting from human use of the land. Generally, the two forms are not easily distinguishable. In addition, natural erosion is usually extremely slow in comparison with erosion caused by man. In Iceland, natural erosion can be severe, such as erosion caused by glaciers and waterfalls, as well as wind erosion of sands that is created during volcanic eruptions or floods in glacial rivers. Differentiating between natural and accelerated erosion does not in itself have much purpose in connection with mapping, since the aim is to *map the level of soil erosion and not its causes*. It is open to debate as to how large a role man has played in creating specific wastelands in Iceland, but it is evident that man’s use of wastelands for grazing has an effect on the ability of vegetation to resist the forces of erosion, and hence to gain a foothold and create soil.

The Great Dust Bowl. The US plains in 1934 (US-SCS).

Soil erosion occurs in various ways, and is discussed in terms of *processes* and *forms,* which are the traces that erosion leaves behind. Two main processes usually determine soil erosion: wind erosion and water erosion. In addition there are landslides and erosion caused by needle ice formation. Wind erosion and water erosion are in reality a combination of many processes that dislodge soil particles and carry them away.

2.3 Soil Erosion

Sensible utilization of soil is the foundation for prosperity, yet despite this the history of scientific research on soil erosion is very short. It is most likely that such research was first conducted between 1877-1895 by a German named Wollny (Sanders, 1992). The term “soil conservation” is still younger. It is probable that it was first used after catastrophic soil erosion occurred on the plains of central United States during the 1920s and 1930s. This was the catalyst for the forming of the Soil Erosion Service in 1930, which became the United States Soil Conservation Service in 1935. When organized soil conservation work began, large amounts of money were earmarked for erosion research, which included developing two models for soil erosion: one for wind erosion and another for water erosion. It was then possible to estimate the quantity of soil lost from fields as a result of specific agricultural techniques.

The loss was estimated as amount of soil lost annually from each hectare or acre of land. The models are named the Wind Erosion Equation and the Universal Soil Loss Equation (USLE), for assessing water erosion. These equations are continually being improved, and scientists from many countries have adapted them to meet the requirements of their local conditions. They have proved to be excellent for the world’s agricultural lands, but not as suitable to assess rangelands. As a result, the Society for Range Management, a USA-based association of rangeland specialists, rejected the use of the USLE equation for assessing erosion on rangeland (SRM, 1992).

As noted earlier, soil degradation involves more than just erosion. The accumulation of salt in soil – *salinization* – is also a problem, caused by evaporation, or irrigation where water has become poor in quality due to repeated utilization along rivers, or because irrigation water is used improperly or drainage is insufficient. Salt accumulation in grazing lands is primarily caused by a lack of the rain needed to leach it. The salt therefore collects on the surface during periods of drought. In order for rainwater to be used efficiently, it must collect on the surface and filter down into the soil relatively unhindered. When vegetation has become sparse and the soil characteristics that promote good absorption have been lost, water runs unobstructed on the surface, causing water erosion instead of seeping into the soil.

In addition to soil erosion and salt, soil can also be damaged or destroyed in many other ways. For example, it can become acid, or develop a hard pan that disrupts or prevents the natural circulation of water. If soil erosion is serious, this impermeable layer appears on the surface of the land, creating poor conditions for vegetation. Soil can also become polluted, or lose some of the characteristics necessary for vegetation, such as its ability to provide a reserve of soil moisture or an environment conducive for organisms living in the soil. It is therefore apparent that there are numerous processes that can erode soil, which can make evaluating soil erosion a complex matter.

2.4 Desertification – Land Degradation

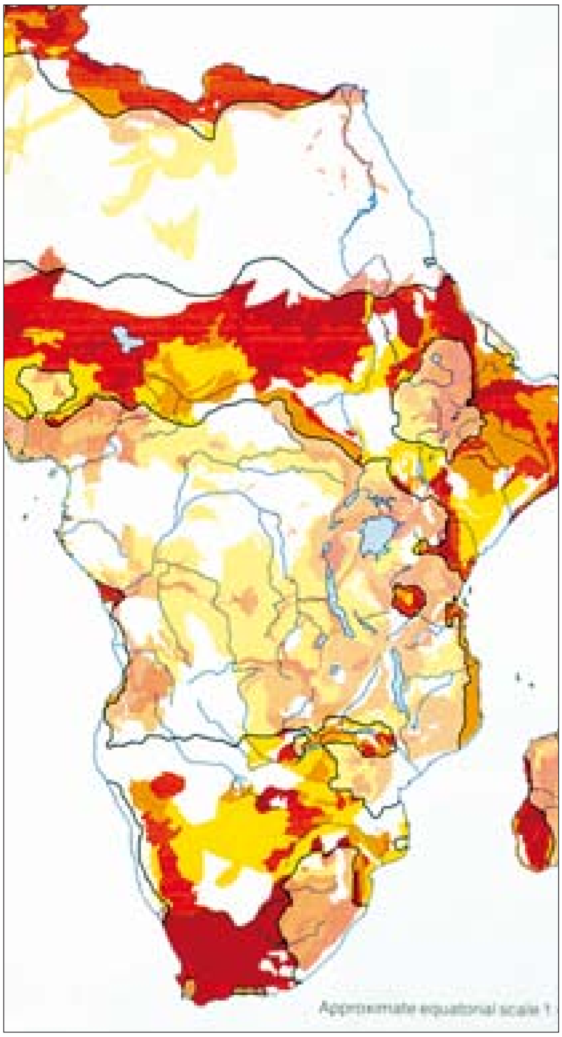
The degradation of Iceland's ecosystem has much in common with a type of land erosion called "desertification". Iceland's wastelands have striking similarities to barren areas in the world that have suffered from erosion.

In order to counteract ecosystem degradation around the world, an international accord was recently agreed by the United Nations. The accord is similar to other such UN conventions, such as the UN Convention on the Law of the Sea, the Biodiversity Convention and the Framework Convention for Climate Change. Enormous sums have been spent on the struggle against erosion, and the developed nations have been assisting poorer countries in the battle. As Iceland can play an important role in this area, there is reason to briefly discuss desertification in an international context.

A severely degraded land in Africa, during drought. Land degradation in Iceland has much in common with desertification in the arid countries. (UNEP).

In 1949, André Aubréville, a Frenchman, coined the word *"desertification"*. It was apparent to scientists at the time that many of the world's infertile deserts were once flourishing ecosystems that had succumbed to erosion. In many areas, the reason was clear: over-utilization of the land. Scientists who visited the Middle East saw sombre indications of over-utilization, and concluded that the deserts were expanding (Lowdermilk, 1939; see Björn Sigurbjörnsson, (1994)). The term "desertification" was much used following the drought in the Sahel area of Africa in 1965-1974. Vegetated land was severely depleted – so much so that yearly changes were clearly seen on satellite images.

The definition of desertification has varied. The definition used by the UN is the following: "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities." This is quite vague, and has caused both misunderstandings and controversy. There is hardly a scientific book on desertification that does not give space to discussion of the numerous definitions that have been put forward, especially the controversial UN definition. There are many reasons for this, including the fact that the term "desert" has different meanings depending on the field of study, whether meteorology, geology, geography or plant ecology. Yet the word's meaning can be much more general: the root is Latin and could be interpreted as "solitude". Webster's Dictionary



A part of a UNEP map of soil degradation in Africa.

(Neilson *et al*., 1938) does not limit the term "desert" to arid areas. Arid areas are included in the definition, but another meaning mentioned corresponds well to the Icelandic "wasteland."

The term "desertification" mainly applies to "enduring decline of land fertility". This description differs from that of the UN, whose definition was intended to reduce the controversy that existed around the term "desertification" by limiting its application to the world's drought areas, ensuring strong support for poor nations in the driest parts of Africa. Because of appeals made by these countries, the older definition was amended to include climatic changes, thereby reducing emphasis on human influence.

The definition of desertification used in this study is not dependent on climate, and does not take a stance on causes. It does not matter in what manner the land is being depleted, nor what the local climate is, which is actually often difficult to define. Wasteland is conceivably just the climax stage in a conditional process. A desert does not have to be present, as it is often difficult to determine what is and what is not a desert. An in-depth discussion on the definition of desertification can be found in articles by Rubio (1995) and Yassoglou (1995), in the book from the European Commission on this subject (Fantechi *et al*., 1995), in books by Mainguet (1994) and Thomas and Middleton (1994), and in the United Nations Environment Programme (UNEP) book on forming concepts and methodology (Odingo, 1990). In addition, UNEP publishes a specialized magazine on land erosion: *Desertification Control Bulletin* (see also Arnalds, 2000).

Confusion in terminology and ignorance of arid ecosystems, have caused serious mistakes when interpreting the condition of land. There has been a certain lack of application of scientific methodology in this area, and emotions have sometimes had more influence. The subject matter has often been approached from a narrow perspective, for example, agronomy, geology or geography.

Research on the condition of land must take into account the nature of land degradation, the influence of land utilization and the environment, together with a perceptive understanding of the ecosystem and natural fluctuations. Starting around 1970, the Sahara Desert began steadily expanding, which brought about famine. The process was of course called desertification. Then it began to rain, and the desert immediately receded; wasteland is not forever. Unfortunately, there are many such examples of confusion between drought and permanent land degradation. In other places, vegetation and soil characteristics have changed so much that the land's capacity to produce has been reduced, even though sparse vegetation cover remains. This is the case in most American deserts, where vegetation became scrubby and the soil infertile shortly after livestock was brought in.

Desertification has not usually been placed in an ecological context, as it is customary to define the condition of the land based on continuity of vegetation cover regardless of vegetation or soil characteristics, or its importance for other elements of the ecosystem, such as the drainage basin. Such an approach is sometimes called "agricultural", as it is based on such factors as vegetation cover, cultivation and production, without taking into consideration the diversity or the quality of the ecosystem as a whole. A good example of this is when Icelanders deliberate on whether soil reclamation can keep up with desertification. The question is of course unrealistic. Land which has been "reclaimed" is in no way comparable to the ecosystem lost to soil erosion – it can take decades or even centuries for an ecosystem to fully regain its fertility. This is in part related to the reason why developing countries were able to have the influence of drought included in the UN's definition of desertification, even though irregular precipitation and drought are natural factors in these ecosystems.

It must be remembered that the assistance provided by industrial nations to help in the fight against deserts is enormous. Actions are often directed by the UN, but results are often controversial. The UN's methodology has been harshly criticized, such as the noteworthy articles by Forse (1989): *Myth of the Marching Desert*, and Pearce (1992): *Mirage of the Shifting Sands*, both of which appeared in the New Scientist. These articles were, for example, contested by Stiles (1995).

Despite a certain lack of scientific rigour when discussing the creation of deserts in the world, it is clear that the problem is enormous. *UNEP believes that at present about 900 million people are threatened by the forces of soil erosion.* Even though it might be necessary to re-examine concepts and scientific methods, it is an inescapable fact that land areas are fast declining, at the same time as mankind proliferates. History, including the Icelandic history, contains innumerable examples of the horrible consequences of soil erosion. It is hoped that Icelanders will be responsible participants in international projects to counteract desertification, since few of the world's richest nations have as much experience in their own backyards.

2.5 Soil Conservation

Soil conservation and vegetation conservation are comparable concepts. As food production is usually dependent on breaking land for cultivation, the generally accepted concept here is soil conservation, not vegetation conservation, which is more associated with preserving

A gully formed by water erosion in a dry area (Africa). (UNEP).

unique ecosystems and biotas. The concept of soil conservation not only includes protecting the soil from erosion, but also protecting the soil's characteristics, i.e. its fertility and capacity to store and deliver water. These characteristics contribute to positive conditions for vegetation and life in general. The ability of soil to absorb water and transfer it is extremely important; if water runs off the surface, or percolates

UNEP

Water is a precious resource. Soil conservation is also water conservation.

quickly through soil layers, it is of little use to vegetation. In addition, surface runoff water causes floods and pollutes lakes. Soil conservation also contributes to saving water and improving its utilization.

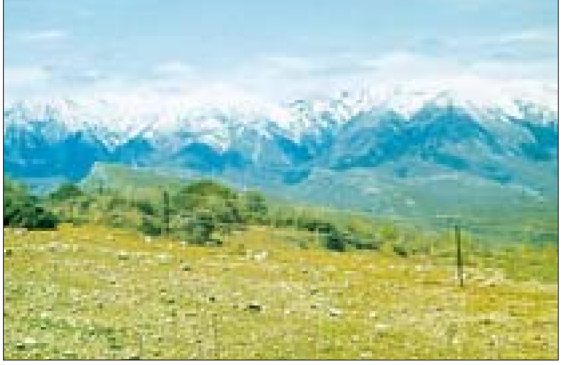
Sanders (1992) stressed three steps that generally had to be taken regarding soil conservation. The first step is to determine the condition of the soil, including where soil erosion is occurring; the next is to organize conservation measures; and the final step is to execute a plan of action. This current publication can be considered as part of the first of these three steps: helping to define soil conditions and soil erosion throughout Iceland.

It is important to remember that soil erosion is a *consequence* and not a *cause*. In his article on soil conservation, Sanders (1992) pointed out that the governments of many countries earmark valuable funding for ineffective measures to conserve soil: ineffective because emphasis is placed on consequences rather than on attacking the root of the problem. Erosion is a consequence, while in most cases the cause can be traced to incorrect land utilization.

Modern methods for protecting the soil are based on increasing the awareness and responsibility of those using the land. This concept is the core of Australia's Landcare plan, which has had a broad-based influence on soil reclamation around the globe. If education and increased responsibility are ineffective in getting landowners to deal with the problem, the government must step in, to ensure sustainable land utilization.

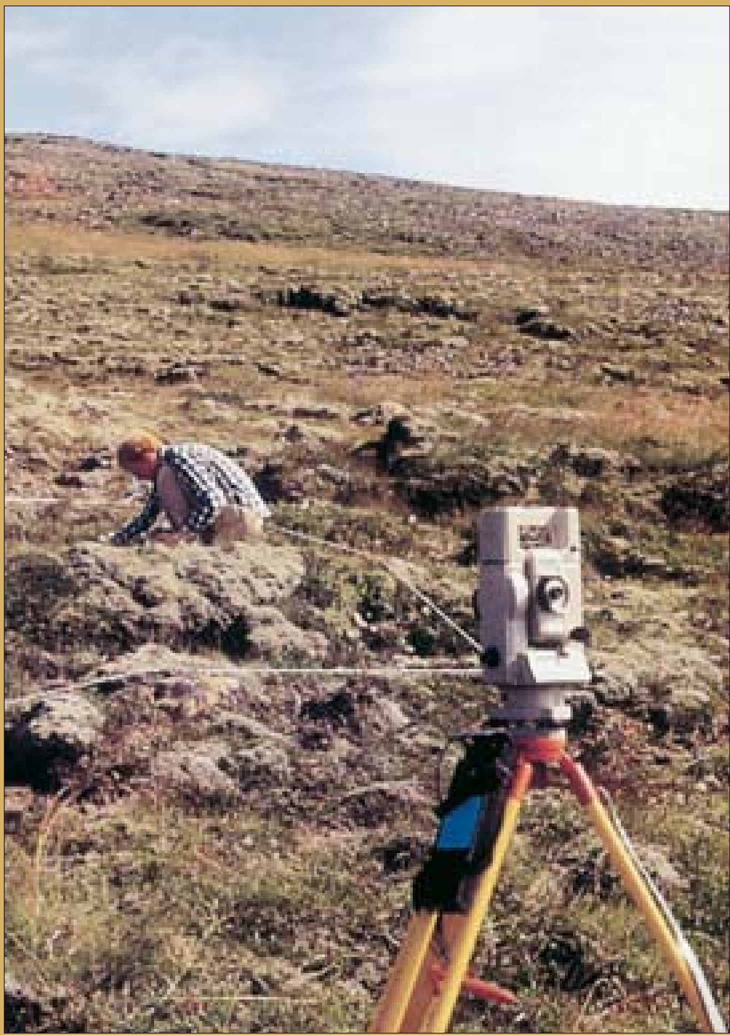
Special laws forbidding use of land in sensitive areas have been passed in the United States, New Zealand and Australia. This primarily applies to cultivated land. After New Zealanders began using the highlands of South Island as pasture, soil erosion increased dramatically. The land was then mapped for soil erosion using methods similar to those discussed here, which resulted in the entire highland area being declared off-limits as grazing land.

It is a commonly held opinion in Iceland that soil conservation and soil reclamation are primarily concerned with halting the rapid decline of vegetation. Soil conservation, however, is equally concerned with sustainable land utilization, without reducing land quality. Protecting wastelands and soil erosion areas from grazing is a normal part of soil conservation work, along with education, encouraging sensible utilization, sowing and increased



Large portions of the New Zealand high country have been protected from grazing. Many degraded areas of Iceland are unsuited for grazing. (New Zealand).

landowner responsibility. An overall soil conservation program must be built on extensive knowledge of vegetation, soil and soil erosion. This involves everything that promotes the rational utilization of land, protects natural resources and reclaims land quality, including research, pasture management, training, planning and legislation.



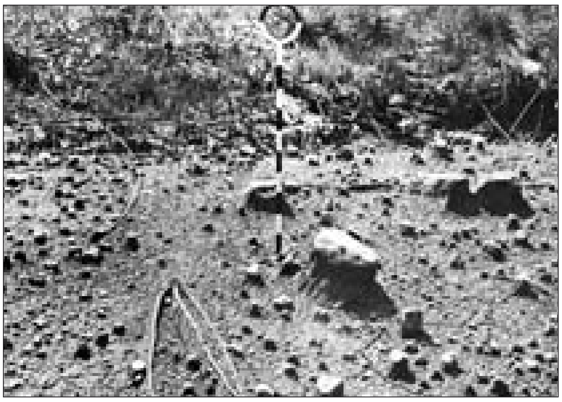
3. MEASURING AND ASSESSING SOIL EROSION

3.1 Soil Erosion Models

As mentioned previously, mathematical models are used to assess soil erosion relating to land broken for cultivation, with results expressed as tons of soil material lost from one hectare of land in one year (t/ha/year). On the whole, this approach has proved successful for agricultural land. However, the models have been ineffective, even useless, for grazing land (SRM, 1992; NRC, 1993). There are numerous reasons for this, including those mentioned below.

Grazing land is not uniform like fields. All fields are ploughed, which opens the way to the forces of erosion. Grazing land in its natural state is covered in vegetation, and earth is only seen through the occasional erosion sore, except in barren wastelands. In these circumstances – application to rangelands – only some aspects of the model are effective. The utilization of rangeland is quite different from that of agricultural land; therefore the premises used in the erosion model are only partially applicable. Neither the depth of the soil nor the speed of soil formation is taken into consideration. Soil thickness is very important in relation to soil erosion. If the topsoil is deep, it is of less consequence if a few centimeters are lost off the top than if a similar amount is lost in an area of shallow soil. In the latter case, a little erosion can cause complete destruction.

Soil formation works against erosion, since the earth is in a continuous state of development. Even rapid soil formation, however, can never keep up with soil erosion as the difference in speed between these two processes is enormous, particularly where the climate is cold or arid.



Water erosion has removed the top 20 cm soil layer. (Landcare, Australia).

The interplay between vegetation cover and erosion is complex. In general, vegetation cover is conducive to soil conservation, but if that vegetation cover is only a superficial layer of lichen crust on the surface, then water moves rapidly along the surface instead of seeping into the ground. Such conditions are therefore considered negative in many places abroad. The situation is different in Icelandic wastelands, as needle ice formation and frost heaving is a major problem, and a crust of this type protects the soil, and is often a prerequisite for the establishment of vegetation.

In Iceland, there are also other factors that detract from the reliability of known models for soil erosion, so much so that such models are virtually worthless. This is particularly true of the brown Andosols under vegetation. If a few centimeters of the surface soil are removed, all soil is subsequently lost with the formation of *rofabards*. That which remains is wasteland. This is naturally dependent on the type of erosion, which is much more diverse than is assumed in the foreign models for soil erosion. Sometimes the soil erodes slowly along the surface, particularly in deserts and where heaths are characterized by rills. Icelandic heaths are also unevenly thick. If a particular quantity of soil is lost from a land area that has shallow topsoil, it may result in no fertile topsoil remaining. Where soils are very thick, however, the loss of a similar amount of soil would cause relatively little damage.

Wind erosion in an Icelandic desert.

It should also be noted that the USLE and the Wind Erosion Equation are based on presumptions concerning specific natural properties of the soil. Andosols (volcanic soils), such as Iceland's dry land soils, have very specific characteristics that correspond poorly with the predetermined parameters of the model. For example, the Wind Erosion Equation is based in part on the proportion of soil grains that are >0.84 mm, a size large enough to reduce drifting (Skidmore, 1994). Soil grains in volcanic soil are much less dense, let alone pumice, which is even lighter. It is not unusual to see grains as large as 30 mm in size lifted off by the wind, which in part, explains the inefficiency of wind erosion equations under Icelandic conditions. Volcanic soil, moreover, is in greater danger from water erosion than other soils due to a lack of cohesiveness (Maeda *et al.,* 1977).

The tendency to use such models to measure soil erosion on rangeland is typical of the emphasis placed on agronomy. They are ill suited for rangeland application – even though some of these methods may be useful aids.

3.2 Soil Erosion on Rangelands

When assessing the condition of rangelands, soil erosion is usually at the top of the list of factors that must be considered (SRM, 1995). This is in part because soil takes a long time to develop, while vegetation can often grow back if conditions are right. It should be noted that vegetation studies play a large role when assessing the condition of rangeland. Assessment of erosion is just one aspect of determining the condition of land, but where soil erosion is serious it is given priority (SRM, 1995).

Most methods used to evaluate the condition of rangeland take into account how much bare soil surface is exposed to the forces of erosion, along with signs of soil erosion. The United States system (BLM, 1973) includes soil and soil erosion as part of the assessment. Signs of soil erosion are examined and various characteristics are identified, which may be included when evaluating erosion. The Bureau of Land Management (BLM) is the institution that supervises utilization of enormous tracts of federally owned rangeland in the USA. The methods were changed little in the updated system prepared by the National Research Council of America (NCR, 1994). The US SCS uses a similar method, and the proportion of non-vegetated land is the most important parameter.

3.3 Methods Used to Assess Erosion in the Pacific

The methods used by RALA and LR for erosion mapping are partly based on methods used to determine the condition of soil in New Zealand and in New South Wales (Australia). This work deserves closer study.

The New Zealand methods are described in a booklet by Eyles (1985): *The New Zealand Land Resource Inventory Erosion Classification*.

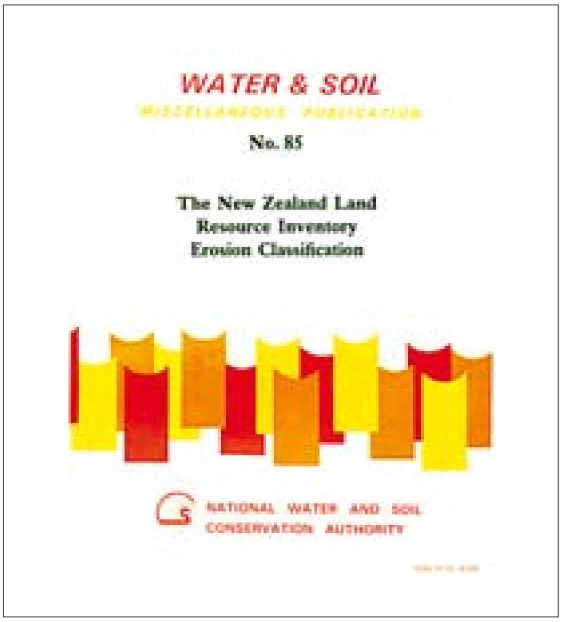
The people of New Zealand are aware that significant soil erosion was caused by their land use, and that actions were needed to avoid damaging the land. They, therefore, began extensive mapping of those factors that were most likely to help in reorganizing land use.

The factors are geology, soil type, slope, soil erosion (type and severity) and vegetation. By combining information on these factors with climatic data, they believe it is possible to formulate a realistic land utilization policy. This major project began in 1952, based to a large degree on US methodology. It appears that erosion assessment was quickly given priority, at least regarding the compilation of erosion data, as “erosion is the main factor affecting the land’s capacity for sustainable agricultural production,” (Eyles, 1985). Work continued on mapping all the factors noted above, and the conclusions are now available.

At first, the New Zealand system was built on mapping how much soil had been lost, as, in some erosion categories, a large part of the soil had been lost, and, in the worst areas, >75% of the land was bare bedrock. Several methods of mapping were used, and were changed with improved knowledge. In 1972, work began on coordinating erosion mapping (New Zealand Land Resource Inventory, NZLRI), in part so that the data could be used as the basis for provision of grants to stem erosion. The system is based on mapping erosion forms and determining erosion severity.

According to Eyles (1985), there were four basic premises for New Zealand’s mapping system:

1. The term “erosion” was used to refer to the physical processes of removal, addition; and transfer of soil from one place to another, which limit the capacity of land to be used productively for agriculture
2. No distinction was made between accelerated and geologic (normal) erosion. The reasons for this were twofold; experience had shown that the distinction can often not be made, and, whether the erosion is accelerated or geologic does not alter the importance or consequences of the erosion
3. Only present erosion was recorded. Erosion was considered present until the exposed or eroded areas were covered by vegetation or - as with slow moving mass movements such as earth flow - until evidence of continuing movement was no longer identifiable.
4. No attempt was made to relate erosion to sediment yield because the relationship between the rate of loss of the pedological soil in an area and current sediment yield from a catchment is highly variable in time and in space. The erosion data therefore should not be used to determine sediment yield information.



The cover of the New Zealand erosion classification manual. Many similarities exist between this system and the Icelandic system.

Erosion intensity is measured on a scale of 0-5, with 5 being the most severe erosion. Details of the New Zealand categories are given in Table 1.

The emphasis placed by New Zealanders on classifying land properties by mapping many natural components is quite significant, such as the work by Blaschke (1985) on the land use capability assessment of New Zealand’s North Island volcanic area. Þorsteinn Guðmundsson (1990) successfully experimented with such mapping in the Borgarfjörður region in west Iceland. Þorstein divided the land into five classifications: the first was land suitable for growing hay, while the last was land without production value, i.e., wasteland, rocky land, steep slopes, wetland, erosion area or areas where the climate is very unfavourable (highland area, based on temperature pattern).

This system was considered when RALA and LR began mapping in 1991, but it was decided against using this type of classification. This was because it was not seen as necessary to collect information beyond that which erosion mapping provides for large areas of the country, including the highland region, deserts and erosion areas. Also, the work would have been much more extensive and therefore would only have been possible with major funding from the government. In addition, vegetation maps of much of Iceland had been completed, and, although the scale of these maps is not precise enough to provide information for managing grazing in rangeland areas or to make land reclamation plans for individual land areas, they nevertheless provide a good basis for organizing larger tracts of continuous land reclamation areas when used together with erosion maps.

As information technology continues to develop, it will become possible to classify agricultural land in lowland areas according to land capability parameters. For example, it is now possible to use a computer to determine slope by analysing contours and other information. Data can then be easily linked to information on land type, erosion, vegetation, etc. If new bases for making maps were sought, land capability mapping would be a strong candidate, as such maps could also be used as the basis for land use planning. Of note is the success of an experimental farm-mapping project conducted by the Skagafjörður Farmers' Association and LR.

Soil erosion is a monumental problem in many parts of Australia. The land is dry and sensitive, and many areas could not tolerate the level of land utilization that the white immigrants introduced when they arrived. In 1982 and 1983, Australia suffered a drought that left a mist of dust enveloping the city of Melbourne. After that event, Australians woke up and have now become leaders in many fields of land reclamation. As in Iceland, land erosion is a subject of major concern to the general public. Action taken to deal with the problems varies depending on location. Emphasis is placed on surveying land degradation before any action is taken, which has subsequently led to extensive legislation and changes in bureaucratic management, as the needs of agriculture and producers were seen as having had too much influence (Hannam, 1991).

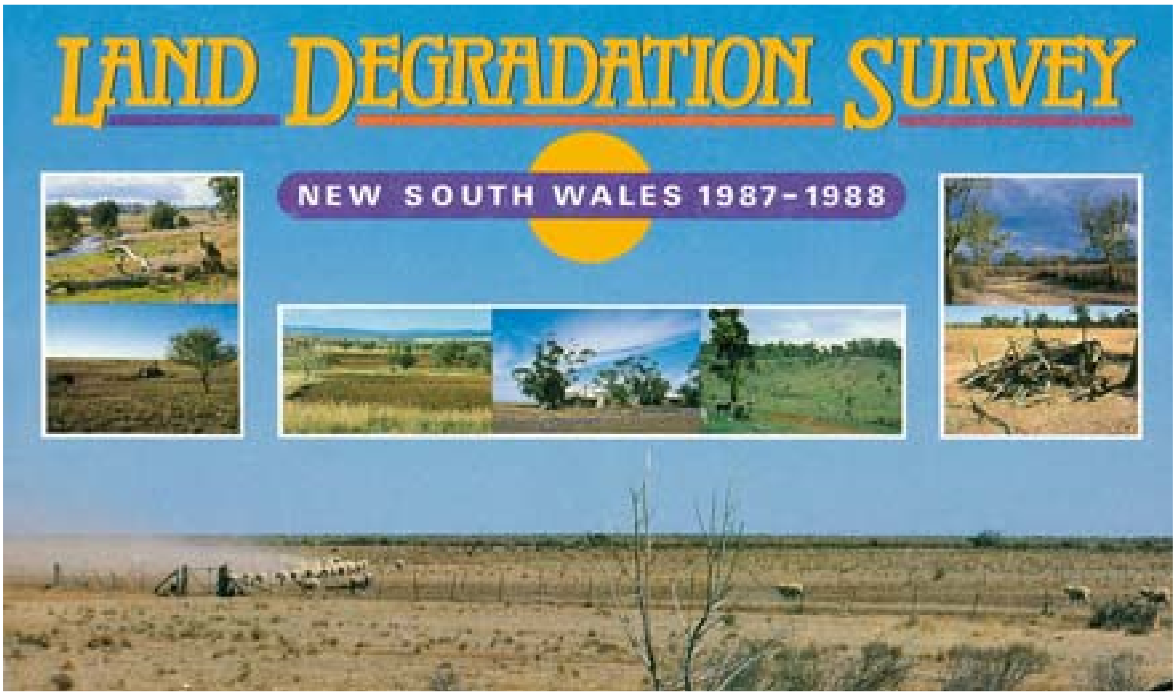
Dust storm over Melbourne, Australia. (Landcare, Australia).

Scalding in Australia, a severe land degradation taking place. (SCS, New South Wales, Australia).

Between 1987 and 1988, the State of New South Wales, Australia, embarked on a major survey on the degradation of land capability (SCS-NSW, 1989; Graham, 1990). Ten forms of land degradation were mapped:

- Sheet and rill erosion (due to water erosion)
- Gully erosion
- Mass movement erosion
- Wind erosion
- Dry land salinity
- Irrigation salinity
- Scalding (surface soil is removed by wind or water erosion)
- Induced soil acidity
- Soil structure decline
- Woody shrub infestation

These methods are in many ways similar to those used in New Zealand, but greater emphasis is placed on drought and the consequences of utilization on very dry ecosystems. The classification they call "scalding" is interesting, as it is similar to Icelandic *melur* areas, where soil cover has been completely lost. It is not necessary to discuss these methods further, but they do give an indication of how other countries have developed methodologies to fit their particular conditions.



The cover of the New South Wales (Australia) land degradation survey.

4. METHODS

The methods used by RALA and LR when mapping erosion have four primary characteristics:

- Classifying erosion according to erosion forms
- Applying standard scales to assess the severity of soil erosion
- Using satellite images as the basic map and as an aid for field mapping
- Use of a Geographical Information System (GIS)

4.1 Developing Classification for Soil Erosion

Soil erosion is apparent to everyone who travels in Iceland – the signs are all too clear. However, people see the land in different ways. Where one person sees soil erosion, another sees no problem whatsoever. The reason for this is that there is no single yardstick for the land. No one has doubts that erosion exists when erosion escarpments (*rofabards*) are conspicuous. Drifting sand is also easily distinguished, both from the dust clouds and signs of abrasion on rock surfaces. Other signs of soil erosion have not received as much attention, such as the enormous amounts of soil that are washed out to sea in rivers and streams.

It seems that research, as well as the focus of people, has primarily been directed at the loss of vegetation, particularly in areas with erosion escarpments and encroaching sand. This is quite understandable, since erosion in Iceland is so dramatically linked to natural forces: where once there was vegetated land with fertile soil, there is now often infertile desert with scattered vegetation. For this reason, Icelanders speak more of "vegetation loss" than of "soil erosion", as commented on previously.

Even though much has been written about vegetation loss and soil erosion, Icelandic scientists conducted little systematic research on how soil erosion occurs, except in sandy areas and around erosion escarpments. There are, however, some exceptions. Research by Sigurður Þórarinsson (e.g., 1961), Guttormur Sigbjarnarsson (1969) and Grétar Guðbergsson

A rofabard. Remnants of soil and vegetation in an Icelandic desert.

(1975) were important steps towards increased understanding of erosion escarpments (*rofabards*). Measurements on *rofabards* reported by Sturla Friðriksson (1988) are also an important addition to the discussion on the characteristics of erosion.

Despite this research, developing methods to assess soil erosion on grazing land began relatively late in Iceland. RALA began formal experiments to assess soil erosion on rangeland in connection with calculation of grazing tolerance levels. In 1983-1984, work was conducted in finding methods to assess grazing lands on the commons of the East-Húnavatnssýsla district (Ingvi Þorsteinsson *et al*., 1984; Ása L. Aradóttir and Ólafur Arnalds, 1985). It became apparent that that it was not enough to consider just *rofabards* and other escarpments to get a good picture of soil erosion; added to that was another sign of erosion: erosion spots. They were considered to be a kind of erosion process called spot erosion. Erosion spots are in fact a very definite sign of degrading vegetation and the precursor of other erosion.

Erosion spots in a typical Icelandic rangeland.

Methods used by RALA during these years were limited to vegetated land; deserts were not included. The methods were used throughout the country in assessing grazing tolerance. The methods proved successful on vegetated heath, but as they were increasingly used, various flaws appeared in relation to soil erosion. It became clear that the methods did not include all erosion, particularly on mountain slopes and deserts, and therefore were not suitable for poorly vegetated areas. In addition, there was no clear difference made between the process of erosion and its signs.

In 1986, the Icelandic Science Foundation funded some general research on soil erosion. That summer, about 30 areas were studied to determine types of erosion. The areas were chosen randomly, with the only condition being that some vegetation be present. Using this data, a new system for classifying soil erosion in Iceland was developed. This classification was part of a doctoral thesis at Texas A&M University, developed under the guidance of Larry Wilding and Tom Hallmark (Ólafur Arnalds, 1990; Ólafur Arnalds *et al.,* 1992), but did not include deserts. Foreign classification systems were taken into consideration, particularly the New Zealand system (Eyles, 1985), geomorphology and, finally, methods used to assess erosion on grazing lands in the USA (USDA-SCS, 1976). In this publication, the Icelandic system is called the RALA/LR Classification. Further categorization of deserts was later carried out by RALA and LR staff (Ólafur Arnalds *et al*., 1994).

4.2 Erosion Forms

As was mentioned earlier, erosion in Iceland is very diverse. This makes it extremely difficult to assess erosion without classifying it. It is difficult to use a simplistic, single process erosion approach, such as either wind erosion or water erosion, to assess erosion, since erosion processes are complex in Iceland, with interaction between processes and season. An example of this is *rofabards* ("erosion escarpments"), which involve numerous erosion processes: water pounds the escarpments, water runs down and along the escarpment, needle ice formation loosens the subsoil and the escarpment collapses. It is therefore clearly difficult to attribute erosion escarpments to a particular type of erosion process.

RALA and LR base their erosion classification on erosion forms, i.e. signs of erosion that can be identified in the field. Any one area may have several active erosion processes. The classification is valid for erosion throughout Iceland, whether for vegetated land, the fringes of vegetation, or desert. The classifications are the following (with their mapping symbol):

1. *Rofabards* (erosion escarpments) (B)
2. Encroaching sand (A)
3. Erosion spots (D)
4. Erosion spots on slopes / solifluction (J)
5. Gullies (V)
6. Landslides (K)
7. Deserts / barren land (many classes)

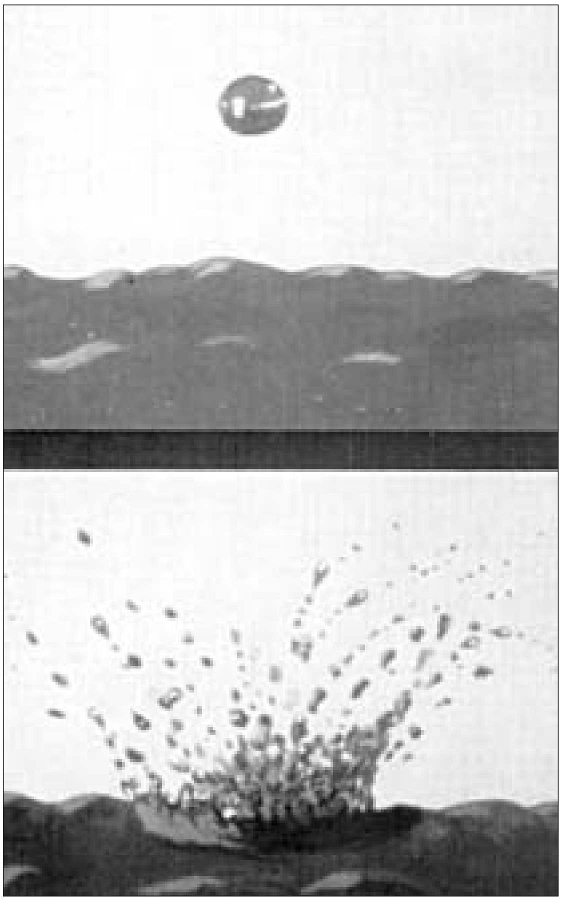
The main difference between erosion spots and solifluction is that erosion spots are on level ground while solifluction indicates both solifluction geomorphic features and erosion spots on slopes. Erosion on hillsides is, in general, much more serious than on more gently sloping land. Running water and gravity are active erosion forces, and there is good reason to include erosion sores on hillsides as special erosion forms. It might, however, have been preferable to use terminology other than solifluction when describing this erosion form.

An important aspect of this erosion classification is that deserts or barren areas are included as erosion forms. Excluding deserts during erosion mapping would give an incorrect picture of the land's condition. When land is poorly vegetated, the forces of erosion have easy access to the soil surface, which is why erosion is most often in inverse proportion to vegetation cover. Erosion forces such as wind, running water, rain, needle ice and gravity cause solifluction and landslides.

Many are not aware of the erosive power of rain-splash, which actually did not become apparent until the early 20th century, with Ellison's research (see Stallings, 1957). As an example, the energy dissipated by 50mm of rainfall is theoretically capable of lifting 18cm of soil 1m into the air. If the raindrops are large, they fragment soil clods and disperse them in all directions. The presence of even a slight slope is enough to cause soil transport, resulting in triple the quantity of soil grains transported down the slope compared to up the slope on a 10% slope or less. This example is taken from the book by Heady and Child about ecology and utilization of grazing land (1994). Other books on soil conservation are e.g., by Morgan (1986) and Stallings (1957), which discuss in detail the erosive power of rain-splash.

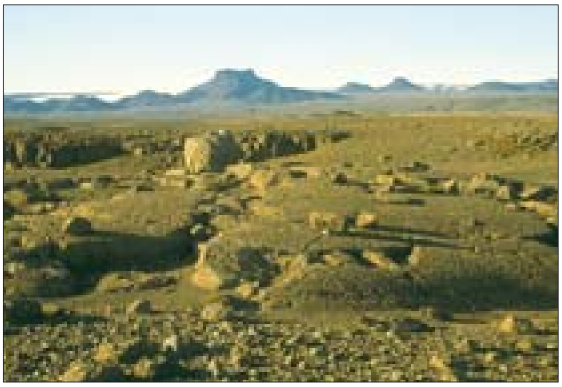
Erosion caused by rain-splash is called *sheet erosion*. All soil that is exposed to rain is in danger of erosion, even if the slope is slight. The impact of raindrops loosens the soil clods and the soil then mixes with water and floats over the surface. On inclines, the water flows downhill, which adds to the erosion caused by rain-splash. Water first collects in rills that then coalesce into deeper *gullies*.

Wind erosion is usually considerable in wastelands, as it is dependent on the ground being exposed to the wind. It is, however, soil grains colliding that causes the most erosion, so wind erosion is mainly on continuous bare areas. This is also true of Icelandic deserts. Irregularities such as rock and lava outcrops do reduce surface wind speed, but wind erosion on deserts, even barren gravel fields, is much more than most realize. The signs are not always apparent, as sand slowly collects under the stony surface; frost heaving constantly pushes rocks to the surface, thereby burying the sand that has blown into the area.



Rain-splash detaches soil particles on the surface. High-speed pictures.(US-SCS).

The formation of needle ice in the soil surface layer causes considerable erosion on bare land, making it difficult for vegetation to gain a foothold. Needle ice is very common, and



A totally eroded surface in South Iceland. This area was covered with birch forest some hundred years ago.

Needle ice can lift up small seedlings that have sprouted in the bare soil surface and hence slow down natural revegetation of an area.

needles can reach a length of > 10 cm. It lifts up soil grains, that are then exposed on the surface when the ice melts, and are subsequently washed away or blown away.

From this it can be seen that the surfaces of deserts are extremely unstable, which is why they are classified as a special erosion form. At first, deserts were not divided into subcategories, but experience gained during the project's first year led to a revision of the classification of barren land into eight groups (with their mapping symbols):

1. *Melur* (Gravel –till) (M)
2. Sand and pumice (S)
3. Scree (C)
4. Lava (H)
5. Sandy *melur (*SM)
6. Sandy lava (SH)
7. Brown soil remnants (O)
8. Mountains (F)

It quickly became clear that there was need for a special classification for gravel (*melur*) and lava with a sandy surface. Land characteristics change significantly with the sand, and erosion becomes much more serious. This separation is also useful when trying to trace the route of sand from its origins to the area where it is destroying vegetation, i.e., encroaching sand.

The cost of mapping the high mountains and mountainous areas was considered uneconomical, so they received a special classification. According to the mapping, the boundaries of mountainous areas are somewhat lower in the north (often 500-700 m above sea level) than in the south (700-900 m), which is in keeping with the differences in climate and growing conditions.

It is easy to use this classification system in the field, and all land showing signs of erosion fits into the system. The authors of this report are aware, however, that the methods used in this classification work will need to be reviewed later as knowledge of erosion increases.

Detailed descriptions of the RALA/LR erosion classification can be found in Ólafur Arnalds *et al.* (1992) and the special RALA report on progress in soil conservation (Ólafur Arnalds *et al*., 1994). [See also Arnalds, 1999; Arnalds *et al*., 2000]

High mountain areas were not mapped.

4.3 Erosion Scale

Erosion mapping involves surveying the type of erosion and its severity. A special erosion scale is used when evaluating erosion severity. The RALA/LR erosion scale ranges from 0-5, where 0 represents no erosion and 5 represents very severe erosion.

RALA and LR have established land use eligibility ratings for rangelands used for grazing that are consistent with the above severity scale. The proposal for grazing according to erosion status is set out in Table 2.

Each erosion form has its own erosion scale that is used when classifying the land.

The erosion scale reflects the recognition of soil both as a living resource that is part of the ecosystem, and as sustainable utilization of the ecosystem.

Sandy areas are given the same classification throughout Iceland, whether at Skeiðarársandur in the south or Mývatnsöræfi in the north. *Melur* (gravel) is always classed the

Table 2. Erosion scale and land use proposals for grazing purposes.

Erosion Class	Suggestions Regarding Grazing
0 No erosion	No suggestion
1 Little erosion	No suggestion
2 Slight erosion	Care needed
3 Considerable erosion	Reduce and manage grazing
4 Severe erosion	Protected (no grazing)
5 Extremely severe erosion	Protected (no grazing)

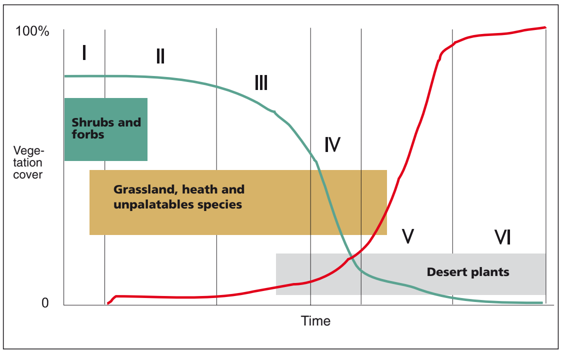
same, whether it is at 600 m elevation at Kjölur or on a non-vegetated hill in a populated area, even though it is easy to cultivate or reclaim the gravely *melur* in the lowlands while nearly impossible in the highlands. Sometimes, a land area that is improving is given a poor grading. This is the case for many areas where the land's poor condition is the result of heavy grazing between 1974-1980, a period when livestock numbers peaked. Also, the condition of vegetation can be poor even though there is little erosion, such as on the Reykjanes peninsula. Considerations of mapping, limitations and potential uses for the data are discussed later.

A short explanation of the erosion scale for each erosion form follows below. In addition, there is a series of color photographs in the RALA Report (Ólafur Arnalds *et al.*, 1994). Further explanations of the erosion scale can be viewed on the web: www.rala.is/desert. The pages also include color photos that describe the scale, with maps that depict the spread of individual erosion forms.

The erosion scale is not a linear scale, nor does it provide information regarding the degree of degradation or the progress of a particular piece of land. Ása L. Aradóttir *et al.*, (1992) described the degradation stages of Iceland's ecosystems. These definitions are used as the basis for the RALA/LR classification for *rofabards*. There are six degradation levels, and the authors describe them thoroughly in their article. A subjective model such as this one may be used to determine the approximate value of the lost resources, and the cost of restoration. When erosion level IV is reached, costs increase rapidly.

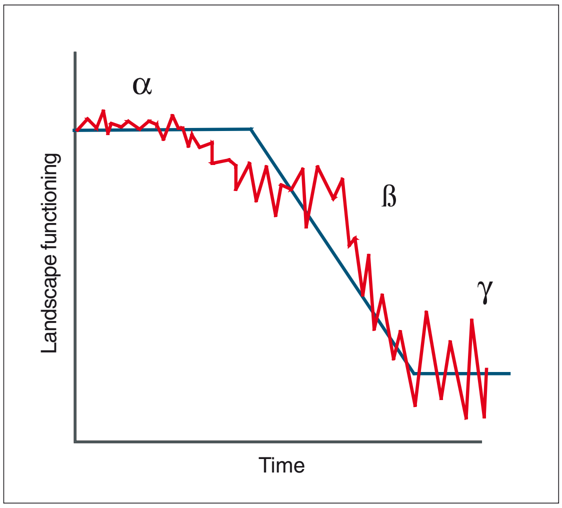
Graetz (1996) described the decline of an ecosystem and the creation of desert in a similar manner, referring to Australian ecosystems (see graph). The fluctuating line in the graph indicates that the decline of ecosystems occurs in spurts, such as during serious climatic events. The steep part of Graetz's graph corresponds to levels III and IV in model by Ása L. Aradóttir *et al.*, (1992). Erosion is most severe at this stage, but becomes less obvious when further decline occurs. Sand is assigned a severity of 4 or 5, while *melur* (gravel) is classed as 3.

A simple graphic illustration of changes to vegetation cover (green line) and the vegetation that could develop after prolonged overgrazing. I-VI represents progressive levels of change. While the vegetation cover is intact and soil erosion minimal (levels II and III), it is relatively simple and inexpensive (red line) to return vegetation to level I if grazing is reduced or stopped. When most soil cover has been lost (levels V and VI), it is much more difficult and expensive to return vegetation to level I, because it is first necessary, if at all possible, to recover soil resources. Illustration: Á.L.A., Ó.A. and S.A./J.B.P.



A simple graphic illustration of changes in vegetation cover (green line) and vegetation types which could develop under prolonged overgrazing. I-VI represent progressive levels of change. While the vegetation cover is intact and soil erosion minimal (levels II and III), it is relatively simple and inexpensive (red line) to return vegetation to level I if grazing is reduced or stopped. When most soil cover has been lost (levels V and VI), it is much more difficult and costly to return vegetation to level I, since it is first necessary, if at all possible, to recover soil resources. Illustration: Á.L.A., Ó.A. and S.A./J.B.P.

It has been pointed out that the cost of repairing damage to ecosystems increases as erosion



Graetz's model (1996). At first the land has certain resilience against setbacks until a specific threshold is reached, after wich the land degrades rapidly. The land improves to some extent after some setbacks, but finally reaches a degree of equilibrium, but in very poor condition.

becomes more severe. In fact it is often too late to repair the damage after desert has become dominant (Ása L. Aradóttir *et al.*, 1992; Graetz, 1996). This is why it is so important to pay special attention to land that is vegetated and has received an erosion severity classification of 3.

4.4 Soil Erosion on Vegetated Land

When evaluating erosion that causes loss of soil and vegetation, the rate of vegetation loss is the key factor in determining the erosion severity class, along with any signs of erosion of soil.

***Rofabards* (Escarpments).** *Rofabard* evaluation is based on measuring the total escarpment length for each unit measure of vegetated land, called the "erosion length" (expressed as km-/km² of vegetated land). Erosion escarpments can be very long – tens of kilometers – for each square kilometer of vegetated land. Erosion ledges need not move much for severe erosion to occur (see also Ólafur Arnalds and Ómar Ragnarsson, 1994). The work of Ása L. Aradóttir *et al*. (1992) on land *degradation stages* is also used when assessing *rofabards*. Land, which is at stage IV and V is assigned highest erosion severity, since *erosion length* can often reach 100 km per square kilometer of vegetated

Rofabards, *remnants of soil and vegetation, are a very visible and common erosion form in Iceland.*

land. Finally, *erosion activity* is also evaluated, on the basis of the height of the escarpments, as well as other signs of soil movement.

The entire erosion scale is used for escarpments, from one to five (B1-B5).

Encroaching Sand (*Áfoksgeirar*). *Áfoksgeirar* are found where sand encroaches onto vegetated land. The destructive power of the sand is great if there is sufficient sand supply. Sand encroachment can total as much as hundreds of meters annually. It is almost without exception in

Advancing sandfront (encroaching sand). The sand buries vegetated area which become sandy desert.

erosion grade 5, assuming that they are active. As not all are active, some receive a lower grading. After the sand moves through, all previous soil cover is lost, leaving sandy desert behind.

Erosion Spots. Erosion spots are bare soil patches in otherwise continuous vegetation cover. Their formation is often linked to hummocky land.

An erosion spot is bare soil in an otherwise vegetated surface.

As hummocks become higher and steeper there is a greatly increased danger of erosion spot forming. The top of the hummocks is more sensitive to erosion where they are comparatively drier, more exposed to wind and where there is less protective snow cover. The method of evaluating erosion spots is based on the *proportion of unvegetated land*, as well as the *height and nature of the hummocks* and signs of *soil movement*. There are usually some erosion spots on vegetated land, which is why erosion classifications D1 or D2 are quite common.

Solifluction. Solifluction is used as a collective name for erosion spots on vegetated hills together with solifluction geomorphic features.

Solifluction terraces and lobes are indicative of gradual downward movement of soils. Such features are given erosion class, even in the absence of erosion spots. With erosion spots present, the erosion severity increases.

Solifluction terraces. Cycles of freeze-thaw cause volume changes in soil which result in the formation of terraces and lobes on slopes. When erosion spots form on such slopes the soil becomes sensitive to water ero-

Erosion classifications J2 and J3 are very common on Iceland's vegetated hillsides.

Solifluction can also be found on unvegetated hillsides, and then desert determines erosion forms as mapping is primarily concerned with loss of vegetated land with solifluction.

Gullies. The basis for evaluating gullies was their number per unit length (km) of hillside, along with how deep or *active* they were. Gullies were often given a B classification, i.e. erosion escarpment. Few areas received bad grades because of gullies, but several areas in east Iceland were given a V4 classification.

Landslides. In effect, the main purpose of this classification is to get an idea of the extent of landslips. The method used to assess them is the same as that used for gullies, i.e. the number per km. Few areas received a poor grading; many heal quickly and are then no longer considered erosion areas.

A landslide. Volcanic soils (Andosols) on slopes are very susceptible to disturbances such as clearing and overgrazing.

4.5 Erosion on Wastelands

No evaluation is made regarding loss of original vegetation cover and soil on deserts. Instead, the *stability of the current wasteland surface* is evaluated. Sandy areas are very unstable, while significantly less erosion occurs on lava surfaces. It is very difficult to develop an erosion scale for wastelands. Based on general methods used abroad, all wastelands would go into the worst classification, grade 5, regardless of whether the surface was lava, gravel or drift sand.

As mentioned earlier, the erosion scale refers to the land's capacity for sustainable utilization. Grazing on wastelands can never be considered sustainable utilization of land. Vege-

Grazing the deserts is very detrimental for vegetation development. Desert surfaces in Iceland can not sustain grazing, but most are still grazed.

tation is sparse and very sensitive to utilization; only a few livestock on a large area are needed to cause overgrazing. Grazing on wastelands prevents vegetation from establishing itself unaided. The reasons are numerous. The following conclusions are drawn from general readings on grazing ecology, rangeland ecology, personal research, the paper by Ása L. Aradóttir *et al.,* (1992) and discussions in Sigurður H. Magnússon's doctoral dissertation (1994).

- Grazing on deserts prevents the natural generation of plant seeds.
- There is poor nutrient status in the infertile ground of deserts, so plants must expend considerable energy to obtain nourishment. Sand desert plants need the nutrients they have acquired. So only a little grazing causes serious damage and reduces their chances of normal growth and reproduction.
- Grazing removes the organic materials that the vegetation has accumulated through great effort, so this material does not return to the soil where it would increase fertility and help promote the natural nutrient cycle.
- Sheep selectively choose young, protein-rich plants when grazing. This prevents the roots from establishing and works against natural succession.
- Good years – humid and warm – do not strengthen the ecosystem because grazing removes the acquired reserve of nutrients.
- Vegetation spreads out with shoots, so that each vegetation patch expands. This type of growth expansion occurs much less on grazed land.

Of course, conditions in many wasteland areas are such that vegetation grows very slowly by itself, if at all, under current climatic conditions – particularly on sandy areas and high mountains. But that does not justify grazing in such areas. All grazing on these sensitive areas must be considered overgrazing, and can have serious consequences.

According to the viewpoints discussed here, all wastelands should have erosion severity 4 and 5, regardless of their erosion form. However, this was thought to be excessive, as it is felt that erosion that causes a loss in vegetated areas is more serious than erosion on desert surfaces: vegetated ecosystems as a natural resource are more valuable than wasteland soils.

In defining "soils", reference is made to the ecosystem and its quality. When vegetated land and original soil is lost because of erosion, a diverse and rich ecosystem is also lost. However, erosion on deserts is different: materials move about within a much poorer ecosystem. The erosion scale for a vegetated ecosystem involves assessing how much is being lost from such ecosystems, while conditions on wastelands are different. On wastelands, surface stability is evaluated. It is possible that erosion measured in tons of surface material could be many times greater on wastelands than, for example, on hillsides where there is severe erosion. But the position is still taken that erosion on the vegetated hillside has much more serious consequences. Of course it can be debated how the erosion scale should be used on wastelands, and it is easy to argue that the lowest grade for deserts should be 4.

It may be said that the emphasis on stopping accelerated erosion and the fundamental wish to maintain the vegetaion cover as well as the soil that exists has had an inluence on creating the erosion scale. Therefore, those wastelands considered most stable were given a grade of 3 (with the exception of lava). Drift sand received a grade of 5. In this instance, there is very severe erosion, which hampers growth, even though other conditions may be good (precipitation, summer heat, etc.).

From the above, it is clear that the scale for erosion connected with loss of vegetated land and the scale for deserts are not completely comparable. Nevertheless, those responsible for the mapping believe that the solution described here fully satisfies current needs.

Information about erosion type and severity is stored in the databank at RALA and LR. This makes it a simple matter to adjust decision-making to changing circumstances, including attitudes towards the two ecosystems: vegetated land and desert.

Detailed explanations of the erosion scale for individual erosion forms on wastelands are as follows:

Melur. *A glacial till with stony surfaceand not much loose sand.*

***Melur* (Gravel).** Gravel has a grade of 3, as long as the surface is not sandy. If vegetation is taking hold in gravel, thereby providing the surface with stability, the grade is lowered. This is why M1, M2 and M3 are common classifications.

Most of the Icelandic sand is basaltic volcanic glass, but also pumice near the most active volcanoes. The volcano Mt. Hekla on the horizon.

Sand and Pumice. Loose sand and pumice have a grade of 5. Some vegetation, such as lichens, on a sand surface indicates that the sand is reasonably stable, and the grade is lowered. Large, continuous areas with the grade of S5 are common along coastlines and near glaciers and glacial rivers.

A lava surface covered with moss.

Lava. There is not much loose soil that can erode in many recent lava areas. Such lava fields get a grade of 1, but the grade increases if there is loose soil or sand.

Sandy melur (sandy lag gravel). Sand has been transported over glacial till surface and accumulated under a stony surface.

Sandy *Melur*. It is common to find a layer of sand under the surface of gravel. This makes the gravel less fertile, and erosion increases considerably compared with gravel without sand. Sandy gravel has a grade of 4, between gravel (M3) and sand (S5). Large, continuous areas that are graded SM4 are common in the highland regions.

Sandy Lava. It is very common to have loose sand in depressions of lava surfaces. Sandy lava (SH) is given a grade of 4, and sometimes 5 if there is so much sand that it drifts as much as if it were on a sandy plain. If there is a lot of vegetation other than lyme-grass (*Leymus arenarius*) in sandy lava, the grade drops to 3, as this indicates that there is not much drifting.

Scree on Hillsides. Unvegetated, landslide-marked hillsides tend to be covered with scree.

Sandy lava surface. Sand has been carried by wind into a lava field.

Scree slopes are a specific erosion form in the classification system.

An example of this is on Mt. Hafnarfjall, south of Borgarfjörður in west Iceland. These hills are very unstable and are graded 5 if the hills are very steep and sparsely vegetated, but are given a lower grading if the incline is less and there is some vegetation.

Brown Soil Remnants. Indications of active erosion were used. If the soil is loose, it gets a

Continuous bare soil areas exist where vegetation has been stripped off by erosion, but a portion of the brown soil still remains. These areas typically become melur or bare lava surfaces once all the soil has been removed by erosion.

Erosion was not assessed for high mountains, but they are assigned a special class in the database as mountainous areas.

grade of 5; if it is hard or rocky, or if sparse vegetation binds the surface, the grade is reduced.

Mountains. Mountains have not yet been given an erosion grading. This area experiences considerable erosion activity due to a lot of precipitation, frost, etc. A grade of 4 would be the likely choice if mountains were included.

4.6 Mapping

Mapping methods used by other countries vary. In some places aerial photographs, relief maps and meteorological data are used to estimate erosion or erosion risk, without much work in the field. It is assumed that erosion is basically directly related to slope and precipitation. Models of this type should be based on extensive databases, which is often not the case. In other places erosion is assessed visually, which is sometimes supported with measurements, for example, the size of erosion spots.

When RALA and LR mapped Iceland, all

Erosion rates being measured with accurate instruments at Krísuvík, South-west Iceland. The retreat rates of rofabards can be calculated by repeating the measurements.

Geographical Information Systems were used to store and handle the geographical data.

evaluations were made visually in the field. Satellite images on a scale of 1:100 000 were used as a base. Infrared images were used to clearly show the boundary between wasteland and vegetated land (which appeared red on the photos). Transparent plastic was placed over each photograph and a line drawn around land considered homogenous. In this way, polygons are formed that are entered as individual units in the database. Erosion within each polygon was then evaluated and the conclusion marked on the transparent plastic cover. Each polygon can include various types of erosion, for example, *rofabard*, erosion spots and even *melur* in between. The marking could then be: B3 D2 M2. Each polygon drawn on the plastic overlay may not be so small that it is not possible to write in it. This means that the smallest polygons are about 12 hectares. While mapping, staff either drove or walked across the land, using suitable places as observation points.

Marking and grading all erosion multiplies the information value of the data collected. In comparison, New Zealanders mark all erosion, but each unit of land is given an overall grade.

Emphasis was placed on observing all the land that was mapped, but sometimes it was possible to use satellite images to provide an assessment for homogeneous land areas that were otherwise inaccessible. Such instances were kept to a minimum. During mapping, every effort was made to ensure maximum comparability of criteria application between staff members. This included having the staff work in pairs, and to ensure that standards remained constant, partners were regularly changed.

4.7 Processing

Data was digitized from the transparent overlays with the help of Ilwis. It was then transferred to the database, hosted on a Sun computer server using the *Arc/Info* geographical information system (GIS), and the *Arc/View* user interface. It is here that each polygon is given attributes in accordance with field markings.

The system also stores information on boundaries between rural districts, counties, designated highland ranges, contours, land reclamation areas, etc. There is also a satellite image of the entire country, which among other things is used as the basic map of Iceland. This information can be used to access data on erosion in particular rural communities, highland pastures, etc.

Leaders of most rural communities have been given maps that show areas with erosion grades of 3, 4 and 5, with the highest grade in each polygon becoming that polygon's map grade. Thus a polygon with grades of D3, B4 and M2 receives an overall grade of 4 since that is the polygon's highest grade. It is also possible to use a computer to show the extent of each erosion form, and distinguish between erosion occurring on vegetated land and on wasteland. These possibilities of the system provide the basis for the overview of Iceland given here.

Infrared satellite image (Landsat) of West Iceland. Satellite images served as base maps and were also used in the field for mapping.

5. EROSION IN ICELAND: OVERVIEW

5.1 Overview

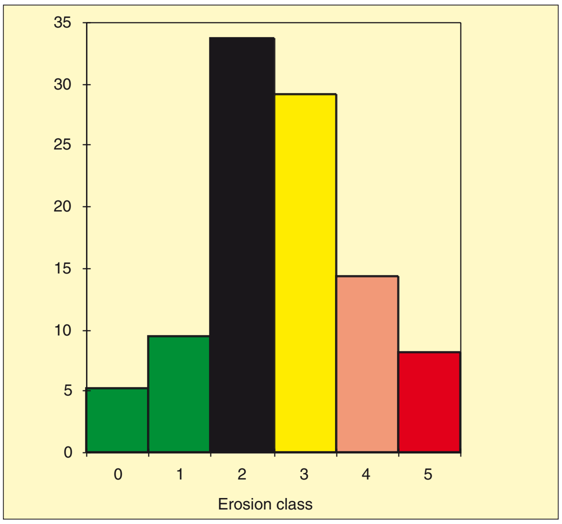
According to the erosion mapping, Iceland's total land area is 102,721 km². It should be noted that islands off the coast of Iceland were not mapped, so this figure is not precise. The country is divided into about 18,000 polygons or units, each one of which has its particular erosion forms and erosion grading. The number of polygons is an indication of how extensive the database has become.

In all, the country can be divided according to erosion grading, as shown in Table 3.

Table 3. Division of land according to erosion classes

Erosion class	km²	% of whole
0 No erosion	4,148	4.0
1 Little erosion	7,466	7.3
2 Slight erosion	26,698	26.0
3 Considerable erosion	23,106	22.5
4 Severe erosion	11,322	11.0
5 Extremely severe erosion	6,375	6.2
Mountains	9,794	9.5
Glaciers	11,361	11.1
Rivers and lakes	1,436	1.4
Unmapped	1,010	1.0
TOTAL	102,721	100

As can be seen from Table 3, areas with minimal or no erosion cover are just over 4,000 km². This applies particularly to cultivated land, forests and wetlands. Land that has been given the erosion grade of 1 or 2 has either vegetation or lava surface. Mountainous areas (the highest mountains), glaciers, rivers and lakes cover 23% of the country. It is appropriate to exclude this area from the overall assessment of the land since it is not considered to be useable grazing land – this is depicted in the next graph. The columns show the extent of the erosion classes as percentages after excluding the lakes, glaciers, rivers and highest mountains. Approximately one-fourth of the country was given the erosion grade of 4 or 5, which are the classifications that are considered unsuitable for grazing. Over half of the land has an erosion grade of 3, 4 or 5, which is severe erosion or worse.



The country divided according to erosion classes as percentage of total after glaciers, high mountains, rivers and lakes are excluded.

These conclusions are a harsh judgment on the condition of the land. Since the methods used in this research were based on Icelandic conditions, it is difficult to compare the results with figures that have been published for other countries. However, it is safe to assert that Iceland's figures are among the worst known, apart from the world's drought-stricken regions.

The conclusions clearly show that the general public has sufficient reason to view soil erosion as the most pressing environmental problem facing Iceland. Yet it must be kept in mind that soil erosion is not just linked solely to loss of vegetation. Nevertheless, land suffering severe soil erosion cannot be considered fit for grazing, whether it is vegetated land or wasteland.

The reasons that land is in such poor condition are not only found in land utilization, as will be discussed later. It must be kept in mind that about 48% of land that is not classified as mountainous has been given an erosion grade of 0, 1 and 2. This land is considered to be in good or acceptable condition in relation to soil erosion. A large part of this land is vegetated, and there are also lava areas that are either unvegetated or covered with moss. It should be noted again that the erosion graphs and tables are in no way a yardstick for the extent of vegetated land.

5.2 Erosion Forms – an Overview

In Chapter 4 it was shown how various types of erosion can occur within a polygon, with each erosion form being given an individual erosion grading. A particular polygon, therefore, could have an erosion classification of B3 D2, which indicates *rofabards* with an erosion grade of 3 and erosion spots with a grade of 2. When the overall size of an erosion form is calculated, many polygons are counted more than once, because more than one erosion form was found within them. When conclusions for all erosion forms are then added together, the overall size is 116,592 km^2, which is about 37,500 km^2 more than the actual land area. It is important to keep this in mind when looking at Table 4.

As can be seen, erosion spots and *melur* (gravel) are the most common erosion forms, with each affecting about a quarter of the country (28,217 km^2 and 25,065 km^2). Most gravel was given erosion grades of 1 and 2, which indicates *melur* within vegetated land or gravel with a vegetation cover, so there is less surface erosion. Such areas are well suited for land reclamation. Sparsely vegetated gravel (M3)

Table 4. Division of the country according to erosion forms and erosion grades(1) (in km^2).

	1	2	3	4	5	Total
Rofabards	1,735	3,511	1,997	1,234	361	8,837
Encroaching sand	2	4	13	40	26	86
Erosion spots	6,929	18,456	2,729	103	0	28,217
Solifluction	924	10,702	5,962	109	1	17,697
Landslide	398	190	89	6	0	683
Gullies	740	2,527	1,236	107	42	4,652
Melur (gravel)	9,939	8,546	6,580	0	0	25,065
Lava	1,832	228	25	0	0	2,085
Sand	195	337	318	1,087	2,828	4,765
Sandy gravel	8	741	5,407	6,217	1,286	13,659
Sandy lava	10	101	1,366	1,757	1,620	4,855
Soil remnants	17	518	350	65	36	987
Scree	64	913	2,378	1,255	392	5,002
TOTAL	22,794	46,775	28,449	11,979	6,595	116,592

Note: (1) Many polygons are counted more than once (multiple erosion forms within the same polygon) which is why the total land area is so large, Mountains, glaciers, rivers, lakes and unmapped areas are excluded from the calculations, covers only 6,580 km². This small size is somewhat unexpected, but it is explained in part by the fact that another 13,000 km² is classified as sandy gravel. The combined size of "gravel" is therefore quite large.

There are several reasons for the large extent of the erosion spots. Included in this classification are extensive heaths and half-vegetated gravel, such as where there is discontinuous moss cover, but then gravel and erosion spots are both cited as erosion forms.

It is interesting to note that areas with *rofabards* (erosion escarpments) are relatively small compared with erosion spot areas, as well as with solifluction areas, even though *rofabards* are the erosion form most people think of when erosion in Iceland is discussed. Severe erosion on *rofabards* (classes B3, B4 and B5) covers an area of 3,592 km², or just under 4% of the country. Erosion escarpments are evident where eolian sedimentation is considerable, particularly near glaciers and along volcanic zones, as will be discussed later. The proportionally small extent of erosion escarpments confirms the opinion that erosion research focusing solely on *rofabards* gives a wrong picture of soil erosion in Iceland. The possibility that erosion escarpments were at one time much more prevalent will be considered later.

The fact that solifluction is widespread is somewhat unexpected, especially since about 6,000 km² of land is classified as J3. Major sores in vegetation cover have developed in such areas. These areas are chiefly found in deep glacially carved valleys. The actual size of these areas is somewhat larger than mapping indicates, because hills often have a considerable slope length, which is not taken into consideration when area calculations are made based on horizontal distances. It is possible to see from these figures that the condition of vegetation on hillsides is poor in many places, and is suffering ongoing degradation.

The most serious erosion is found in the deserts, as they are most vulnerable to the forces of erosion. Sand erosion is severe. Sandy areas in Iceland (S, SM, SH) with an erosion grading of 3, 4 and 5 total about 22,000 km². This will be discussed in more detail later.

Lava covered with soil is not classified as lava for erosion mapping, and is therefore not considered to be as extensive as might be thought. It is interesting to note that sandy lava is more extensive than bare lava.

Table 5. The country divided by erosion class and erosion form within each erosion class (%)[1].

	Division by severity						Division by erosion form				
	erosion class						erosion class				
Erosion Form	1	2	3	4	5	Total	1	2	3	4	5
Rofabards	19.6	39.7	22.6	14.0	4.1	100	7.6	7.5	7.0	10.3	5.5
Encroaching sand	1.9	5.0	5.6	46.8	30.8	100	0.0	0.0	0.0	0.3	0.4
Erosion spots	24.6	65.4	9.7	0.4	0.0	100	30.4	39.5	9.6	0.9	0.0
Solifluction	5.2	60.5	33.7	0.6	0.0	100	4.1	22.9	21.0	0.9	0.0
Landslide	58.2	27.8	13.1	0.9	0.0	100	1.7	0.4	0.3	0.1	0.0
Gullies	15.9	54.3	26.6	2.3	0.9	100	3.2	5.4	4.3	0.9	0.6
Gravel	39.7	34.1	26.3	0.0	0.0	100	43.6	18.3	23.1	0.0	0.0
Lava	87.9	11.0	1.2	0.0	0.0	100	8.0	0.5	0.1	0.0	0.0
Sand	4.1	7.1	6.7	22.8	59.4	100	0.9	0.7	1.1	9.1	42.9
Sandy gravel	0.1	5.4	39.6	45.5	9.4	100	0.0	1.6	19.0	51.9	19.5
Sandy lava	0.2	2.1	28.1	36.2	33.4	100	0.0	0.2	4.8	14.7	24.6
Soil	1.8	52.5	35.4	6.6	3.7	100	0.1	1.1	1.2	0.5	0.6
Scree	1.3	18.3	47.5	25.1	7.8	100	0.3	2.0	8.4	10.5	5.9
							100	100	100	100	100

Notes: (1) Mountains. glaciers. rivers, lakes and unmapped areas are excluded from the calculations.

Scree on hillsides covers an area of about 5,000 km², and is common in all deep valley areas of Iceland. Some of these hills were once vegetated, for instance in the southeast.

Erosion classification is shown in two ways in Table 5. The left-hand side shows the proportional distribution of gradings for each erosion form. For example, 19.6% of *rofabards* have a grade of 1, while 4.1% of erosion escarpments have a grade of 5.

The right-hand side shows how erosion classes are distributed among erosion forms. About 5.5% of the land that has been given an erosion grading of 5 is a *rofabard* area, and 24.6% of land with a grade of 5 is classified as sandy lava.

The last column shows that the most severe erosion occurs in wastelands, and over 85% of the land that has an erosion grading of 5 is sandy desert (sand, sandy gravel and sandy lava).

It is interesting to note that 44% of the land given an erosion grading of 1 is considered gravel. These melur (gravel) areas are, to a large degree, also affected by other types of erosion, such as *rofabards* and erosion spots.

Each erosion form will be discussed in detail later in this publication.

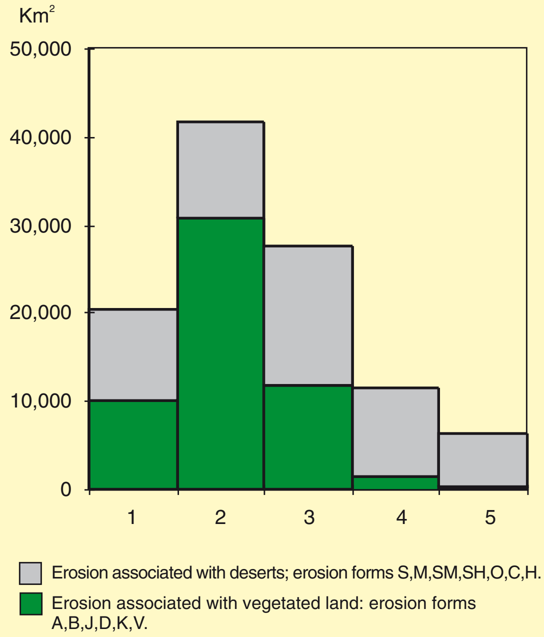
5.3 Erosion in Vegetated Land and Deserts

It is possible to use the database to distinguish between erosion usually associated with vegetated land, and that associated with wastelands (see graph). This has practical applications, as emphasis is currently on stopping erosion that causes accelerated vegetation loss.

Here, vegetated land means both discontinuous vegetated land, such as half-grown *rofabard* areas, and continuous vegetated land. This classification includes erosion that causes the loss of fertile soil, while in wastelands the soil is infertile. These classifications overlap in large areas where there is both mapped erosion connected with vegetated land, and erosion on wastelands.

As can be seen in the graph, the largest part of land assigned grades 4 and 5 is desert. It should be kept in mind that many sandy areas are in fact pathways – called sand routes – for sand moving towards vegetated land. Such sandy deserts are connected with erosion on vegetated land.

Erosion in vegetated areas and erosion on deserts (km²).

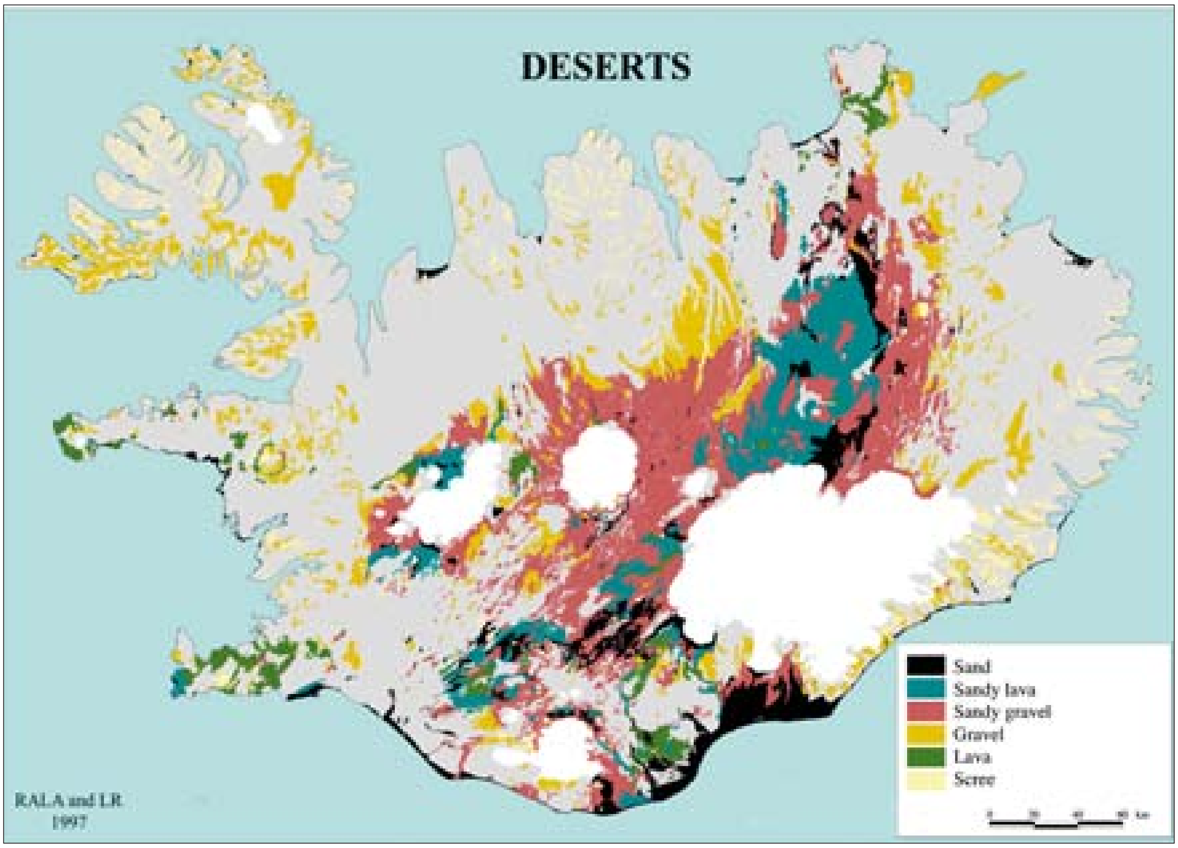


The overall extent of erosion connected with vegetated land and with wastelands is similar. Nevertheless, erosion on wastelands is usually given a higher average grading, i.e. severe erosion in wastelands is more common than erosion associated with vegetated land.

Severe erosion (erosion grades 4 and 5) covers only an area of just under 2,000 km² that is considered vegetated according to the vegetation map produced by the National Land Survey of Iceland (LMÍ, 1993) (see Section 7.3, below). Some 1,208 km² of land considered vegetated has been given an erosion grade of 3. In Table 6, the conclusions from the vegetation map (LMÍ, 1993) are compared with the soil erosion mapping results. The table shows that severe erosion (erosion grades 3, 4 and 5) occurs on 2,400 km² of land that is considered well vegetated according to the vegetation map, out of a total 14,235 km² of well-vegetated land. As can be expected, the proportion of land experiencing severe erosion increases as vegetation decreases.

5.4 Reasons for Soil Erosion

By looking carefully at erosion forms and erosion gradings, many causes for soil erosion can be inferred. This study on erosion in Iceland, therefore, can certainly answer many questions about the causes of erosion, even though this was not the study's initial purpose.


DESERTS
Sand
Sandy lava
Sandy gravel
Gravel
Lava
Scree
RALA and LR
1997

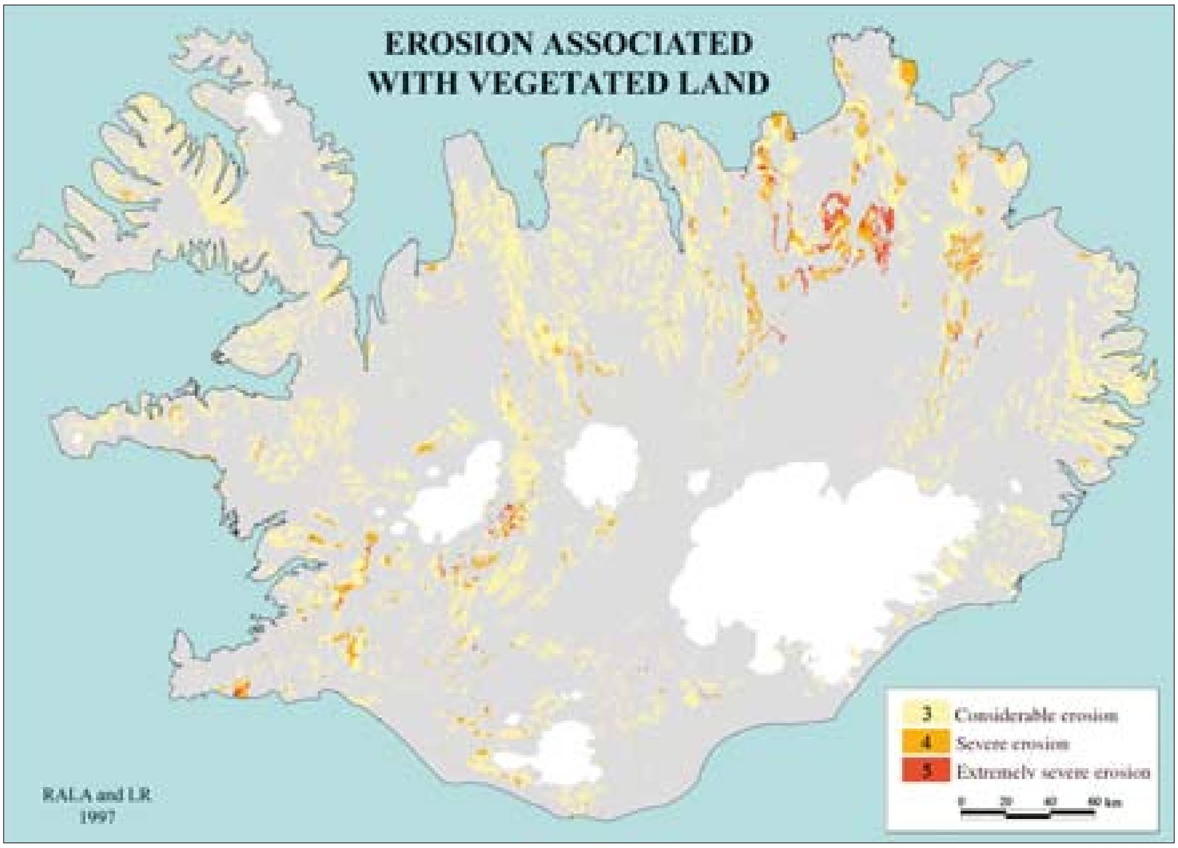

EROSION ASSOCIATED
WITH VEGETATED LAND
3 Considerable erosion
4 Severe erosion
5 Extremely severe erosion
0 20 40 60 km
RALA and LR
1997

Table 6. Comparison of the findings of the vegetation map (LMÍ, 1993) and of erosion mapping[1].

Vegetation Class	Erosion Classification 0	1	2	3	4	5	Mountains	Total
	km²							
Well-vegetated land	2,828	2,793	5,962	2,104	279	59	89	14,114
Vegetated land	776	1,851	7,737	2,537	466	134	156	13,657
Sparsely vegetated	424	1,221	7,655	4,277	723	186	596	15,082
Poor land	145	413	2,435	3,010	635	189	1,216	8,043
Deserts	147	337	2,764	11,702	8,655	5,643	6,829	3,607

Note: (1) Lava areas according to the erosion mapping are excluded.

Erosion spots, *rofabards*, solifluction, landslides and gullies are all erosion forms that are intrinsically connected with land use. This connection, however, is not absolute; for example, erosion spots are common on land that is healing.

The relation between cause and effect becomes more complex when considering wastelands. Large areas of gravel in Iceland are the result of fertile soil and vegetated land being destroyed due to land use under difficult environmental conditions. The situation is different for mountains, as it is debatable whether such areas were ever fully vegetated. It would be more realistic to ask whether mountains were more vegetated than now. This is quite likely, for the simple reason that mountains are used as grazing land, and vegetation in higher altitudes cannot withstand much grazing. Even nominal grazing can have a serious effect on such sensitive ecosystems.

The extent of sandy areas is striking. The overall size of these areas is more than 20% of the country, and it is likely that a large part of this land was vegetated at the time of Settlement: soil remnants under the sand and islands of vegetation in the wastelands are witness to this (e.g., Ólafur Arnalds, 1992). In contrast, it is very unclear as to what degree erosion in these areas is related to land use. Iceland's rugged environment has also had a say, with eruptions, glacial events and harsh climatic periods. Sandy areas will be discussed in more detail later in this report, and it is postulated that expanding glaciers, volcanic eruptions under glaciers and glacial bursts are the main reason for the destruction of continuous vegetation in many areas, though livestock grazing has certainly played a role.

Dyngjusandur, north of Vatnajökull glacier.

This spread of sand and the depletion of vegetation go together with the cooling climate of the 12th century (Páll Bergþórsson, 1969), which undoubtedly increased the speed of the erosion process. The retreat of glaciers during the 20th century has left behind vast tracts of sand, and there are many indications that sand drifting has greatly increased as a result. As sand areas grow in size, sandstorms increase significantly, which causes the brown Andosols under vegetation to become thicker and less stable.

Land utilization has probably also had an effect on how vegetated land fared in its struggle with sand and volcanic activity. Well-vegetated land, such as that covered with scrub woodlands, significantly reduces wind force along the surface. This type of ecosystem provides strong resistance against drifting sand. It is known that forest areas can bind large amounts of volcanic ash without suffering damage, as the wooded land in the vicinity of Mt. Hekla demonstrates. Natural revegetation hinders sand drifts over vegetated land as the plants bind the sand, and good years help by increasing the vegetation's vitality.

Grazing greatly reduces nature's ability to "dress its wounds", as Sigurður Þórarinsson worded it. When vegetation is strong, seed production is considerable and vegetation, particularly lyme-grass, is more likely to follow glaciers as they retreat, which reduces erosion. In lowland areas, birch and other vegetation can easily clothe the land as glaciers retreat, thereby preventing sand drifts and the creation of wastelands. However, this only occurs where land is protected from grazing.

The volcanic eruption in Vatnajökull glacier, 1996. Photo Ragnar Th. Sigurðsson.

When an eruption occurs under a glacier followed by a flood on glacial sands, a large, continuous sandy area is created, which reduces the potential for vegetation to regain a foothold. It is the authors' opinion that such events weigh heavy in the creation of sandy areas in both the lowlands and highlands. It is likely that land use, volcanic eruptions, glacial floods and bad weather conditions all work together to cause erosion.

This section has emphasized land utilization as an important factor in soil erosion and the creation of deserts. It should be pointed out, however, that grazing has been reduced over large areas of land as a result of a reduction in the national flock. Grazing time on the rangelands has also been considerably shortened. Damage to vegetation and soil caused by sheep when they were most numerous (1970s and 1980s) is still very visible; erosion requires a long time to heal by itself. Erosion that is currently seen is often the consequence of grazing methods that are no longer practised.

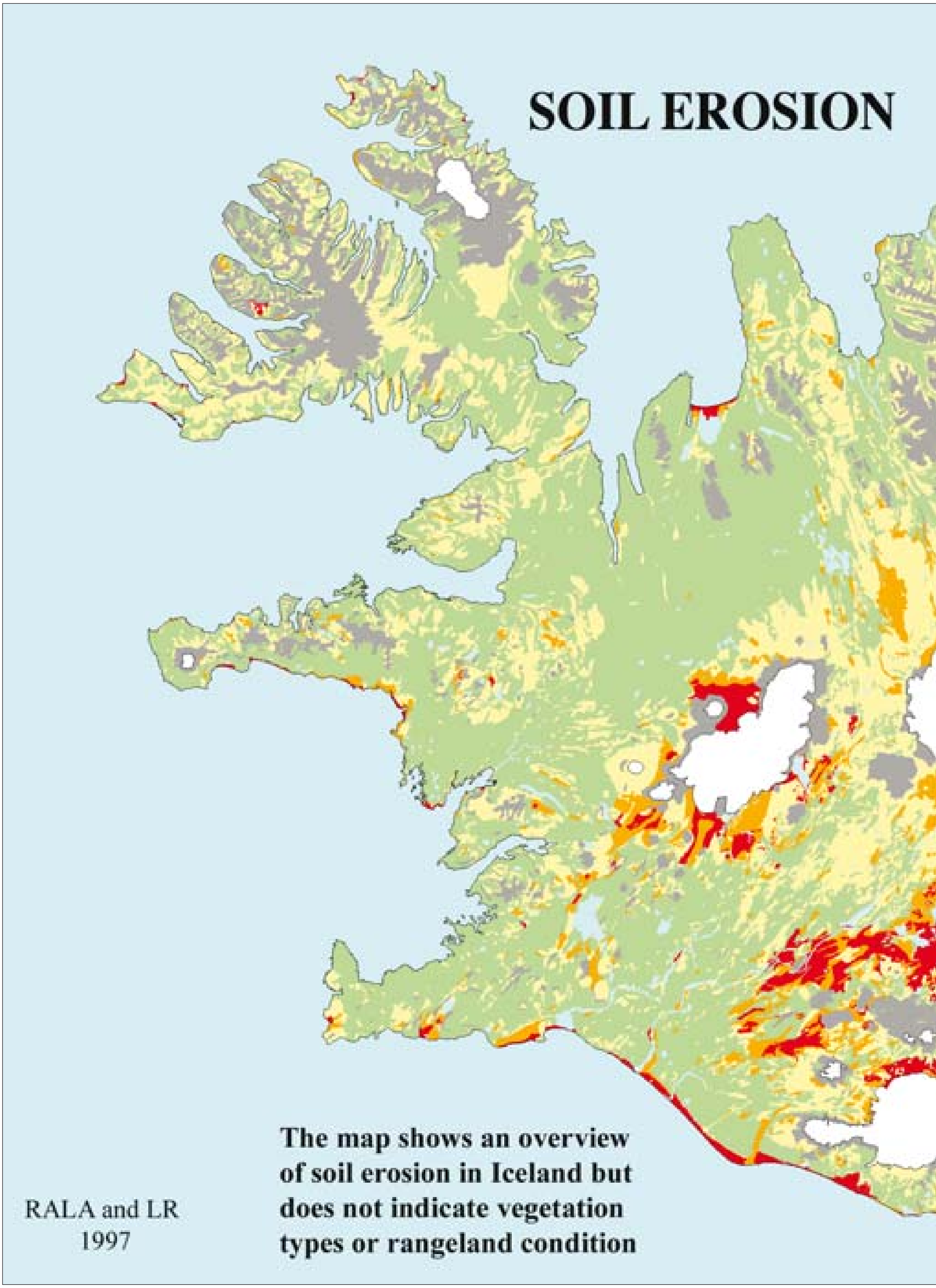
5.5 Erosion Map of Iceland

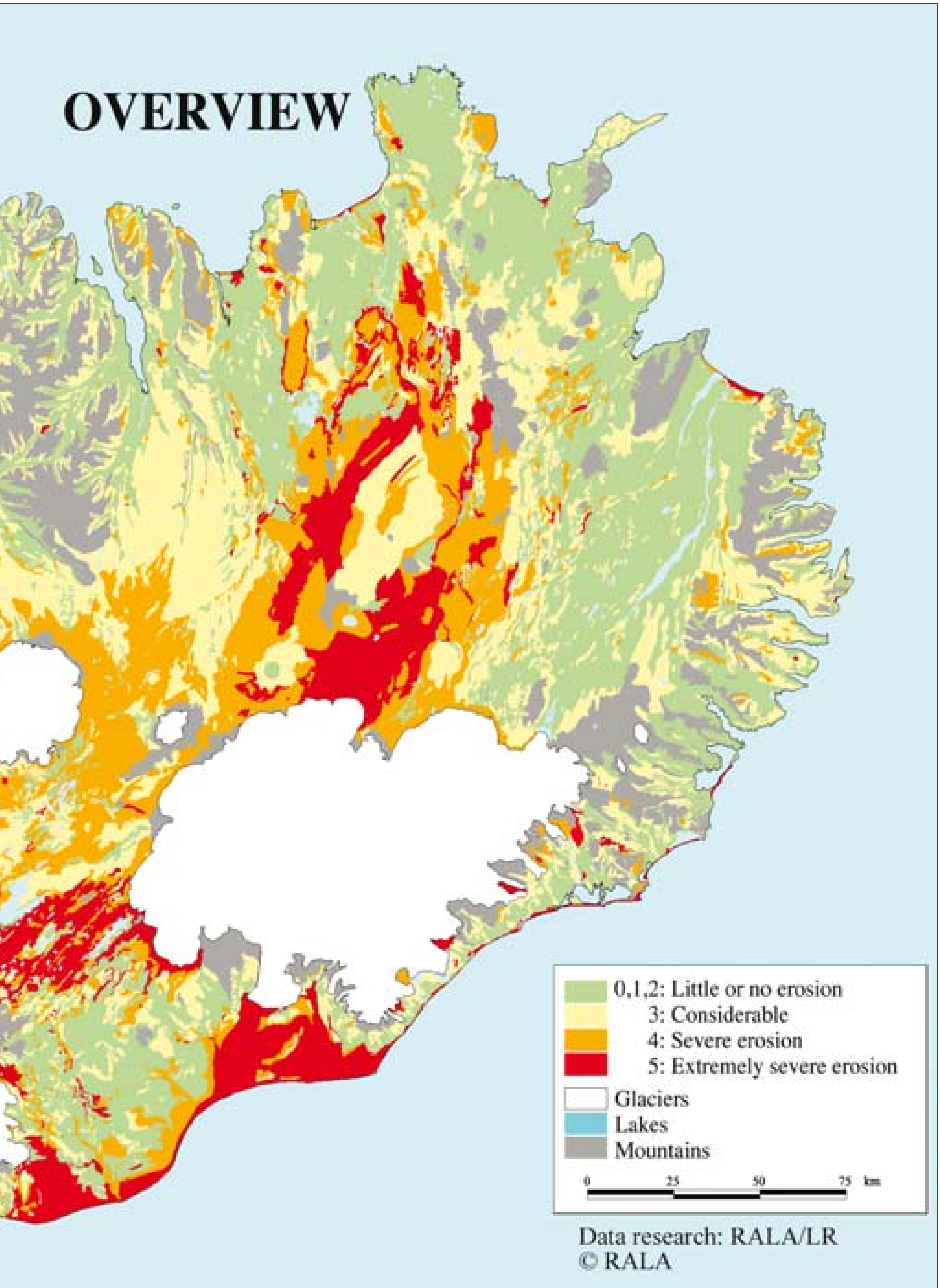
Conclusions of the erosion mapping may be depicted in several ways. The authors believe that the colour map included here summarizes the overall condition of the country regarding erosion. The map shows land classifications according to erosion gradings, i.e. the severity of erosion at each site. Erosion forms are not represented in the map. It should be reiterated that land reclamation involves not only reclaiming the land and stopping accelerated erosion, but also coordinating land-use possibilities. Attention should not be focused solely on accelerated erosion. Instead, the overall condition of the land must be evaluated and decisions made on where it may be used and where it must be protected.

A decision on land utilization is part of the erosion scale. Land that receives an erosion grading of 4 or 5 is considered unsuitable for grazing, while a grading of 3 is marginal, implying that special assessment is needed.

The erosion map shows areas that have received these classifications (yellow, orange and red for grades 3, 4 and 5, respectively). Areas where the condition is considered good or acceptable with regard to soil erosion are coloured green (grades 0, 1 and 2). The map clearly shows areas where it is difficult to organize grazing so that it fits in with environmentally-friendly land use. Also shown, and just as important, are the areas where little soil erosion has occurred. In these areas, sheep grazing should not be implicated with large-scale soil erosion.

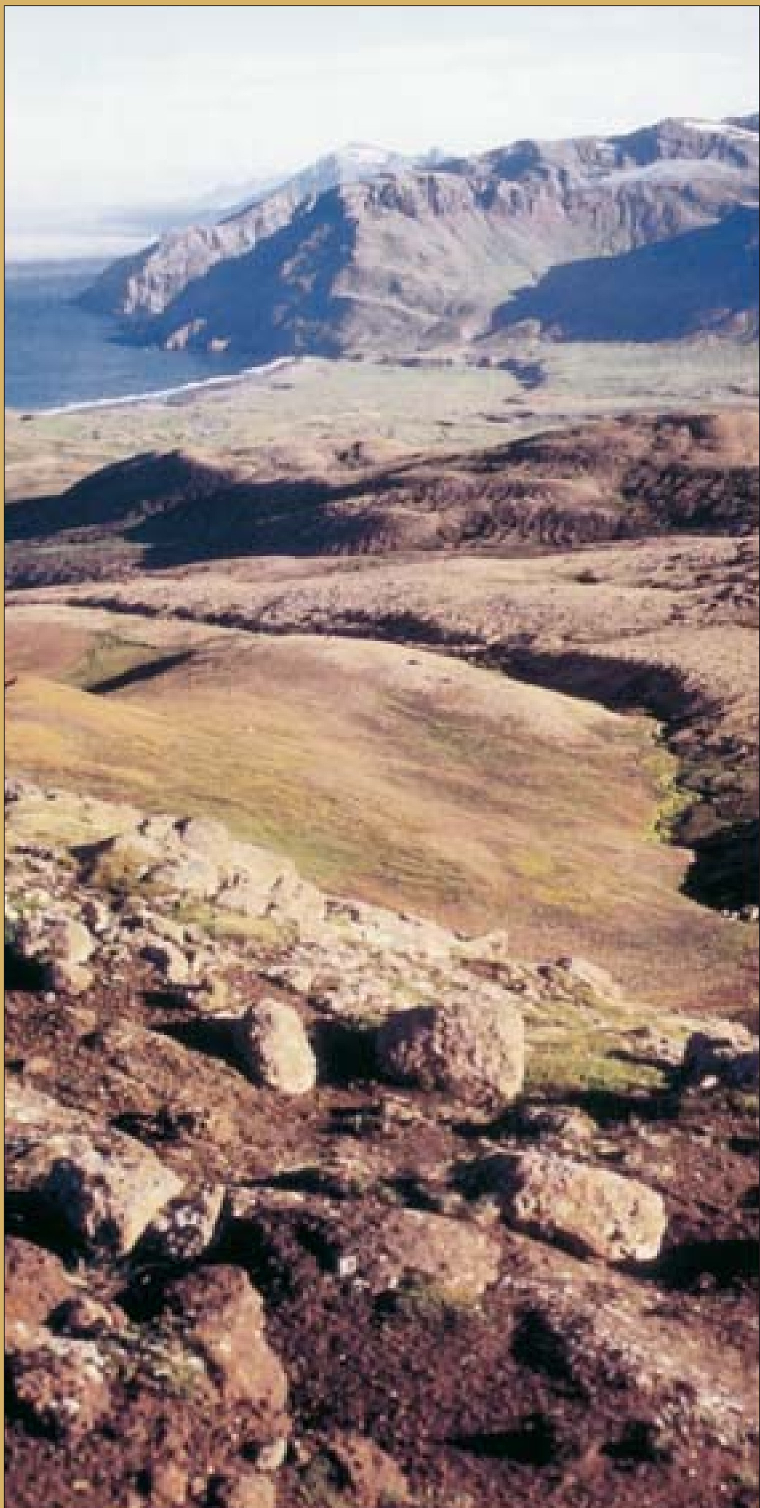
The characteristics of the main erosion areas have already been discussed. Sandy areas are the largest part of the erosion areas that received erosion grades of 4 and 5, especially the sands north of the Vatnajökull glacier and along the south coast. The least severe erosion


SOIL EROSION
The map shows an overview
of soil erosion in Iceland but
does not indicate vegetation
types or rangeland condition
RALA and LR
1997


OVERVIEW
0,1,2: Little or no erosion
3: Considerable
4: Severe erosion
5: Extremely severe erosion
Glaciers
Lakes
Mountains
0
25
50
75 km
Data research: RALA/LR
© RALA

is in the lowlands in the south, west and northwest, the parts of the lowland, and east of the Jökulsá á Brú river in east Iceland. Roughly, the map shows severe erosion in the highlands from the Langjökull glacier east to the Fljótsdalsheiði common, and in the highlands north of the Mýrdalsjökull glacier.

Several important points should be kept in mind when examining the erosion map. It does not try to indicate which areas are the most important to reclaim, since there are many different views, and various other data (which do not yet appear on the map), that need to be considered. In addition, there is no information about grazing tolerances or vegetation growth in those areas that were given an erosion grade of 0, 1 or 2 (green area). The erosion map does not indicate whether the land is improving or not. It only indicates how much soil erosion occurs according to defined grading parameters. The map primarily gives a good overview of the condition of the land with regard to erosion.



6. EROSION IN INDIVIDUAL REGIONS

6.1 Counties

The environmental conditions of Iceland's various counties differ: some are almost fully vegetated while others are characterized by high mountains and poorly vegetated wastelands. Land also varies within individual counties. For these reasons, erosion averages in each county should be interpreted with care.

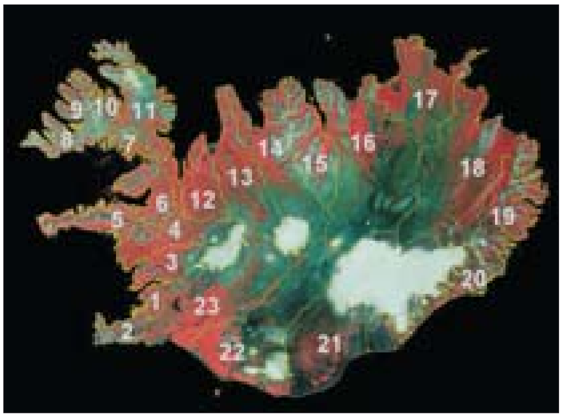
Table 7 summarizes data on erosion for all of Iceland's counties. The extent of erosion is depicted in terms of both area (km^2) and as a percentage breakdown of erosion severity classes. Municipalities were not included in this compilation.

As Table 7 shows, counties vary in size, from 664 km^2 to 11,134 km^2 (glaciers not included) according to the RALA/LR data.

Table 7. Soil erosion in counties

		km^2							%			
County	Size	0	1	2	3	4	5	Mts.	0+1+2	3	4+5	Des.
1 Kjósarsýsla	664	70	36	315	167	31	2	37	68	28	5	20
2 Gullbringusýsla	1216	152	379	416	176	57	13	8	79	15	6	15
3 Borgarfjarðarsýsla	1903	183	169	699	545	120	36	110	60	31	9	32
4 Mýrasýsla	2971	451	403	1139	571	123	169	71	70	20	10	26
5 Snæfellsnessýsla	2163	302	385	695	412	94	29	229	72	21	6	23
6 Dalasýsla	2078	132	125	1191	557	39	0	22	71	27	2	20
7 A-Barðastrandarsýsla	1074	40	61	449	359	14	0	149	60	47	1	43
8 V-Barðastrandarsýsla	1519	38	60	433	693	21	11	254	42	56	3	64
9 V-Ísafjarðarsýsla	1221	31	28	253	451	114	21	320	35	48	15	65
10 N-Ísafjarðarsýsla	1958	26	87	432	656	49	8	692	43	54	5	63
11 Strandasýsla	3465	59	82	1941	816	16	0	540	71	30	1	30
12 V-Húnavatnssýsla	2496	129	495	1595	133	15	4	96	94	6	1	7
13 A-Húnavatnssýsla	4146	140	276	2063	1146	141	22	229	65	33	4	25
14 Skagafjarðarsýsla	5355	284	203	1378	1990	453	0	995	43	42	11	47
15 Eyjafjarðarsýsla	4089	241	52	691	1403	715	4	972	32	42	23	63
16 S-Þingeyjarsýsla	11134	531	661	1153	3428	2853	1685	717	23	33	44	69
17 N-Þingeyjarsýsla	5393	208	505	2014	1216	590	360	390	56	25	19	34
18 N-Múlasýsla	10568	222	892	3830	2180	1647	491	1119	53	24	23	42
19 S-Múlasýsla	3949	163	183	1239	1325	219	28	740	50	42	8	37
20 A-Skaftafellssýsla	2962	93	188	374	727	267	866	373	26	31	40	76
21 V-Skaftafellssýsla	5663	242	593	1047	895	538	1602	303	42	17	41	55
22 Rangárvallasýsla	7365	274	880	820	1662	1790	1094	510	30	26	44	67
23 Árnessýsla	7932	436	611	2508	2350	989	271	464	50	32	18	39

A few counties have land areas of less than 50 km² with erosion grades 4 and 5 (severe) , namely Kjósarsýsla, Dalasýsla, Barðastrandarsýsla, Strandasýsla and Vestur-Húnavatnssýsla. There are three counties that have more than 1,000 km² of land with erosion grade 5, namely Suður-Þingeyjarsýsla, Vestur-Skaftafellssýsla and Rangárvallasýsla. These counties suffer from being in close proximity to glaciers and volcanic activity. Overall, severe erosion areas (erosion grades 4 and 5) are comparatively limited in west Iceland, the West Fjords and in northwest Iceland. Mýrasýsla is an exception, as it has land bordering sandy areas north and west of the Langjökull glacier and around the Eiríksjökull glacier. From Suður-Þingeyjarsýsla county and south to Árnessýsla county, excluding Suður-Múlasýsla county, there is land with erosion grades of 4 and 5 covering more than 900 km². Suður-Þingeyjarsýsla stands out, in that it has 4,500 km² of land with erosion grades of 4 and 5.



Map showing county borders.

As stated earlier, mountainous areas (i.e. the highest areas) are excluded from the calculations in Table 7. Such areas are extensive in the Skagafjörður, Eyjafjörður and Norður-Múlasýsla counties. That which is considered mountainous in this study is so high that it is not generally considered as feasible grazing land, and should therefore be classified with land that is given erosion grades of 4 or 5.

As can be seen in Table 7, many counties have land areas with erosion grades of 4 and 5, but which account for less than 5% of the total area. This must be considered quite acceptable. These counties are all in the west, West Fjords and northwest. Vestur-Húnavatnssýsla county is a special case regarding soil erosion. About 94% of the land has little erosion cover (0+1+2), while less than 1% receives an erosion grade of 4 or 5. A few counties have 70% or more of their land area erosion-classified as 0+1+2, all of which are in the western part of Iceland.

As the condition of land within each county varies considerably, it would be unwise to draw broad conclusions about soil erosion for counties as a whole.

Here follows a discussion of land conditions by region. In the next chapter, discussion centers on soil erosion in each rural district and highland rangeland area. Each region of the country is shown in two facing maps.

One of the two maps for each region is an infrared satellite image, which shows the main features for the area. Vegetation appears red: the more vegetation, the redder the image. Complementing the satellite images are erosion maps of the same areas, which also show administrative boundaries.

6.2 West Iceland

West Iceland is considered one of the best-vegetated areas of the country, as can be seen from the infrared satellite image. It was surprising how much erosion there was in some parts of the otherwise well-vegetated valleys of Borgarfjarðarsýsla county. The erosion most often consisted of erosion spots and solifluction /ero-

Sandy area between Eiríksjökull and Langjökull glaciers. A glacial river disappears into a lava-field, leaving it's sediments on the surface which are then exposed to wind.

sion spots on vegetated hills, erosion forms which are primarily a result of grazing. This is good reason to urge that the hills of Borgarfjarðardalur valley be utilized cautiously, particularly in early spring when the soil is sodden. In areas where soil is exposed on hillsides, measures should be taken to close off the area to prevent the possibility of soil washing out to sea over the coming years and decades. Solifluction and sandy gravel are the most common erosion forms in Borgarfjarðarsýsla county where erosion is serious (erosion severity 3, 4 or 5). The most common erosion in Mýrasýsla county is particularly in the form of solifluction, sandy gravel and sand.

Erosion spots on slopes/solifluction are serious in a great part of the Snæfellsnes and Dalasýsla counties. These counties are otherwise well vegetated, so these conclusions should be seen as a warning that major vegetated areas could be lost for good over the coming decades if grazing is not carefully supervised. Large-scale grazing of horses on hillsides, therefore, should be prohibited over all of the country.

The most serious erosion is in the highlands, particularly from sand carried by glaciers and glacial rivers. Mapping has verified many very sandy areas west of the Langjökull glacier and around the Eiríksjökull glacier. Hítardalur in the easternmost part of Mýrasýsla county is another well-known erosion area, but is now for the most part a fenced-in reclamation area.

Gravel is conspicuous in many areas of west Iceland, where the land should be fully vegetated. It is common to see alternating patches of gravel and vegetated land. These are given erosion severity grades of M1 or M2, i.e. gravel with erosion severity of 1 or 2. This gravel is the consequence of erosion that presumably had been worse at one time. It is often an easy matter to heal land with such problems in the lowlands, as demonstrated by the excellent results achieved by many farmers.

6.3 West Fjords and Strandir

Erosion intensities in the West Fjords reflect that these are highlands with steep hills and scanty vegetation in the highland plateau.

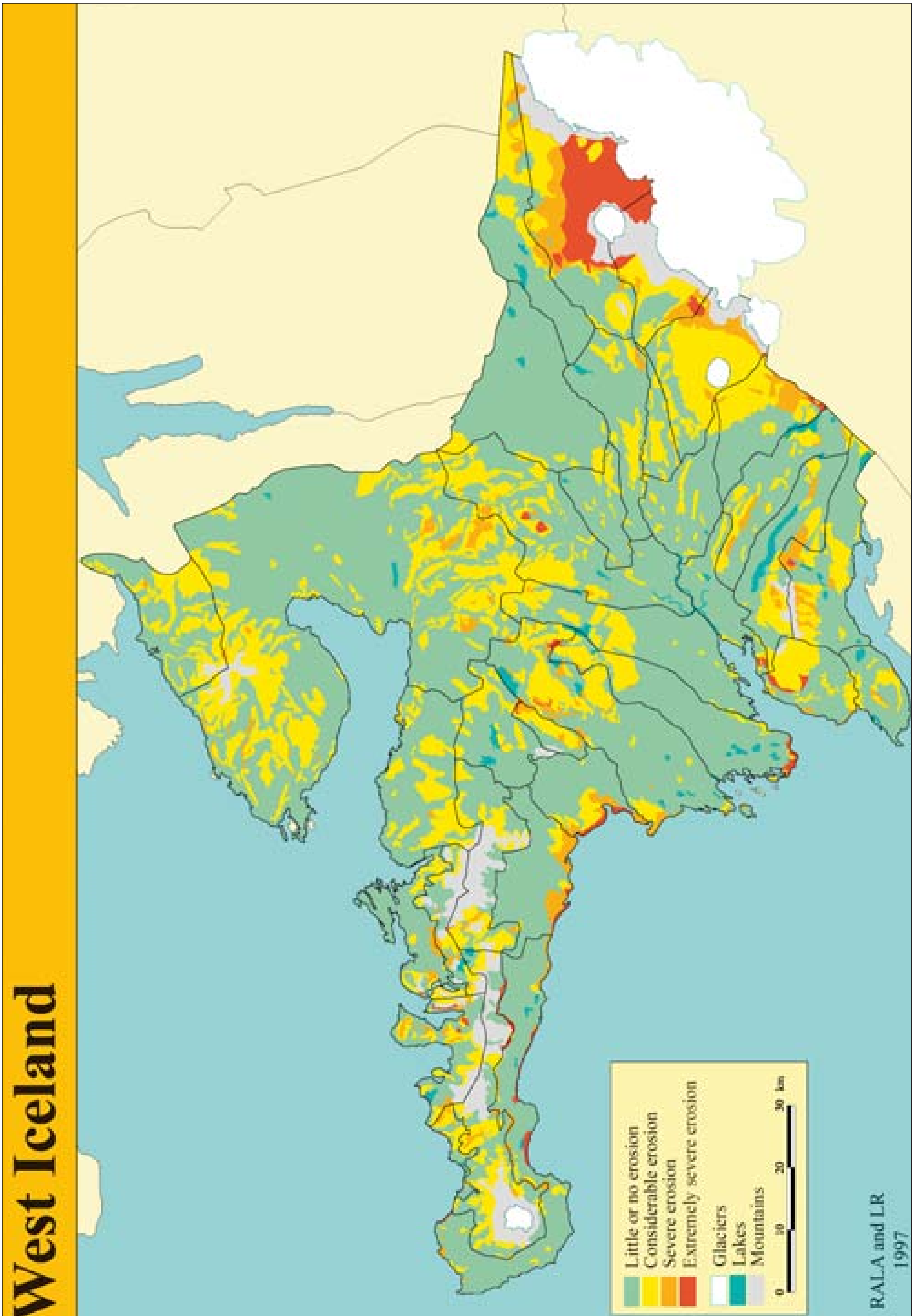
Vestur-Barðastrandarsýsla and Ísafjarðarsýsla counties are dominated by mountains and wastelands – often 60-70% of the land area. An erosion severity of 3 (considerable erosion) is common, particularly because there is a lot of scree and solifluction on vegetated hills. Erosion spots are widespread where the high country is vegetated, in particular in Vestur-Barðastrandarsýsla. Water erosion is also common, as might be expected in such steep landscapes. However, there are a few areas where erosion is considered severe (erosion severity 4 and 5).

The highlands in the West Fjords are not so sandy as those surrounding the glaciers situated in the central highlands of the interior. There is not much lowland area, so the proportion of well-vegetated land where erosion is minimal is less than in many districts, often between 30% and 40%.

Strandasýsla county is generally more vegetated than the Barðastrandarsýsla and Ísafjarðarsýsla counties, and has less land with an erosion severity of 3. The proportion of land where there is little erosion is higher, especially in the Kirkjubólshreppur and Bæjarhreppur districts.

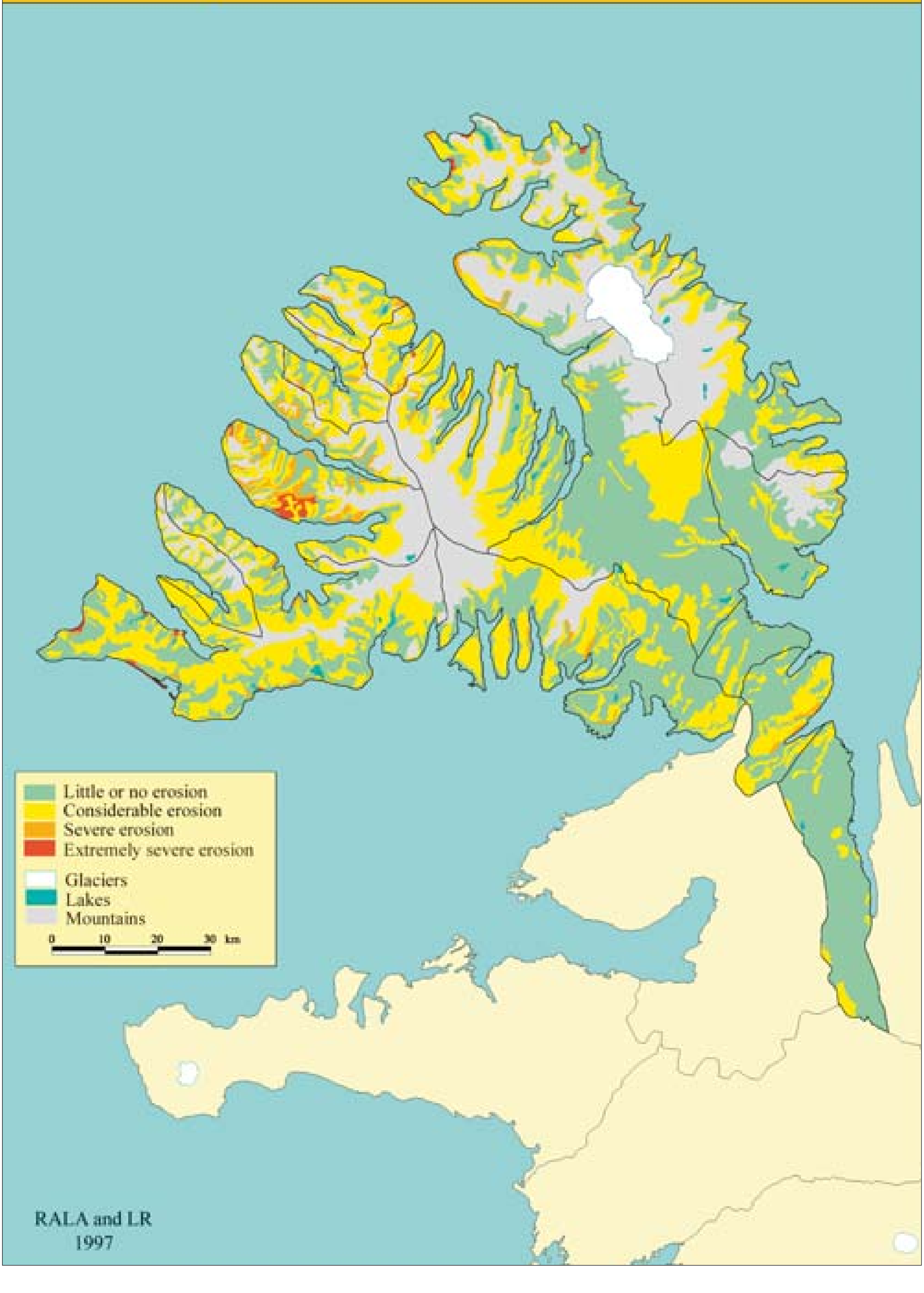
Lightly grazed valley in the West Fjords with minimal erosion problems.

A valley in the West Fjords with good vegetation cover, but a large number of the slopes are scree slopes. Most of the slopes were previously vegetat-


West Iceland
Little or no erosion
Considerable erosion
Severe erosion
Extremely severe erosion
Glaciers
Lakes
Mountains
0 10 20 30 km
RALA and LR
1997


0 10 20 km
© ESA/LMÍ/JV 1997
Image processing: LMÍ/RALA
Satellite image: Landsat 5

West Fjords and Strandir




© ESA/LMÍ/JV 1997
Image processing: LMÍ/RALA
Satellite image: Landsat 5
0 10 20 30 40 km

6.4 Northwest Iceland

Vestur-Húnavatnssýsla county is considered the best vegetated county in Iceland, with the fewest erosion problems, according to the vegetation map (LMÍ, 1993). It should be noted that a satellite image taken in 1987 shows considerably less vegetation thriving to the south than to the north of the common grazing land fence. This could possibly be seen as an indication that highland pastures have been fully used or overused. It is apparent that while Vestur-Húnavatnssýsla county is well vegetated, care must be taken when utilizing vegetated land, especially highland rangeland. The total amount of land considered in good condition (0, 1 and 2) compares well with well-vegetated land and sparsely-vegetated land on the vegetation map. Wetlands are abundant in the highlands, so the land is better able to withstand grazing than many other areas, where vegetation has disappeared.

Austur-Húnavatnssýsla county is also widely well vegetated in settled areas, as well as in the highlands to the west of the Blanda river. Erosion spots, however, are widespread in highland ranges (grade 3). The Grímstunguheiði and Auðkúluheiði commons are poorly vegetated on their southern parts, and there are areas where erosion is severe. The land gets higher east of the Blanda river, and eventually becomes a continuous desert in the highlands, stretching all the way to east Iceland.

A sandy area stretches along the sea at the southern part of Húnaflói bay, but few other settled areas have an erosion severity of 4.

Horse grazing is beginning to damage rangeland in Húnavatnssýsla county, and could detract from its currently green appearance. Serious erosion is rather widespread on hillsides as a result of horse grazing, particularly in the east of the county. It was previously discussed how such erosion could easily cause considerable damage over a short period of time, and in addition, solifluction on such hillsides increases the danger of landslips.

Solifluction features on a slope in Northwest Iceland. Such slopes are very susceptible to disturbance. This slope is used for grazing by horses, which are too heavy animals for these vulnerable slopes.

6.5 Central North Iceland

There is less vegetated land in the highland rangelands in Skagafjörður county than on the commons of Austur-Húnavatnssýsla county. Considerable erosion occurs along the margin of the lower highland areas, with erosion encroaching onto vegetated areas, and higher areas merge into highland desert. North of the Hofsjökull glacier, are some very sandy areas, but remnants of vegetation still linger in low areas where there is ground water. This includes remarkable vegetation areas with palsa permafrost features on the site of the Orravatn lake, situated over 700 m above sea level north of the Hofsjökull glacier. Unfortunately, the area is still used for grazing. Horse grazing could easily destroy these vegetation remnants over the coming years if nothing is done.

Orravatnsrústir north of Hofsjökull. Permafrost features in vegetation remnants in North Iceland. The mounds (about 10 x100 m in picture) are so-called palsas (rústir in Icelandic), with a frozen ice core.

The lowlands of Skagafjörður county are well vegetated, but horse grazing causes damage to both vegetation and soil in many areas. It is clear that grazing by horses in many places around Skagafjörður is much more than can be considered sensible. Most pastures are too small, however, to register on maps with a scale of 1:100 000.

Hillsides are very susceptible to erosion, as they are steep and cut by landslips in many places. A large part of Skagafjörður county received an erosion severity grading of 3 (42%). The highlands between the Skagafjörður and Eyjafjörður counties were chiefly mapped as mountains, since most are higher than 1,000 m.

Eyjafjörður county is a thriving agricultural region. This is not denied, but it should be noted that vegetation in Eyjafjörður county is actually not very extensive. It is concentrated on valley bottoms and steep hillsides. Extensive highland ranges do not reach the valleys of Eyjafjörður. As a result, rangeland is a limited resource. There are indications that there were far too many sheep when sheep farming was at its peak.

Solifluction on hillsides is a widespread problem, as many hills are steep and therefore vulnerable. It was mentioned before that there is a relationship between landslips, solifluction and grazing pressure. Landslides are a natural part of nature's processes, but frequency increases as vegetation is removed (see discussion on solifluction in Chapter 8). Most districts in Eyjafjörður county enjoy a green vegetation cover, but the people of the region should think seriously about the hillsides, as recent landslips have demonstrated. Excessive horse grazing on these hillsides is not sensible land utilization.

6.6 North east Iceland

Þingeyjarsýsla is an area of great contrasts. Some areas have erosion levels that are among the lowest found in Iceland, yet there are also widespread wastelands and erosion areas that are massive. It is quite apparent that depletion of vegetated land due to erosion is occurring more rapidly in Þingeyjarsýsla than anywhere else in the country. The land is widely sensitive – dry and hummocky – with coarse-textured volcanic ash layers in the soil.

There is a continuous sandy area in Suður-Þingeyjarsýsla county from the Skjálfandafljót river east over the Jöklulsá á Fjöllum river and stretching all the way north to the Mývatnssveit district, where vegetation is shielded by the Bláfell and Búrfell mountain ranges. There is also a sandy area west of the Skjálfandafljót river, which originates from Sprengisandur (central Iceland) and from as far south as the Hofsjökull glacier. Sand is continually being carried north, and some sand tongues reach north to the Eilífsvatn lake. There is sand at Hólasandur, which is continually expanding and moving north.

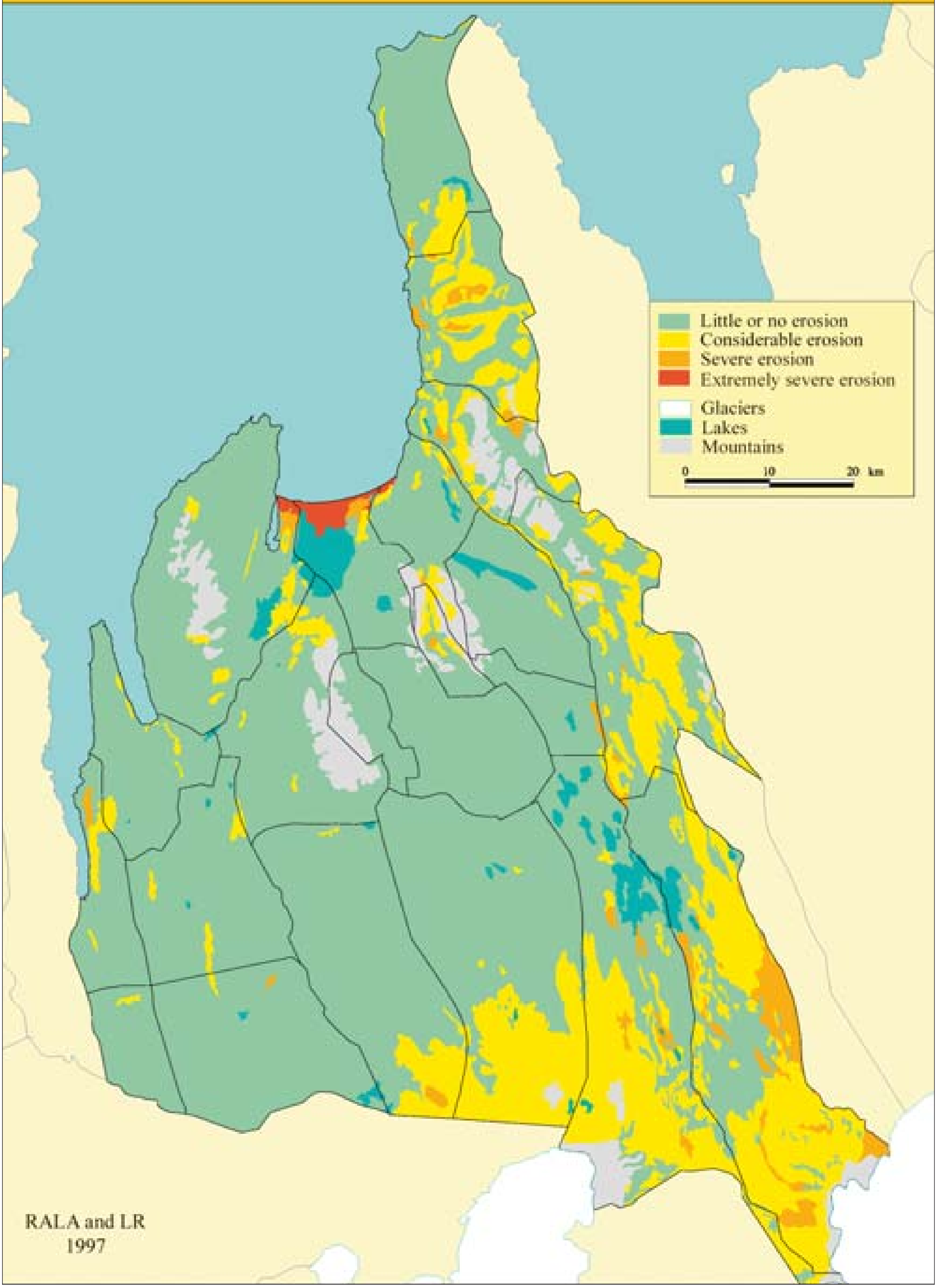
Severe erosion in the Hólsfjöll region Northeast Iceland. The area has been protected from grazing and erosion is actively being halted.

One of the country's worst erosion escarpment areas is found in Suður-Þingeyjarsýsla county. Yet there is also well-vegetated land in most districts, for example, Aðaldalur valley and Mývatnssveit district. It often happens that care is not taken to separate erosion areas from well-vegetated grazing land. This leads to the average erosion severity grade being rather poor, even if the land is generally in good condition.

Sandy deserts dominate the southernmost part of the highlands in Norður-Þingeyjarsýsla county, and large sand drifts stretch from the Jökulsá á Fjöllum river north to the Hólsfjöll glacier and down to the Öxarfjarðarhreppur district. LR accomplished a great achievement when, in 1954, it halted the advance of sand in Öxarfjörður valley. A sand area still exists

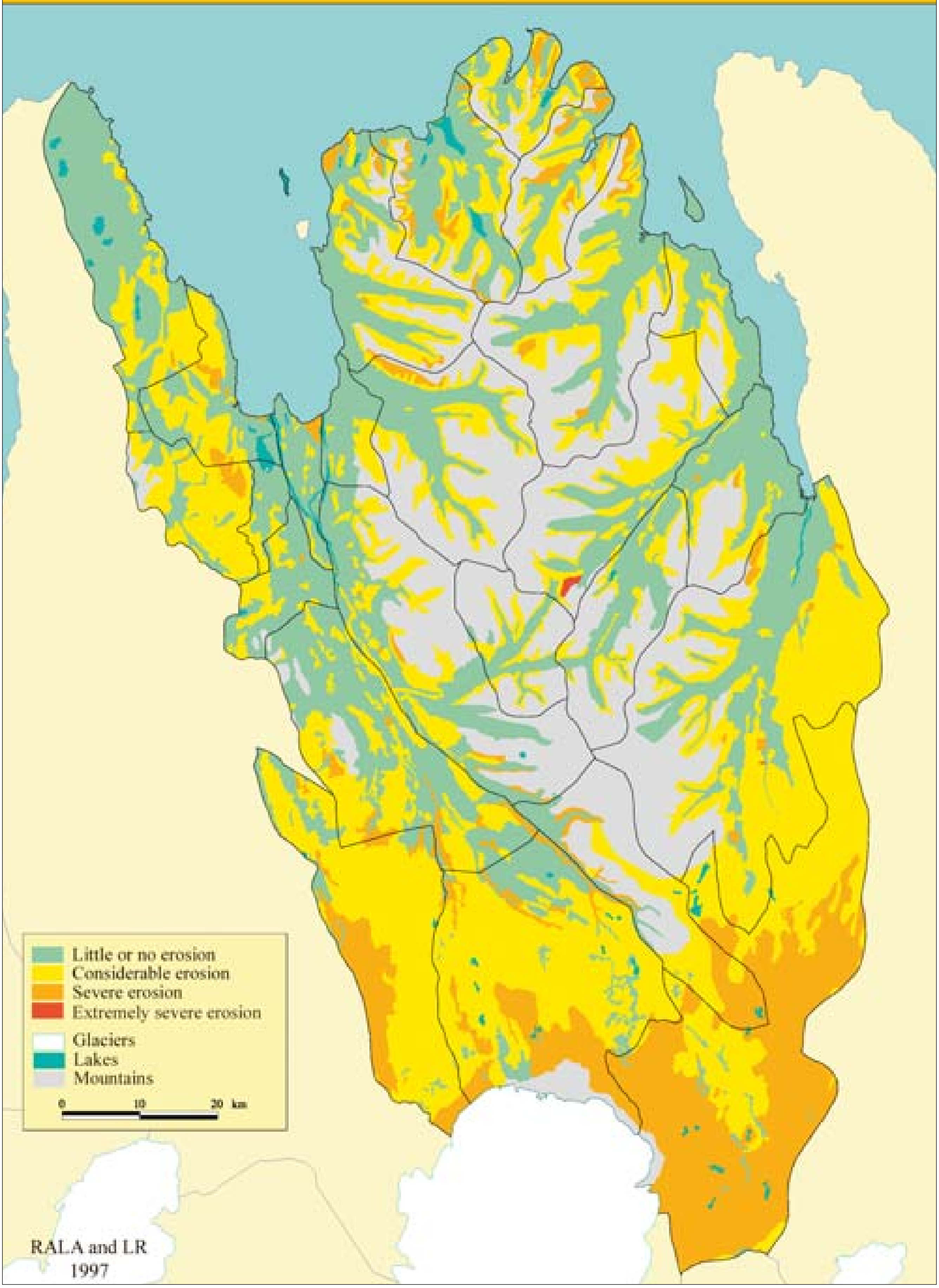
Solifluction slopes in Northeast Iceland, near the shore. This land is very vulnerable to disturbance and erosion.

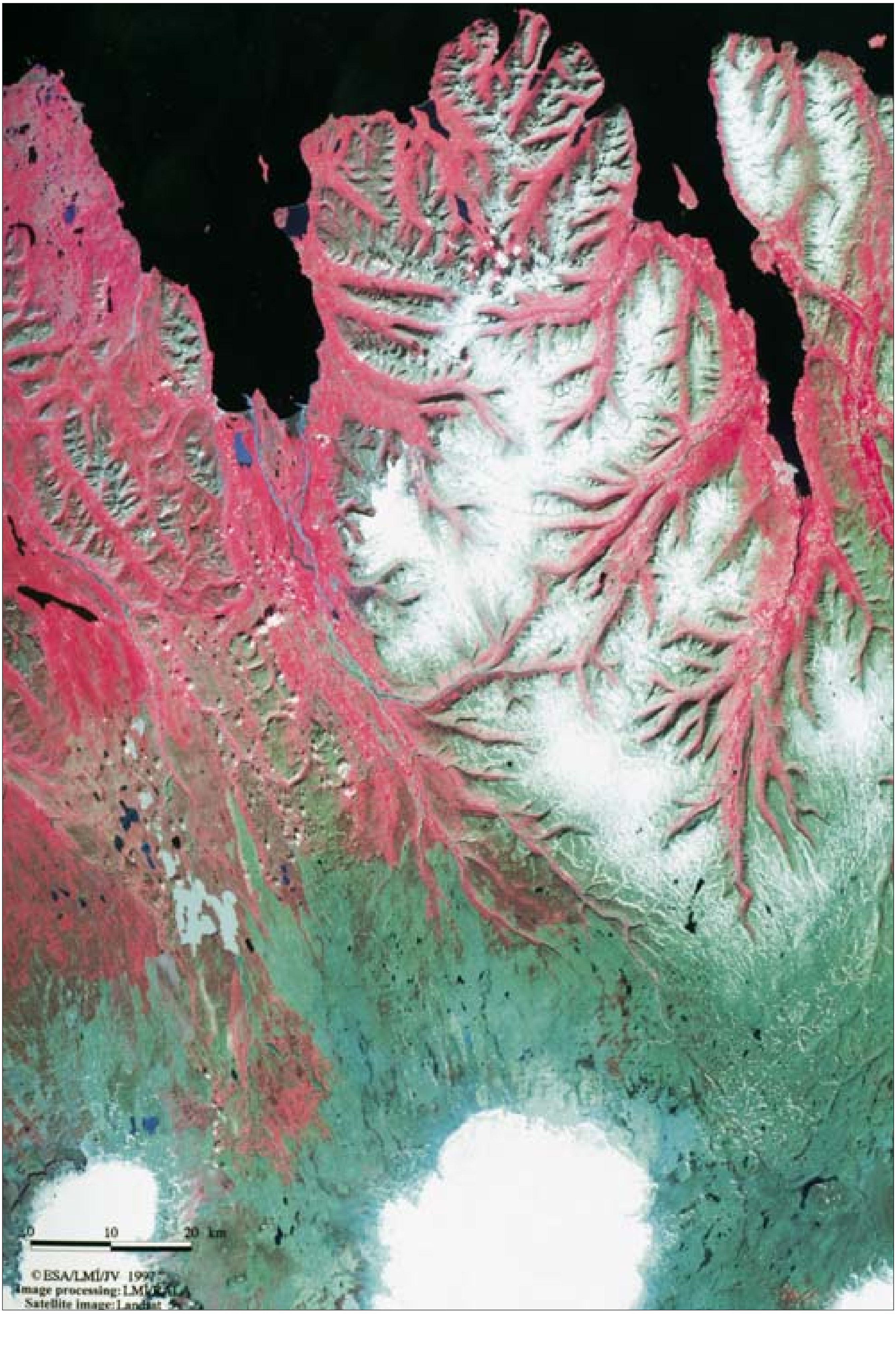
Northwest Iceland




0 10 20 30 km
@ESA/LMÍ/TV 1997
Myndvinnsla : LMÍ/RAEA
Grunnmynd : Landsat 5

Central North Iceland

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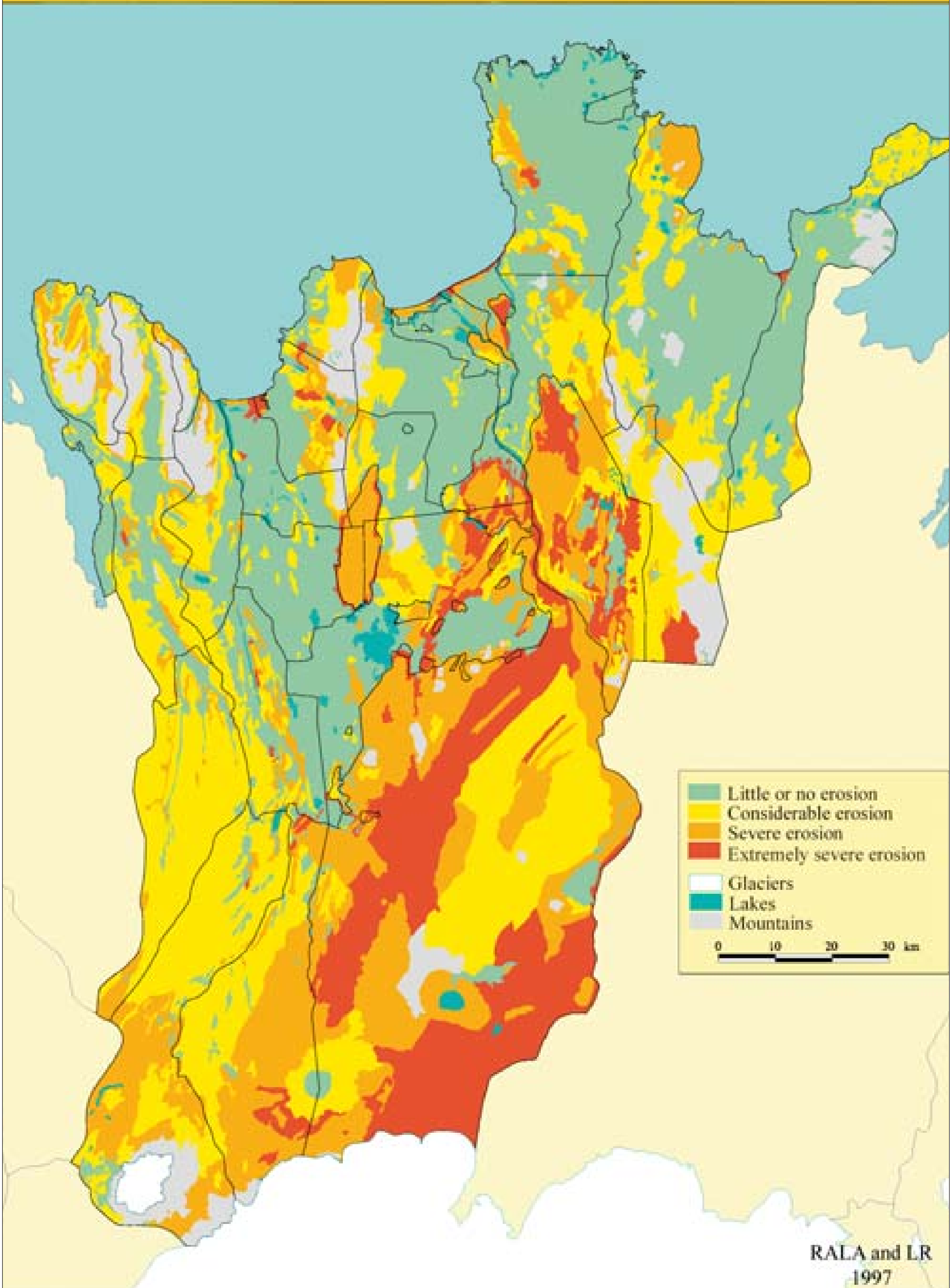
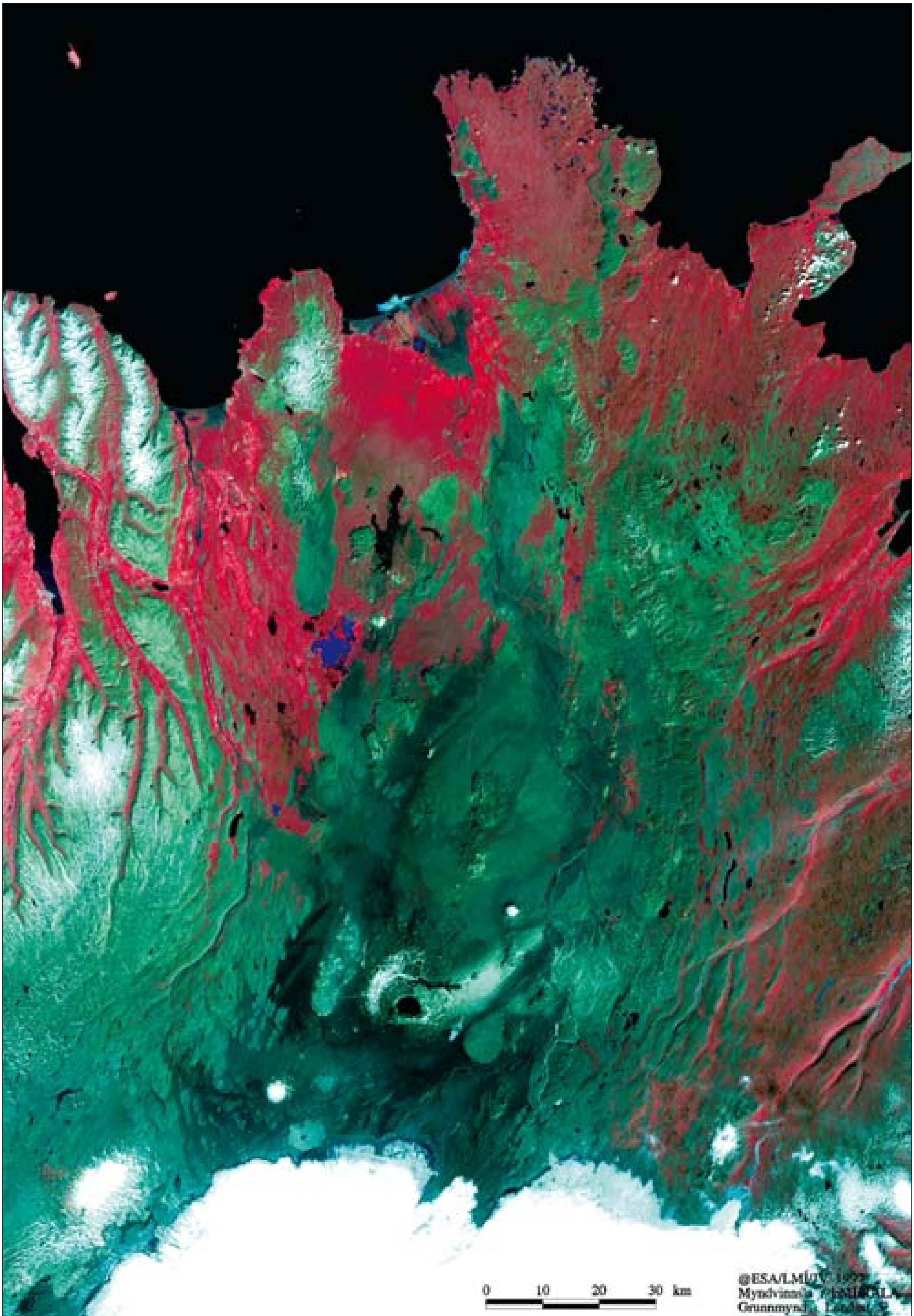
Northeast Iceland

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along the shore of Öxarfjörður fjord. There are vast vegetated areas at the Kelduhverfi, Öxarfjörður and Melrakkaslétta heaths, where erosion is considered minor. A large solifluction area is at Afréttur to the north of the Þistilfjörður fjord, and significant frost heaving is evident at Slétta, in Þistilfjörður and Bakkaflói. Hummocks are often prominent and solifluction considerable. Such ecosystems are extremely sensitive and should not be grazed by horses.

There are many conservation fences in Þingeyjarsýsla county, totalling 324 km in length and enclosing 1142 km^2. Important work has been done there in stopping the encroachment of sand onto vegetated land. Fencing, however, is only a short-term solution and falls far short of protecting all the areas where severe erosion is occurring. It is of utmost importance to protect much larger areas from grazing, and increase land reclamation measures where there is most danger to vegetated land, such as at the rofabard areas around Mt. Jörundur. In addition, a special campaign is necessary to stop sand drifting that feeds áfoksgeirar (encroachment), which is degrading vegetated land in the Skútustaðahreppur district. Also, new methods need to be found for land reclamation work, with the aim of diverting sand away from vegetated areas to areas where it will not cause damage, such as into glacial rivers. The flow of sand from glaciers is significant and will not be stopped. It is therefore only a temporary solution to stop sand in encroachment areas where sand travels over vegetated land, such as at Dimmuborgir in the Mývatn lake area. The flow of sand to the areas must be reduced.

It has long since become necessary to protect the wastelands at Ódáðahraun and Mývatnsöræfi from grazing, along with the sandy areas to the

Highlands north east of Vatnjökull glacier. Vegetated

south and west of settled areas in the Mývatnssveit district, as well as Grænavatnsbruni and highland areas south of the Bárðardalur valley. The Hólsfjöll area in Norður-Þingeyjarsýsla county has now been protected from grazing and the results are already evident.

6.7 East Iceland

Land quality varies in east Iceland, from well-vegetated highland areas to the deserts of Möðrudalsöræfi and Brúaröræfi. Sand is prominent on the highlands, and vegetated areas in the vicinity have declined. Nevertheless, the condition of grazing land is generally good on well-vegetated rangelands, such as on Hofteigsheiði heath and south over the Fljótsdalsheiði common to the highlands near the Vatnajökull glacier. Many of these rangelands are among the best in the country regarding soil erosion. But Múlasýsla county also has areas that receive among the worst erosion severity grades in Iceland. Considerable erosion on vegetated land occurs in the highland rangelands of Vopnafjörður and Jökuldalsheiði common and in the valleys of Brúaröræfi. From Borgarfjörður south to Seyðisfjörður, steep slopes that have little vegetation, are common.

Both the southern part of east Iceland and southeast Iceland sometimes receive enormous

A combination of water-channels and rofabards on hill-slope in East Iceland. Only about 50% of the soil/vegetation surface remains.

amounts of precipitation in a very short period. Land characterized by steep hills is also common to both areas. The soil in these areas is very sensitive to erosion and in many places soil and vegetated cover have been replaced by scree. If there are soil sores on hillsides, serious erosion can occur very quickly. Hillsides, therefore, are particularly sensitive to erosion and many districts receive poor grades in regard to soil erosion. It should be pointed out that poor conditions can be traced to landscapes that are particularly sensitive to grazing for reasons such as steepness, precipitation and the slowness of landslip sores to recover.

It is common for mountainsides in east Iceland to be poorly vegetated, but there remain scattered vegetated areas that bear witness to plant growth that had previously protected them from wind and water. Severe erosion has occurred on these mountains, and they are very sensitive to grazing. It is necessary to reduce grazing as soon as erosion sores begin developing. Under such conditions, flourishing scrub woodlands are the soil's best protection. Land utilization should be directed at increasing the growth of woody shrubs on these mountainsides wherever possible.

6.8 Southeast Iceland

In the discussion on east Iceland, it was stated that enormous amounts of precipitation can fall in a very short time in east and southeast Iceland. The area is further characterized by steep landscapes, so erosion can become considerable if sores open in the vegetation cover. It is a fact that a large part of the mountains in east and southeast Iceland have lost their vegetation cover, exposing infertile scree. There is not much lowland area. Approximately one-fourth of the land in Austur-Skaftafellssýsla county, apart from Skeiðarársandur, is considered severely eroded (grades 4 and 5) because of steep landscapes and unvegetated scree on hillsides.

After glacial rivers were canalized in Skaftafellssýsla county to prevent lowland flooding, significant revegetation has occurred in the glacial outwash areas. Vegetation is now widespread in these areas.

Sand characterizes a large part of the western section of this land area, as two of the country's vastest sand areas, Skeiðarársandur and Mýrdalssandur, are found there. Sand is on all the coastal areas between these two areas.

Large amounts of sand are blown from the fringes of Vatnajökull glacier and the Skaftá river to the heaths of the Skaftárhreppur district - and threaten vegetation. There are many indications that this sand movement began in earnest in the 19th century, and in some places primarily in the 20th century. It is extremely important to protect sandy areas and their surroundings from livestock grazing, and encourage land reclamation in order to retard the advance of sand, in particular where it threatens valuable vegetation or natural heritage. The discussion on grazing in Chapter 4 and on sand in Chapter 9 should be noted. It could be that sandy areas along the coast heal rather than decline, despite some grazing, but progress would be much faster if the land were protected. The general rule is that deserts should not be used for grazing. Birch can be expected to take hold in the lowlands of southeast Iceland that are protected from grazing.

Highland rangeland is limited in Austur-Skaftafellssýsla county, but there are expansive commons in the Skaftárhreppur district. The vegetated part of Skaftárhreppur is generally in good condition. The land is gradually healing after the damage done when the number of sheep grazing was at its highest. This points to this highland rangeland being sensitive, and caution indicates that the number of sheep grazing there should be limited. To the north of the Skaftá river in the Skaftártunga rangelands, there is a range of mountains named Fögrufjöll. There is some vegetation to the south, but yield is poor, vegetation sensitive and the overall environment is characterized by desert. It is imperative to protect such areas from grazing, particularly since their value as grazing land is comparatively small when compared to the district as a whole.

South of Vatnjökull glacier in South east Iceland. Grazing lands between the shore and glacier are limited in size, and the landscape often characterized by steep scree slopes.

It should be remembered that the easternmost part of this area – east and south of the Mýrdalsjökull glacier – is territory threatened by the Katla volcano. Considerable amounts of volcanic ash can be spread over the area during eruptions. Land utilization must be based on such inevitable setbacks, and it is important that the ecosystem is prepared to meet them.

East Iceland

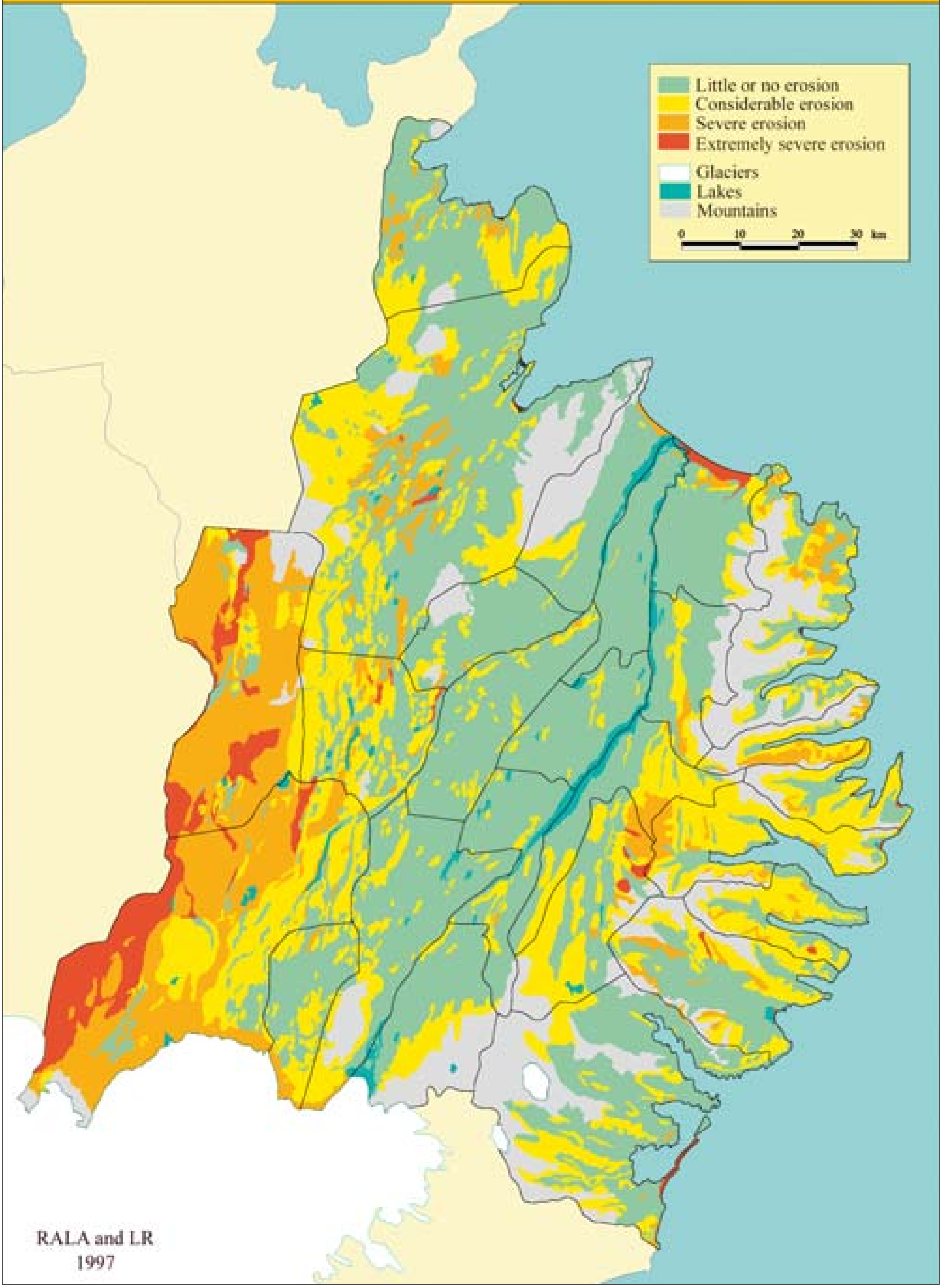


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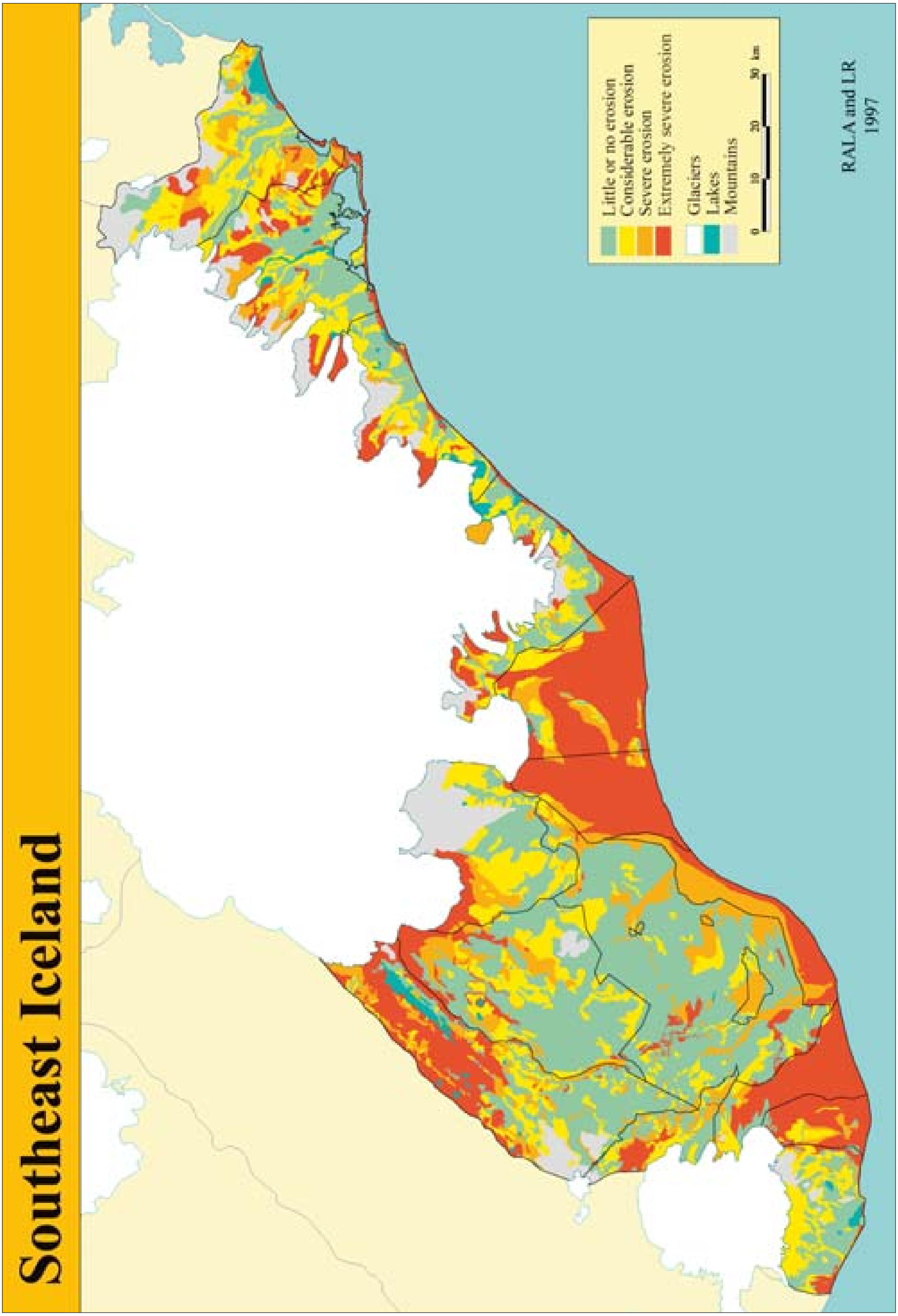
Image processing: LMÍ/RALA
Satellite image: Landsat 5


Southeast Iceland
Little or no erosion
Considerable erosion
Severe erosion
Extremely severe erosion
Glaciers
Lakes
Mountains
0 10 20 30 km
RALA and LR
1997

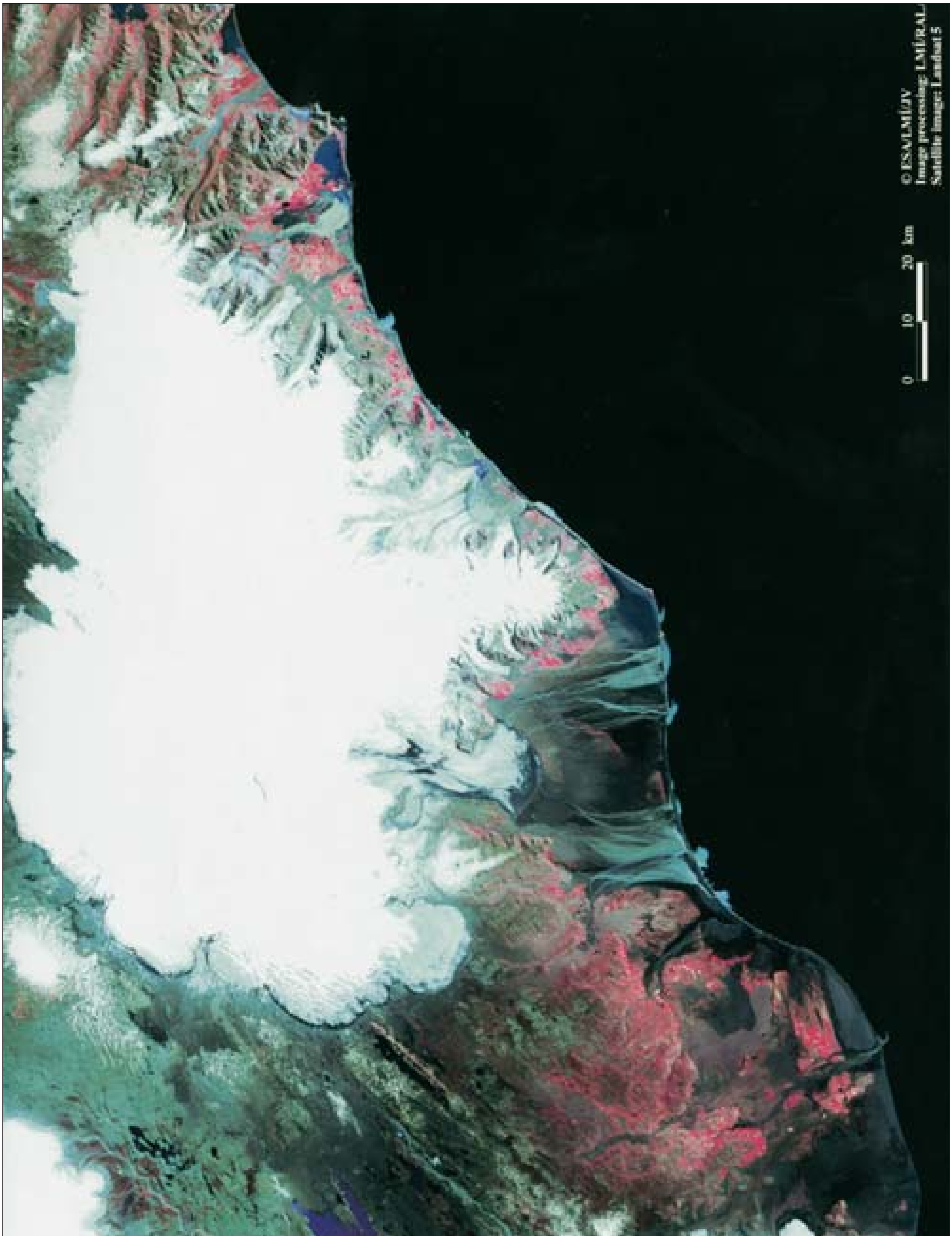

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Image processing: LMÍ/RAL
Satellite image: Landsat 5
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6.9 South Iceland

The lowlands of south Iceland are an extensive agricultural area with little erosion, while its mountains have some of the worst erosion areas in Iceland. Sheep grazing is diminishing from what it used to be, and several highland rangelands are protected from grazing, such as Emstrur, Þórsmörk, Almenningar, part of Landmannaafréttar and a few areas south of the Langjökull glacier. Overall, the highland pastures of south Iceland receive a poor grade, as most are very badly vegetated due to prolonged soil erosion, volcanic activity and sand encroachment. Much of the destruction may be directly traced to land use: removal of trees and grazing on sensitive land that often suffers setbacks due to weather, volcanic ash or flooding. Most of south Iceland's highland rangelands are assessed as unsuitable for grazing.

A desert road in in a melur area, South central Iceland.

Volcanic ash frequently falls on the southernmost highland pastures of the Rangárvallasýsla county. Land utilization there, as in the vicinity of the Katla volcano, should be based on these unavoidable events, and therefore the Mt. Hekla area should not be used for grazing. Vegetation needs protection in order to build up the reserves needed to withstand volcanic ash and sand, to survive such catastrophic events and to recover.

Overgrazed horse pasture in a wetland area in South Iceland.

At the turn of the 20th century, sand was blown down the Landsveit and Rangárvellir areas and turned one farm after another into a wasteland. The achievement that the pioneers in land reclamation accomplished by halting drifting sand in Rangárvallasýsla county is immeasurable. They manually constructed protective stone walls using only primitive equipment. These walls are now a valuable part of Iceland's cultural heritage. The land, however, is still very sensitive, and there are many areas where open sand could begin spreading again if conditions worsened. It must be assumed that these areas will eventually suffer negative effects caused by volcanic ash and bad weather conditions. Therefore, the authors of this report believe that it is wrong to use land for grazing again where at one time great effort was made to successfully stop sand encroachment. Instead, all should strive to cover the land with strong vegetation, especially woody shrubs, which is the best cover for sand.

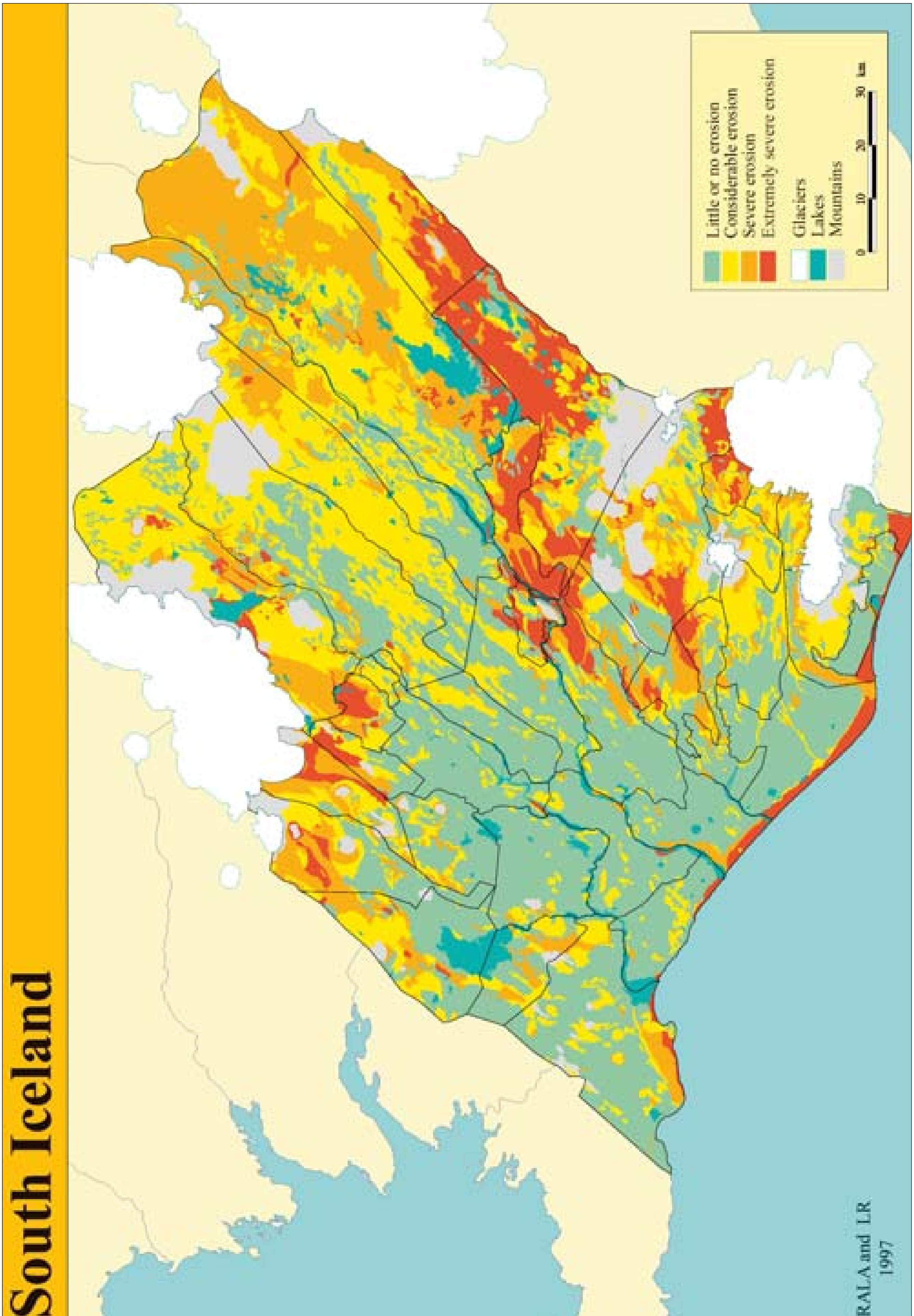
Horse grazing on some parts of south Iceland's lowlands is so intense that it has begun to cause soil erosion. When mapping, areas overgrazed by horses are mostly classified as erosion spot areas, with a grade of 3. It should be kept in mind that these lowland areas are not intrinsically in danger of erosion. An erosion grade of 3, therefore, indicates significant land degradation: vegetation has declined considerably and soil has begun to erode. Serious damage needs to have occurred to areas grazed by horses before an erosion severity grade increased from 2 to 3.

6.10 Southwest Iceland

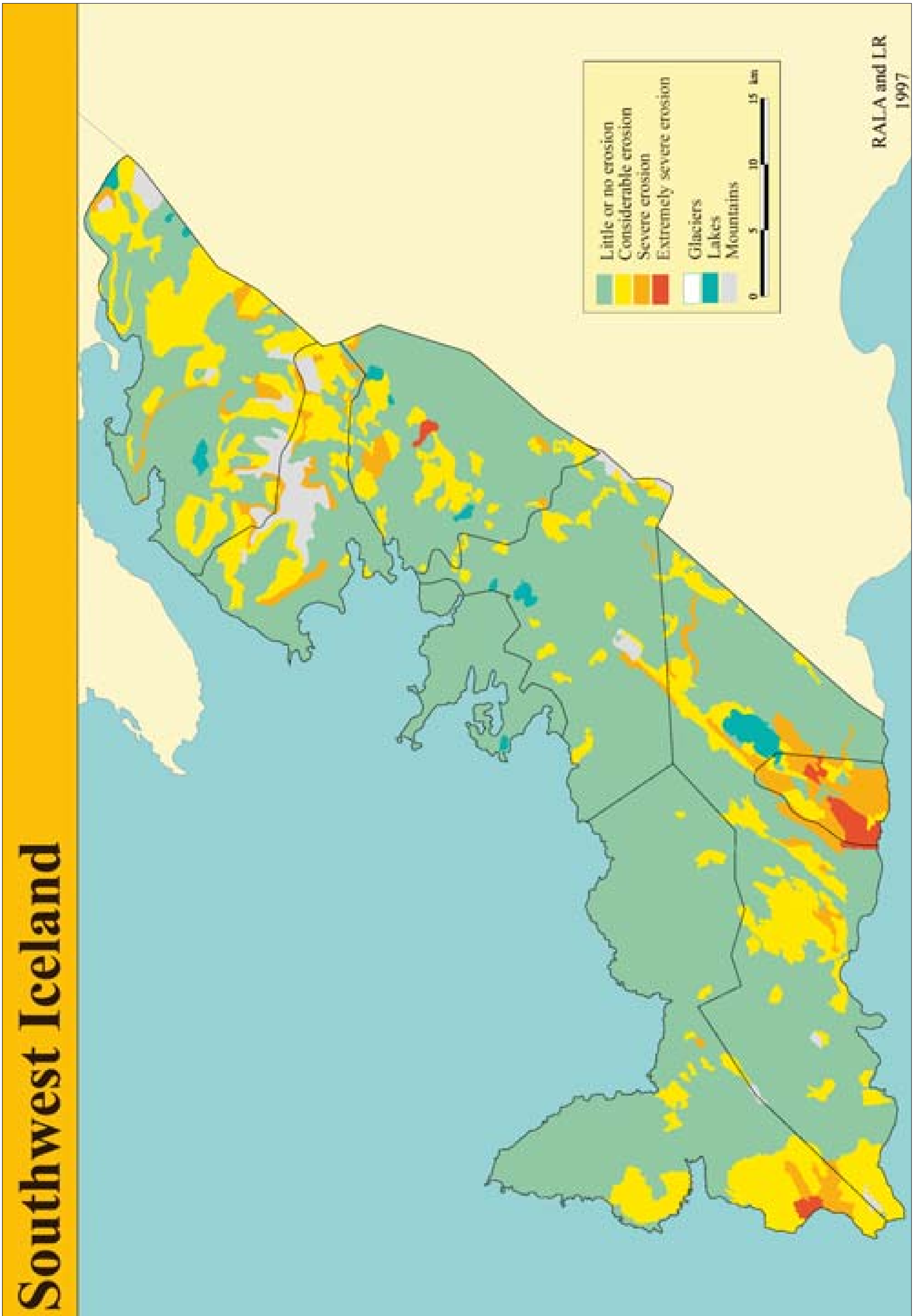
There is generally little erosion in southwest Iceland, if the Krísuvíkur area and the southwest tip of the Reykjanes peninsula are excluded. Soil erosion has decreased significantly after the number of sheep declined, and many erosion areas have now been fully reclaimed because of work done by towns and non-governmental organizations. Horse grazing, however, is beginning to damage the land in Greater Reykjavík, not least of all in Mosfellsbær and at Kjalarnes.

A rofabard area in Krísuvík, South Iceland.

As previously mentioned, soil erosion assessment does not reveal much about the condition of vegetation and its development. The Reykjanes peninsula is a good example of how erosion data by itself can, in some instances, be misleading. This area has little erosion, but nevertheless vegetation is very sparse and not at all in keeping with the vegetation that should, under normal circumstances, be present. *The Vegetation Map* (LMÍ, 1993) published by the National Land Survey of Iceland, in cooperation with RALA and LR, based on satellite images, testifies to the sparse amount of vegetation on the Reykjanes peninsula.


South Iceland
Little or no erosion
Considerable erosion
Severe erosion
Extremely severe erosion
Glaciers
Lakes
Mountains
0
10
20
30 km
RALA and LR
1997


0 10 20 km
© ESA/LMI/JV 1997
Image processing: LMI/RALA
Satellite image: Landsat 5


Southwest Iceland
Little or no erosion
Considerable erosion
Severe erosion
Extremely severe erosion
Glaciers
Lakes
Mountains
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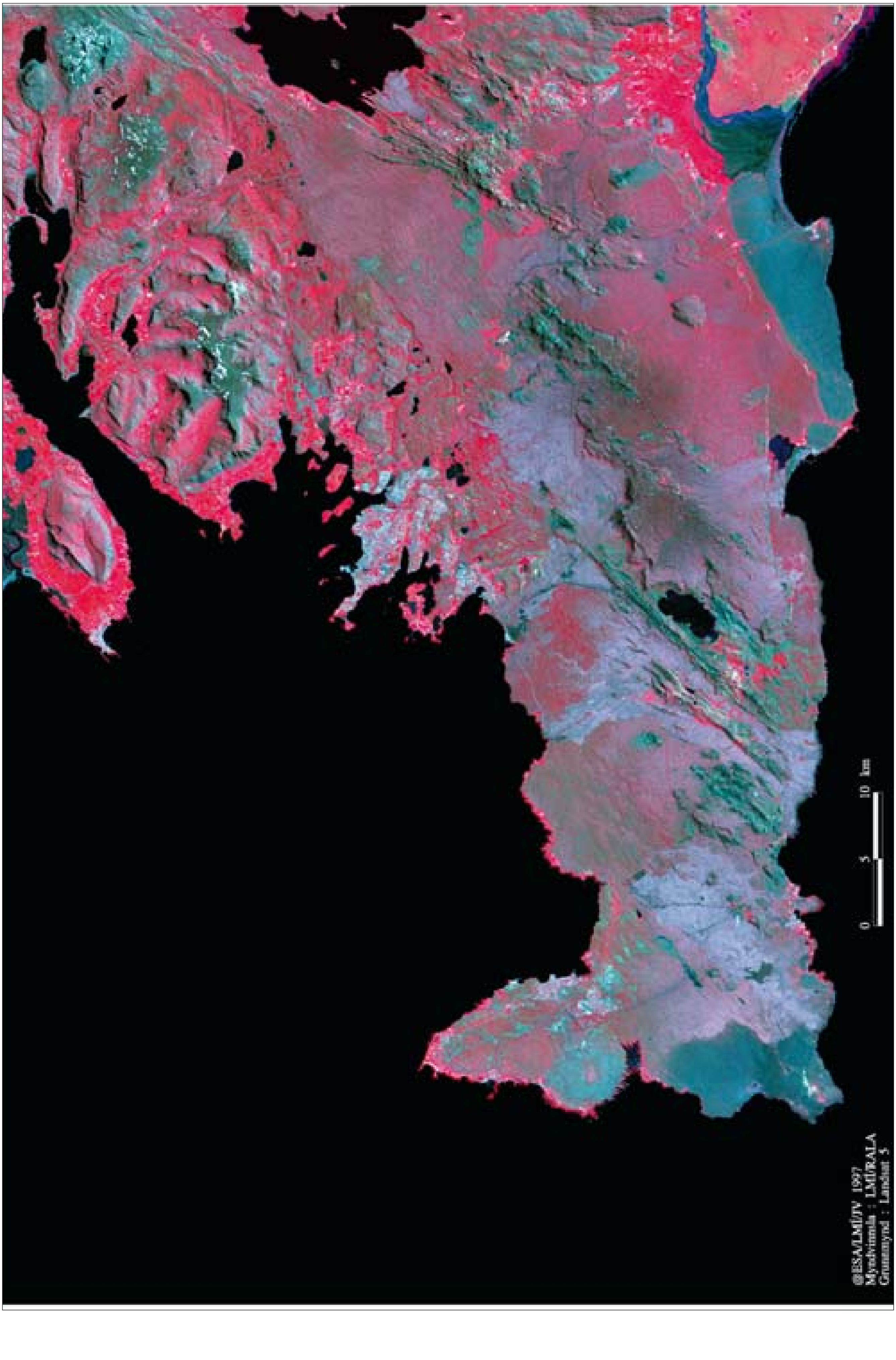
RALA and LR
1997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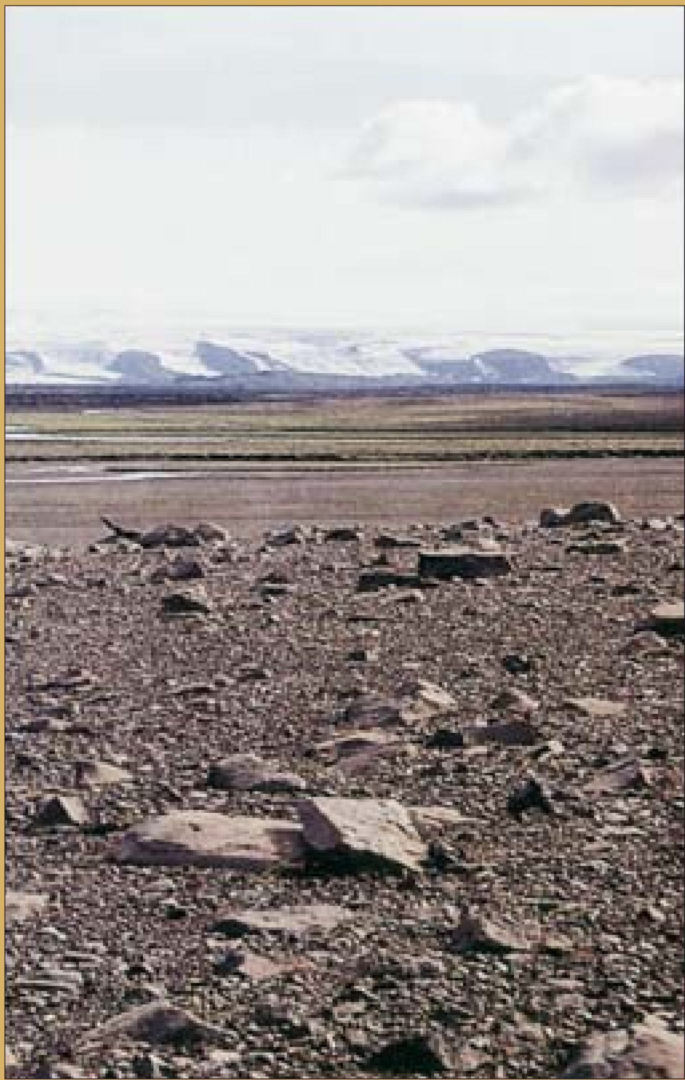
Myndvinnsla : LMÍ/RALA
Grunnmynd : Landsat 5



7. COMMUNITIES AND COMMONS

7.1 Soil Erosion in Communities and Commons

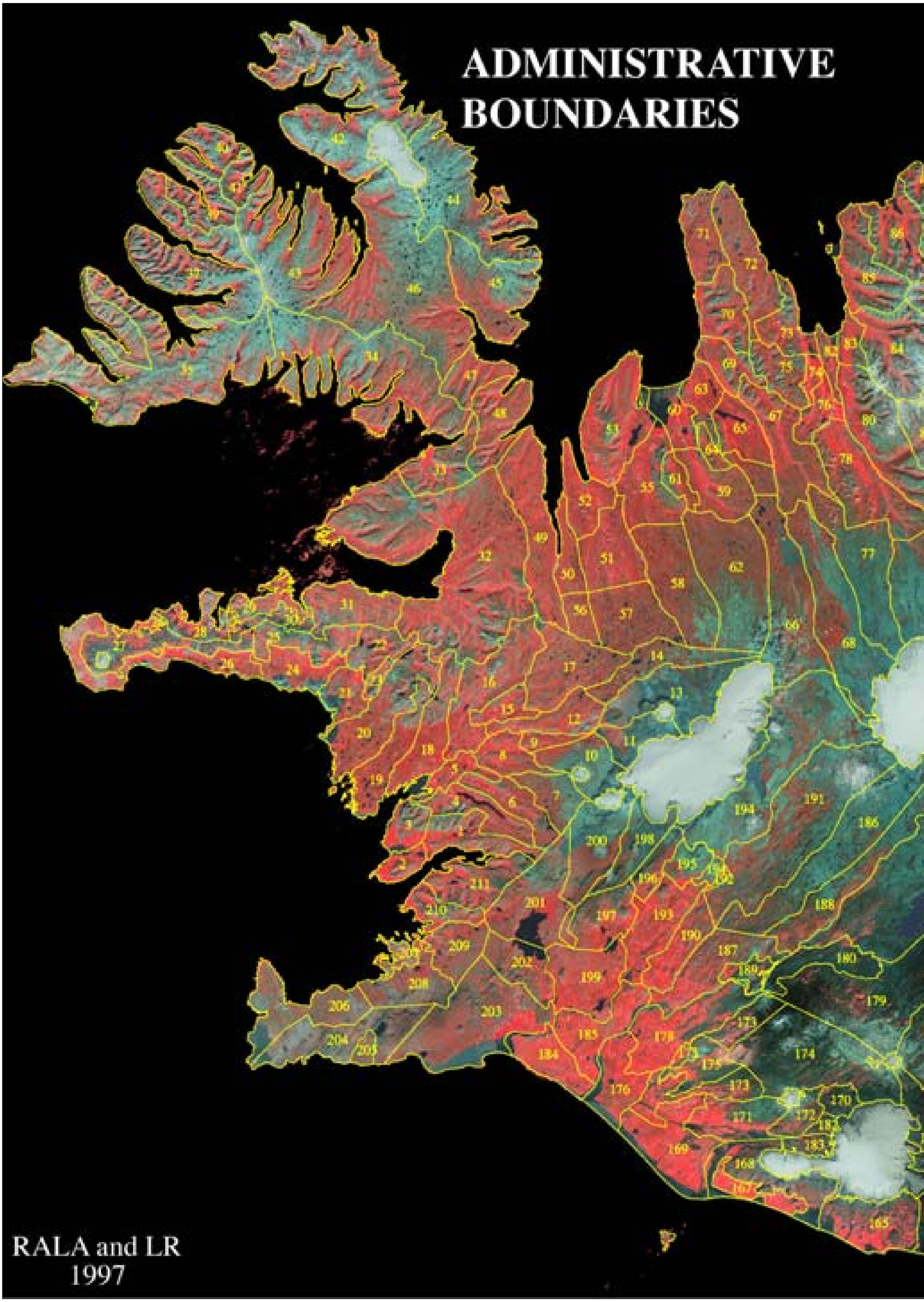
One of the project's most important goals was to obtain reliable information about soil erosion in individual communities and highland commons. It would be tediously long to describe fully the scope of erosion in every individual area. Such information is better presented in tables, but an attempt was made to briefly describe soil erosion in each district in the Appendix of the Icelandic edition. The summary tables are, however presented herein. Additional information can also be found at www.rala.is/desert. That database has much more information than is presented in this report. It must be stressed that, in order to get an overall view of the condition of land, it is necessary to add information to the database about weather conditions, etc.

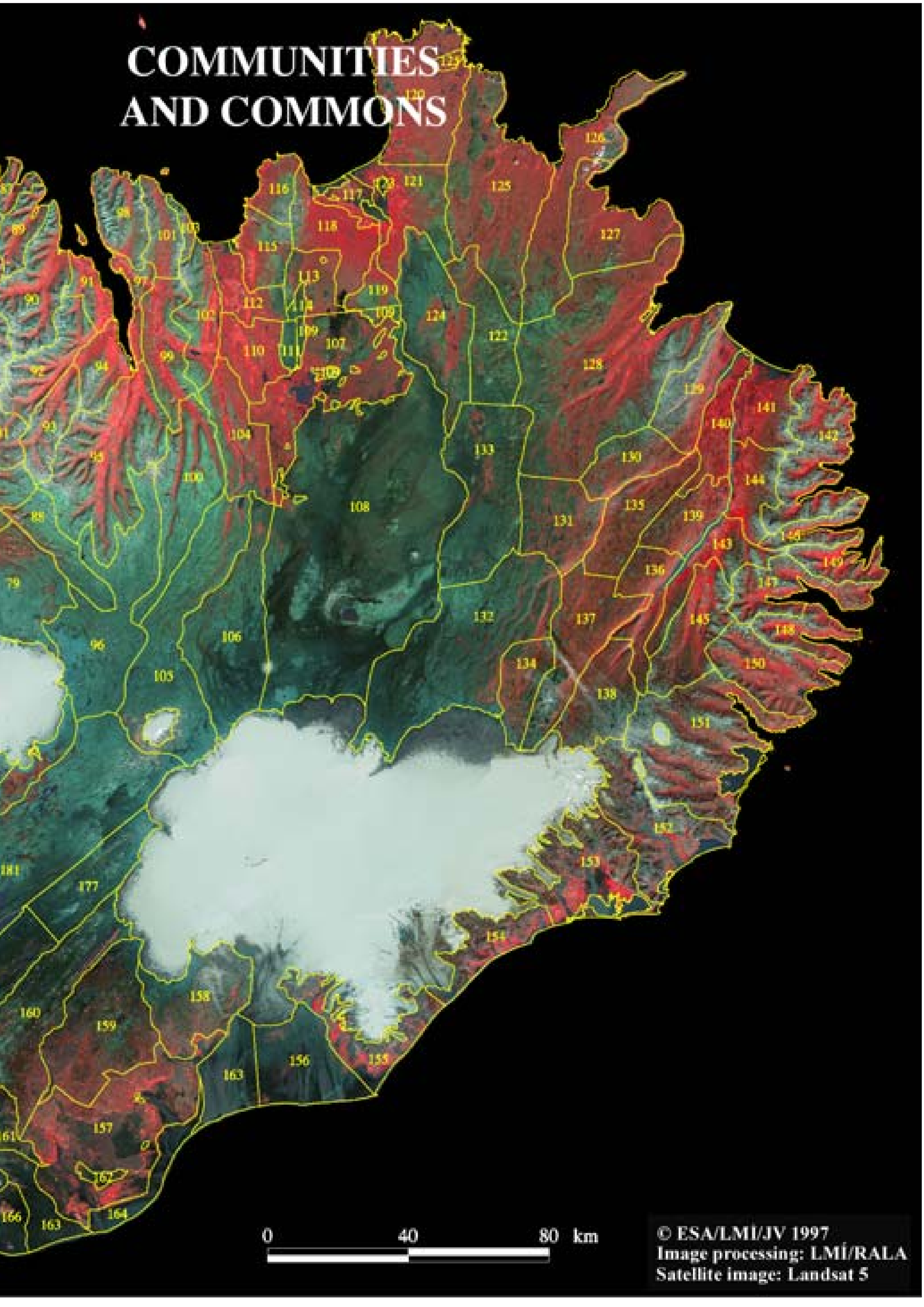
The information that follows is of necessity merely an introduction to more detailed discussions elsewhere. The data on erosion are used as the basis for the recommendations on a district and range basis in Chapter 9.

7.2 Demarcated Areas

Property boundaries need to be clear in order to provide an overview of erosion in individual districts and rangelands. Boundary lines, however, are often uncertain, which makes it a complicated matter to incorporate administrative boundaries and rangeland limits into the database. Several years ago the RALA Land Utilization Department, under the direction of Guðmundur Guðjónsson and Ingvi Þorsteinsson, collected information regarding boundary

lines for municipalities, districts and traditional rangelands. Registered documents concerning boundaries were collected, data was obtained from the National Library of Iceland and information from municipalities accumulated. These boundaries were then put onto a map on a scale of 1:250 000 and onto a vegetation map. The data demonstrate that there are significant disagreements as to where boundaries lie. The information collected by the RALA Land Utilization Department (later the Environmental Department) has been used to delimit the administrative and rangeland boundaries in the RALA/LR database. Municipal boundaries were also obtained from the National Planning Agency, derived from the base municipality map produced by the National Land Survey of Iceland. This map is drawn on a very large scale, and is made with reservations as to the accuracy of ambiguous boundaries. Other sources used were vegetation maps, regional descriptions, the Touring Club of Iceland year-


ADMINISTRATIVE
BOUNDARIES
RALA and LR
1997


COMMUNITIES
AND COMMONS
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40
80 km
© ESA/LMÍ/JV 1997
Image processing: LMÍ/RALA
Satellite image: Landsat 5

books and personal observation where possible.

When boundary lines were uncertain, decisions were taken based on what was thought to be most natural, in order for calculations to be carried out. It may be that this position is not correct in all instances. The database needs to be updated as formal determinations are made regarding these boundaries, but the purpose here is not to depict precise municipal boundaries, rather to obtain an overview of erosion in the areas they cover. Deviations from these boundaries have little or no effect on the conclusions regarding erosion mapping.

During calculations for each district, emphasis was placed on obtaining the best possible picture of continuous grazing areas. Attempts were made to separate densely-populated agricultural areas from rangelands, for example, in valley bottoms with continuous hay fields versus other land in the district. It became apparent that in most cases such demarcations make very little difference to the overall calculations for each district.

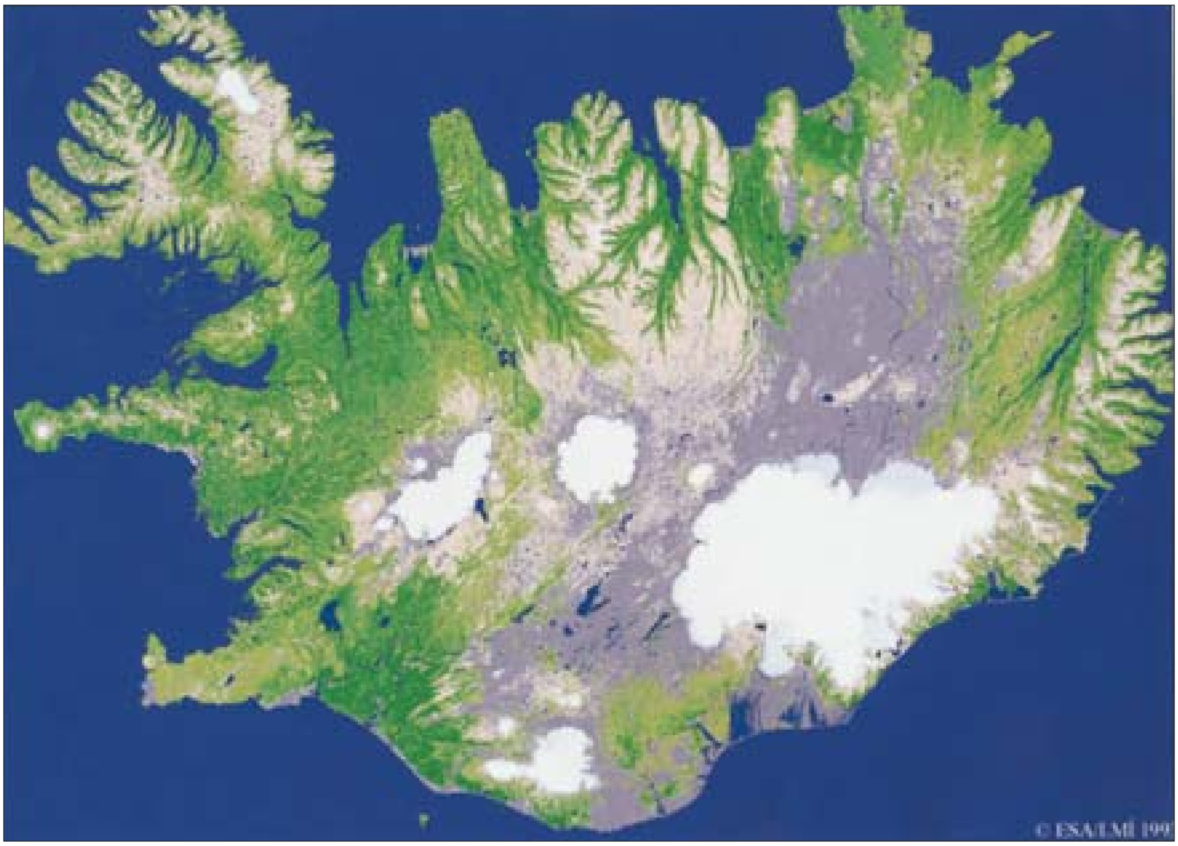
The administrative division of land is shown on the previous page. There is also additional information for each district in the database. Calculations were made on a total of 211 administrative areas, both lowland rural communities and highland rangelands.

7.3 Data

When vegetation mapping concludes and the data are available in digital form, it should be possible to correlate the vegetation map conclusions with conclusions from erosion maps, which will greatly increase the ability to assess grazing land in Iceland.

It is interesting to note the correlation between land that is assessed as wasteland and mountainous through erosion mapping, and the combined wasteland and sparsely vegetated land on the vegetation map ($r^2 = 0.98$). There is also a close relation between land that receives low erosion gradings (0, 1 and 2) and vegetated land ($r^2 = 0.88$).

It should be noted that glaciers are not included in the calculations for the overall land area in these tables. Furthermore, glaciers, mountains and lakes are excluded from calcu-



Vegetation map of Iceland. The map is produced from Landsat 5 satellite images.

lations on the relative size of land assigned particular erosion classifications.

Occasionally, two or more districts were coupled together because of their small size, or for other reasons. Also, several districts were divided into populated areas and highland pastures because the condition of these areas were so dissimilar. Well-defined highland rangeland received special attention.

The combined data were used further in Chapter 9 when a position was taken towards land quality and utilization.

8. EROSION FORMS

8.1 Erosion is Varied

Many erosion forces are active in Iceland, including wind, water, frost and landslides. Erosion forms are those signs visible on the surface, and many processes can be at work in any one area. Thus, erosion escarpments are formed where wind and water breach the vegetation cover. Erosion progresses in many ways.

Having completed the bulk of the erosion mapping, an overall view emerges of erosion processes in Iceland. Erosion forms vary in extent. As noted in Chapter 5, erosion spots and gravel are the most common erosion categories (28,200 km^2 and 25,000 km^2 respectively), followed by solifluction areas (17,800 km^2) and sandy gravel (13,700 km^2). Other erosion forms are less than 10,000 km^2. These figures, however, say nothing about the severity of erosion, which varies according to the erosion form. Sand is always given a high erosion grading, while solifluction generally receives a much lower grade.

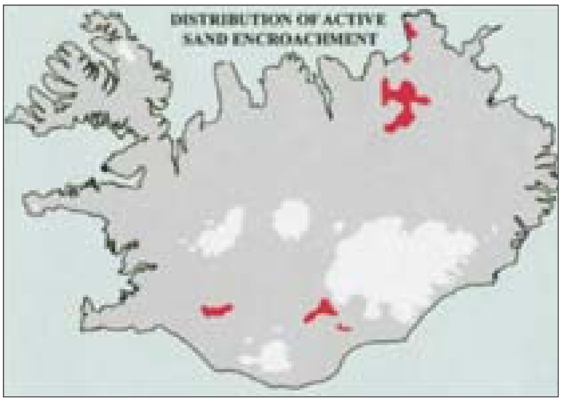
The following discussion focuses on each erosion form individually. Discussion of *rofabards* and sandy areas is much more detailed than for the other forms, in part because more research has been conducted on *rofabards* Sandy areas are discussed in more detail, since one of the main conclusions from the erosion mapping is that sandy areas are much more extensive than previously thought.

8.2 Sand Encroachment (Áfoksgeirar)

Sand tongues are formed where sand encroaches on vegetated land. This is the least

Sand from Skaftá river forms a broad encroaching sand.

extensive erosion form, accounting for less than 100 km^2. Sand encroachment is most common in northeast Iceland. Although covering



only a small area, it must be remembered that where sand encroachment is active, the sand can invade rapidly from year to year over vegetated land. There are a few areas where the sand front has advanced over 100 m/year, such as at Hólsfjöll (encroaching 300 m in 1954) and at Grænulág in the Mývatnsöræfi desert (advancing 300 m during one storm in 1988, and 125 m during all of 1989). There are also other such examples. The sand that blew over Landsveit and Rangárvellir at the end of the 19th century and the early part of the 20th created sand tongues that can still be seen on aerial photographs.

There are numerous sand tongues south of the Langjökull glacier, but in general there is very little advancement at present. Sand gathers in depressions, such as at Rótarsandur (south of Hlöðufell mountain) and at Sandkluftavatn to the north of Þingvellir National Park. These sands need to be monitored closely.

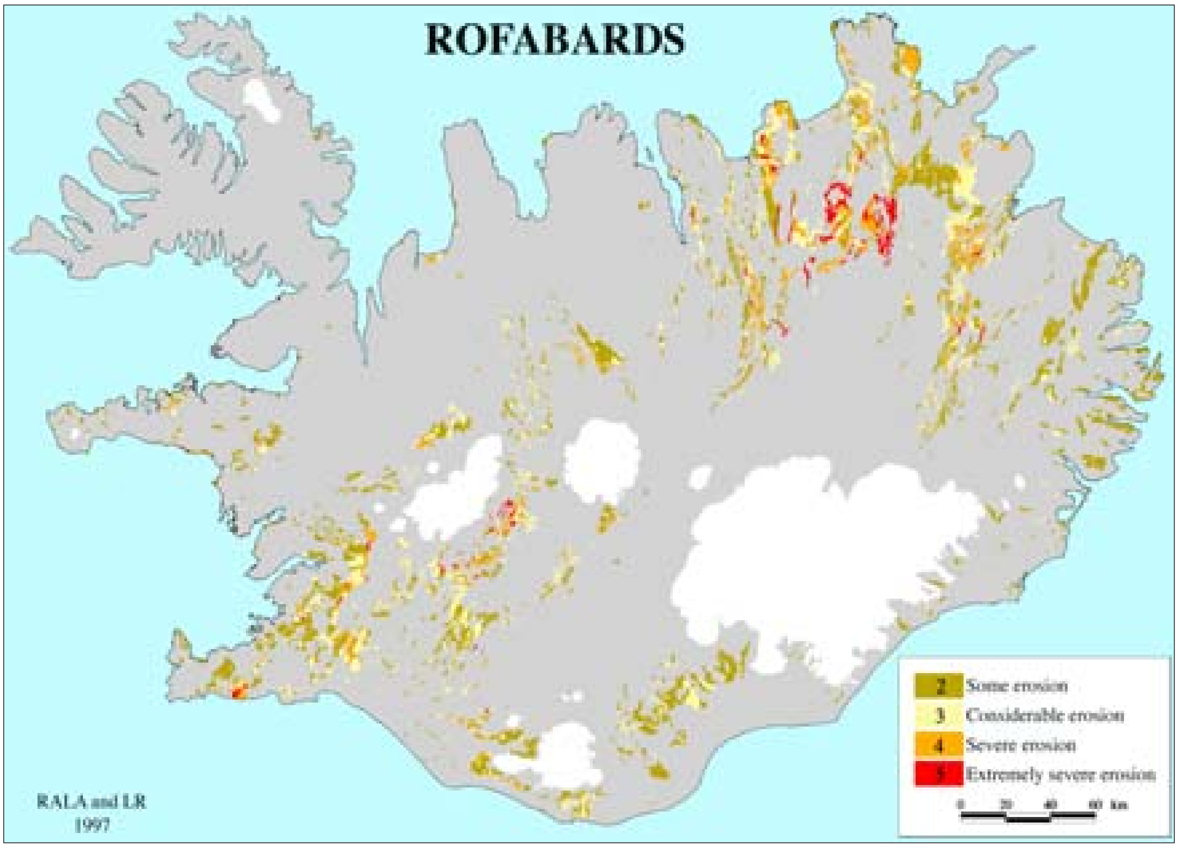
When sand encroachment is active, it is necessary to act quickly in order to halt sand movement. SCS has considerable experience in stopping the advance of such sand.

Sand encroachment will be discussed further in the chapter on sand.

8.3 *Rofabards* (Erosion Escarpments)

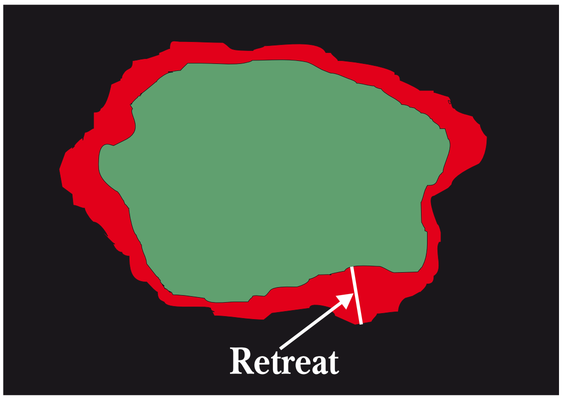
Erosion escarpments typically form where eolian deposition has created thick enough volcanic loessial soils (Andosols), e.g. >30 cm. Such eolian deposition areas are mainly in the vicinity of highland deserts, particularly where sand is picked up from the glacial sands. Deposition of volcanic ash during eruptions also contributes to soil thickening, which partly explains the prevalence of erosion escarpments on the Snæfellsnes peninsula. It has previously been pointed out that the distribution of erosion escarpments is closely linked with areas prone to the effects of volcanic eruptions: the glacial sands, highland deserts and deposition of volcanic ash that provides the material for dust and sand storms. These areas are primarily along Iceland's volcanic belts.

It is important to keep in mind the secondary effects of sand blowing from sandy areas and expanding deserts. A large portion of the eolian deposition that enters vegetated surfaces, probably originates from deserts. The role of sediment transport from brown Andosol areas may have been overrated in this connection, except where both wind erosion and eolian deposition occur within the same area. It is a different matter with erosion escarpments on poorly vegetated areas, where soil is carried from the escarpment banks up to vegetated



land, which causes the ground to rise rapidly at the top of the *rofabard*.

As the soil thickens, the Andosol is in more danger of erosion as the erosion ledge becomes higher. As the ground rises, soil materials are generally coarser, and when coarse volcanic ash layers are present, the *rofabards* become even more susceptible to erosion.



The retreat of a rofabard. *Erosion is calculated as loss of vegetated land (red area) by multiplying the length (the perimeter) by the retreat each year (white line). Soil loss can be calculated by multiplying by the soil thickness (often >1 m) and the bulk density of the soil (often about 0.7 t/m3).*

In order to assess the erosion in *rofabard* areas, it is necessary to know how much the escarpments retreat on average, and how long they are on the landscape. By multiplying these figures, the loss of vegetation cover can be estimated.

Sturla Friðriksson (1988) was the first to report on the rate of erosion at escarpments, and found that high and unstable erosion escarpments in the vicinity of Mt. Hekla disappeared at the rate of 16 cm/year. Measurements made by Sturla Friðriksson and Grétar Guðbergsson on erosion escarpments around Iceland indicated an average annual loss of 4.5 cm, but the changes were quite varied: from just a few mm to >20 cm annually (Sturla Friðriksson and Grétar Guðbergsson, 1995). Erosion rates at individual erosion escarpments were also estimated during the erosion mapping operation, and the conclusions were similar: erosion of erosion escarpments proceeds at a rate of several centimeters annually. (Ólafur Arnalds and Ómar Ragnarsson, 1994; Ólafur Arnalds *et al*., 1994).

Another method of measuring the erosion rate of *rofabards* is based on comparing aerial photographs of an area taken at intervals over many years (Ólafur Arnalds *et al*., 1994). Where erosion amounts to only a few centimeters, changes are difficult to discern, even when the photographs are greatly enlarged. By applying GIS technology, it is possible to align the photos precisely, and the lines drawn around the escarpments are microscopically thin. This method has the advantage of being able to measure a large area in one pass, instead of having to measure escarpments individually.

Table 8. **Estimated Loss of Vegetated Land on Erosion Escarpment Areas around Iceland**

Erosion Severity	Area km²	Retreat(1) mm/year	Length of Escarpments(2) km/km²	Annual Loss Loss ha/km²	Total Loss in Iceland ha/year
1	1,735	3	0.5	0.0002	0.3
2	3,511	7	1	0.0007	2.5
3	1,997	10	5	0.005	10
4	1,234	50	15	0.075	93
5	361	100	35	0.35	126
Total					232

Notes: (1) Estimated average based on measurements made by the authors and collaborators (Ólafur Arnalds and Ómar Ragnarsson, 1994; Ólafur Arnalds *et al.*, 1994, and unpublished data) and Sturla Friðriksson and Grétar Guðbergsson (1995).
(2) Length of erosion ledges is based on computerized measurements of aerial photographs (Ólafur Arnalds *et al.*, 1994, and unpublished data).

The method also provides direct information concerning loss of vegetation within the measured area, as well as information on the edge length of *rofabards*. Such measurements revealed that the length of escarpments can total tens of kilometers per square kilometer. The length of escarpments is generally longest in areas with erosion grade 5, but becomes shorter on average as the erosion grade lowers.

A small rofabard. This area used to be covered with brown Andosols and vegetation.

Figures regarding erosion speed, along with information on extent, may be used to estimate how much vegetated land has been lost on erosion escarpment areas throughout the country. It should be clearly noted that average figures are used, so the conclusions primarily indicate *merely the possible magnitude* of erosion in *rofabard* areas.

The results clearly show that by far the largest loss of vegetated land occurs in areas with erosion grades 4 and 5. Collectively, the loss of vegetated land in erosion escarpment areas appears to be 232 ha/year according to these calculations, which gives an indication of the magnitude of this erosion.

It is not easy to estimate the extent of vegetated land that has been transformed into desert on erosion escarpment areas. For example, it is unclear whether the desert at Ódáðahraun should be included in this category, yet erosion escarpments were undoubtedly widespread when the vegetated land suffered degradation and sand spread over the area. South Iceland's highland pastures can most certainly be categorized as having had erosion escarpments that were degraded by erosion. It is therefore clear that the extent of land that has changed into desert because of such erosion processes amounts to thousands of square kilometers. But it is certainly an exaggeration to blame the loss of all vegetated land on this particular process, as has sometimes been done. Based on a total estimated loss of 7,500 – 15,000 km^2, the average loss of vegetated land over the past 1100 years would have had to have been 700 – 1400 ha/year. That is considerably more than the approximately 230 ha/year currently being lost. It is therefore apparent that, in the past, erosion was much faster than today, such as when the highland rangelands of south Iceland were lost. This is in line with the model developed by Ása L. Aradóttir et al. (1992), where it is assumed that erosion speed is highest at the so-called "erosion stage" and less when desert has become dominant (as discussed earlier, in Chapter 4). It should be understood that erosion is not fixed from year to year; rather it moves in leaps, as was shown on Graetz's model in Section 4.3. The period that our measurements span is considered somewhat calm.

Similar calculations can also be done for other erosion forms, but it is doubtful if there is sufficient basis for it at present.

It is worrisome that 1,600 km^2 of land is considered erosion escarpment area with an erosion grade of 4 or 5. It is both difficult and expensive to stop erosion that has reached such severe stages, since the escarpments are very long.

Approximately 2,000 km^2 of land is considered escarpment area with an erosion grade of 3, while over 3,500 km^2 of land is designated escarpment area with an erosion grade of 2. These figures indicate that land is widely being opened, or has opened in recent decades when, for example, the number of sheep in Iceland was at its peak. It is important to close escarpments in areas with these lesser grades; many escarpments close by themselves if land use is moderate. It is much less expensive to protect areas with grades of 2 and 3 than to stop erosion in areas that have reached grades of 4 or 5.

Continuous erosion escarpment areas experiencing the worst erosion are at Krísuvík; Grafningur, Þingvallasveit, east of the Langjökull glacier at the Biskupstungnaafréttur and Hrunamannaafréttur highland pastures, and at the edge of continuous vegetation west and north of the Langjökull glacier and the Hofsjökull glacier from Mýrasýsla county to Skagafjörður. The largest and worst escarpment areas are in the Þingeyjarsýsla and North-Múlasýsla counties: from Bárðardalur, the Mývatnsöræfi desert, Reykjaheiði common and north to Tjörnes, at Hólsfjöll and in a few areas along the Þistilfjörður fjord, and finally along the low highland area in east Iceland from Vopnafjörður south to Jökuldalsheiði in the Brúaröræfi desert (see map).

About 3,500 km^2 of land is considered erosion escarpment area with severe erosion (grades 3, 4 and 5). These areas are rather large on a countrywide basis, and of all erosion forms, erosion escarpments are the ones most noticed by foreign travelers. Yet other erosion forms are much more widespread. Focusing only on erosion escarpments gives an inaccurate picture of the magnitude of soil erosion in Iceland.

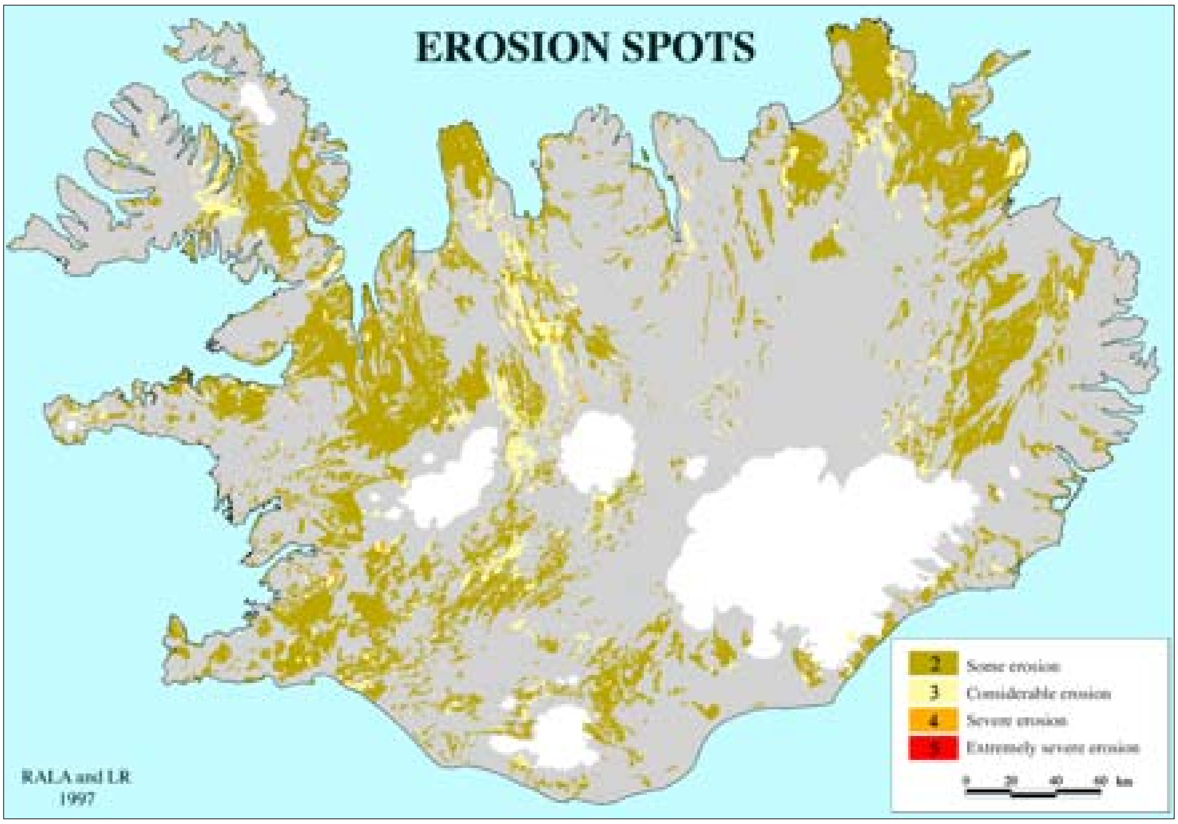
8.4 Erosion Spots

Erosion spots are extremely widespread in Iceland (approx. 28,000 km^2), as they are found virtually everywhere in dry, vegetated areas with hummocks. Erosion spots are, however, rarely found in marshy or wooded areas. Fortunately, low erosion grades (1 and 2) are usually associated with erosion spots, but there are about 2,700 km^2 of land considered erosion

Erosion spots in a vegetated land.

spot areas that have an erosion grade of 3. It would be desirable to discuss them in detail, but since research on erosion spots is limited, this discussion is rather short.

Erosion spots are a clear sign that vegetation has been seriously degraded - especially when the erosion grade is 3 or higher. It is interesting to note that erosion spots with an erosion grade of 2 are widespread in areas where erosion is otherwise considered the least in Iceland. This indicates that land in these areas is sensitive, including the areas that are well vegetated. These figures could be interpreted as an indication that this land was over-



grazed when sheep numbers were at their peak, and the land has not yet fully recovered. It should be borne in mind that erosion spots can form in a relatively short time, but take a long time to heal. The formation of erosion spots involves a reduction of vegetation cover equal to the erosion sore. Initial studies show that there are examples of vegetation cover being reduced by about 50% in grazing areas that have been overgrazed for a long period.

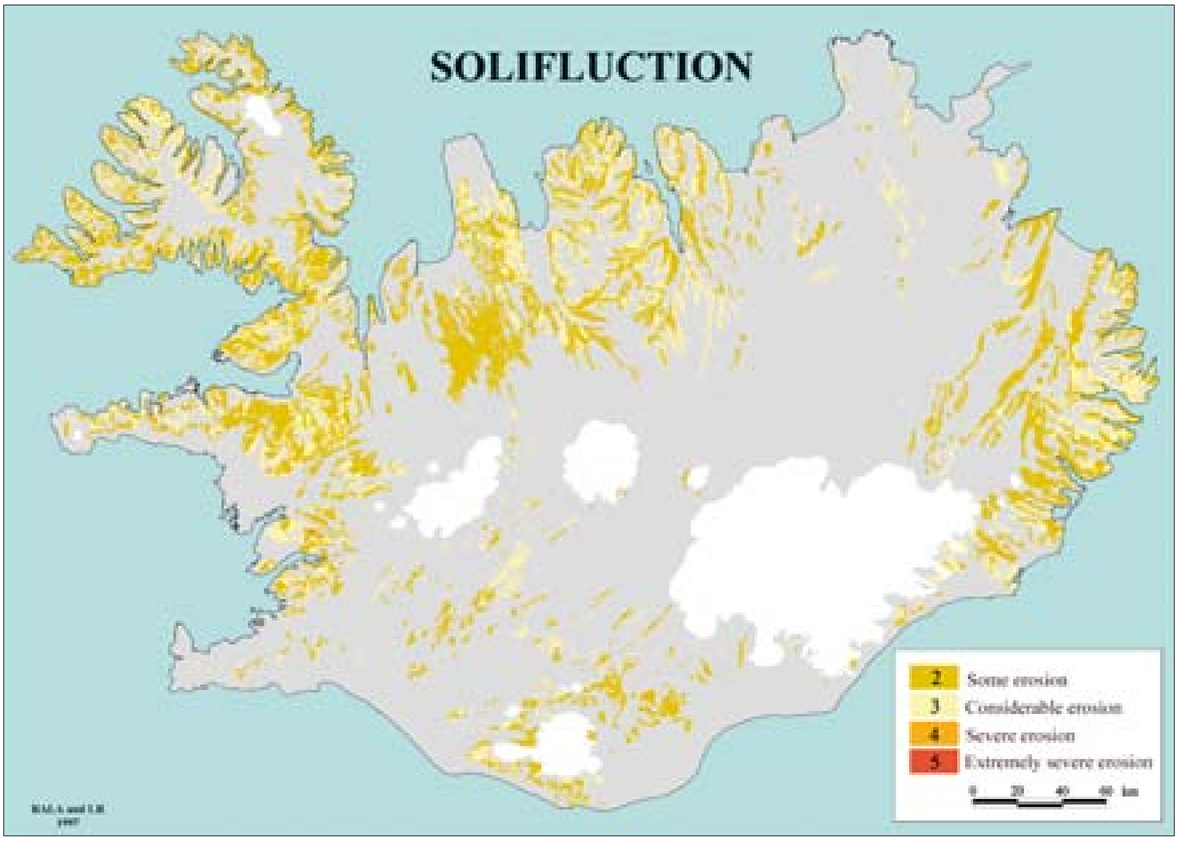
8.5 Solifluction

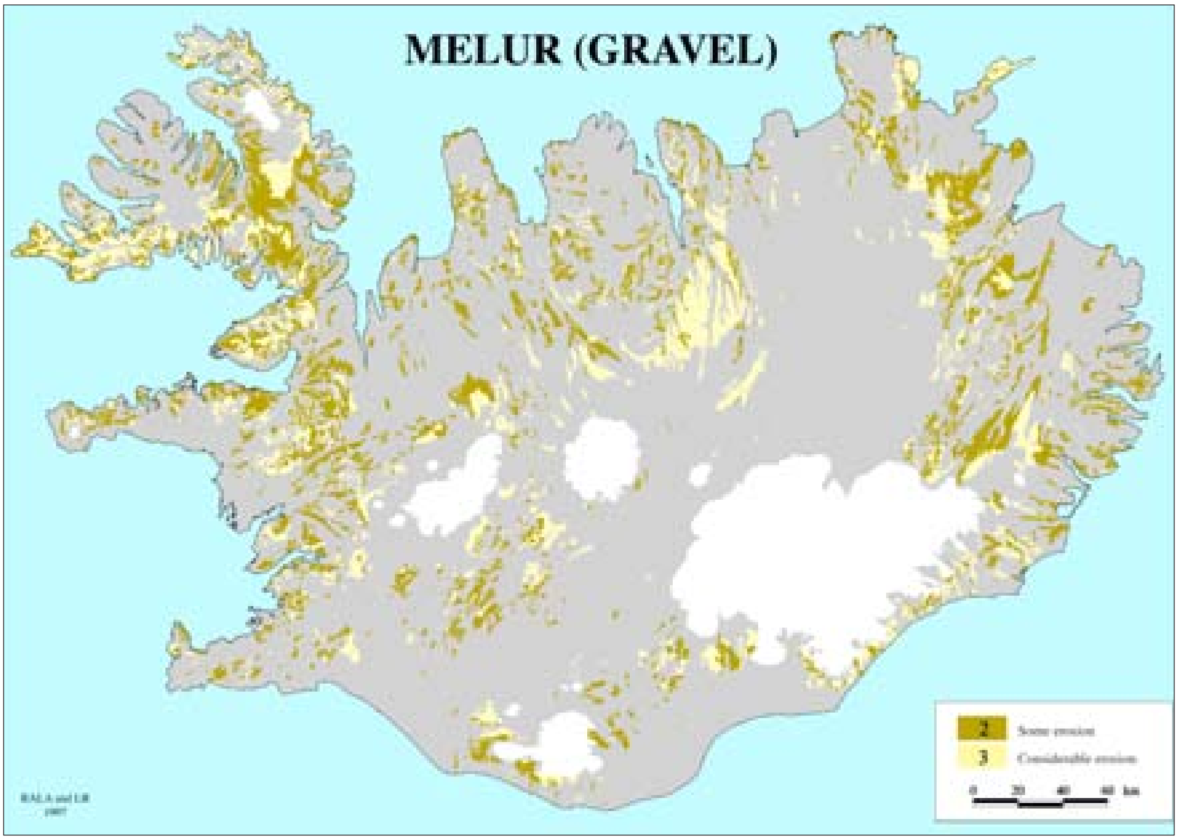
"Solifluction" is a term that describes the slow and steady movement of soil down hillsides caused by freeze-thaw cycles, whereby terraces and solifluction lobes are formed that are quite noticeable in the landscape. During erosion mapping, the term "solifluction" took on a wider meaning as it was also used to denote erosion sores on hillsides. This use of the term "solifluction" is unfortunate; it would have been better to use another term instead of "solifluction" when referring to erosion sores on hillsides and soil erosion associated with solifluction.

Much more erosion occurs in erosion sores that are on hillsides compared to sores on more level areas, as running water gets into the sores. As such, there is good reason to distinguish erosion sores on plains from erosion sores on hillsides.

Solifluction lobes. Cycles of freeze-thaw cause volume changes that result in the formation of terraces and lobes on slopes. When erosion spots form on such slopes the soil is susceptable to water erosion.

Solifluction is a very common erosion form, and was mapped on about 17,500 km^2 of land. As could be expected, these areas are most common in the deep glacially carved valleys of the Tertiary basalt rock formation. The results show that soil on Iceland's hillsides is very sensitive, and in fact there are widespread bare scree areas where formerly there had been





vegetation and soil. This is especially true of southeast Iceland, where rain can reach tens of millimeters in a short time. Under such conditions, soil in erosion sores is easily washed away (see discussion on south-east Iceland in Chapter 6).

Water can wash away a considerable amount of soil even though gullies have not actually formed, which is why this type of erosion does not receive much attention unless streams become dark brown from soil during rainy periods.

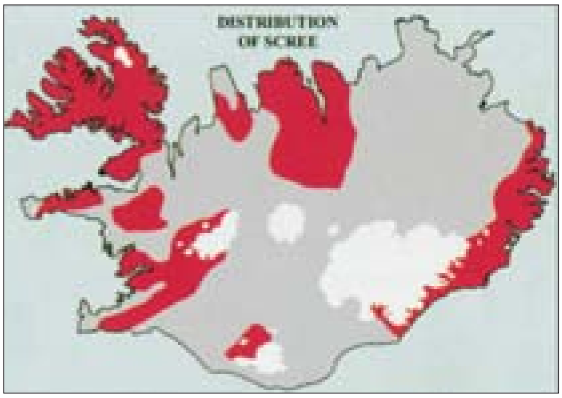
About 6,000 km^2 of the country's hillsides were given an erosion grade of 3 because of solifluction. This grade is very high and is reason for further examination. It points directly to hillsides being widely over-utilized, and to the need for finding ways to moderate utilization.

Vegetation and soil on hillsides form an ecosystem that is generally so sensitive that grazing by heavy livestock should be severely limited, especially in spring when the ground is soft. Winter grazing on hillsides is very damaging, and it is the opinion of the authors that regulations should be set to limit horse grazing on steep hillsides.

8.6 Melur (Gravel)

The actual amount of continuous melur area is about 6,500 km^2. These are areas that have been mapped as gravel with an erosion grade of 3, and the area is considerably less than expected. It should be noted that sandy gravel, which is more extensive (>13,000 km^2 with erosion grades of 3, 4 or 5), is excluded from this figure. The overall size of gravel within vegetated land, or where gravel is healing (gravel with an erosion grade of 1 or 2), is surprisingly about 18,500 km^2. It is easy to heal

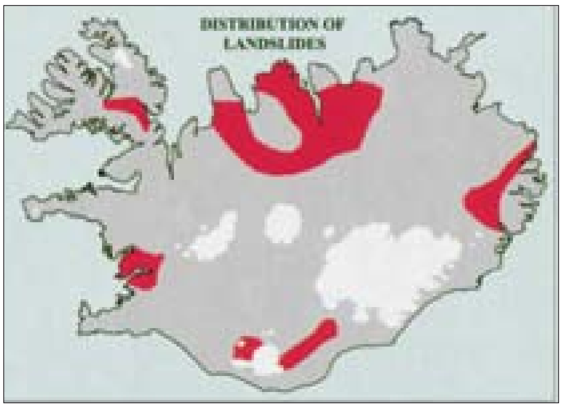
Melur, a lag gravel surface. This desert surface was formed after the brown soils associated with the old vegetated surface were removed by erosion. Soil and vegetation remnants (rofabards) on the horizon.



these areas when they are located in the lowlands, either through sowing grasses or planting woody species, depending on the circumstances. Large expanses of gravel with low erosion grades in areas that otherwise are considered well vegetated with little erosion, indicate that the land is sensitive. Obviously, erosion had been greater at some time, resulting in the formation of these gravel areas, but is less now – otherwise gravel areas would still be forming.

8.7 Landslides, Gullies and Scree

According to the erosion maps, landslides are obvious on an area of about 680 km^2. Their distribution is similar to that of solifluction. The connection between landslides, solifluction and land utilization should be noted. While landslides occur in nature without land being utilized, the frequency multiplies as land utilization increases. Solifluction causes soil to gradually push against obstacles and create pressure points on hillsides. Eventually these hindrances give way, causing a landslide. This is particularly common during large rainfall events, when the ground becomes sodden. Solifluction occurs much less when vegetation and its root systems bind the soil. Landslides, therefore, are more common where land utilization is heavy.

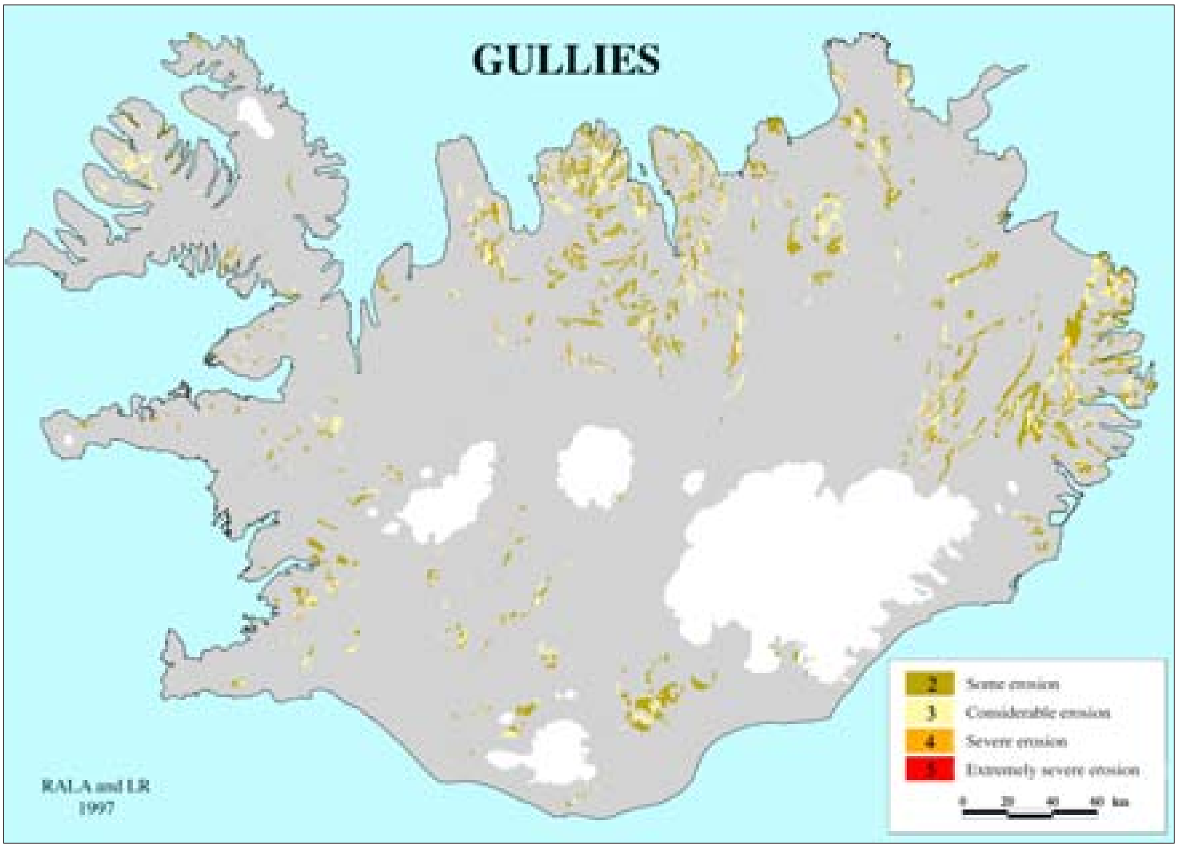


Most gullies are found in several areas in east and north Iceland, as well as the West Fjords. They are particularly apparent where there is considerable eolian sedimentation and the soil is thick. Where there is less eolian sedimentation, soil in erosion sores is washed away without gullies being formed.

It is not necessary to discuss in too much detail the spread of scree, i.e. steep, unvegetated scree hillsides. These are mostly found in mountainous areas and on hillsides of active volcanoes and table mountains, such as the Eiríksjökull glacier. They are also quite apparent in rhyolite areas, e.g. in southeast Iceland. High hillsides are excluded as they are mapped as mountains. Scree is associated with mountainous areas, such as the basalt areas of the West Fjords and of north Iceland. South Iceland stands out in regard to scree: the ground on hillsides has given way and as a result steep, scree hillsides have developed, as previously described.

A small landslide.

A water channel formed on a small slope as a result of four-wheel drive traffic.



It is not known for certain how much of these hillsides were previously covered with vegetation. It can be assumed, however, that a large proportion was quite well vegetated. This opinion is based on relic vegetation still to be found around Iceland, such as in the Lónsöræfi desert, which has been comparatively isolated in comparison with other areas nearer populated areas. In addition, current erosion processes on these hillsides indicate what has happened. It is nevertheless certain that vegetation has had a difficult time where scree is at its steepest and many hillsides have probably never been fully vegetated.

This lava surface is partially covered with moss, a common sight for young lava surfaces.

8.8 Lava

During the erosion mapping, only lava that is unvegetated and free of sand is considered lava. This is usually a young lava surface where soil formation and plant colonization has not progressed very far.

Lava that is mostly free of sand or minimally vegetated is not very extensive, only about 2,000 km^2. In comparison, sandy lava covers an area of about 4,900 km^2. These figures do not give a realistic picture of the overall amount of lava surfaces in Iceland because areas where soil and vegetation cover the surface are not considered lava areas for the purpose of erosion assessment.

8.9 Bare soil Remnants

It was considered necessary to categorize bare soil remnants as a special erosion form. At such erosion sites there are remains of soil, even though it has for the most part disappeared. Wind erosion of bare soil remnants can become very evident when the weather is dry and windy. Bare soil is common, for instance, in the eastern part of the Mývatnsöræfi desert and the Ódáðahraun lava fields, where it is the remains of old soil. The somewhat brown, silty, coastal

Bare soil is a very unstable surface when dry.

area at Mýrar, and other places, were mapped as bare soil because they fitted best in this category. Wind erosion is rare in these areas because of moisture, and as such, most were given a low erosion grade. Bare soil covers less than 1,000 km^2 and the most common erosion grading is 2.

8.10 Sand and Sandy Areas

There are four maps of sandy areas on the following pages. One map shows the extent of sands, another of sandy lava and the third of sandy gravel. Finally, these three maps are combined into one that depicts the extent of sandy areas in Iceland. As can be seen, sandy gravel is the most extensive, covering a large part of the highlands. Sandy lava characterises the Ódáðahraun desert, and is also found in the volcanic area stretching west from the Vatnajökull glacier, past Mt. Hekla and around the Langjökull glacier.

When the map for sandy areas is examined, it is notable how extensive the sand and sandy areas are. Sandy areas now cover about 20,000 km^2 and the area is expanding. These sandy areas prompt questions about:

- why sandy areas are as large as they are;
- the causes of erosion and loss of vegetated land in such areas;
- evolution of climate and glaciers and their influence on sand transport;
- the importance of singular events, such as floods or volcanic ash falls, in degrading vegetated land;
- the nature of sand movement from its origins to distant encroaching sand drifts;
- the influence of expanding sandy deserts on other areas that eolian sand renders more sensitive to erosion; and
- the influence of land use in the formation and development of sandy areas.

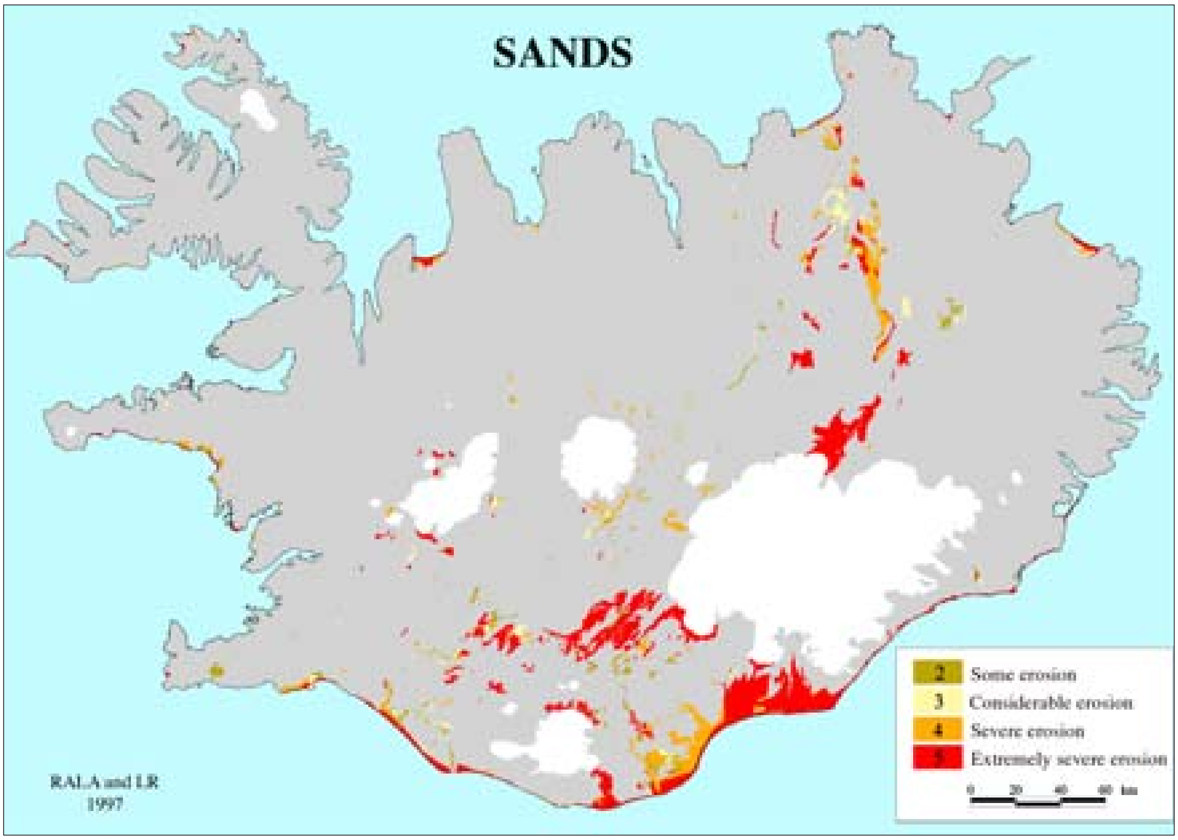
8.10.1 Main Sand Areas

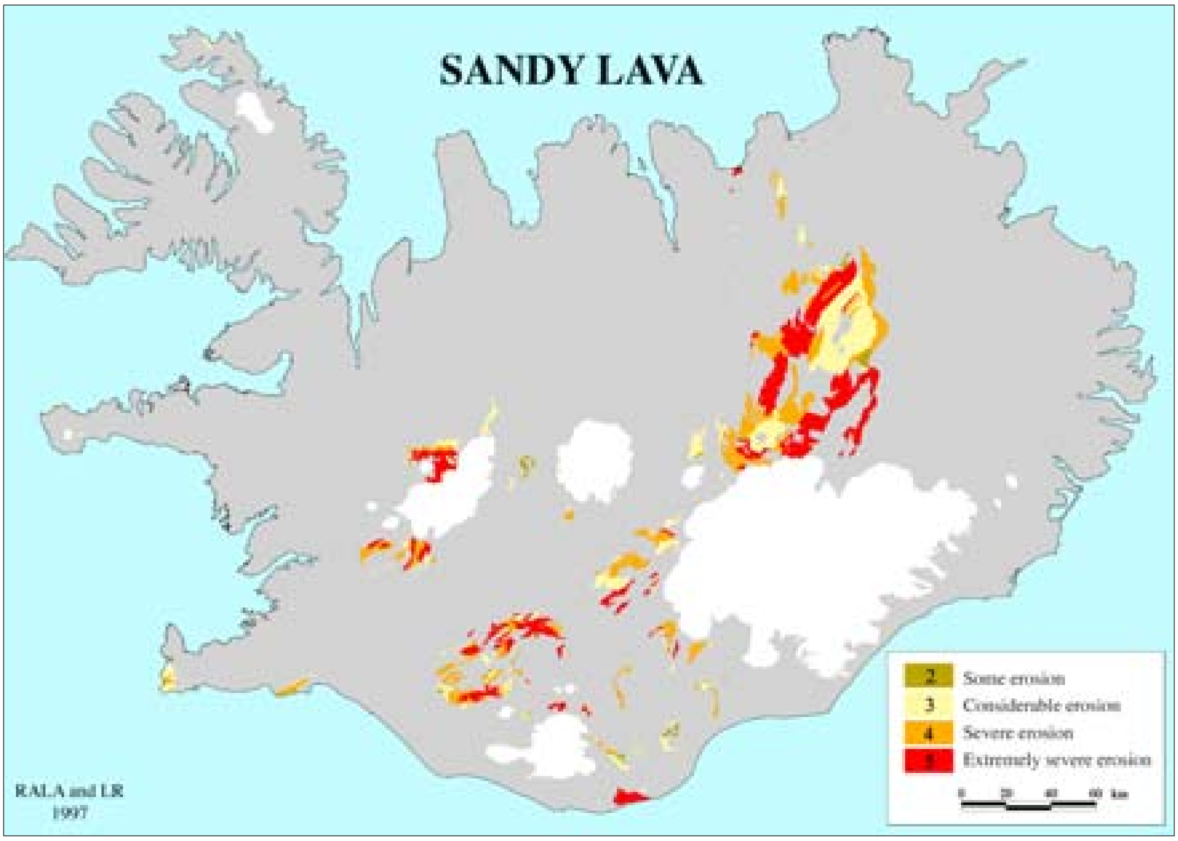
Research has shown that a large part of the deserts in north Iceland were once vegetated areas (Ólafur Arnalds, 1992), but it is not definitely known when these areas became victim to sand. It is probable that the decline began long before the Settlement of Iceland in the 9th century AD.

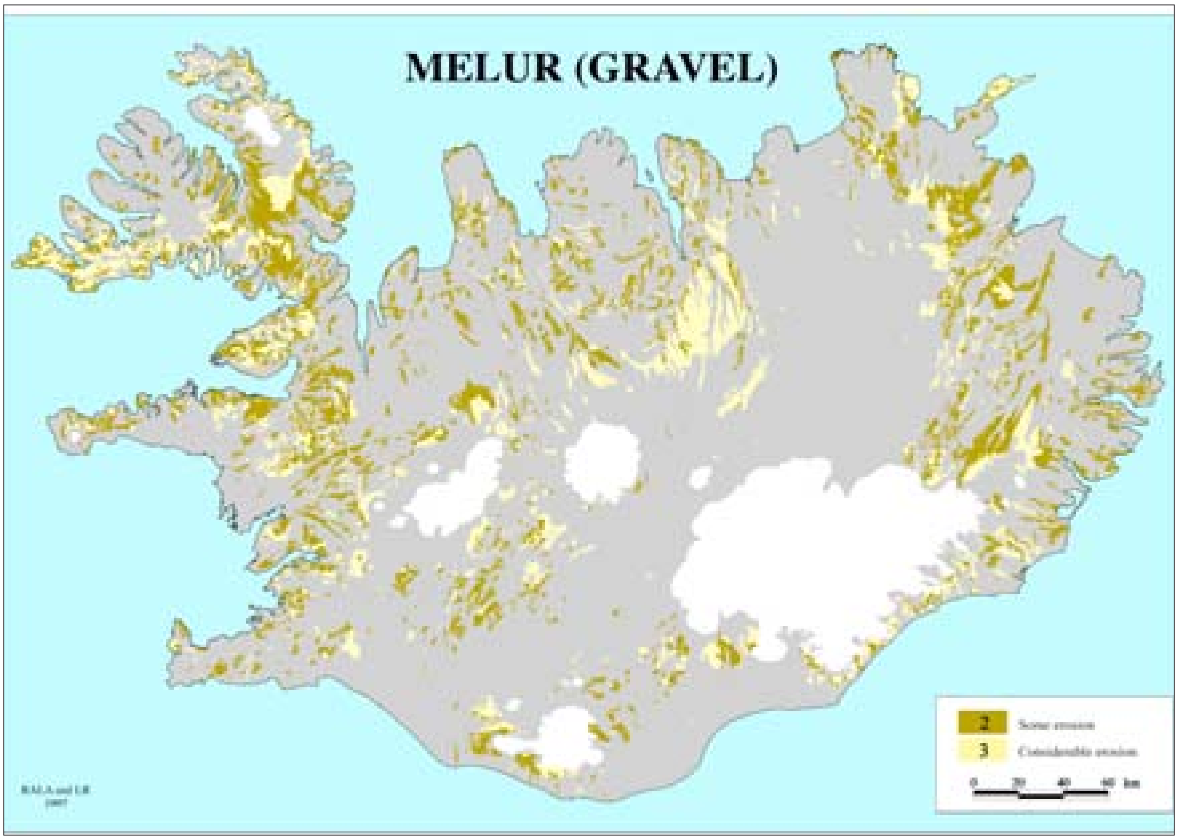
In northeast Iceland there is little that can stop drifting from the enormous sand bowl that originates in the headwaters of the Jökulsár á Fjöllum, Skjálfandafljót and Köldukvíslar rivers, and from sand-bowls left after major floods caused by volcanic eruptions and snow melt. The sand moves rapidly north over a wide area that stretches all the way from Skjálfandafljót and east over Jökulsá á Fjöllum (see map of sandy areas). The Möðrudalsöræfi desert and Hólsfjöll are part of these sandy areas, but at Kvensöðull, which is somewhat north of the Dettifoss waterfall in the Hólsandur area, some of the most magnificent sand formations in Iceland can be seen, where sand has gathered into huge sand dunes. The eastern border of this great sand area is clearly delineated north of the Vatnajökull glacier. The division is approximately at the origin of the Kverkár river in the direction of the Þríhyrningsfjallgarður mountain range, but the reason can be traced to conditions at the glacial margin.

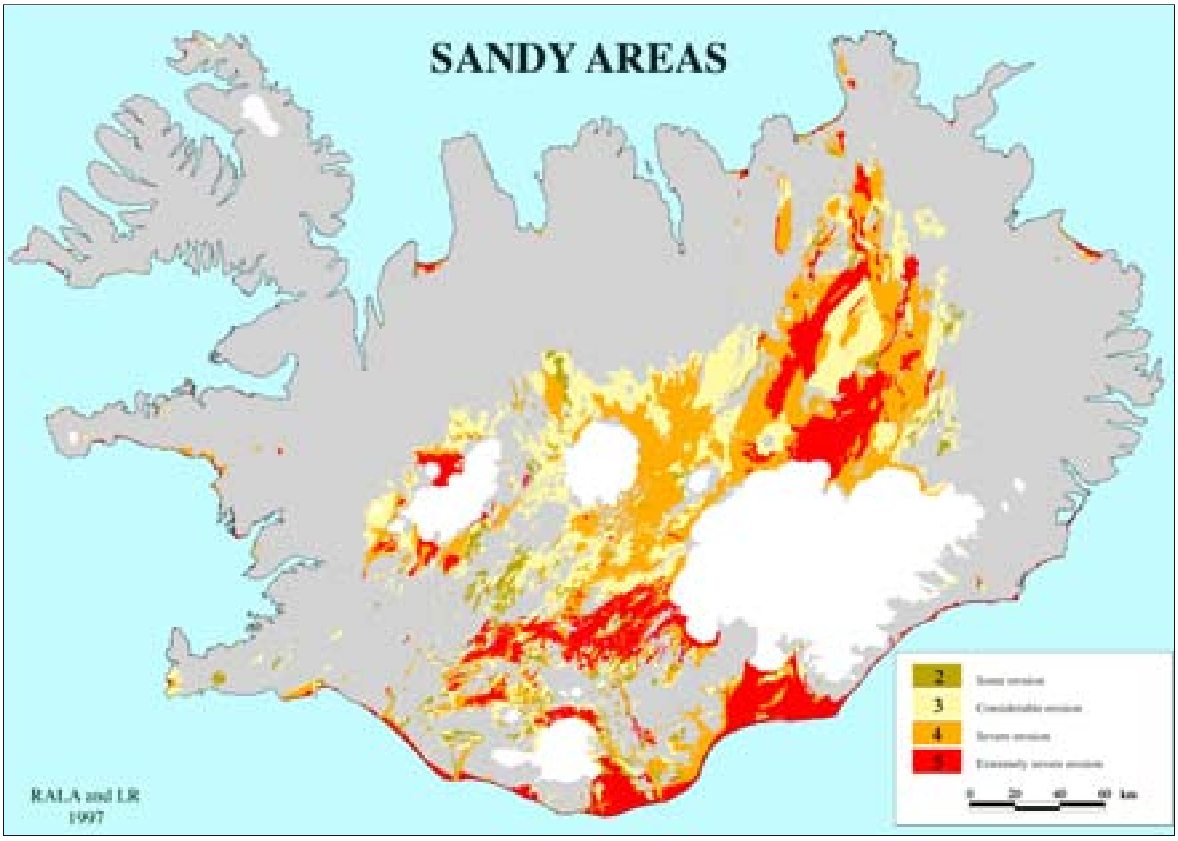
Active sand in Mývatn region in North Iceland.

Sand brought by glacial waters and remaining in the vicinity of glaciers, also causes considerable damage, for example, where rivers disappear and later return as spring water far from the glacial margin. Among places where this has occurred is south of the Þórisjökull and Langjökull glaciers, and widely to the north of the Vatnajökull glacier. Changes in water lev-


SANDS
2 Some erosion
3 Considerable erosion
4 Severe erosion
5 Extremely severe erosion
0 20 40 60 km
RALA and LR
1997


SANDY LAVA
2 Some erosion
3 Considerable erosion
4 Severe erosion
5 Extremely severe erosion
0 20 40 60 km
RALA and LR
1997


MELUR (GRAVEL)
2 Some erosion
3 Considerable erosion
0 20 40 60 km


SANDY AREAS
2 Some erosion
3 Considerable erosion
4 Severe erosion
5 Extremely severe erosion
0 20 40 60 km
RALA and LR
1997

Sand. Mælifellssandur, north of Mýrdalsjökull glacier. This surface is very unstable and sand storms are frequent. The origin of the sand is from glacial rivers and possibly floods during volcanic eruptions.

els, which now seem to be occurring along the southern edge of the Langjökull glacier, can lead to large increased eolian activity.

Sandy areas around large glaciers have increased in overall size as glaciers retreated during the 20th century. The fate of these sand accumulations varies. For example, mountains that are near glacial tongues can modify the wind direction and create shelters, thereby causing sand to accumulate relatively close to the glacier (e.g., south-west of the Langjökull glacier). In some places, glacial rivers run alongside the glacier, collecting drift sand and, in so doing, protecting distant areas (e.g., the Brunná river south of the Síðujökull glacier). The Emstrurár rivers apparently collect a large part of the sand that drifts from Mælifellssandur north of the Mýrdalsjökull glacier. There, the direction of dry winds is particularly southward to the glacier and the Emstrurár rivers.

Sand movement around Hofsjökull glacier appears formerly to have been more than at present, based on analysis of current sand drifting, even during the 20th century. There can be many explanations: climate alteration, declining sand-bowls at the glacier front or dwindling sources of sand formed during particular events (floods). Additional drift sand resulting from the retreating glacier may also have had an effect, but more balance exists now between supply and removal of drift material.

The developing sandy area around Langjökull glacier should be carefully monitored. Sand moves south from the Ásbrandsá river (Tungufljót) west to Uxahryggir, passing down Hauksdalsheiði heath, along Hlöðufell, down to Rótarsandur, up the hillsides of Skjaldbreiður and south to the Sandkluftavatn lake. The sand routes vary in activity, reflecting changes at the sources, which are determined largely by the flow of glacial water and water levels. There are sandy areas north of the Langjökull and Eiríksjökull glaciers that appear to be expanding, and should be monitored carefully.

Sandy lava. Sand is slowly filling up a lava field in Eldhraun, in the Skaftá area in South Iceland.

Major changes have now occurred in the vicinity of the Skaftár river's channel due to glacial bursts from glacial lakes situated over high temperature geothermal areas. They leave behind significant amounts of sand where there was little before. There is, therefore, every reason to follow closely the development of drift sand in this area.

Volcanic eruptions have created a large amount of sandy material with volcanic ash, in addition to the material brought forth by glacial floods. There are enormous amounts of sand in the Veiðivötn lake area and in the vicinity of Mt. Hekla, including volcanic ash that has buried countinuous vegetated land during his-

A sandy lag gravel surface. This type of surface becomes unstable during extreme storm events.

torical times. The Mt. Askja pumice from 1875 is very unstable over a large area east of Askja. Not all encroaching sand tongues and sandy areas originate from known glacial moraines and volcanic ash. This is the case for Hólasandur sands, northwest of the Lake Mývatn, which apparently has its origins from particularly sandy glacial moraines from the end of the last Ice Age. Also widely seen are encroaching sands and drift sand deriving from dried-up lakes (see, for example, Þröstur Eysteinsson, 1994).

The importance of seasonal rivers on sandy areas should also be noted. Such streams are not formed every year but are probably most active when large amounts of snow thaw rapidly. Routes taken by water often explain the origins of encroaching sands, such as that of Grænulág, in Grænavatnsbruni (Gyðuhnúksgil ravine), and in the Mývatn lake area. Water carries sand down from hills, e.g. down the north side of Skjaldbreiður, filling low areas with sand, such as at Hólasandur. Sand sources can become exhausted in such areas if long periods elapse between floods, but form again if new conditions are conducive to flooding.

A sand-dune and sandy lava NW of the volcano Askja in Ódaðahraun, north of Vatnajökull glacier. This dune is in a major sand-drift pathway over the lavas towards NE.

8.10.2 Glacial History, Floods and Land Use

It appears that many sandy areas are relatively young, most having even formed in recent centuries. At the same time, it is apparent that glaciers have a major influence on the development of sandy areas. It is therefore natural to consider how Iceland's glaciers looked at the time of Settlement, over 1,100 years ago. Most

Skeiðarársandur in South Iceland the day after the 1996 catastrophic flood, which resulted from volcanic eruption under Vatnajökull glacier.

indications are that they were smaller, and expanded up to the 20th century. When glaciers began receding during the warm period that began in the early 1920s, sandy areas in front of them were exposed and spread out.

It is clear that knowing the history of glaciers is important in order to understand the history of the sands, and the creation of highland deserts. This story is for the most part still unwritten.

There are indications that floods resulting from volcanic activity beneath glaciers are very influential in the development of sandy areas, such as the eruption at Bárðarbunga or other places on the north side of Vatnajökull. The recent glacial burst at Skeiðarár river demonstrated the enormous destructive power of such events. An eruption in 1477 created the volcanic ash layer "a" in the soil in northeast Iceland (Jón Benjamínsson, 1982), and may have caused a flood, which would explain the sand that is north and west of Dyngjufjall. This, however, is mere conjecture.

Little is known about floods from early Settlement times, but they could have conceivably affected the highland ecosystems, so that, combined with their utilization, the vegetation's rejuvenating power was reduced and even destroyed. It is conceivable that this applies to the area from the Blanda river in the west across to east Iceland, as well as extensively in south Iceland. It is imperative to piece together the story in order to better understand the destruction that has caused the largest erosion area in the country. How did land use influence the formation of deserts? It was previously mentioned that lush vegetation is better prepared to deal with drift sand by binding the sand. If the premise is correct that on large areas sand blows over in a kind of gust, and the sand drift diminishes when the sand source dwindles, then it is very important that the area has lush vegetation that can spread out when conditions improve. Grazing prevents this from happening, as described in Chapter 4. It is therefore likely that the indirect effect of grazing is widely significant. In early times, the highlands above the timberline were grazed relentlessly and grazing periods were long (Andrés Arnalds, 1988). This grazing may have been fateful. It can be pointed out that the vegetated land existing when the weather began to cool in the 12th century would have developed and thrived under better weather conditions than later occurred. Such vegetated land can well withstand atmospheric changes since vegetation has qualities of flexibility and resilience after it has gained a foothold. Grazing significantly reduces these qualities, particularly when that vegetation has a weak footing. When a major flood and sand passes over a land area, vegetation does not always return if conditions for growth have declined significantly.

Landslide in North Iceland. The frequency of such landslides is directly related to land use. Horse grazing can be detrimental for such slopes.

The role of land use in degrading highland sandy areas is unclear. In some places, grazing probably has not had much effect, while in other areas it may have been a decisive factor. Yet the fact remains that grazing on deserts is always overgrazing, which needs to be restricted and the highlands should be off-limits.

9. SOIL EROSION, LAND CONDITION AND LAND USE

9.1 Land Quality and Land Management

The large extent of soil erosion in Iceland has stimulated broad-based discussion on land condition, the reasons for erosion and steps needed for improvement. Most can agree that grazing on deserts and erosion-prone areas is improper land use. However, it is often pointed out that there is a lack of the information needed to restructure grazing management to match the true land conditions. Consequently, measures needed to control land use often arrive only after long delay. However, such demands for proof of problems contradict basic conservation principles. Where there is a question concerning the consequences of land use, the land should be given the benefit of the doubt. Landowners, district councils and government should never use lack of exhaustive data as an excuse to do nothing, or to allow unsuitable land use, least of all in deserts and erosion areas. Knowledge is never absolute, rather a stage on the road of development. Landowners and government must use the knowledge available at any given time to protect the land. This is in the interest of everyone in the long term.

Soil erosion and the state of the vegetation are the two primary factors indicative of the condition of grazing land. It is a basic tenet of soil conservation that land condition is considered bad when soil erosion is severe. Such judgements are made regardless of vegetation, even in areas of lush growth. The opposite can also be true: little soil erosion where the condition of vegetation is poor.

Vegetation that has significantly deteriorated without signs of significant erosion is an indication that erosion by itself does not provide conclusive information concerning the condition of the land. There is good reason to intensify research on vegetation and the effects of utilization on the land. Thus far, a vegetation map has been made covering a large part of the land, the plant preferences of grazing livestock have been studied, and coupled with wide-ranging grazing experiments.

9.2 Erosion and Assessment of Grazing Land

Soil erosion has a major influence on decisions concerning management of land use. In the opinion of LR and RALA, land with an erosion grade of 4 or 5 is not suitable for grazing. Considerable erosion occurs on land with an erosion grade of 3, and decisions on land use under these circumstances must take into consideration the nature of the erosion, the state of the vegetation and the known grazing history. Deserts are not considered suitable for grazing for the reasons described in Chapter 4. All these factors have been used to assess the condition of land in respect to soil erosion.

Each of the main factors is classed from A to D (A best; D worst). The average of these three classes then becomes the final classification for the respective area. The classification formula is described further in Table 9.

Assessment of land condition in relation to soil erosion is based on three factors:

- the distribution and extent of areas with severe erosion (4 or 5) and considerable erosion (3);
- the area of wasteland and mountains; and
- the extent of land where there is little erosion.

1st Assessment Factor: Areas with Severe Erosion

The criteria for assessment conform to internationally accepted principles and methodology for land assessment. Soil erosion that causes lasting damage induces rapid degradation and loss of natural resources, so standards for assessing soil degradation need to be relatively stringent. Some might feel that the limits set out in Table 9 are narrow, when in fact they are not.

In order to attain a classification of A, severe erosion (grades 4 and 5) may not cover more than 5% of that area. If severe erosion is more than 15% of the land area, it is classed D

2nd Assessment Factor: Deserts and Highlands

The demand that wastelands and highlands be spared from grazing is of course self-evident. However, the discussion in Chapter 4 on grazing on wastelands should be noted.

An A classification is assigned even where wastelands and highlands cover up to 25% of the land area. Class B applies to areas with up to 50% wasteland and highland, which is quite significant. If the percentage of wastelands and highlands exceeds 75%, it is considered class D. The distinction between classes is such that, in practice, stringent requirements are not made.

3rd Assessment Factor: Little Erosion

It is only natural to also consider the percentage of land where there is little erosion. When there is little erosion on >75% of land area, a class of A is given for that factor, but D if the percentage of land with little erosion is <25% of the area. Highlands are excluded from calculations of land area that are in good condition (which should actually rather be called satisfactory condition). This is done so that good land characterised by valleys and highlands receives a comparatively good classification for that factor. Consideration is given to the percentage of highlands when deriving the final classification (see Table 9).

Exceptions

Three exceptions are made regarding the assessment requisites shown in Table 9.

1. Assessment characteristics give only limited consideration to land that receives an erosion grading of 3. Additional assessment is required for land characterised by erosion grade 3 when the final classification is assigned.
2. When severe erosion (grades 4 and 5) covers over one-third of a land area, the extent of land with little erosion does not matter (3rd assessment factor); the condition of the overall area is invariably bad and it is given a final class of D. The same applies

Table 8. Criteria for Classification of Grazing Land in Relation to Soil Erosion.

Class	Proportion of Land (%) in a Particular Category		
	Severe erosion (4+5)	Deserts and Highlands	Little erosion (0, 1 and 2)
A	0 - 5	< 25	> 75
B	5 - 10	25 - 50	50 - 75
C	10 - 15	50 - 75	25 - 50
D	> 15	> 75	< 25

Exceptions:

1. If more than 50% of the land area is grade 3, the final class is reduced by one letter, but never from C to D.
2. If the extent of 4+5 exceeds 33%, the area is given a final class of D, irrespective of other factors. If 4+5 exceeds 20% of the area, the maximum possible class is C, although this does not apply if 4+5 is solely scree.
3. If deserts and highlands exceed 90% of the area, the final class is D, irrespective of other factors.

regarding the 20% rule for erosion grades 4 and 5: land cannot receive a class higher than C if severe erosion covers more than 20% of the area.
3. An exception is made to ensure that virtually unvegetated land (highland + wasteland) receives the appropriate class.

However, it is worth noting that these exceptions were rarely applied.

It is again reiterated that, when assessing land in the manner described above, the only criteria used were soil erosion and vegetation cover. No consideration was given to vegetation condition. However, one could assume that when no erosion is occurring, or when the primary erosion forms are erosion spots, solifluction or erosion escarpments and the erosion grading is low (1 or 2), then the land area is mostly vegetated. The National Land Survey of Iceland's vegetation map supports this assessment. Erosion grades, on the other hand, do not indicate the condition of vegetation or its development. Surveys of the condition of vegetation would often result in lower grades in those areas that are given a good grade here. The Reykjanes peninsula is a good example of this, as there is little erosion, but vegetation is sparse and does not in conform to the environmental conditions.

It is a matter of argument regarding where to draw the line between the individual classes in Table 9; distinctions are both subjective and debatable. The distinctions made here are believed to be a fair compromise. Some might feel that vegetation and soil are not given the benefit of the doubt, or that distinctions should be much more rigid. Others might feel that land they believe to be good for grazing receives too low a classification according to this method.

It is important to keep in mind that most grazing areas thus assessed are very large, and are frequently divided into well-vegetated grazing areas on the one hand and wastelands and erosion areas on the other. This is one reason why the class "little erosion" (erosion grade 0, 1 and 2) is important when implementing this method. It would be reasonable to re-assess these distinctions in the light of experience and as knowledge of the land increases.

On the basis of the three main assessment factors (Table 9), an average is calculated and the respective area given a final class. The final classes, which reflect soil erosion and are based primarily on use of land for grazing, are as follows:

Class A: Good Condition; Erosion Generally Little
No restrictions on grazing.
Class B: Satisfactory condition
Erosion is generally little, but with definite erosion areas. Restrictions on grazing in some areas.
Class C: Poor condition
Either generally severe erosion or deserts and highlands cover a large part of the land area. Significant restrictions on grazing are necessary even though good grazing areas may be found between erosion areas and wastelands.
Class D: Bad condition
Erosion areas and/or deserts are prevalent. Such areas should be protected immediately, or the erosion and wasteland areas isolated from the more favourable grazing areas.

When districts or highland pastures were assigned final classes, an attempt was made to exclude land not used for grazing, such as land reclamation areas, erosion areas along the coast etc., which would influence the final classification.

Classes were assigned for a total of 211 highland grazing areas. Maps following this chapter show the final classes for the whole country.

There is a clear difference between the condition of land given a bad classification (D) and that of land considered in good condition – at least as regards soil erosion. Two areas in the same part of the country serve as good examples: the Brúaröræfi desert and Hofteigsheiði common north of Jökuldalur (Table 10).

It is apparent that Iceland's highlands receive a poor classification with regard to soil erosion. In much of this area it is not possible to reconcile traditional attitudes towards grazing with approaches based on sustainable use of land.

The northwest and west part of the Norður-Múlasýsla county and the southern lowlands differ from other areas of the country in that most of these areas receive good classification, as – in terms of soil erosion – the condition of the land is considered good.

The southeast is widely characterised by mountains, and in addition, scree slopes with high erosion grades are common, resulting in many districts in the southeast receiving poor final classifications. The same applies to low classes assigned to the western part of the West Fjords.

It is often possible to divide the highland commons into two parts: wastelands and erosion areas on the one hand, and well-vegetated grazing land on the other. Auðkúluheiði and Síðuafréttur are two good examples of such commons, where relatively short lengths of fencing would be needed in order to protect the erosion areas, thus allowing sustainable use of grazing land on the rest of the common.

There are many highland pastures where the only solution is to discontinue grazing, because continued use cannot be justified for the foreseeable future. Examples of such areas are most highland commons in the Rangárvallasýsla and Árnessýsla counties, and highland commons in the north, from Eyvindarstaðaheiði east to the Jökulsá á Brú river.

The conclusions of the erosion mapping operation are that many areas receive a final classification of C or D. It is clear that there is no possibility of instituting appropriate measures instantly, but we hope that these conclusions will be used to harmonize grazing policy with land capacity.

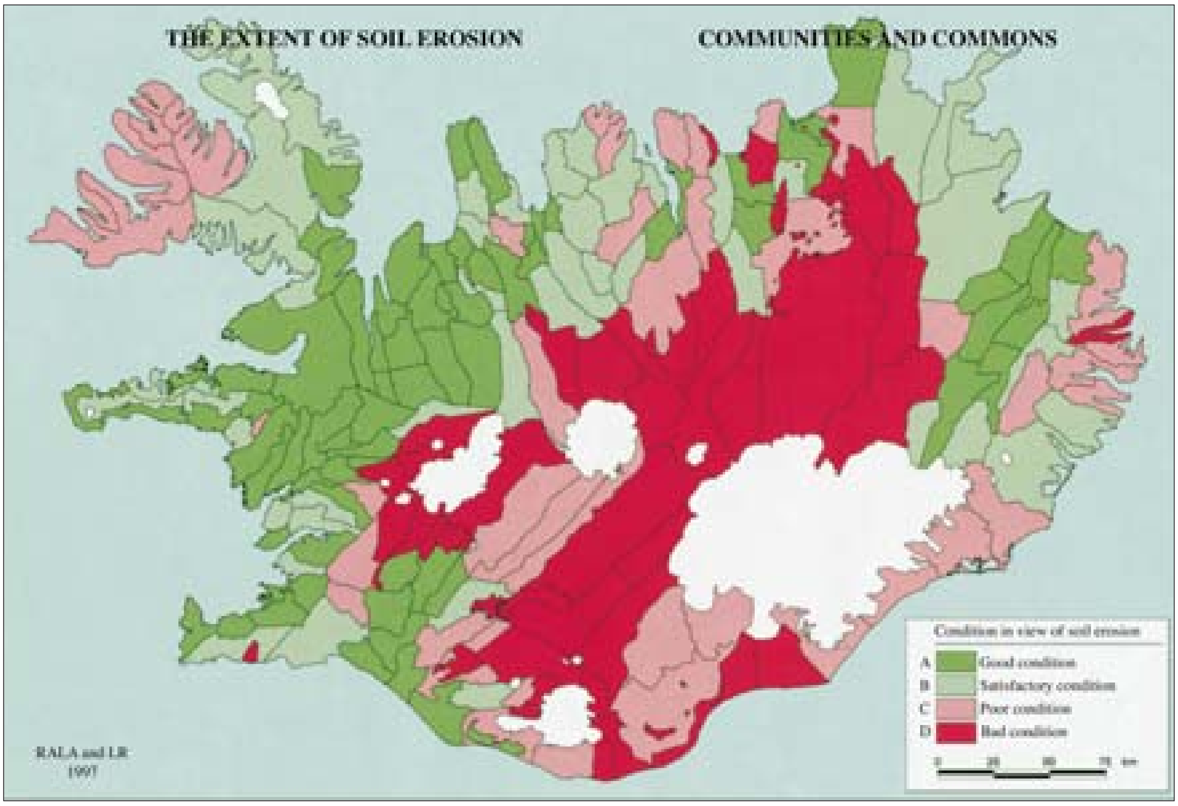
Land in good condition protected from erosion by a complete vegetation cover.

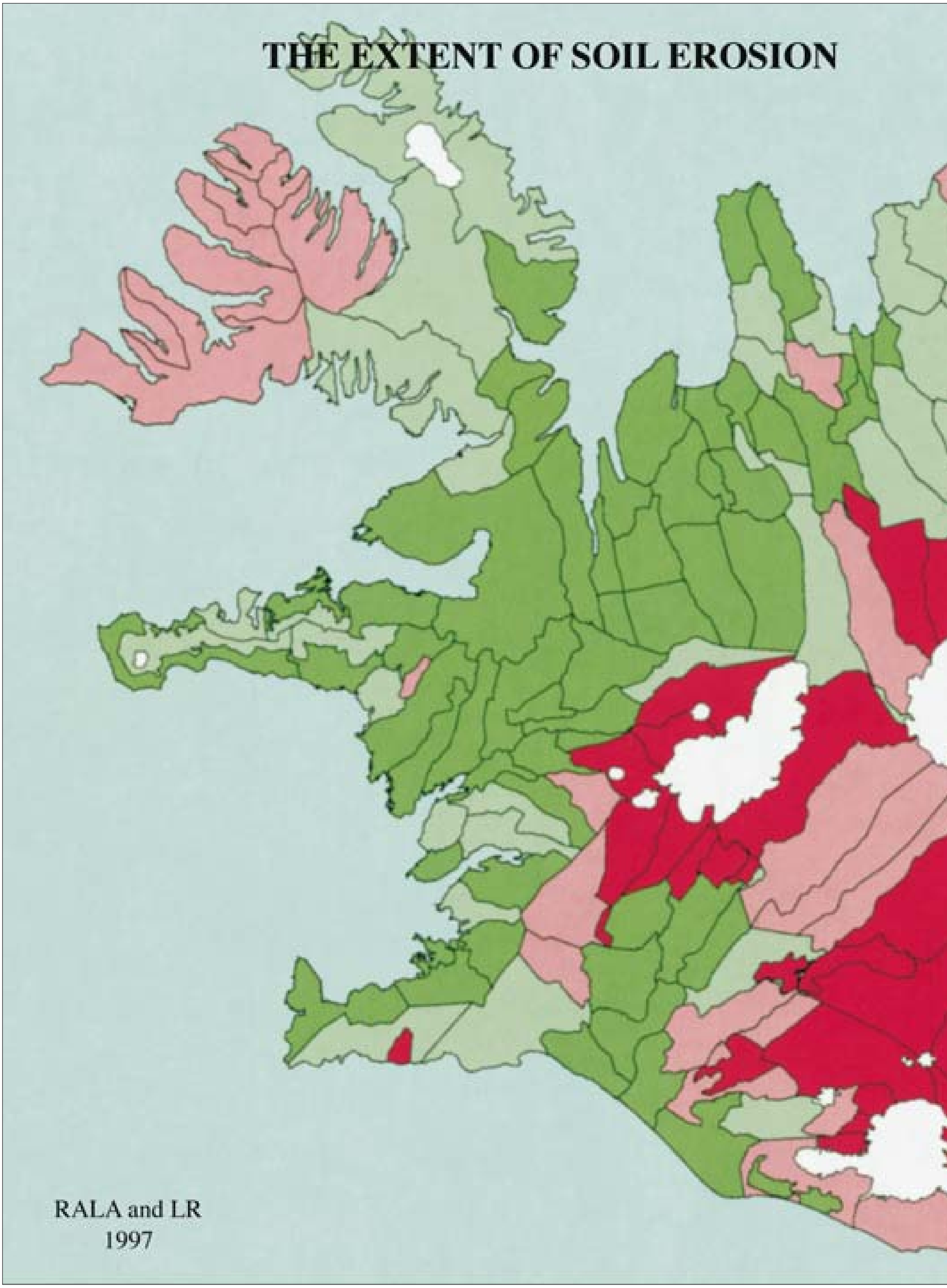
Severely degraded land, not suitable for grazing. Rapid erosion is taking place along the edges of the remaining vegetation (rofabards).

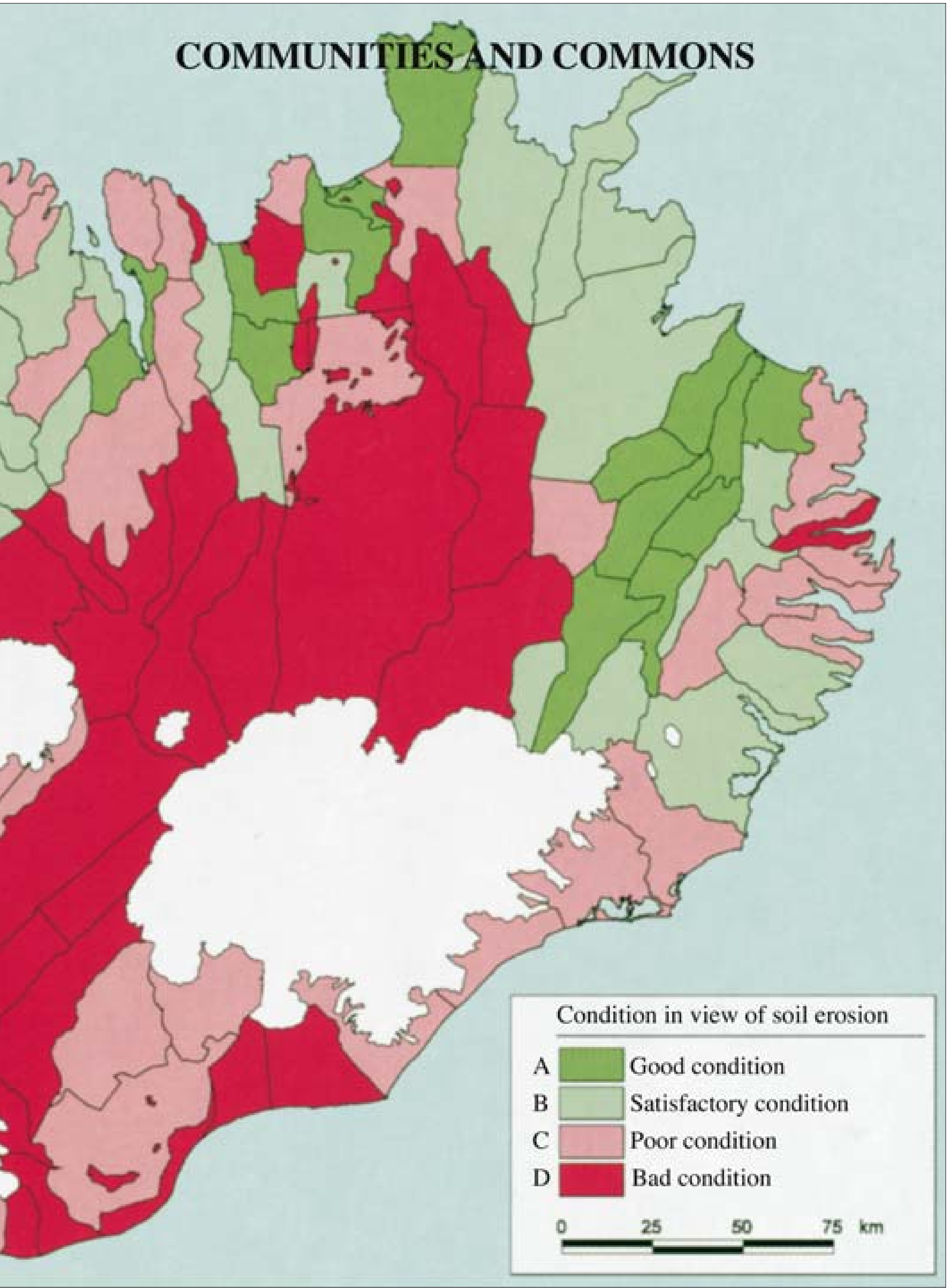
Table 10. Comparisons of Two Areas: One Considered in Good Condition; the Other Receiving a Bad Classification.

Area	Extent (%) of factor: Severe Erosion (Grades 4+5)	Highlands and Deserts	Good Condition (Grades 0+1+2)	**Classes**	**Final Classification**
Brúaröræfi	64	84	8	D(1)DD	D
Hofteigsheiði	1	19	88	AAA	A

Note: (1) In addition, class D because >33% has an erosion grade of 4+5.


THE EXTENT OF SOIL EROSION
COMMUNITIES AND COMMONS
Condition in view of soil erosion
A Good condition
B Satisfactory condition
C Poor condition
D Bad condition
RALA and LR
1997


THE EXTENT OF SOIL EROSION
RALA and LR
1997


COMMUNITIES AND COMMONS
Condition in view of soil erosion
A Good condition
B Satisfactory condition
C Poor condition
D Bad condition
0 25 50 75 km

10. CONCLUSIONS

When Iceland was settled, Norsemen brought with them knowledge about land use that had evolved in Europe over centuries. They were not aware of the sensitivity of Iceland's natural resources, nor of its special soil characteristics. People and livestock multiplied rapidly, the result being massive degradation of vegetation and soil erosion. A cooling climate and sand drifting aggravated the deterioration, and the degradation of natural resources has ever since molded the nation's environmental conditions.

Soil erosion is one of two key factors when assessing the condition of land; the other is vegetation. A basic tenet of soil conservation states that when soil erosion is severe, the condition of land is considered bad, without regard to vegetation. But it is important to keep in mind that vegetation can decline significantly even in the absence of obvious erosion. Under such conditions, data about erosion does not provide sufficient information about the condition of the land.

Most can agree that grazing on wastelands and erosion areas is improper land use. Nevertheless, it has often been stated that the information required to draw up a "proper" grazing plan to match land capacity is lacking. This has resulted in necessary measures being delayed. It has not helped that short-term economic considerations have often dominated decisions on land use.

International obligations and government policy are based on sustainable land use. The research described here clearly demonstrates that soil erosion occurs widely in Iceland, and that a large part of the highlands is not suitable for grazing. Action is needed.

Research also shows that in some districts, and on many farms, there is extensive, well-vegetated pasture land with little soil erosion, where it would be easy to ensure sustainable livestock production practices.

It is important to create a consensus regarding land use. When deemed necessary, grazing management must be implemented. But above all, it is necessary to increase the knowledge and initiative of land users by instilling in them the need to view land use on a long-term basis. Sustainable utilization assures land quality for coming generations.

LR celebrated its 90th anniversary in 1997. Presently, the route-map for the future is being developed, based on, among other things, the knowledge contained in this study of the extent of soil erosion. This plan involves a new basis for elaborating a broad-based land reclamation strategy that spans land utilization, vegetation conservation, surveys, research and development, planning and education.

In order to attain the twin goals of land reclamation and sustainable land use, a research environment must be created that has the capacity and ability to tackle the broad-ranging problems now awaiting solution. It is the opinion of this publication's authors that research and development in the field of land reclamation has been much too narrowly defined. The most urgent task in the field of soil conservation today is, without any doubt, the need to intensify research, development and planning.

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APPENDIX. OVERVIEW, EROSION AND VEGETATION IN COMMUNITIES AND COMMONS

County/ community, common	No.	km2 Size	Erosion map % 0+1+2	3	4+5	Erosion in Veget.land	Deserts Mountains	Vegetation % Deserts	Scarce	Rather Scarce	Good
Borgarfjarðarsýsla		**1903**	**60**	**31**	**9**	**18**	**32**	**24**	**8**	**18**	**50**
Hvalfjarðarstrandarhreppur	1	247	63	26	11	24	26	7	10	27	57
Akraneshreppar.	2	98	78	19	3	12	8	7	4	12	77
Leirár- og Melahreppur	3	141	52	41	7	31	32	21	11	15	54
Skorradalshreppur	4	227	68	26	6	29	8	7	7	24	62
Andakílshreppur	5	117	88	11	2	8	5	6	5	14	75
Lundarreykjadalshreppur	6	207	76	19	5	15	10	7	8	23	63
Oddstaðaafrétt	7	190	50	35	15	15	48	35	11	26	27
Reykholtsdalshreppur	8	171	87	13	0	7	6	5	5	18	72
Hálsahreppur	9	71	64	36	0	26	13	7	6	15	72
Rauðgilsafréttur	10	258	23	65	13	11	75	66	8	8	18
Geitland	11	176	27	40	33	14	79	74	5	8	13
Mýrasýsla		**2975**	**70**	**18**	**10**	**13**	**26**	**18**	**7**	**20**	**55**
Hvítársíða	12	219	80	19	2	16	9	4	6	22	68
Einkaland Kalmanstungu	13	450	20	21	59	10	82	76	14	7	3
Arnarvatnsh. Lambatungur	14	262	67	26	7	17	33	24	10	40	27
Þverárhlíðarhreppur	15	115	88	12	0	10	4	3	5	19	73
Borgarb. Norðurárd. Stafht.	16	456	69	29	2	24	16	5	7	22	66
Þverárrétt	17	412	94	6	0	4	3	3	3	27	68
Borgarhr. og Borgarnes	18	308	78	22	0	11	18	6	6	17	72
Álftaneshreppur	19	284	81	16	3	10	16	6	6	15	73
Borgarb. og Hraunhafnarhr.	20	465	71	23	6	14	23	13	8	17	62
Snæfellsnessýsla		**2163**	**72**	**21**	**6**	**17**	**23**	**14**	**12**	**19**	**55**
Kolbeinsstaðahr. láglendi	21	157	76	12	13	1	13	23	6	13	59
Kolbeinsstaðahr. innri hluti	22	170	79	21	0	7	17	8	14	32	46
Kolbeinsstaðaafréttur	23	45	41	45	14	47	36	20	11	22	47
Eyja- og Miklah.sv. láglendi	24	203	82	5	14	5	14	13	5	7	76
Eyja- og Miklah.sv. hálendi	25	221	59	39	3	28	38	18	15	25	41
Snæfellsbær láglendi	26	376	86	7	7	7	9	3	5	13	79
Snæfellsbær hálendi	27	297	55	39	6	38	46	21	23	25	31
Eyrarsveit	28	150	61	28	11	28	32	21	17	17	46
Stykkishólmur láglendi	29	149	78	17	5	17	9	10	11	19	60
Stykkishólmur hálendi	30	97	57	34	9	0	41	33	23	21	23
Skógarstrandarhreppur	31	299	71	29	0	15	17	7	9	23	61
Dalasýsla		**2078**	**71**	**27**	**2**	**18**	**20**	**7**	**7**	**26**	**61**
Dalabyggð	32	1827	72	26	2	17	18	6	6	25	63
Saurbæjarhreppur	33	251	60	40	1	21	36	13	8	33	46

County/ community, common	No.	Erosion map % km2 Size	0+1+2	3	4+5	Erosion in Veget.land	Deserts Mountains	Vegetation % Deserts	Scarce	Rather Scarce	Good
A-Barðastrandarsýsla		**1074**	**60**	**47**	**1**	**19**	**43**	**16**	**13**	**31**	**40**
Reykhólahreppur	34	1074	60	39	1	19	43	16	13	31	40
V-Barðastrandarsýsla		**1519**	**42**	**56**	**3**	**14**	**64**	**16**	**28**	**28**	**28**
Vesturbyggð	35	1326	42	55	3	13	63	15	28	28	29
Tálknafjarðarhreppur	36	192	41	57	1	24	70	18	29	31	23
V-Ísafjarðarsýsla		**1221**	**35**	**48**	**15**	**32**	**65**	**35**	**22**	**14**	**29**
Þingeyrarhreppur	37	540	33	43	24	23	70	37	24	14	25
Mýrarhreppur	38	273	40	47	13	32	64	33	22	14	31
Mosvalla-og Flateyrarhr.	39	210	36	57	7	30	60	35	19	12	33
Suðureyrarhr. og Bolungarv.	40	198	32	64	4	57	57	35	19	13	33
N-Ísafjarðarsýsla		1958	43	54	5	36	63	34	18	19	30
Ísafjörður vestan Djúps	41	130	28	65	7	59	46	32	17	16	35
Ísafjörður austan Djúps	42	1052	51	43	6	16	68	38	21	16	25
Súðav. Ögurhr. Reykjafj.hr.	43	776	38	60	2	55	59	28	14	23	34
Strandasýsla		**3465**	**71**	**30**	**1**	**15**	**30**	**26**	**11**	**22**	**41**
Árneshreppur	44	698	54	46	1	12	63	54	17	12	17
Kaldrananeshreppur	45	471	84	15	0	14	25	80	28	34	58
Hólmavíkurhreppur	46	1295	67	33	0	14	33	28	14	27	31
Kirkjubólshreppur	47	178	84	16	0	12	7	3	5	30	62
Broddaneshreppur	48	309	57	40	3	38	8	4	4	29	63
Bæjarhreppur	49	514	91	9	0	7	2	1	1	11	86
V-Húnavatnssýsla		**2496**	**94**	**6**	**1**	**4**	**7**	**5**	**3**	**19**	**73**
Staðarhreppur	50	143	89	8	3	11	0	1	1	6	91
Fremri-Torfustaðahreppur	51	323	97	3	0	3	0	1	1	6	92
Ytri-Torfustaðahreppur	52	212	96	4	0	3	1	1	1	6	92
Kirkjuhvammshr. Hvammst.	53	198	98	2	0	1	9	4	4	16	77
Þverárhreppur	54	309	89	8	3	7	13	7	4	14	75
Þorkelshólshreppur	55	349	94	6	0	6	16	5	5	17	73
Afréttur Hrútfirðinga	56	107	99	1	0	1	0	1	1	10	88
Afréttur Miðfirðinga	57	369	99	0	0	1	0	2	3	32	64
Víðidalstunguheiði	58	486	87	12	1	6	12	14	6	34	47
A-Húnavatnssýsla		**4146**	**65**	**33**	**4**	**16**	**25**	**27**	**7**	**25**	**42**
Áshreppur	59	269	100	0	0	0	1	1	2	25	72
Sveinsstaðahreppur	60	167	77	3	20	15	23	19	6	13	62
Víðidalsfjall	61	88	100	0	0	0	26	9	7	17	67
Grímstunguheiði	62	690	72	28	0	4	25	29	9	38	23
Torfalækjarhr. Blönduós	63	161	86	12	3	11	16	8	5	14	73
Sauðadalur	64	58	70	27	3	30	28	9	9	33	49
Svínavatnshreppur	65	217	98	2	0	1	7	2	3	12	83
Auðkúluheiði Hálsaland	66	742	57	40	3	24	28	26	11	30	33
Bólstaðarhlíðarhreppur	67	419	55	44	1	41	12	3	3	26	68
Eyvindarstheiði, A-Hún.	68	667	35	51	14	11	56	55	4	17	24
Engihlíðarhreppur	69	167	65	31	5	28	34	11	8	23	58
Vindhælishr. Höfðahreppur	70	260	54	41	5	39	16	9	8	26	57
Skagahreppur	71	241	88	12	0	11	6	1	3	34	62
Skagafjarðarsýsla		**5357**	**43**	**42**	**11**	**27**	**47**	**38**	**7**	**20**	**35**
Skefilsstaðahreppur	72	382	75	25	0	24	4	5	5	33	56
Skarðshreppur Sauðárkr.	73	190	46	48	6	44	13	0	8	31	62
Staðarhreppur	74	52	72	28	0	28	0	0	0	6	94
Staðarafréttur	75	98	23	72	5	65	28	15	10	28	47
Seyluhreppur	76	132	73	27	0	24	5	1	2	16	82
Eyvindarsth. Austari	77	527	10	69	22	30	61	68	8	14	10
Lýtingsstaðahreppur	78	516	56	38	6	36	12	6	5	30	58

County/ community, common	No.	Erosion map ---- % ---- km2 Size	0+1+2	3	4+5	Erosion in Veget.land	Deserts Mountains	Vegetation ---- % ---- Deserts	Scarce	Rather Scarce	Good
Hofsafrétt	79	769	15	65	20	9	79	77	5	13	6
Akrahreppur	80	586	62	35	3	28	53	48	7	15	29
Silfrastaðaafréttur	81	197	54	46	0	46	68	66	6	12	16
Rípurhreppur	82	79	83	10	7	6	11	13	6	17	65
Viðvíkurhreppur	83	97	75	25	0	25	15	14	6	26	54
Hólahreppur	84	463	54	42	4	42	61	51	9	16	23
Hofshreppur	85	360	55	40	5	31	44	21	11	24	43
Fljótahreppur	86	329	61	31	8	25	36	19	13	21	47
Siglufjörður	87	157	40	47	14	38	50	33	18	18	31
Nýjabæjarafréttur	88	322	20	47	34	1	89	84	7	6	3
Eyjafjarðarsýsla		**4089**	**32**	**42**	**23**	**24**	**63**	**58**	**5**	**9**	**27**
Ólafsfjörður	89	210	36	50	14	51	58	37	16	16	31
Svarfaðardalshr. Dalvík	90	550	57	37	5	32	54	41	8	15	37
Árskógshr. Arnarneshr.	91	165	65	35	0	32	25	18	4	12	65
Skriðuhreppur	92	417	43	55	2	51	56	43	6	16	35
Öxnadalshreppur	93	290	68	32	0	32	52	52	7	11	30
Glæsibæjarhr. Akureyri	94	257	78	21	1	20	32	31	5	11	54
Eyjafjarðarsveit	95	1116	34	64	2	36	53	50	7	11	32
Fjöllin	96	1085	1	37	62	1	98	99	1	0	0
S-Þingeyjarsýsla		**11134**	**23**	**33**	**44**	**13**	**69**	**70**	**4**	**7**	**19**
Grýtub.hr. Svalbarðsst.hr.	97	136	68	29	3	29	20	12	6	22	60
Afréttur Grýtubakkahrepps	98	329	28	39	33	46	65	53	9	18	20
Hálsahreppur	99	425	44	46	11	28	33	33	7	15	45
Suðurafréttur Fnjóskdæla	100	684	9	81	10	18	76	80	4	5	11
Flateyjardalsheiði	101	231	48	45	6	50	51	46	7	18	29
Ljósavatnshreppur	102	367	45	45	10	20	49	46	5	10	39
Viknalönd	103	57	24	38	38	42	72	64	7	13	16
Bárðdælahreppur	104	470	54	32	14	21	25	29	6	12	53
Vesturafréttur Bárðdæla	105	1153	6	58	36	4	91	93	3	2	2
Austurafréttur Bárðdæla	106	949	5	38	57	5	92	95	3	1	1
Skútustaðahr. byggð, gróðurl.	107	931	56	15	29	29	21	25	8	24	42
Skútustaðahr. auðnir	108	3858	2	25	73	2	96	98	1	0	0
LR girðingar í Skútustaðahr.	109	137	8	10	82	35	70	57	10	12	20
Reykdælahreppur	110	330	90	7	3	9	3	3	1	5	91
LR girðingar í Reykdælahr.	111	59	1	0	99	4	99	100	0	0	0
Aðaldælahreppur	112	260	82	9	9	7	16	18	4	11	67
Þeistareykjaland	113	235	67	26	6	18	25	17	11	31	40
LR girðingar á Þeistareykjum	114	39	7	1	91	6	83	77	5	5	13
Reykjahreppur Húsavík	115	284	45	21	34	45	23	35	4	16	45
Tjörneshreppur	116	189	39	38	23	60	26	34	5	19	42
N-Þingeyjarsýsla		**5393**	**56**	**25**	**19**	**20**	**34**	**29**	**9**	**19**	**43**
Kelduneshreppur	117	121	87	4	9	1	13	10	5	19	67
Afréttur Keldhverfinga	118	456	78	15	7	18	10	12	3	12	73
Þjóðgarður (LR girðing)	119	172	36	11	53	27	53	41	7	12	40
Presthhr gamli án Raufarh.	120	861	84	9	7	13	7	14	9	22	56
Öxarfjarðarhreppur	121	509	49	32	19	28	28	26	9	20	45
Afréttur Öxarfjarðarhrepps	122	510	6	74	19	38	73	73	13	10	4
LR girðingar í Öxarfjarðarhr.	123	14	11	3	87	26	89	64	14	14	7
Hólsfjöll	124	724	8	23	69	27	77	71	7	8	14
Raufarhöfn Svalbarðshr.	125	1273	66	25	9	23	25	3	0	21	76
Þórshafnarhreppur	126	750	68	31	2	7	30	16	11	35	37

County/ community, common	No.	Erosion map ---- % ---- km2 Size	0+1+2	3	4+5	Erosion in Veget.land	Deserts Mountains	Vegetation ---- % ---- Deserts	Scarce	Rather Scarce	Good
N-Múlasýsla		**10568**	**53**	**24**	**23**	**13**	**42**	**43**	**10**	**21**	**25**
Skeggjastaðahreppur	127	597	68	25	7	31	5	6	7	37	50
Vopnafjarðarhreppur	128	2181	59	33	8	21	32	34	10	23	33
Hlíðarhreppur	129	420	86	12	3	12	33	42	10	15	34
Hofteigsheiði	130	339	88	11	1	4	19	25	18	32	25
Jökuldalsheiði	131	499	38	52	11	21	41	42	10	25	23
Brúaröræfi	132	1592	8	27	64	8	84	87	4	6	4
Möðrudalsöræfi	133	988	5	10	86	3	94	90	4	4	1
Vesturöræfi	134	306	62	31	7	12	29	36	18	32	14
Klausturs. Stuðla-. Hnefsth.	135	456	89	10	1	4	7	11	16	49	24
Fljótsdalshreppur, láglendi	136	357	89	11	0	8	7	13	16	37	33
Fljótsdalsheiði	137	671	77	21	2	7	26	28	12	35	25
Múli, Suðurfell	138	473	72	28	0	2	50	44	26	22	8
Fellahreppur	139	326	95	5	0	4	2	10	16	31	42
Tunguhreppur	140	295	99	0	0	1	0	6	4	16	74
Hjaltastaðarhreppur	141	393	79	12	9	12	21	22	6	20	52
Borgarfjarðarhr. Seyðisfj.	142	676	48	38	14	36	54	45	10	14	31
S-Múlasýsla		**3949**	**50**	**42**	**8**	**31**	**37**	**33**	**15**	**19**	**33**
Vallahreppur	143	362	53	41	7	21	28	30	13	16	40
Egilsstaðir, Eiðahreppur	144	320	72	22	6	28	19	25	10	18	47
Skriðdalshreppur	145	496	43	46	11	17	48	32	20	19	29
Mjóifjörður	146	189	15	51	34	56	61	51	9	14	25
Reyðarfjörður, Eskifjörður	147	405	18	70	12	62	35	36	11	18	35
Búðahreppur, Fáskrúðsfj.	148	272	34	59	6	50	26	28	9	19	44
Neskaupstaður	149	228	32	64	4	54	32	31	9	17	43
Breiðdalur, Stöðvarfjörður	150	551	56	34	10	35	28	23	12	21	43
Djúpavogshreppur	151	1126	71	27	2	11	46	40	20	21	19
A-Skaftafellssýsla		**2962**	**26**	**31**	**45**	**11**	**76**	**60**	**13**	**11**	**15**
Bæjarhreppur	152	745	29	42	29	14	75	56	19	13	12
Hornafjörður	153	737	36	31	33	20	69	47	16	13	24
Borgarhafnarhreppur	154	376	33	39	28	9	72	56	14	12	18
Hofshreppur	155	490	36	29	36	9	67	54	10	16	20
Skeiðarársandur	156	615	4	10	87	1	96	93	5	2	0
V-Skaftafellssýsla		**5663**	**43**	**17**	**40**	**5**	**55**	**56**	**15**	**18**	**12**
Skaftárhreppur, láglendi	157	1411	70	10	20	3	26	26	21	28	25
Fljótshverfi, afréttur	158	637	39	39	22	5	69	61	20	15	4
Síðuafréttur	159	947	56	22	22	9	36	50	22	22	7
Skaftártunguafréttur	160	969	35	16	50	5	65	73	9	14	4
Álftaversafréttur	161	208	40	22	38	4	59	73	10	13	4
LR girðingar í Skaftárhr.	162	52	28	17	55	2	70	69	15	10	6
Skeiðarár- og Mýrdalss.	163	655	5	4	91	0	95	95	3	2	0
Fjörusandur í Skaftárhr.	164	240	0	0	100	0	100	91	2	5	2
Mýrdalshreppur	165	374	46	42	12	20	40	28	11	21	40
Mýrdalssandur í Mýrdalshr.	166	172	5	10	85	5	91	90	4	5	2
Rangárvallasýsla		**7365**	**30**	**26**	**44**	**7**	**67**	**67**	**6**	**7**	**20**
Eyjafjallahreppur, láglendi	167	123	83	7	10	5	12	4	2	7	86
Eyjafjallahr. ofan byggðar	168	372	32	36	32	38	44	44	18	22	15
Landeyjahreppar, Hvolhr.	169	452	77	8	15	2	21	14	3	7	77
Emstrur	170	83	7	27	66	22	87	82	7	7	4
Fljótshlíðarhreppur	171	280	47	45	8	14	42	36	8	13	42
Afréttur Fljótshlíðinga	172	118	25	63	12	37	46	42	18	23	16
Rangárvallahreppur láglendi	173	406	52	19	29	6	43	38	10	11	41
Rangárvallaafréttur	174	789	26	35	39	7	76	83	7	7	3

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LR girðing í Rangárvallahr.	**175**	**173**	**34**	**14**	**52**	**4**	**63**	**38**	**16**	**17**	**28**
Ásahreppur, Djúpárhreppur	176	270	78	4	18	2	20	16	2	4	78
Afréttur Ásahrepps	177	505	7	36	57	0	93	99	1	0	0
Holta- og Landsveit	178	435	69	8	23	4	28	19	8	7	66
Landmannaafréttur	179	953	14	20	66	12	83	86	6	6	2
LR girðing í Landmannaafr.	180	222	9	8	83	1	91	93	2	3	1
Holtamannaafréttur	181	2073	11	32	57	1	88	92	3	3	2
Almenningar	182	38	13	40	47	4	75	68	16	14	3
Þórsmörk	183	72	17	48	36	0	79	51	17	20	12
Árnessýsla		**7932**	**50**	**32**	**18**	**19**	**39**	**39**	**9**	**19**	**33**
Sunnanverður Flói	184	237	81	14	6	14	6	6	2	4	88
Norðanverður Flói og Skeið	185	314	89	9	3	6	5	4	2	4	90
Flóa- og Skeiðamannaafr.	186	710	22	64	14	11	71	78	11	10	1
Gnúpverjahreppur	187	378	66	24	9	20	15	15	10	28	47
Gnúpverjaafréttur	188	617	39	30	31	14	51	56	9	23	11
Friðað svæði í Þjórsárdal	189	87	30	22	48	12	62	51	13	17	19
Hrunamannahr. heimalönd	190	224	79	19	2	16	6	5	9	17	70
Hrunamannaafréttur	191	1026	40	52	8	30	41	49	14	26	10
LR girðing í Hrunam.afrétt	192	15	51	35	14	20	29	20	13	27	40
Biskupstungnahr. heimalönd	193	339	89	10	2	8	4	4	4	7	85
Hólaland Biskupstungnaafr.	194	1022	15	61	25	27	67	68	10	17	5
Haukadalsheiði	195	116	16	25	60	27	60	67	9	5	19
Afréttur Úthlíðar	196	125	38	25	37	21	49	40	16	9	35
Laugardalshreppur	197	260	76	15	8	13	15	15	19	16	51
Laugardalsafréttur	198	230	13	28	60	8	82	78	12	7	4
Grímsneshreppur	199	380	91	8	2	9	2	2	2	8	88
Grímsnesafréttur	200	394	39	20	41	15	55	53	7	24	16
Þingvallahreppur	201	468	50	29	21	38	28	18	8	23	50
Grafningshreppur	202	237	52	24	23	41	24	7	7	35	51
Hveragerði, Ölfushreppur	203	753	72	19	10	14	22	17	6	37	41
Reykjanes - Reykjavík		**1216**	**79**	**15**	**6**	**7**	**15**	**13**	**15**	**38**	**34**
Grindavík	204	445	75	20	5	8	20	19	25	50	6
Krísuvík	205	47	11	18	72	75	23	34	15	26	26
Reykjanesbær og Vatnsl.st.	206	387	81	16	3	0	19	19	14	50	17
Höfuðborgarsvæði, byggð	207	74	100	0	0	0	0	13	14	27	46
Höfuðborgarsv. utan byggðar	208	262	91	8	1	5	6	9	13	50	29
Kjósarsýsla		**664**	**68**	**28**	**5**	**20**	**20**	**10**	**12**	**29**	**49**
Mosfellsbær	209	215	81	16	4	15	6	10	12	29	49
Kjalarneshreppur	210	152	64	28	9	20	32	5	7	38	51
Kjósarhreppur	211	297	60	35	5	24	23	13	13	22	52

Fertile brown Andosols once covered most of Iceland, along with birch and willow woodlands. Soil erosion is one of the most active geomorphic processes shaping the surface of Iceland. Land degradation has severely damaged the country's ecosystems, destructing woodlands and creating vast deserts.

This report is the result of combined efforts of the Agricultural Research Institute and the Soil Conservation Service. It clearly demonstrates both areas in good condition and the severe and widespread soil erosion. The project received the Nordic Nature and Environmental Award in 1998.

The assessment results are a foundation for new strategies for soil conservation and sustainable land use in Iceland.

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