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Land Degradation in NE Iceland
An assessment of extent, causes and consequences

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1. INTRODUCTION

Geographers at the University of Lund have been active in research on desertification/ land degradation and environmental change monitoring of African drylands since the mid 1970's and of Asian drylands since the beginning of the 1990's (Helldén 1991, 1998; Olsson 1993). The importance of human impact versus the impact of climatic fluctuations for land degradation is focussed on in the studies.

The results obtained so far do not confirm the concept of desertification as a mainly man made phenomenon but indicate that the importance of climate variability and change has been underestimated. To learn about the importance of climate versus human impact on land degradation in environments outside the drylands of the world, Iceland was selected as an example for further studies.

There are few areas in Europe that have suffered such a severe and extensive land degradation as Iceland, leading to the creation of long lasting desert like conditions. It is estimated that when Iceland was settled, in 874 , at least 60% of the country was vegetated and that forests covered 15-25% of the country's area (Bergþórsson 1998, Þórarinsson 1961, Einarsson 1963, Þorsteinsson 1973). The vegetative cover is now about 27%. There is almost no forest only some

shrubs of willow and birch (The Agricultural Ministry 1986, IGI/LMÍ 1993, Arnalds et al.1997).

The decline is thought to be the result of vegetation degradation and accelerated erosion that began shortly after the settlement (Einarsson 1961, 1962, 1963, Hallsdóttir 1987, Þórarinsson 1944, 1961, Þórarinsson 1974). The main causes are considered to be overgrazing, the use of wood for fuel and charcoal, highly erodible soils and a harsh climate (Arnalds 1987, 1988, Bjarnason 1942, 1974, Þorsteinsson 1973, Þórarinsson 1974, Friðriksson 1978, Runólfsson 1987).

2. CONCEPTS AND DEFINITIONS

Desertification has been defined and described in many ways as summarized by Helldén (1991).

According to the United Nations Conference on Environment and Development (UNCED 1992) and the Intergovernmental Negotiating Committee for a Convention to Combat Desertification (INCD 1994) *"Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities".*

"Land" in this concept includes soil and local water resources, land surface and vegetation or crops.

"Degradation" implies a reduction of the resource potential by one or a combination of processes acting on the land. Long term reduction of the production of biomass (plants and animals) in the drylands is often considered to be a serious consequence and a symptom of desertification.

Aridity zones were defined by UNEP, using the annual precipitation over potential evapotranspiration (calculated by the adaption of the Thornthwaite formula as opposed to the Penman formula used in 1977), as indicated below (UNEP 1991):

Hyper-arid	< 0.05
Arid	0.05-0.20
Semi-arid	0.21-0.50
Dry sub-humid	0.51-0.65

Iceland is not an arid, semi-arid or dry sub-humid region. Therefore the land degradation it is suffering from cannot be called "desertification" in the strict sense as defined by the UN. On the other hand there is no doubt that land degradation has led to the creation of desert like conditions in many areas of Iceland. In this sense, "desertification" is an Icelandic reality indicating the introduction and spread of desert like conditions in landscapes where there should not be any.

3. GEOGRAPHY

3.1 General physiography and geology

Iceland extends approximately from latitude 63° to 66° N and longitude 13° to 24° W (Fig. 3.1.1). The land area is 103 300 km^2.

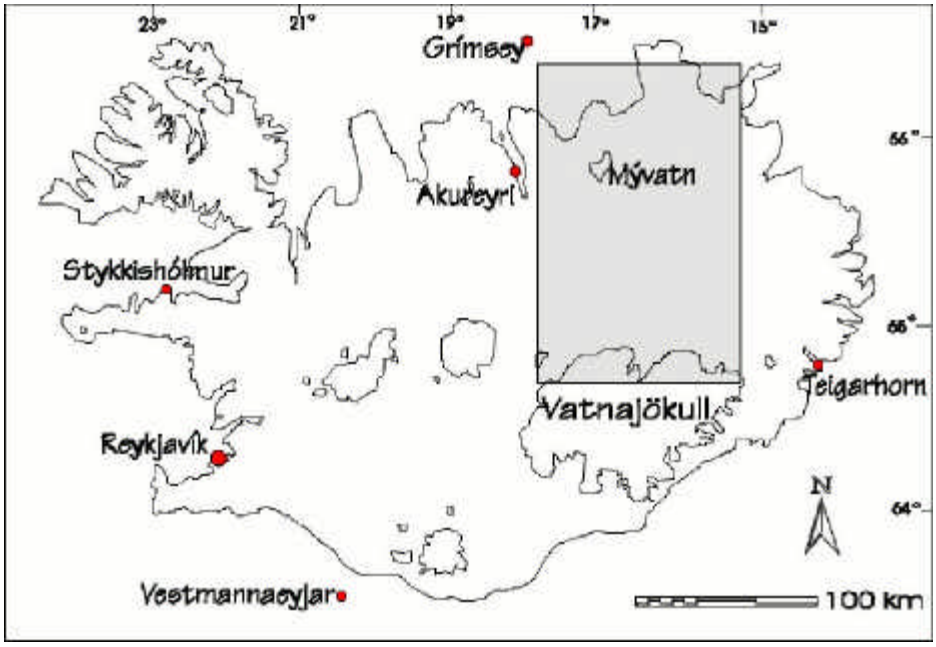

Fig. 3.1.1. The location of the study area and the long record climate stations in Iceland.

The country is characterized by its Tertiary and Quaternary volcanic origin. It appears on the whole roughly hewn, abrupt and jagged, without the softness of outline that characterizes a more mature landscape. Volcanic eruptions have been numerous and frequent, averaging 20 per century during historical time (Gísladóttir 1998). Elevation ranges from sea level to 2119 m a.s.l. Only 24% of the land area is located below 200 m and about 30% is higher than 600 m a.s.l. (Bergþórsson et. al. 1987). About 90% of the land area is volcanic rocks, mainly basalts, while the remaining land is covered by eolian, fluvial and glacial deposits (Jakobsson 1979). The glaciers of Iceland cover about 10% of the land surface (Cf. Fig.3.1.1.)

3.2 Climate

Iceland is situated at the junction of two climatic zones, i.e. the temperate zone in the south and the arctic zone in the north. The climate description below is condensed from Gísladóttir (1998) unless stated otherwise.

The climate is characterized as cool-tempered oceanic, with cool summers and mild winters. Shifts between frost and thaw are very common and storms are frequent. The south and west, as well as the interior of northern and eastern Iceland have an average temperature >10°C for July, the warmest month of the year. The corresponding value for the coldest month is warmer than –

3°C in the lowlands. In these areas the climate is temperate and humid, Cfc, according to the Köppen´s classification system (Köppen 1936). On the peninsulas in the north and the highlands the mean temperature in the warmest month never reaches 10°C. The climate is arctic, ET, according to the Köppen´s system.

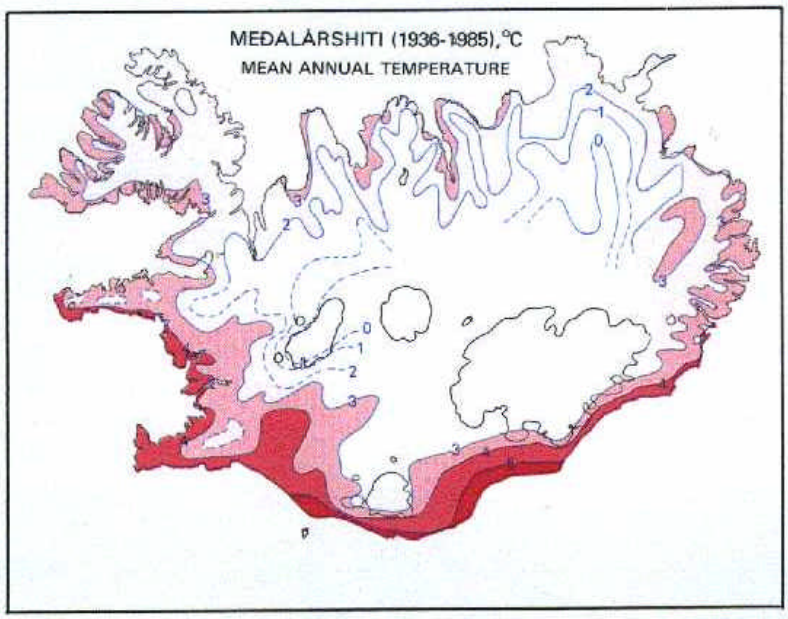

Fig. 3.2.1a. Mean annual temperature 1931-1960 (° C) (from IGI/LMÍ 1996).

Annual rainfall averages 400 mm in the NE and more than 4000 mm in the SE (Fig. 3.2.1 b). The prevailing winds that giving precipitation are southerly or south-easterly which results in much less rainfall in the north. (Einarsson 1976).

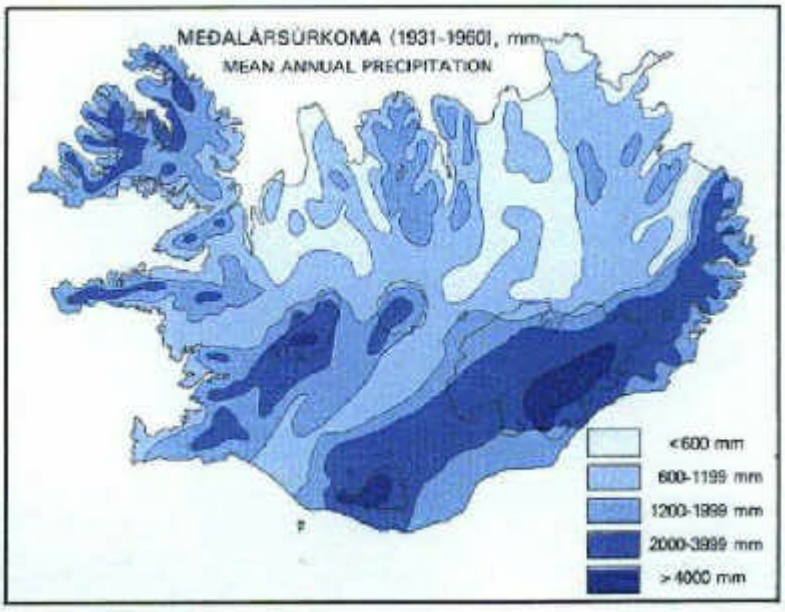

Fig. 3.2.1b Mean annual precipitation 1931-1960 (mm) (IGI/LMÍ 1996).

Much has been written about the climate that prevailed about 1000 years ago when the island was recently settled. Most of it is based on literatures, such as annals and the Icelandic Sagas. It is generally concluded that the climate was appreciably warmer at the time of the settlement (874-930) than during the following period 1200-1920. The mean annual temperature at the time of settlement has been estimated at 4.4^{o}C according to Gísladóttir (1998). By relating temperature, sea ice observations and reported historical famine/severe years Bergþórsson (1967) reconstructed annual temperature all the way back to the time of the settlement (Fig. 6.2.1.-6.2.2). He concludes that during the 12th to the 15th centuries the temperature reached its lowest point around 1300. The estimated annual temperature was 3.2^{o}C at this time according to Gísladóttir (1998). The estimates of the historic temperatures mentioned refer to the Stykkishólmur area, i.e. to the lowlands of west and south Iceland (Cf. Fig.3.1.1).

Ogilvie (1984), basing her conclusions on references to the distribution of sea ice, describes the 14th century as experiencing cold climate with many long and severe winters. Indications from advancing glaciers by the end of the 14th century are another proof of cool climate. The conditions grew colder again from the middle of the 16th century and remained so until the beginning of the 20th century (Bergþórsson 1969). According to Ogilvie (1997) ice observation data suggest that for the period 1600 to around 1900 the decades with most ice present were the 1780s, early 1800s, 1830s and the time from 1850 to around 1900 (Cf. Fig. 6.2.1-6.2.2). According to Ives (1991) it has been difficult to choose a rational starting date for the Little Ice Age. He has, however, chosen 1500 in conformity with reconstruction of climate in the Alps. Bergþórsson (1998) on the other hand, suggests the beginning of 1200 as the most appropriate start of the Little Ice Age (Cf. Section 6.2.). The coldest periods can be found during the 18th and 19th centuries.

Sveinbjörnsdóttir (1993) demonstrated a strong relationship between the results of the Greenland Ice Core Project (GRIP) and the estimated historical climate of Iceland as presented by Bergþórsson (1967, 1969) and Ogilvie (1984, 1997). However, notable mismatches around 1500 and 1700 have been reported (Guðmundsson 1997).

The climate is further discussed in section 6.2.

3.3 Soils

The soils are of volcanic origin (Andosols) mainly. They may be grouped as *1: soils of barren surfaces, 2: eolian-andic soils* or *tephra loess* on dry ground and *3: organic* or *wetland soils* (Arnalds 1988a, 1990, Einarsson 1994).

The characteristics of the soils of barren surfaces vary considerably. They are often glacio-fluvial accumulations, coarse in texture, lack organic material and are infertile. The surface is commonly covered by loose stones, lifted and exposed by frost/thaw processes combined with deflation.

The eolian-andic soils are loessial, partly formed by wind-transported materials. According to Arnalds (1990) such material causes a rapid thickening of the soil profiles when supplied by tephra from volcanic eruptions, glacial and glacio-fluvial deposits and frost weathering. The Andosols contains a lot of pumice and hyaloclastites, having a major influence on the physical

and chemical properties of the soil (Guðbergsson 1975, Sigbjarnarson 1969, Arnalds 1988b). Due to the low bulk density, the soil is highly erodible by wind (Arnalds 1988b, 1990, Sigurðardóttir 1992). The low density of soil grains, especially coarse tephra grains, makes particles up to 30 mm in size saltate (Arnalds 1990). Normally, soil particles larger than 0.5 mm do not saltate. The soils are characterized by a high water absorbing and water holding capacity. It favours freezing and thawing processes resulting in solifluction, landslides, needle ice formation and the formation of hummocks.

The chemical and biological processes involved in soil formation react slowly in the cool climate (Arnalds 1988a, 1990, Jóhannesson 1960, Einarsson 1994).

3.4 Vegetation

Somewhat more than 25% of Iceland is vegetated (IGI/LMÍ 1993, Arnalds et al. 1997). Forests, dominated by birch and willow, occupy 1% of the land area (Sigurðsson 1977, Bjarnason and Sigurðsson 1977, The Agricultural Ministry 1986). The lack of trees is a striking feature like the nakedness of the interior highlands. The lowland is characterized by grassland, heathland and dwarf shrubland (birch and willow) up to 600-700 m a.s.l. Its average upper limit lies at 200-300 m. The lowland belongs to the Boreal zone of the biotic regions or more precisely the Sub-Alpine Birch forest belt of Fennoscandia, while the interior, the highlands, belongs to the Arctic zone (Sjörs 1963).

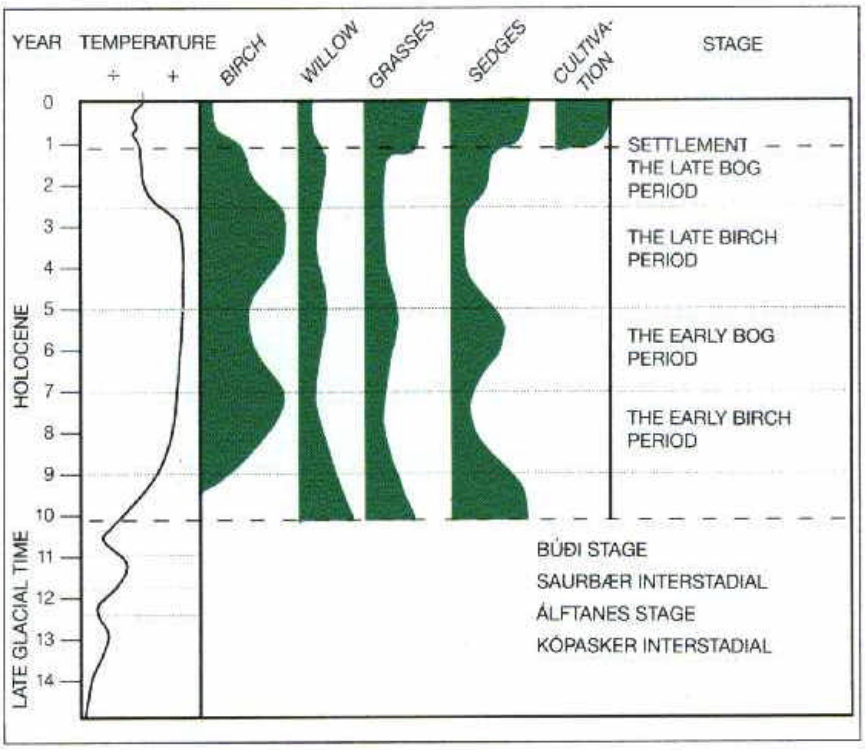

Fig. 3.4.1. Changes in mean annual temperature and vegetation from late glacial time and the Holocene in Iceland. Furthest to the left thousands of years. The curves show proportional changes in vegetaion and apply mainly to the south of the country. (from Einarsson Þ. 1994).

The highest limit of continuous vegetation cover is around 700 m a.s.l. in the northeastern part of the highlands, north of Vatnajökull. The major part of the highlands is a desert with isolated plants (Þórhallsdóttir 1991). Moss and various types of lichen cover some areas in the island interior and many of the extensive lava fields.

Pollen analytical studies indicate that at least ¾ of the country was covered by vegetation, half of it might have been covered by forests, during the climatic optimum of the Holocene, 3000-4000 years ago (Einarsson 1961, 1962, 1963, Hallsdóttir 1987, 1992, 1995). According to the pollen studies the vegetation began to decline due to a changing climate 2500 years ago. Following the human settlement, 1100 years ago, there seems to be a sudden change in the vegetation pattern (Fig. 3.4.1). It is believed that more than half of the country's area was covered with continuous vegetation before the settlement and at least 15-25% was forested (Bergþórsson 1998, Þórarinsson 1961, Einarsson 1963, Þorsteinsson 1973). It is a common opinion that land previously covered with woods became open natural pasture, i.e. grass and heathland through the impact of the settlers rather than through a change in climate (Fig. 3.4.2).

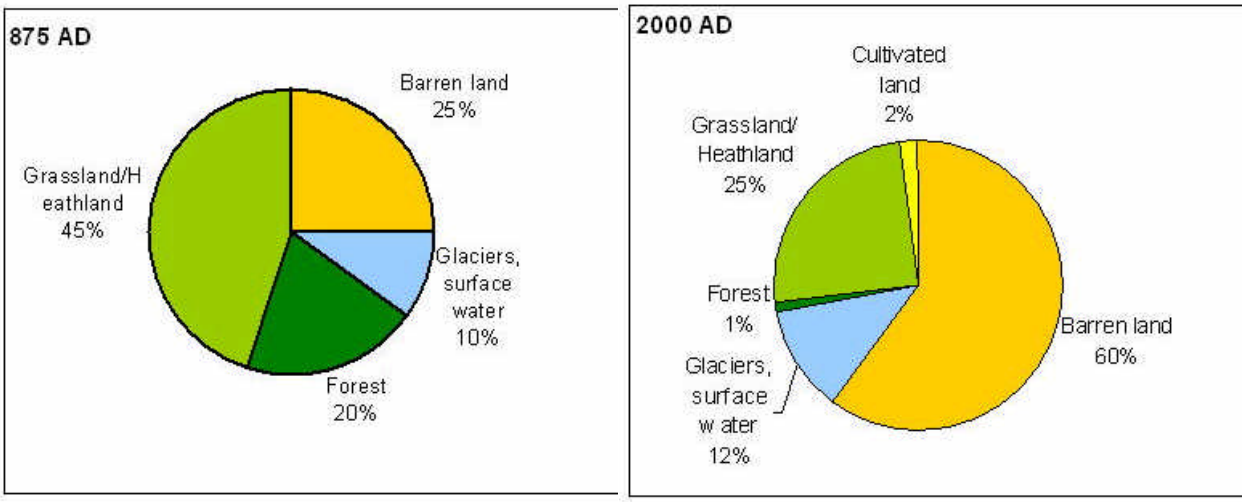

Fig. 3.4.2. Estimated land cover proportions around 875 and 2000 respectively. Data is compiled and averaged from Þorsteinsson 1973, Þórarinsson Þ. 1974 and Arnalds Ó. et. al. 1977.

However, the conclusions of the studies are uncertain. So far, pollen analysis has been carried out in a few sites only. An interesting study of the vegetation history is presented by Júlíusson (1995). After comparing a map of the distribution of forests today with reliable historical documents of the distribution of the forests in the 14th-16th centuries, he concludes that hardly any changes have occurred in the forest extension. Hauksson (1996) presents the same conclusion regarding the distribution of forests in the 12th-15th centuries after a similar comparison of present time data with historical documentation.

The importance of temperature for the growth of birch was demonstrated by Bergþórsson (1985) and Bergþórsson et al. (1987). Slightly modifying and applying a Norwegian temperature dependent birch growth model he found that 60% of 48 examined Icelandic lowland climate stations had the potential to grow birch during the normal period 1931-1960. Only 4% of the same stations had that potential during the cold period 1859-1868. The Stykkishólmur mean annual temperature difference between the two periods is 0.9^{o}C.

3.5 Population and land use

Nothing is known for certain about the size of the population of Iceland during the first eight centuries. An idea of the early population pressure is indicated in the Book of Settlement (Landnámabók 1925), that was written down more than 200 years after the settlement, mentioning the existence of about 540 farms.

It has been suggested that Iceland could support a maximum of 60 000 inhabitants in the early years following the settlement (Eldjárn 1981). Júlíusson (1995) presents a population estimate of 38 000-48 000 around the year 1100. The first population census was carried out in 1703. The population then numbered 50 358 (Statistics Iceland 1997a). A few years later it declined to 34 000 people because of a small-pox epidemic. The population passed the 50 000 in 1823 and remained between 50 000 and 70 000 throughout the rest of the century. It reached 100 000 in 1925, 200 000 in 1968 and 270 000 in 1997 (Statistics Iceland 1997a, The Central Bank of Iceland 1998).

Not much is known with certainty about the everyday life of the Icelandic pioneers and the structure of their farming. The oldest written Icelandic documents are from the early 12th century. The Icelandic Sagas are still younger, the oldest from the 13th century. Certainly they account for episodes in the life of these pioneers but their trustworthiness as evidence about life in the 9th and 10th centuries has been questioned by many scientists, as more than three centuries passed until they were written down (Rafnsson 1977).

According to Gísladóttir (1998) livestock raising, mainly cattle and sheep, must have been the basis of the domestic economy since the supposed date of the first settlement of the Vikings in 874. The settlement pattern had the character of extreme dispersions, with single farms based on the distribution of the available grazing and hay production resources. All farms had, and still have, access to most of the natural grazing lands outside the private pasture fields located adjacent to the farmhouses. Today less than 2% of the land is cultivated, mainly for hay production together with some grazing. Subsidiary occupations, like fishing, seal hunting, collecting eggs and utilization of driftwood were of great importance until the present century.

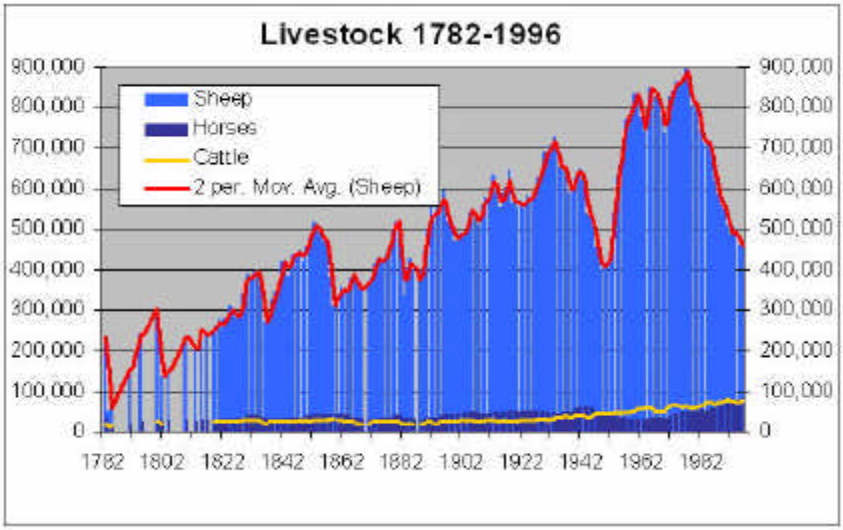

Fig. 3.5.1. Livestock development 1782-1996. (Data source: Statistics Iceland 1997a, 1997b).

Þórarinsson (1944) indicates that barley was grown in Iceland during the first centuries of the settlement. In all northern and northeastern Iceland this type of farming probably ended before the year 1200. It diminished during the next two centuries in the south and SW. It probably persisted until the end of the 16th century in the coastal areas of SW Iceland but was eventually abandoned because of the changing climate. However, Þórarinsson (1944) does not exclude the possible importance of socio-economic factors behind the change. According to Júlíusson (1995) the barley cropping was abandoned because of an increasing barley import and the spread of plague.

The introduction of a colder climate during the Little Ice Age assumingly affected the grazing and hay production conditions. It has been estimated that a 1°C decrease in annual mean temperature yields a 10-20% decrease in carrying capacity of the rangelands (Dýrmundsson and Jónmundsson 1987). A one degree decrease of the mean annual temperature from the normal period 1901-1930 (3.2^{o}C) will reduce the potential livestock carried by cultivated grassland in Iceland by some 30% and reduce the fodder yield by 15% according to Bergþórsson (1985). Correspondingly, a 1°C increase in mean annual temperature is estimated to result in a 15-25 % increase in hay yield. (Bergþórsson 1985, Bergþórsson et al. 1987). The results presented are based on an empirical regression model describing grass yield as a function of mean annual temperature and nitrogen fertilizer. Models exchanging annual temperature with winter (Oct-Apr) and summer (May-Sep) temperatures have also been presented. The coefficient of determination, R^2, is 0.94, i.e. 94% of the annual variation in national hay yield is explained by Stykkishólmur temperature data in a 1901-1975 time series.

Hallsdóttir (1987) concluded after extensive pollen analysis that the land use practice of the medieval society did not fundamentally change until the late 19th/early 20th century. However, Júlíusson (1995) points out that extensive changes took place in agriculture in the period 1400-1700. The proportion of cattle-sheep was 1:4 at the farms in the beginning of the 15th century. It had changed to 1:10 at the beginning of the 18th century. It implies a corresponding increase in grazing pressure on the rangelands, especially the highlands, commonly used for sheep raising in summer.

In recent years the Icelandic agricultural sector has been undergoing a change after decades of protectionism and subsidies. The country's policy from World War II up to 1979 aimed at increasing the number of sheep and producing more land for hay crop cultivation. At the end of 1977 the total sheep population (winterfed sheep) peaked at about 900 000 (The Icelandic Agricultural Information Service 1997) (Fig. 3.5.1). The agricultural production has been subject to quotas since 1979. The export subsidies were abolished in 1991. The total sheep stock is now reduced to 464 000 (The Icelandic Agricultural Information Service 1997).

Since 1970 the number of horses has increased from 33 500 to 80 500 (The Icelandic Agricultural Information Service 1997). Today horses are mainly raised for recreation purposes. They are usually grazed in home areas. During the past decades the rangelands have been growing in importance as a resource for tourist exploitation.

3.6. Erosion

The frequent shifts between frost and thaw result in intence frost-weathering and the development of periglacial features such as hummocks, palsas, stone and frost polygons (Fig. 3.6.1). In addition, the basaltic lavas and tuffs are cracked and rich in pores, enabling rain to be lashed into the rock formations and running water to percolate into the rocks facilitating the frost weathering process. Tephrochronology indicates that a period of polygon formation, more intense than the present, occurred in the 1600´s and 1700´s (Friedman et al. 1971).

Fig. 3.6.1. Hummocks at Þeistareykir north of Hólasandur. Please note the desert wound/desert patch in the background. (Photo R. Olafsdottir, August 1997).

Wind erosion causes abrasion of rocks and deflation wherever soils can be swept away. Among the most important soil sources for wind transport are the deposits left by glacial rivers on the extensive outwash plains (Fig. 3.6.2). Erosion is more widespread and progressive in the active volcanic zone than outside it. Eolian-andic soils, which are more prone to wind and water erosion than the organic soils, characterize the volcanic zone. Currently, the major land degradation in Iceland occurs in the northeast (Fig. 3.6.3).

Fig. 3.6.2. Outwash plain, Kverkfjöll, northern Vatnajökull. (Photo R. Olafsdottir, August 1997).

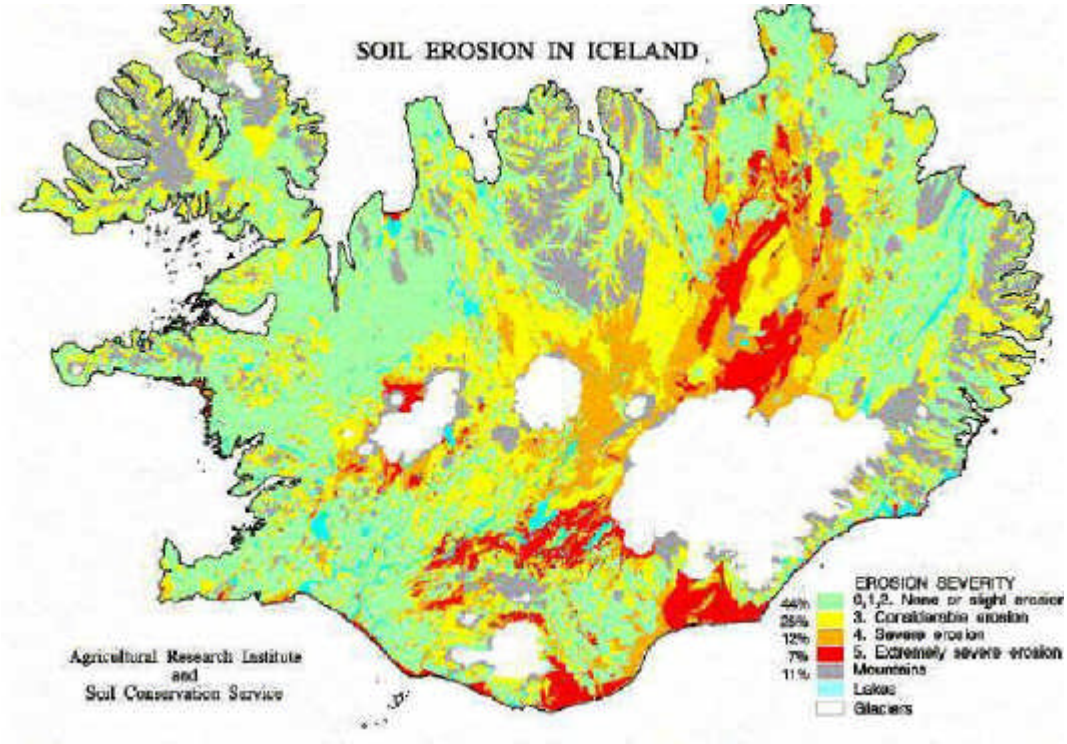

Fig. 3.6.3. Erosion map, Source: Arnalds. Ó. et. al. 1997, for further information please refer to http://www.rala.is/desert/.

Arnalds (1990) outlines the main characteristics of erosion in Iceland. When discussing wind erosion he considers *erosion escarpments* (Icelandic: rofabard) to be the most striking erosion form in Iceland. *Advancing sand fronts* make up another dominating phenomena.

The escarpments have till, alluvium or lava at the base and vegetation growing on eolian-andic soils at the surface (Fig. 3.6.4). The occurrence of erosion escarpments is associated with areas that consist of eolian-andic materials of sufficient thickness to form the escarpments.

Fig. 3.6.4. Escarpment (rofabard) at Haukadalsheiði southwest Iceland. The glaciar Langjökull can be seen in the back. (Photo R. Olafsdottir, August 1997).

Advancing sand fronts are the result of wind erosion and accumulation when enough material is available for saltation. Tongues of saltating material move across and cover vegetated areas, destroying the vegetation and ultimately leaving barren surfaces behind. (Arnalds 1988b, 1990). There are examples from NE Iceland that advancing sand fronts can move more than 100 m per year (Arnalds et. al. 1997).

Arnalds et. al. (1994, 1997) made an effort to assess the erosion problems on a national scale using Thematic Mapper false colour composite imagery from the earth resources satellite Landsat. The classification approach resembles one that was used for mapping in New Zealand (Eyles 1985). Existing erosion forms were classified in the rangelands and the severity for each erosion form was assessed into severity classes by field observations. Areas of different erosion forms and corresponding severity class were then manually delineated, digitized and mapped on the basis of satellite image interpretation.

According to the Icelandic erosion assessment programme (Arnalds et. al. 1997) the extent of the two mapped categories extremely severe and severely degraded areas cover almost 18 000 km^2. More than 23 000 km^2 show considerable degradation with limited plant production. These areas cover 40% of the country (Fig. 3.6.3). Most of the deserts and the degraded areas are assumed to be the result of adverse human impact initiated at the time of the settlement of Iceland .

Dugmore and Buckland (1991) and later Dugmore and Erskine (1994) reported stratigraphic evidence on soil erosion from local studies in southern Iceland. They suggest a widespread regional increase in eolian erosion at the time of the settlement followed by extensive changes and a systematic increase in sediment accumulation rates, as a result of corresponding erosion rates, between 1510 and 1918.

4. STUDY AREA

The 20 000 km^2 study area is located between the 65th and 66th degrees north latitude and the 16th and 18th west longitude in north eastern Iceland (Fig. 3.1.1).

It is located in the rainshadow of the Vatnajökull glacier. The mean annual precipitation is ranging from 400 mm in the south up to 1000 mm in the north. Elevation ranges from sea level in the north to more than 1000 m in the south. The highlands area (> 600 m.a.s.l.) is characterized by alpine/arctic climate while the lowlands are temperate and humid. The natural vegetation outside the highlands is grassland and heathland with bushes and shrubs. A few small areas close to the coast are covered by birch woods. The vegetation covered soils are often made up of the loessial eolian-andic soils, 0.3-2 m thick, resting on lava or a substratum of glacio-fluvial origin intermixed with eolian deposits. Desert patches, varying in size from a few to several thousand m^2, are frequent in the vegetated northern half of the area (Fig. 4.1-4.2 and 6.1.4) The southern part comprises huge arctic gravel deserts of glacio-fluvial origin and lava fields with less than 1% vegetation cover (Fig. 4.3).

Fig. 4.2. The eastern edge of the huge "desert patch" Hólasandur. (Photo U. Helldén, August 1997).

Fig. 4.3. A desert patch grazed by sheep north of Hólsfjäll. (Photo R. Olafsdottir, August 1997).

The study area is made up of nine municipalities and administrative divisions located within the counties of Norður- and Suður-Þingeyjarsýsla. There are presently about 300 farms distributed over the northern half of the study area (Schuler 1994). Most of them are raising livestock (Fig 4.4). The area has most probably been used for grazing and hay production ever since the settlement time (Gunnlaugdóttir 1985). The estimated number of farms was 400-500 in the region (the Norður- and Suður-Þingeyjarsýsla) already in the 14th century and about 400 farms in 1703 corresponding to some 2 800 people (Júlíusson 1995). The farming population was about 3 100 in 1800, 5 100 in 1900 and 2 300 in 1990 corresponding to some 450, 638 and 513 farms respectively (Statistics Iceland 1997, Júlíusson 1995, Schuler 1994). The different sources present somewhat different figures.

Fig. 4.4. Glacio-fluvial desert (sandur-plain) in the highlands east of Askja north of Vatna with a dust storm in the background. (Photo U. Helldén, August 1997).

Fig. 4.5. Typical farms with fenced pasture and hay production lands in the area north of Akureyri. (Photo U. Helldén, July 1975).

5. OBJECTIVES AND WORKING TASKS

The objective of the study is to assess and explain the land degradation history of the area for a better understanding of the role of human impact versus natural, mainly climatic, impact on desertification in an environment outside the drylands of the world.

The data collection and analytical methods are based on remote sensing, GIS and field observations combined with studies of existing climate data, tephrocronology, agricultural and

population archives, literature and relevant maps as well as interviews and questionnaires to obtain environmental information from the local population. The study focuses on environmental change during this century. However, outlooks to earlier periods are carried out whenever possible. The major working tasks include:

Land use/land cover change. Assess changes in vegetation cover and land use over the 1945-2000 period by analysis of a time series made up of B/W air photos (1945, 1960, 1975), Landsat TM satellite data and SPOT data (1984, 1987, 1997) combined with ground surveys.

Land degradation assessment. Assess land degradation rate and trends as indicated by the change and distribution of remotely sensed soil and geomorphological indicators monitored over the 1945-2000 period. Assess the change of land cover and land use as indicators, but also possible causes, of desertification over the last 50 years in NE Iceland.

Farmer desertification perception. Study the farmers' perception of changes in land use and land degradation over the past 100-150 years through interviews and questionnaires.

Climate assessment. Assess spatial and temporal changes of precipitation and temperature in NE Iceland through analysis of observed data, 1823-2000, for a comparison with the indicators of land degradation and land production.

Geomorphological events. Assess volcanic and tectonic impacts on land degradation in historical and recent time through a review of published information.

Model climatic and anthropogenic impact on land degradation. Develop and apply models to assess and understand land degradation in a historic perspective.

6. RESULTS

6.1. Field survey.

A field survey was completed during the second half of August 1997. It was carried out with a 4-wheel drive transversing the landscape along 2500 km of roads and tracks (Fig. 6.1.1). Notes were taken on land use, vegetation cover, vegetation type and dominating species, soils, geomorphological indicators of erosion and accumulation. Interviews were carried out at three farms in the surroundings of Lake Mývatn to form the basis for the development of a questionnaire to be distributed among some 200 farms at a later stage. A 12 channel global positioning system (GPS) was used for the navigation and latitude – longitude reference of each observation point. The positioning accuracy is estimated to 50-100 m depending on the number of satellites included in the processing. The environmental data collected is a first input in the remote sensing training, mapping and accuracy evaluation procedure forming a planning basis for the work to come.

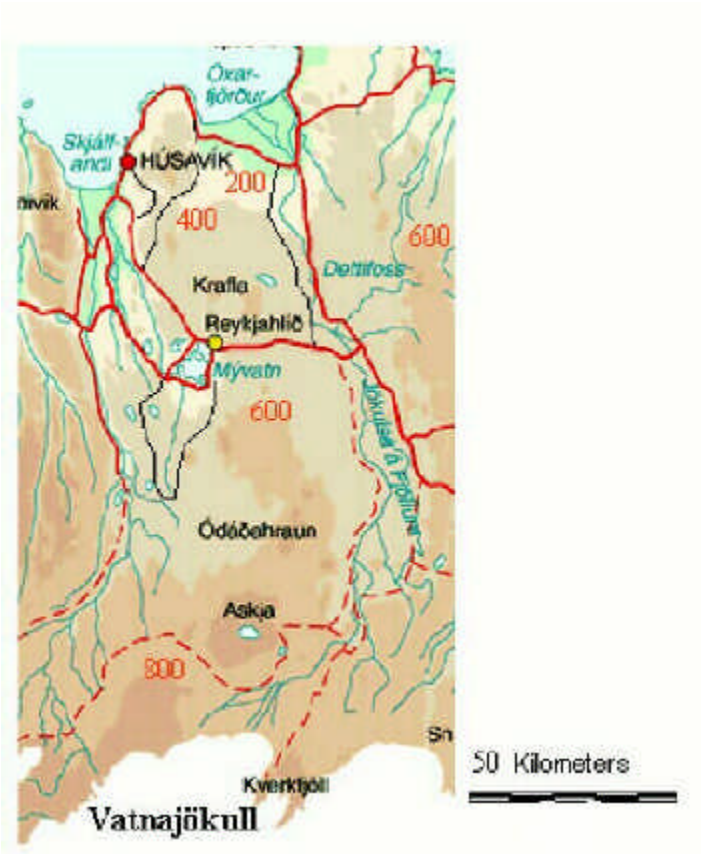

Fig. 6.1.1. The study area (top right corner: N15° 46', W66° 15', bottom left corner: N64° 38', W17° 56'). Tracks (dotted) and roads are indicated in red. Black track indicate the 1997 field survey route.

It was noted that many small and medium sized desert patches (< 2 ha) were located at, or close to, hill summits. Many of them, once initiated, seemed to grow along the hill crest forming elongated patches with a secondary water erosion driven expansion in a perpendicular direction, i.e. downhill (Fig. 6.1.2-6.1.3). Large clusters of such elongated desert patches along hill crests can be identified on Landsat TM satellite data (Fig. 6.1.4). A possible explanation is given below.

Fig. 6.1.2. Elongated desert patches in Jökulsárgljúfur area. (Photo U. Helldén, August 1998).

Fig. 6.1.3. Elongated desert patches in Jökulsárgljúfur area. (Photo R. Olafsdottir, August 1997).

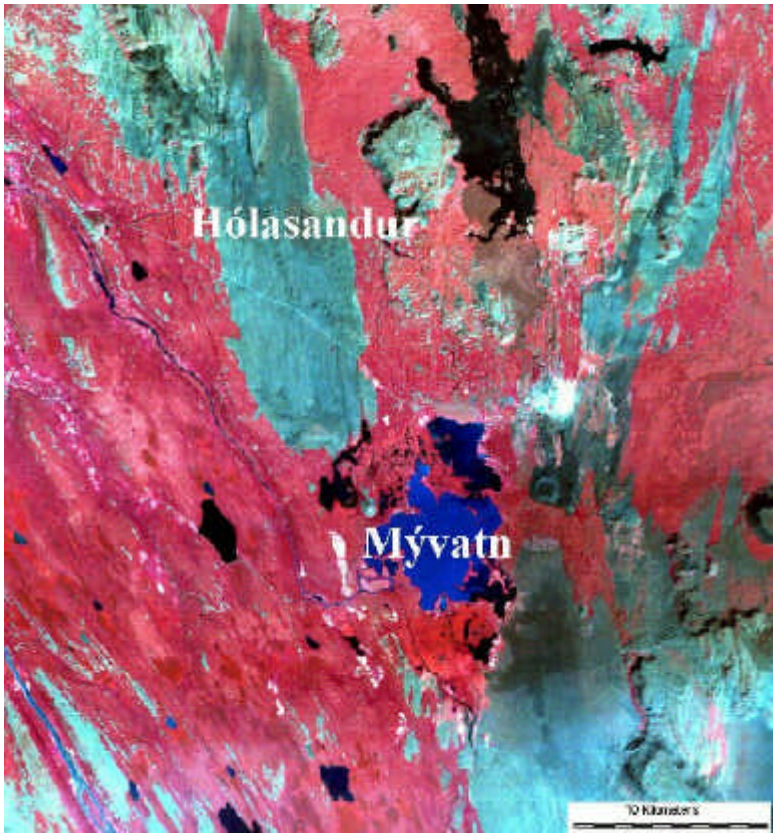

Fig. 6.1.4. Landsat TM False Colour Composit (FCC) covering 40 by 43 km. The blue areas are deserts and desert patches. The reddish areas are vegetation covered heathlands (Path/Row 218/000, 97-08-13, FCC TM5,3,2).

The heathland on the summits and along the hill crests are more exposed to wind than other areas. They are the least snow covered, i.e. least insulated surfaces during winter and spring, exposing them to intense freeze-thaw processes. The process generates hummocks, fissures and small wounds in the dense vegetation carpet exposing small pockets of the underlying eolian-andic soils for wind and water erosion (Fig. 6.1.5).

Fig. 6.1.5. Small wound/desert spot in the vegetation cover north of Hólasandur. (Photo U. Helldén, August 1998).

The process was possibly enhanced by the traditional sheep winter grazing habit which was common all over the country until the 1950´ies, even longer in some areas. The sheep concentrated on the snow free top and crest located surfaces where grazing was available during winter and spring. Grazing and trampling made the insulating vegetation cover grew thinner and more small wounds to evolve. The frost process acting on the peat/root layer grew in importance, developed more hummocks and opened more fissures and wounds in the heath layers exposing the soil for erosion (Cf. Fig. 3.6.1 and 6.1.5)

We assume, as a working hypotheses, that periods of cold and dry climate favour the described frost initiated erosion process. The annual number of frost/thaw occurrences is likely to increase with a decreased annnaul temperature. A decreased annual temperature may also result in a shorter vegetation growing season and a decreased vegetation growth as indicated under section 3.5. It implies that the ground will become less insulated during winter and spring after a cold summer. The ground insulation capacity is likely to decrease even more during periods of a dry winter climate with less snow available to insulate the ground.

It was noted at several desert patch locations in the north that a characteristic tephra layer was present at the base of the eroded soil layer (Cf. Fig.6.3.1). The location and significance of the the layer in the soil profile makes us believe it represents the Hekla layer, H_3, dated 2 800 – 2 900 BP, described by Þórarinsson (1971) and Larsen & Þórarinsson (1977). If so, it indicates that the eroded andosols in the northern part of the study area were developed and then eroded away during the past 2,800 years.

6.2. Climate study.

Complete time series of monthly temperature and precipitation data for the stations mentioned below were kindly provided by the National Meteorological Survey of Iceland. The World Climate Disc database generated by the Climatic Research Unit, the University of East Anglia was used as a complementary source of data. A detailed description of the database is given by Chadwick-Healy (1992).

As pointed out in the climate section (3.2), Iceland experienced a cold period from about 1200 to the beginning of the 1920´ies (Fig. 6.2.1-6.2.2). The data available indicate that this period is an appropriate extension of the Little Ice Age in Iceland as suggested by Bergþórsson (1998). Some of the coldest and most frequent cold spells during this period can be noted during the second half of the 18th and 19th centuries, respectively. The annual temperature variation for the Stykkishólmur climate station in west Iceland is presented in Fig 6.2.3. The mean is based on the full length of the observation period 1823-1997. The plotted curve indicates the five years running mean.

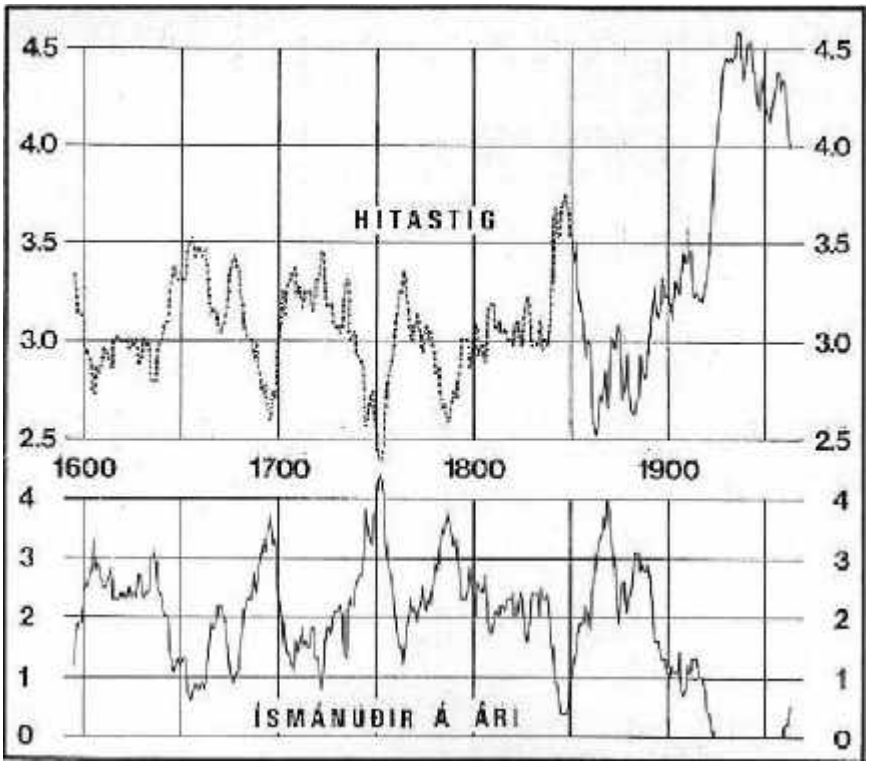

Fig. 6.2.1. Decadal running means of temperature (top) and ice incidence in months per year (below). Estimated values: dotted line (from Bergþórsson 1969).

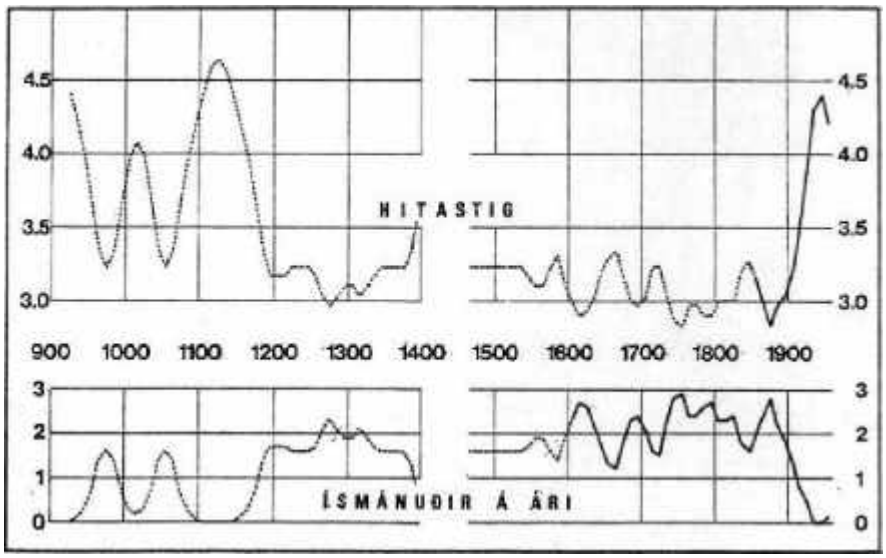

Fig. 6.2.2. Running 30year means of temperature (top) and ice incidence in months per year (below). Estimated values: dotted line (from Bergþórsson 1969).

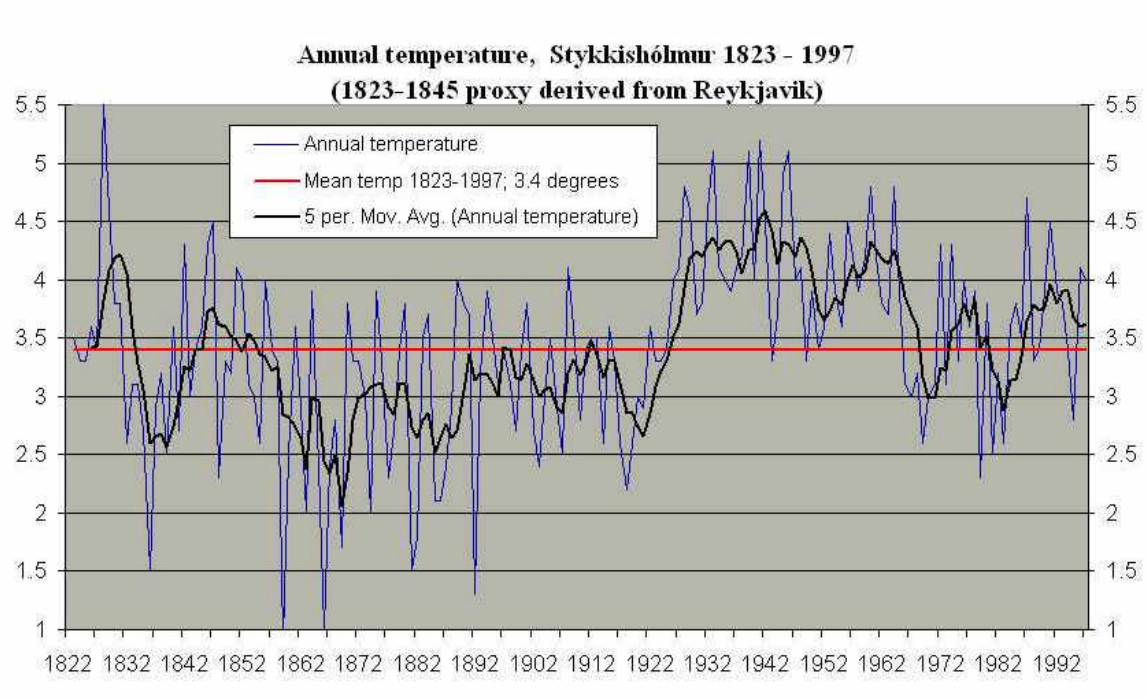

Fig 6.2.3. Annual temperature at Stykkishólmur 1823-1997. The smoothed curve indicates the 5-years running mean. The input data was kindly provided by the National Meteorological Survey of Iceland.

There are only five Icelandic stations with observed temperature data all the way back into the last century. Beside Stykkishólmur in the west they are Grímsey and Akureyri in the north, Vestmannaeyjar in the south and Teigarhorn in the east (Fig. 3.1.1). To indicate the representativity of the Stykkishólmur data the annual temperature data for Akureyri and Teigarhorn are presented in Fig. 6.2.4- 6.2.5. Akureyri was 1-2°C colder than the average during the end of last century.

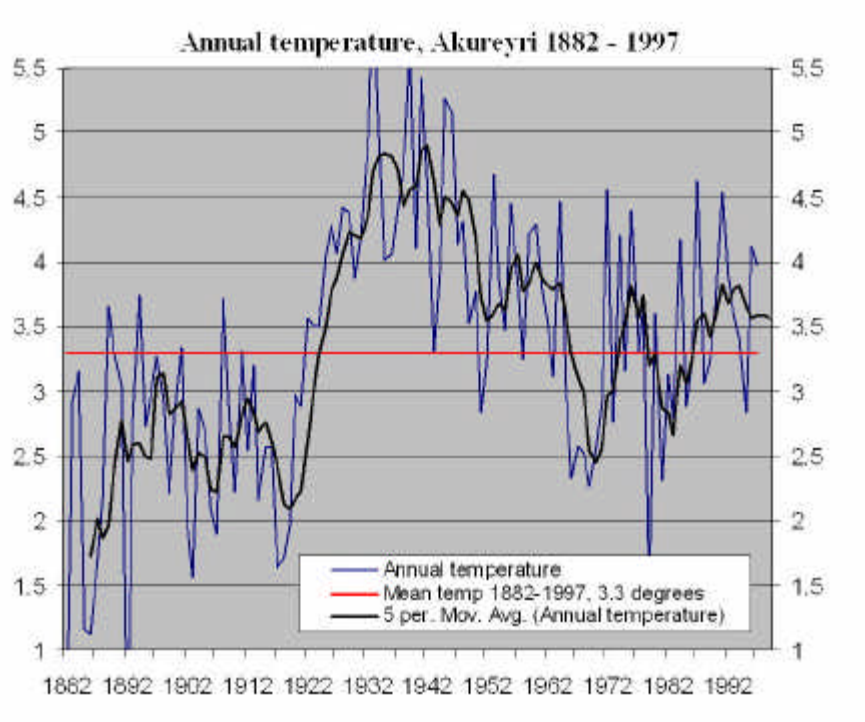

Fig 6.2.4. *Annual temperature at Akureyri, 1882-1997. The smoothed curve indicates the 5-years running mean. The input data was kindly provided by the National Meteorological Survey of Iceland*

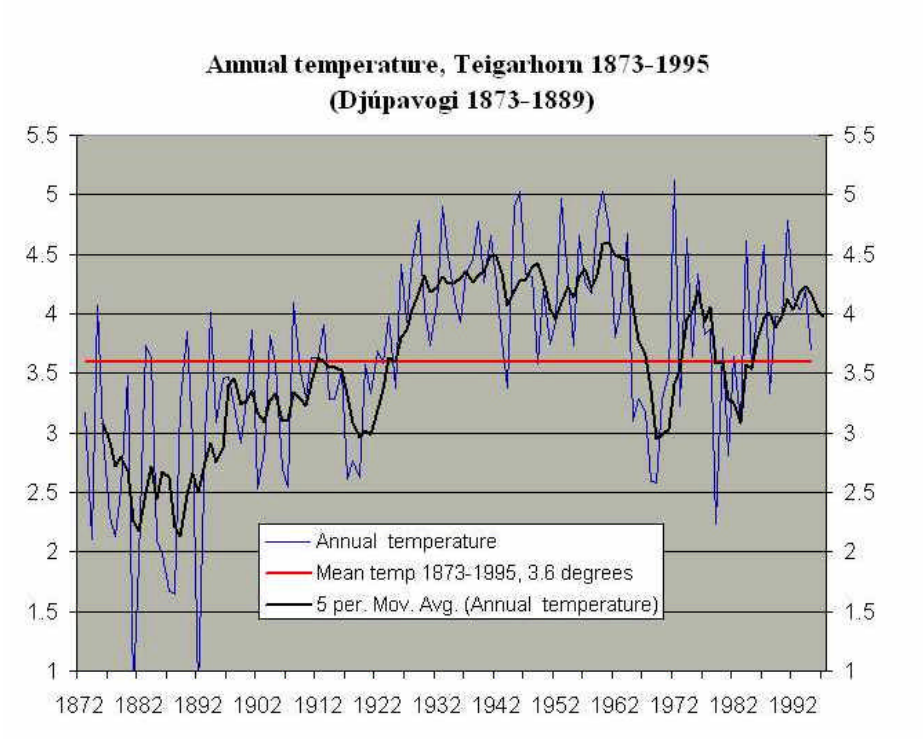

Fig 6.2.5. Annual temperature at Teigarhorn 1873-1995. The smoothed curve indicates the 5-years running mean. The input data was kindly provided by the National Meteorological Survey of Iceland

Useful precipitation records including last century are only available from Stykkishólmur, Teigarhorn and Vestmannaeyjar. The annual precipitation for Stykkishólmur and Teigarhorn are presented in Fig. 6.2.6-6.2.7. Both indicate strong negative rainfall anomalies during the cold spells of the second half of 1800. In general the period was about 1°C colder than the average and 15-20 % dryer.

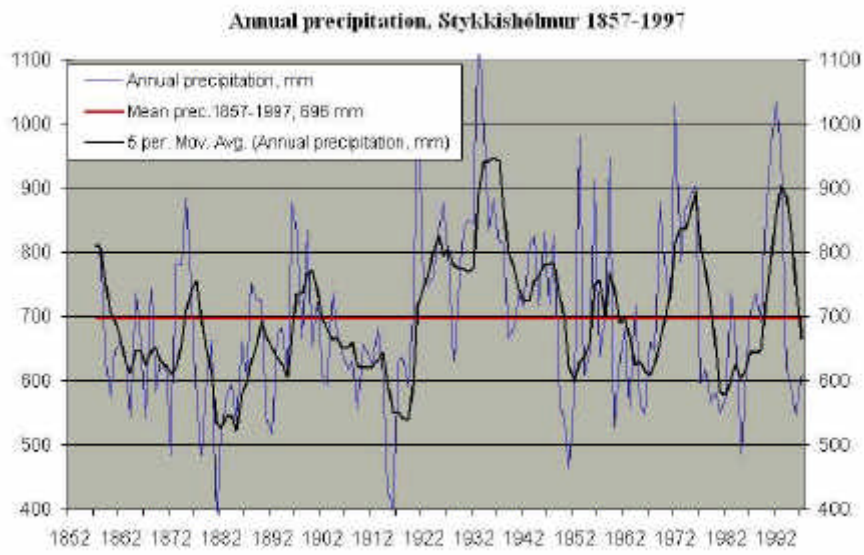

Fig 6.2.6. Annual precipitation at Stykkishólmur 1857-1997. The smoothed curve indicates the 5-years running mean. The input data was kindly provided by the National Meteorological Survey of Iceland

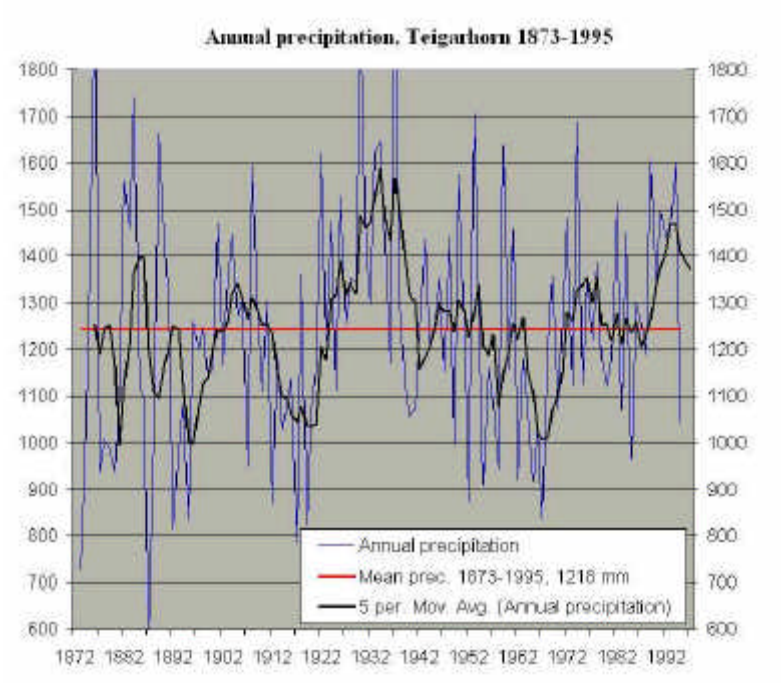

Fig . 6.2.7. *Annual precipitation at Teigarhorn 1873-1995. The smoothed curve indicates the 5-years running mean. The input data was kindly provided by the National Meteorological Survey of Iceland.*

The analysis of monthly and seasonal rainfall and temperature changes and trends has not yet been completed. They may contribute to our understanding of the possible importance of frost/thaw periods in the degradation process. Bergþórsson et al. (1987) demonstrated that winter season temperatures are important for the explanation of the variations in vegetation development the coming season, cold winters decreasing the vegetation growth of the following season.

It is also important to find relations between the used lowland climate records and existing study area station (20) records. The local stations are characterised by observation records of varying length (>15 years) limited to the 20th century. Twelve of them are located below 45 m a.s.l. Five of them are located between 285 and 450 m a.s.l. There are only scattered observations available from higher altitudes.

6.3. Farmer concepts.

A questionnaire was developed and distributed to 190 farmers at the end of 1997. Most of the 25 questions concern the age, origin and growth of the existing desert patches. Questions concerning the farmers' perception of the problem from an economical and farming management point of view are included in the questionnaire. Sixty percent of the farmers have returned their answers. The results of the first screening are summarized below:

Some of the farmers do not have any opinion about the age of the desert patches. Many of them are of the opinion that many patches were initiated during the second half of the last century. Still many believe the patches originated before the settlement.

Most of them have not noted any negative change during the past 50-100 years. The desert patches have not grown in size during the period. The vegetation cover has possibly improved. Please compare Fig. 6.3.1a-6.3.1c The first photo was taken in Aug. 1965. The second photo was taken in Jul. 1975 and the third photo in Sep. 1997. The area has not changed very much during the past 32 years.

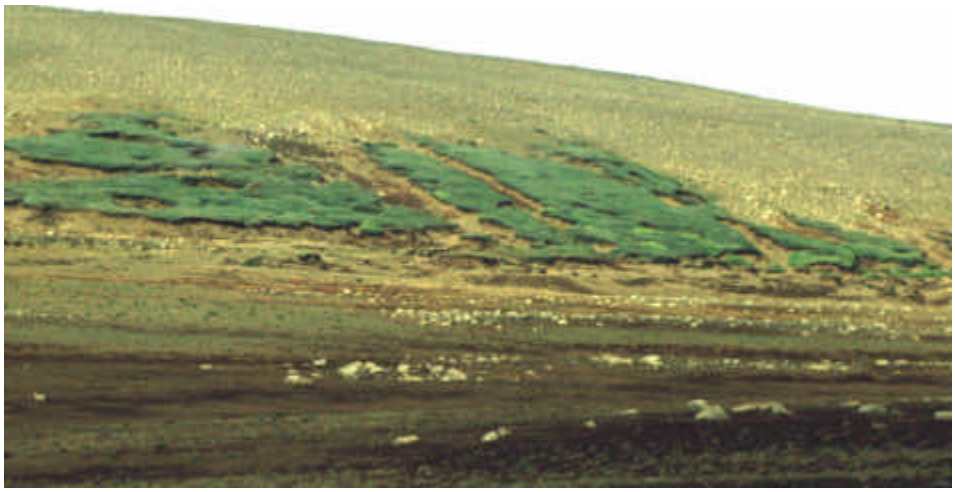

Fig. 6.3.1a Vegetation covered erosion remnants in the area east of Dettifoss. (Photo H. Svensson, August 1965)

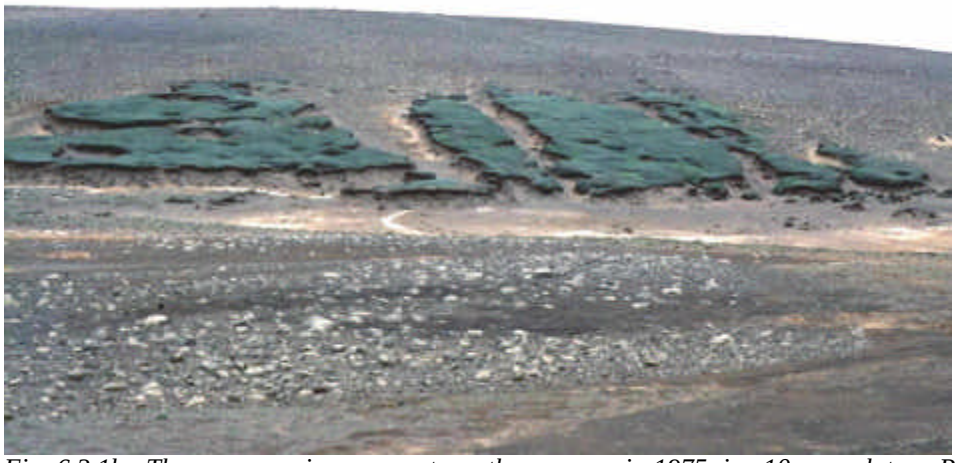

Fig. 6.3.1b. The same erosion remnants as they appear in 1975, i.e. 10 years later. Please note the white tephra layer, H_3.. (Photo U. Helldén, July 1975).

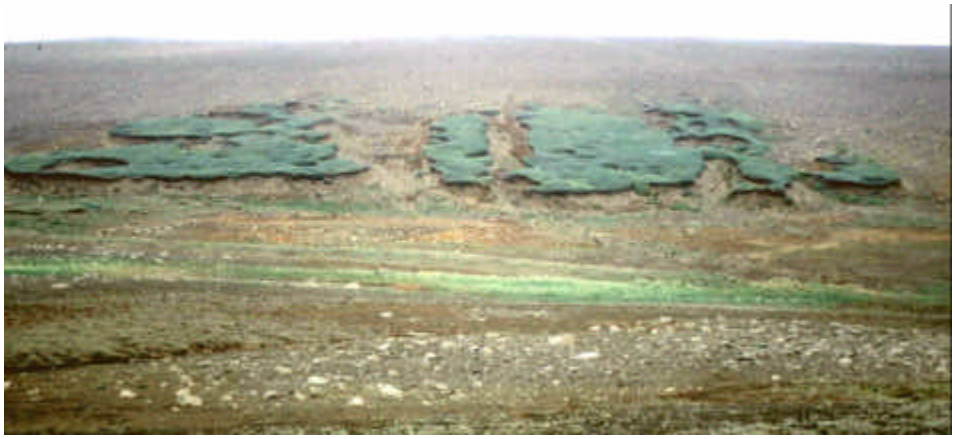

Fig. 6.3.1c. The same erosion remnants as they appear in 1997, i.e. 37 years later. (Photo R. Olafsdottir, August 1997).

There seems to be a common opinion that the origin and the speed of the expansion of the desert pathches is very much related to climatic factors. Dry winters, with a limited snow cover, combined with dry SW storms during early spring are considered to favour the growth of the patches. The development of the patches is strongly believed to be discontinuous and related to isolated storms. Summit locations of the hills are favoured because they are often free from snow cover. Many believe the old winter grazing tradition played an important role in the degradation process.

Most farmers seem to be of the opinion that the "desertification" problem does not have any economic or management significance. Land degradation and desertification is not discussed as a problem in the farming community. There is an abundance of good and "free" rangeland for everybody.

6.4 Discussion

The scientific and political societies in Iceland often relate the land degradation problems to human over use of the rangelands, starting with the introduction of cattle and sheep raising at the time of the settlement in 874. They consider overgrazing and overuse of the forests for fuelwood and charcoal production to be the most important processes opening and exposing the landscape for soil erosion with growing desert patches and deserts as a consequence.

Most farmers, on the other hand, seem to believe that the desert patches and deserts are natural phenomena. The initiation and expansion of the phenomena are supposed to be related to unfrequent climatic events, possibly enhanced by the traditional winter grazing custom, no longer practiced.

Our results indicate that the importance of climate may have been underestimated as a possible and important contributor to land degradation and desertification in Iceland. We assume, as a working hypotheses, that cold and dry periods have favoured the development and expansion of desert patches and deserts. We think that the Little Ice Age, especially during the second half of the last century, has offered favourable conditions for frost initiated soil exposure followed by events of severe erosion. The second half of the last century is also characterized by an outstanding high rural population pressure and a correspondingly high grazing pressure adding to the degradation risk in the study area.

7. ACKNOWLEDGEMENTS

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