Land-use Development in South Iceland 1900 - 2010

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60ECTS thesis submitted in partial fulfillment of a *Magister Scientiarum* degree in Environment and Natural Resource Management

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Abstract

Human population growth and the degradation of ecosystems caused by land use intensification have turned land use into one of the most critical global issues of the 21st century. This study describes and quantifies changes in land use and land cover in the southern lowland region from 1900 to the present day. It is Iceland's most important agricultural area and a region with a relatively diverse and intensive land use compared to the rest of the country. Data extracted from topographical maps for 1900, 1950 and 1980 and various other sources were subjected to GIS analyses. The study period reflects a radical transformation from traditional subsistence agriculture to mechanization, exemplified by large-scale wetland drainage, industrialization and urbanization, including recreational land use and second home development. For example, land area used for roads increased 11-fold between 1900 and 2010, and the number of second homes rose 54-fold since 1950. Agricultural land expanded 15-fold since 1913, while wetland area declined by at least 77% in 1900-2010. Afforestation efforts have increased forests and woodland area by 160% since 1950. In 2010, an estimated 39% of the area was impacted by roads, drainage and built-up land, and 143 km^2 of land was simultaneously affected by those land uses. The land conversion rate often exceeded national average and was likely motivated by population growth, high living standard and legislation.

Útdráttur

Breytingar á vistkerfum og ofnýting náttúruauðlinda samfara fjölgun mannkyns eru eitt stærsta úrlausnarefni nútímans. Markmið rannsóknarinnar var að lýsa og greina þróun, eðli og hraða landbreytinga á láglendi Suðurlands frá 1900 til 2010. Kort frá 1900, 1950, 1980 og 2010 voru greind með landfræðilegum upplýsingakerfum og fyrirliggjandi gögn um landbreytingar dregin saman. Rannsóknatímabilið endurspeglar þær róttæku breytingar sem urðu á íslensku hefðbundnu bændasamfélagi með vélvæðingu landbúnaðar, framræslu votlendis, iðnvæðingu, þéttbýlismyndun og sumarhúsabyggð. Flatarmál lands sem farið hefur undir vegi hefur 11-faldast frá 1900, fjöldi sumarhúsa 53-faldast frá 1950 og land sem tekið er undir landbúnaðarnytjar hefur 15-faldast frá 1913, einkum með framræslu mýra. Votlendi hefur dregist saman um a.m.k. 77% frá 1900 en skóglendi jókst um 160% frá 1950, einkum vegna skógræktar. Árið 2010 voru 39% svæðisins undir áhrifum vega, framræslu eða bygginga og 143 km^2 voru taldir undir áhrifum af öllum þessum gerðum landnotkunar. Þessi þróun var hraðari en víðast annars staðar í dreifbýli á Íslandi. Samspil fólksfjölgunar, efnahags og löggjafar hefur líklega ráðið mestu um hraða og eðli þeirra breytinga sem orðið hafa.

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Glossary

AS – Agricultural Society – *Búnaðarfélag Íslands*

AUI – Agricultural University of Iceland - *Landbúnaðarháskóli Íslands*

BSSL - Farmers Affiliate South Iceland - *Búnaðarsamband Suðurlands*

EEA – European Environmental Agency

EC – European Commission

EA – Environment Agency of Iceland – *Umhverfisstofnun*

FAI – Farmers Association of Iceland – *Bændasamtök Íslands*

FIEI - Federation of the Icelandic electricity industry – *Samorka*

HI – University of Iceland - *Háskóli Íslands*

IES – Institute of Earth Sciences - *Jarðvísindastofnun Háskóla Íslands*

IFS – Iceland Forest Service – *Skógrækt ríkisins*

IINH – Iceland Institute of Natural History - *Náttúrufræðistofnun*

IMO - Icelandic Meteorological Office – *Veðurstofa*

IRA – Icelandic Road Administration – *Vegagerðin*

ISE – Iceland State Electricity – *Rafmagnsveitur ríkisins, RARIK*

ITB – Icelandic Tourist Board - *Ferðamálastofa*

LR - Soil Conservation Service – *Landgræðsla ríkisins*

LV – National Power Company – *Landsvirkjun*

ME – Ministry for the Environment - *umhverfisráðuneytið*

MFA – Ministry of Fisheries and Agriculture - *sjávarútvegs- og landbúnaðarráðuneytið*

MIET – Ministry of Industry, Energy and Tourism - i*ðnaðarráðuneytið*

NEA – National Energy Authority – *Orkustofnun*

NLSI – National Land Survey Institute – *Landmælingar Íslands*

NPR – National Property Registry – *Fasteignaskrá*

RALA - Agricultural Research Institute - *Rannsóknastofnun landbúnaðarins*

RE – Reykjavík Energy - *Orkuveita Reykjavíkur*

SI – Statistics Iceland – *Hagstofa Íslands*

TSO – Transmission System Operator - *Landsnet*

VR - Project Committee and Ministry of Industry Energy and Tourism - *Verkefnisstjórn rammaáætlunar um vernd og nýting náttúrusvæða með áherslu á vatnsafl og jarðhitasvæði*

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1 Introduction

1.1 Land use: Global trends

Much of the Earth's surface has now been transformed through the conversion of natural landscapes for human use, leaving less than ¼ of the Earth's ice-free land in a natural state (Ellis & Ramankutty, 2008). Croplands and pastures now occupy more than 60% of the land surface (Ellis & Ramankutty, 2008). Urban areas are expanding world-wide, accommodating the majority of the worlds human population, which is expected to exceed 9 billion people by 2050 (McKinney, 2006; UN, 2011). Land use practices, although varying greatly between countries, have caused ecological degradation across local, regional and global scales (Foley, DeFries et al., 2005). About 60% of the world's ecosystems are degraded or used unsustainably, 75% of fish stocks are over-exploited or significantly depleted and an estimated 13 million hectares of tropical forests are cleared each year (CBD, 2010; FAO, 2010; MA, 2005a). The sustainability concept has been implemented in international treaties, national laws and policies, but the vague definition of sustainable development has left much room for interpretation. This has resulted in uneven implementation between countries, coordination difficulties within countries or inaction (George & Kirkpatrick, 2006; Volkery, Swanson et al., 2006).

In Europe, land-use changes induced by the industrial revolution since the end of the 18th century are considered devastating and characterized by the loss of biodiversity (Antrop, 2005). Only 17% of habitats and 11% of key ecosystems protected under EU legislation have remained in a favorable state. The benefits of actions taken by EU member states to halt biodiversity loss have been outweighed by land-use change, over-exploitation of biodiversity and its components, the spread of invasive alien species, pollution and climate change (EC, 2011). More than a quarter of the European Union's territory has been directly affected by urban land use, with more than 75% of the European population living in urban areas (EC & EEA, 2006).

A direct consequence of land use intensification is the spatial segregation or fragmentation of landscapes, mainly caused by transportation infrastructure, urban sprawl and intensive agriculture (EEA & FOEN, 2011). Landscape fragmentation is considered a major threat to biodiversity and ecosystem functions, but also affects human communities more immediately in a range of ways (Di Giulio, Holderegger et al., 2009; EEA, 2003; EEA & FOEN, 2011; Leadley, Pereira et al., 2010; OECD, 2008). The creation of barriers and edges in natural habitats alter biophysical and chemical characteristics of adjacent land area and affect wildlife distribution patterns (Benítez-López, Alkemade et al., 2010; Forman & Alexander, 1998; Forman, Reineking et al., 2002). Eventually, the area between fragmenting elements becomes too small to sustain local populations (Fahrig, 2003), and will be invaded by species more adaptable to disturbances or non-native species. This can result in similar species compositions and homogenization across landscapes (Hansen & Clevenger, 2005; Joshi, Stoll et al., 2006; Luck, Daily et al., 2003; McKinney, 2006).

The concept of ecosystem services has become a widely used model for linking biodiversity and ecosystem functions to human welfare and economic value (Costanza, d'Arge et al., 1997; Daily, Alexander et al., 1997; MA, 2005a). These services, also expressed as natural capital, are for instance food, fresh water, clean air, shelter, medicine, and climate regulation. But regardless of the dependence of human societies on ecosystem services, their importance is still undervalued and tends to be ignored (CBD, 2010; EC, 2011).

Ecosystem services don't operate in isolation, but interact in complex often unpredictable ways and across spatial and temporal scales (Haines-Young, 2009). By selecting one set of services, others might be reduced or impaired. Such trade-offs for instance are the use of fertilizer to increase agricultural productivity at the expense of water quality or the impounding of streams for hydroelectric power with implications for fisheries downstream. Restoration of ecosystems or ecosystem services following degradation is usually time-consuming and expensive, if possible at all (Arnalds, 2005; Gunnarsson, Eysteinsson et al., 2005; Olesen, 2011; Rodríguez & Beard, 2005).

1.2 Development in Iceland

1.2.1 Land use

Iceland was one of the last large terrestrial areas to be settled at around 870 A.D., when Norse settlers arrived and introduced livestock and agriculture (Bolender, Steinberg et al., 2008; Gísladóttir, Erlendsson et al., 2011). For centuries, subsistence farming based on animal husbandry was the dominating livelihood as the environmental conditions and technology did not allow for vegetable or grain cultivation (Jóhannesson, 2010). Consequently, the farmsteads were very dispersed with little necessity to communicate (Sveinbjarnardóttir, 2004). This is unlike most European countries where villages formed during the Middle Ages, based on farming and the three-field crop rotation that needed coordination (Júlíusson, Guðmarsson et al., 2005).

The population size is believed to have ranged between 40.000-100.000 people, but presumably averaged at 50.000. It was brought down several times by epidemics, volcanic activity and climatic conditions until the first half of the 19th century (Friðriksson, 1972; Guðmundsson, Larsen et al., 2008; Karlsson, 2000; SI, 2011d). By that time increased trading activities had improved the living standard (Júlíusson et al., 2005). The import of mechanical equipment enabled greater land use efficiency at the end of the 19th century and initiated the urbanization of the country (AS, 1988; Júlíusson et al., 2005; Valsson, 2003).

Horses were the main means of transportation and a road infrastructure did not exist until the latter part of the 19th century, when the use of horse wagons required the broadening of main roads (Guðnason, 1975; Júlíusson et al., 2005; Valsson, 2003). The transportation of people and goods between places was though mainly served with steamboats, which were considered more efficient than the demanding land route (Júlíusson et al., 2005). Eventually, the road system expanded but progressed slowly since road construction was generated from Reykjavík as starting point to other parts of the country (Guðnason, 1975).

1.2.2 Natural Resources: Land cover

At the time of the settlement, the extent of forest and vegetation cover is presumed to have been significantly more than today. This is indicated by place names, pollen analysis and charcoal pits, but also literary references and the Land Registry (1703) (Arnalds, 2005; Eysteinsson & Blöndal, 2003; Hallsdóttir & Caseldine, 2005; Steindórsson, 1994). Natural forests that covered much of the lowland areas were dominated by downy birch (*Betula pubescens*) and willow species (*Salix spp.*) (Hallsdóttir & Caseldine, 2005), which are considered the climax vegetation at elevations up to 400 m a.s.l (Dugmore, Church et al., 2005). The unsustainable use of forests and the introduction of livestock are believed to be the main reasons for the degeneration and decline of the vegetation cover within the first 200 years of settlement. Wood was excessively used for housing and heating, and deforestation practiced such as slash and burn to extend grazing land (Dugmore et al., 2005). Overgrazing led to the deterioration of the vegetation on the sensitive volcanic soils and caused the desertification of vast areas, while tephra deposits from frequent volcanic eruptions buried the low plant cover (Arnalds, 1987; Arnalds, Þórarinsdóttir et al., 2001; Dugmore et al., 2005; Smith, 1995). The climatic conditions and anthropogenic influences have prevented the rejuvenation of the previous vegetation but instead supported the formation of heath- and wetlands in the lowland areas (Hallsdóttir, 1995; Hallsdóttir & Caseldine, 2005).

The natural conditions, such as climate and volcanic activity, may have played an even greater role in the vegetation deterioration than previously acknowledged and the effects aggravated with the settlement and subsequent land use practices (Gathorne-Hardy, Erlendsson et al., 2009). The cooling of the climate is presumed to have started before the settlement era and the vegetation already entered the degradation phase prior to the settlement of the country (Ólafsdóttir, 2001). The subsequent Little Ice Age, approximately in 1400-1900 (Jónsson, 2007), resulted in increased storminess and loss of vegetation that correlated with anomalies in sea-ice accumulation, drift, and water salinity (Jennings, Hagen et al., 2001). Such conditions amplified soil erosion that peaked in 1780-1920, which is later than previously assumed (Jennings et al., 2001). The layers of tephra produced by volcanic eruptions not only buried but enhanced the drainage of the previous vegetation types and have been found to be notably involved in the deterioration of certain areas (Erlendsson, Edwards et al., 2009; Vickers, Erlendsson et al., 2011). The high erosion susceptibility of volcanic soils (Arnalds, 2008) together with climatic conditions, glacial and volcanic activity have the potential to induce and maintain desertification beyond anthropogenic involvement (Dugmore, Gísladóttir et al., 2009).

1.3 Objectives and thesis structure

In view of the vulnerability of the Icelandic vegetation cover, land use development and changes are significant, especially in a region with relatively high utilization such as the South Iceland plain. The region comprises the largest continuous lowland area in the country and is amenable to a variety of land use types that eventually may compete for space and natural resources present. It is the most productive agricultural area in Iceland (FAI, 1985-2010), but about ⅔ of the region are also considered suitable for forestry (Blöndal, 1991; NL, 1986), whereas planned hydropower projects will consume substantial areas of vegetated land (LV, 2009; MIET&ME, 2011).

The region's natural features and the close proximity to the capital area has made it the most visited place in the country year round (ITB, 2011), while recreational land uses such as vacation homes stimulate infrastructure development and increase the pressure on the most visited sites. Fertile hayfields and pasture land are needed for large livestock populations (FAI, 1985-2010), but the restoration of wetlands to retain their functions, e.g. as CO_2 sinks, is also considered of national and international importance, formally approved at the Durban Climate Change Conference in December 2011 (Garðarsson, Magnússon et al., 2006; ME, 2010; UNFCC, 2011). Such conflicting land uses need spatial organization, coordination and an interdisciplinary land management approach (Buizer, 2011; Fry, 2001; Robinson, 2004), whereby past developments and activities can provide informative facts for future land use agendas (Antrop, 2005; Eriksson, Cousins et al., 2002; Rodríguez & Beard, 2005).

This study is thus aimed to:

- Describe land use patterns in the southern lowland region from 1900 until present, and relate them to socio-economic factors and physical characteristics.
- Quantify the land-use changes that modified the natural environment.
- Estimate the impact area of land use types on the natural environment, individually and cumulatively.
- Calculate the vegetation types potentially affected relative to what remains intact.
- Discuss the drivers responsible for the land use developments.
- Place the land-use changes in South Iceland in national and international context.

The study is a combination of new analysis and compilation of existing data that has not been compiled previously to this extent. The results need historical context for clarification and to describe the land use patterns of the past. For that reason, the thesis was structured by uniting results and discussion and dividing it into three main blocks: a) Historical land use patterns and land conversions b) Impacts on the natural environment c) Drivers of the land-use changes, and national and international context. The thesis closes with concluding remarks and recommendations.

1.3.1 Study area: characteristics and environment

Size and location

The area investigated is 6,415 km^2 in size, which is about 6% of Iceland's terrestrial surface. It is located within the county boundaries of *Árnes*- and *Rangárvallasýsla* in South Iceland, excluding land > 400 m a.s.l. and contains either partly or entirely 11 administrative districts and 14 towns or settlements with more than 50 inhabitants (Figure 1.1). *Selfoss (*6,512 inhabitants) is the economic center of the region and the third biggest town in the country (SI, 2011f). The towns *Hella* and *Hvolsvöllur* form service centers in the eastern and *Hveragerði* in the western part of the region. In 2011, a total of 18,650 people lived in the area (SI, 2011g).

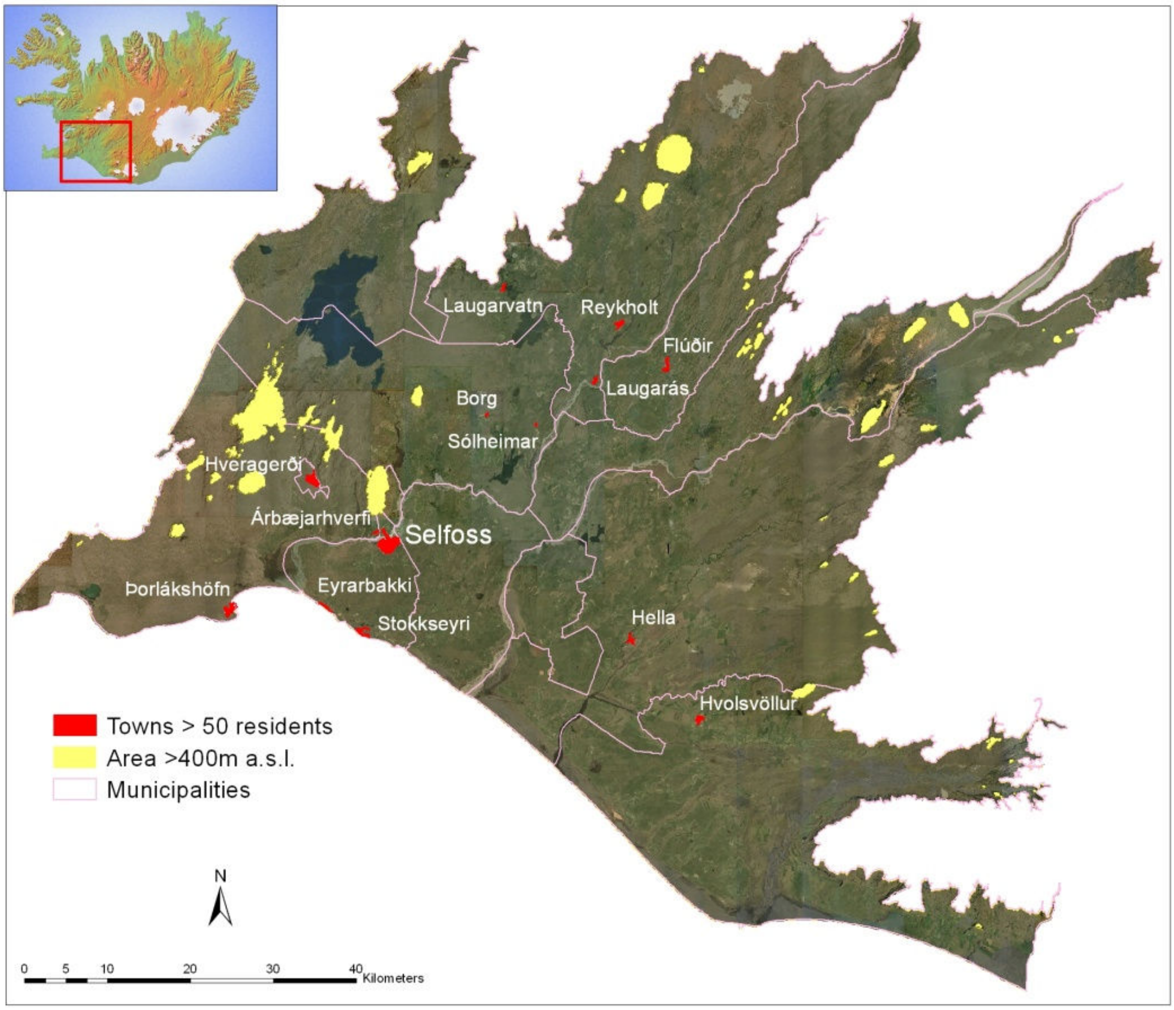


Figure 1.1 Location and delineation of the study area in South Iceland. The area lies within the Árnes- and Rangárvallasýsla counties, excluding land that exceeds 400 m a.s.l.

Climate

The Icelandic climate is cold-temperate oceanic and generally characterized by relatively cool summers and mild winters. The southern lowlands have a mild climate compared to other parts of the country, a relatively high precipitation and a long growing season. The climatic conditions at *Hæll* weather station are typical for much of the lowland region, with a mean annual temperature of 4.2°C and a mean annual precipitation of 1,113 mm (Table 1.1) (IMO, 2011). In the 1980's, the growing season was approximately 90-100 days (NL, 1986) but it may have expanded with a warming climate (Jónsson, 2007).

Table 1.1 Climate measured at Hæll weather station at 121 m a.s.l. (64°03.904', 20°14.471' or 64.0651, 20.2412) in the southern lowlands in 1990-2010. Source: IMO

Climate	20-year mean		
	Annual	July	January
Temperature (°C)	4.2	11.5	-0.8
Precipitation (mm)	1,113	82.3	99.5

Topography

The southern lowlands (< 400 m a.s.l) are characterized by a flat landscape. Only 2.5% of the area has a gradient of > 20° (Table 1.2), which is generally located at the base of mountains that exceed 400 m a.s.l (Figure 1.2).

Table 1.2 Topography statistics in the southern lowlands < 400 m a.s.l., based on the results of the surface analysis.

Slope	Area ha	% of total land area	NE & NW exposure ha	% of Slope
0°-10°	589,150	92	N/A	..
10°-20°	35,556	5.5	15,043	42.3
20°-30°	11,866	1.8	5,341	31.7
> 30°	4,944	0.7	2,197	13

N/A = not applicable

About 45% of the land sloping 20° and more (Table 1.2), has a northern exposure, which indicates that there may be a colder microclimate, shorter growing season and higher soil humidity (Figure 1.2) (Bennie, Huntley et al., 2008).

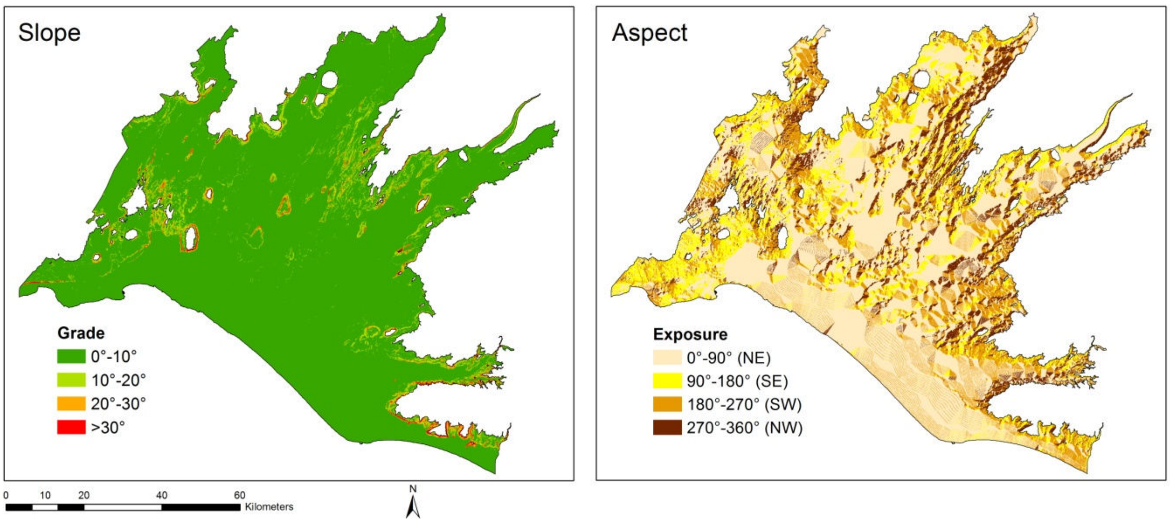


Figure 1.2 Topography, slope and aspect (< 400 m a.s.l.) in the southern lowlands.

Geology, hydrology and soils

Geologically, the region is referred to as the South Iceland Seismic Zone, situated between two active rift zones (Einarson, 2008). The main geological formations are Plio-Pleistocene bedrock, lavas and sediments (Jóhannesson & Sæmundsson, 1999). Several central volcanoes are present on the eastern (*Eyjafjallajökull*, *Tindafjallajökull and Hekla)* and western (*Hengill)* margins of the lowland plain (Jakobsson, Jónarsson et al., 2008). The most active volcano, *Hekla,* has erupted 18 times since the settlement of Iceland in the 9th century, depositing large quantities of tephra, lava and volcanic debris especially in the northeastern part of the area (Guðmundsson et al., 2008). High-temperature geothermal fields exist in the *Hengill* area and low-temperature geothermal fields are spread across the region (Arnórsson, Axelsson et al., 2008). Several epicentral faults generate frequent earthquakes of various strengths (Árnadóttir, Geirsson et al., 2008; Jakobsdóttir, 2008).

The land covered by water approximates 278 km² of the area investigated (Árnason & Matthíasson, 2009a; AUI, 1999-2010; NLSI, 2010). The most prominent rivers are *Hvítá*, *Ölfusá* and *Þjórsá*. *Ölfusá* with a mean flow volume of 423 m^3/s is Iceland's largest river (SI, 2011c). *Hvítá* and *Þjórsá* are glacial rivers, while the river *Ölfusá* forms at the confluence of *Hvítá* and *Sog*, a spring fed river that originates at the lake *Þingvallavatn* (83.7 km²), Iceland's biggest natural lake.

Andosols, including Brown-, Gleyic-, and Histic Andosols, are the main soil types in the region (Figure 1.3) (Arnalds & Óskarsson, 2009) and cover more than ⅔ of the study area (Table 1.3). Andosols are formed from volcanic ash, pumice and related parent material and are very porous and dark colored soils with high organic content. Their large water retention capacity makes them susceptible to frost action, i.e. freeze-thaw cycles that lead to hummock formation. Icelandic Andosols are often interspersed with volcanic ash or tephra layers especially in the vicinity of active volcanoes (Arnalds, 2008; Jones, Stolbovoy et al., 2010). Andosols occur across the world in areas with common volcanic activity, and cover around 1% of the northern circumpolar region (Jones et al., 2010).

Table 1.3 Soil types in the southern lowlands. Source: Soil map of Iceland (Arnalds, Óskarsson et al., 2009)

Soil type	ha	% of total
Andosol and Andosol Formations*	459,994	71.7
Leptosol	18,076	2.8
Gravel/Gravel-Sandy Soils	61,705	9.6
Sand/Sand-Sandy Soils	76,919	12

*Brown Andosol, Gleyic Andosol, Histic Andosol

Erosion, a major environmental problem in Iceland, also affects a part of the southern lowlands. Based on the national erosion assessment, 467.7 km² of the study area are affected by extremely severe erosion (RALA & LR, 1997), primarily at higher elevations along the slopes of the central highland plateau and along the coast (Figure 1.3). These areas are characterized by sandy soils and a sparse vegetation cover and have been subject to land reclamation measures such as afforestation and the stabilization of sand with *Leymus arenarius* or jetties (Aradóttir, Sigurjónsson et al., 2005; Arnalds et al., 2001; Gunnarsdóttir, 2009).

Erosion also is a natural process in volcanic areas and sandy coasts across the globe. Sandy coastlines are characterized by wind and water erosion as part of their natural dynamics. They act as buffers between land and sea, and mitigate storm surges. Erosion along coasts primarily becomes a problem for near shore habitation and land use (Jefferey, Gardi et al., 2010). In turn, shoreline modifications, i.e., development or artificial structures, have the potential to alter currents and sediment delivery and reduce the natural buffer capacities. This either triggers further erosion or transfers erosion processes to other locations (Burke, Kura et al., 2001), which is the opposite of what is desired. Such areas are not entirely comparable to the desertification process as consequence of unsustainable land use, i.e. overgrazing, and should be evaluated differently.

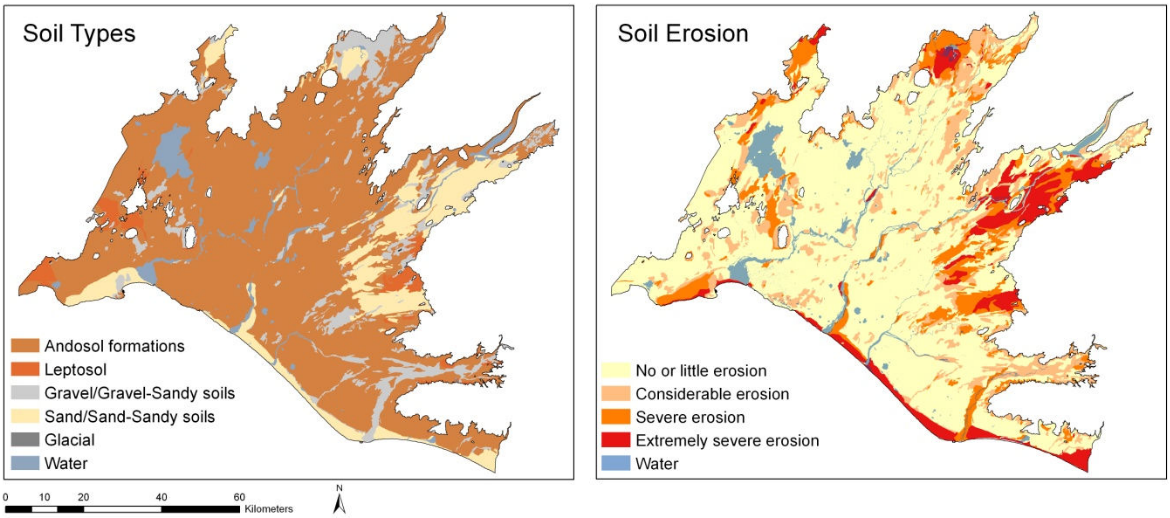


Figure 1.3 Soil types and erosion in the southern lowlands. Source: Soil map of Iceland (2009) & Soil erosion map (1997), AUI & RALA

Vegetation and protected areas

The vegetation types of the lowland region have been mapped by remote sensing surveys and classified by the *Nytjaland* project by AUI and the Pan-European project *Corine Land Cover (CLC)* (Árnason & Matthíasson, 2009a; AUI, 1999-2010). Much of the *CLC* data is based on the *Nytjaland* project, though differences in classification and data format (raster and vector data) result in discrepancies of area estimates (Table 1.4).

The category wetland includes mires, fens and ecotones characterized by a high water level and a high abundance of sedges *(Carex spp)*. Grassland is land dominated by perennial grasses and heathland includes both rich and poor heathland based on sheep grazing capacity (Nytjaland, 1999). In *Nytjaland* the moss category defines land where at least ⅔ of the vegetation is dominated by mosses, whereas in the *CLC2006* classification system, moss is part of the heathland category (Árnason & Matthíasson, 2009b), which explains the differences in area (Table 1.4). Woodland as defined by *Nytjaland* includes areas where 50% of the land is covered by trees and shrub exceeding 50 cm in height, while *CLC2006* uses the data produced by the Forest Service (Table 1.4). Partly or sparsely vegetated land includes land, with very sparse vegetation cover and soils of predominantly gravel, sand or volcanic debris with very low organic content. Despite the high precipitation rate, these areas are desert-like and suffer from erosion (Arnalds, 2008). The largest area with a vegetation cover < 20% is located in the northeastern part, in the *Þjórsár* valley close to the volcano *Hekla* (Figure 1.4).

Table 1.4 Vegetation categories and area in the southern lowlands in 2010, classified by the Nytjaland and Corine Land Cover (CLC2006) projects.

Vegetation category	Nytjaland ha	% of total	CLC2006 ha	% of total
Wetland	77,609	13.5	76,377	11
Grassland	48,747	7.6	42,947	6.7
Heathland	199,674	31	277,471*	43
Moss land	63,780	10	N/A	..
Woodland and shrub	21,893	3.4	51,353	8
Cultivated land	52,071**	8	63,817	10
Vegetation cover 20-50%	82,231	12.8	58,783	9.2
Vegetation cover < 20%	67,522	10.5	72,212	11.2

**Moss and heathland combined; **Hayfields only; N/A=not applicable*

About 211 km² of the study area are protected by national legislation under the categories national park (Figure 1.4), nature reserve, natural monument and country park (Jónsson Geirsson, 2010).

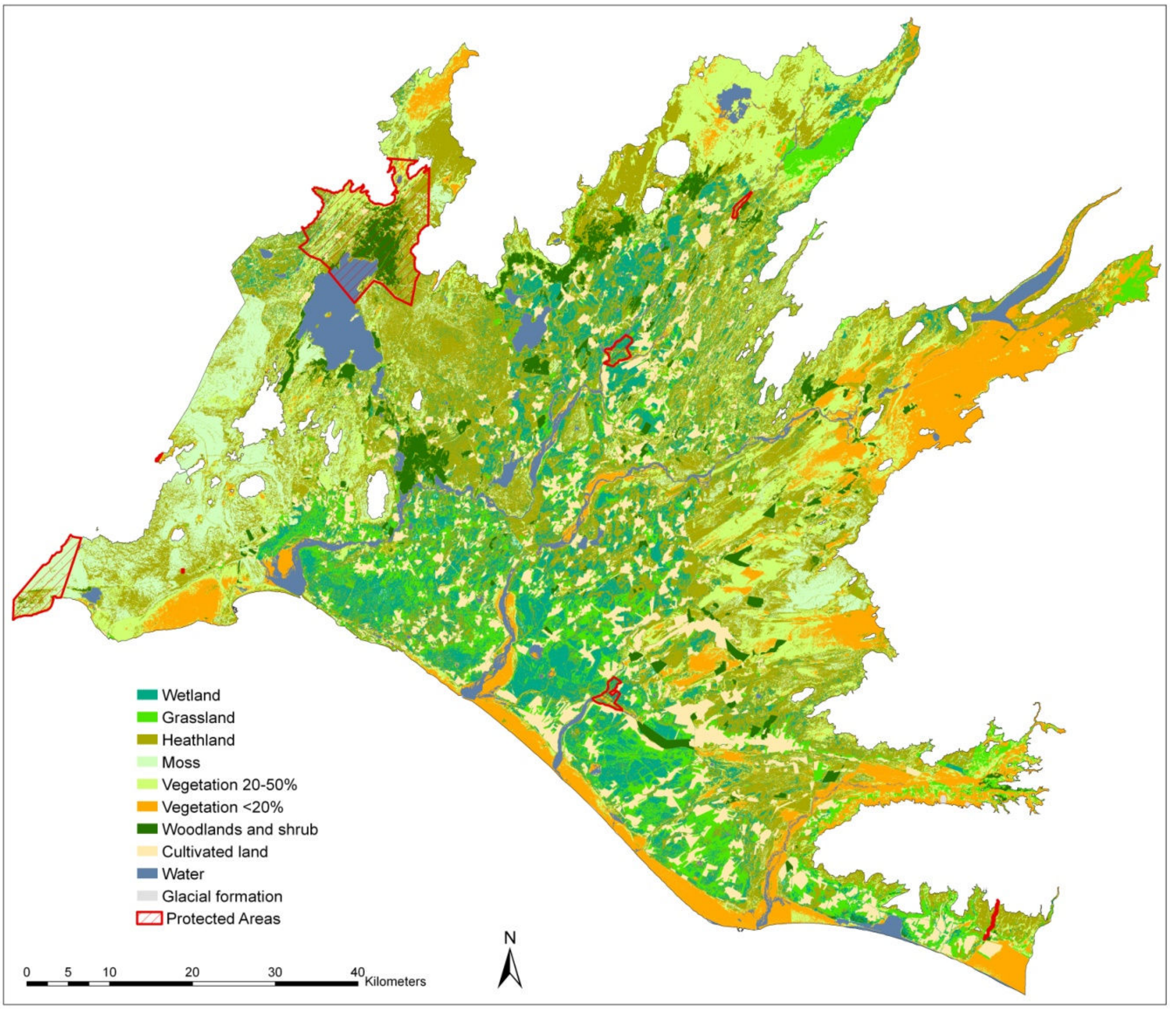


Figure 1.4 Vegetation categories (Nytjaland) and areas protected by national legislation in the southern lowlands in 2010. Source: AUI & EA

2 Materials and Methods

2.1 Spatial and temporal delineation

Using a GIS contour layer, the study area was defined as the southern lowland plain, up to an elevation limit of 400 m a.s.l. The administrative boundaries of the counties of *Árnessýsla* and *Rangárvallasýsla* reach far into the uninhabited central highland plateau therefore this elevation limit was set to restrict the analysis to inhabited areas in the south.

The temporal dimensions of the project were constrained by data source availability and project size. Four time intervals were selected to reflect land-use changes in the period 1900-2010:

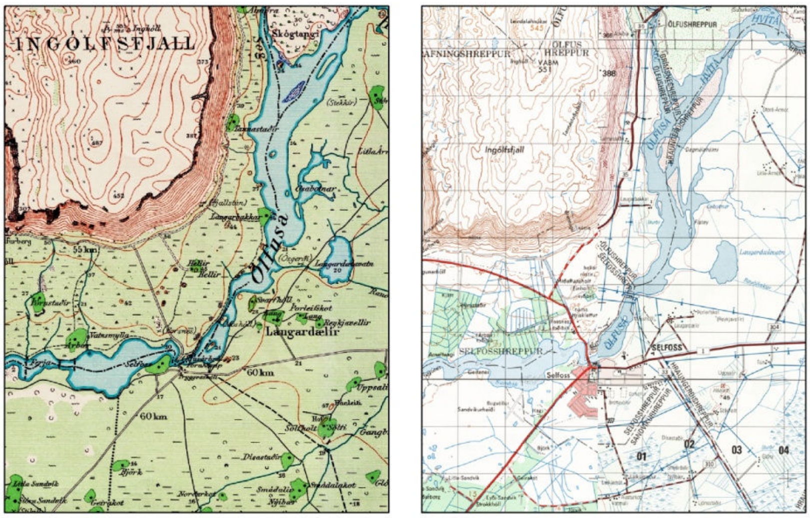
- 1900 and early 20th century. The first available maps are those made by the Danish General Staff at the scale of 1:50.000. These topographic maps were produced 1905-1911, and provide information about land cover and land use categories (Figure 2.1).
- 1950. In the post World War II era, mechanical equipment greatly increased the land conversion rate. The cartographical material available is the revised version of the Danish General Staff maps from the 1900-period, produced 1948-1957.
- 1980. This was the time of economic growth, and the turning point from a predominantly rural to an urban society. Topographic maps produced by the US Defense Mapping Agency (DMA), were available at the scale of 1:50.000 and produced 1980-1990 (Figure 2.1).
- 2010. This represents the present situation. The electronic data currently accessible from a range of sources (Table 2.1) were used for the analysis.

The maps that characterize the time periods 1900, 1950 and 1980, are electronically available at the National Land Survey Institute (NLSI) (NLSI, 2011b), and served as basis for the data extraction of the categories focused on (Table 2.1).

Table 2.1 Land use categories focused on in the southern lowlands in 1900-2010.

Categories	Specifics
Buildings	Residences, outhouses, services, institutions, shelters, deserted farms
Ditch network	Irrigation and drainage
Transportation	Horse tracks, walkways, unpaved and paved drivable roads
Towns	Settlements > 50 residents
Power generation	Geothermal- and hydropower plants, reservoirs, dams, power lines, boreholes
Wetlands	Mires, fens and ecotones
Woodlands	Natural birch forest and afforestations

Agricultural land use although not sufficiently identifiable on the maps was included in the analysis as it is a significant land use category in the region. The relevant data about hayfield area, livestock numbers and artificial fertilizer were obtained from agricultural reports by Statistics Iceland (SI, 1913-1963), the Agricultural Year Book (Sigurjónsson, 1970), and the Farmers Association of Iceland (FAI), calculated for the southern lowlands specifically (FAI, 1985-2010).



Danish General Staff Map (Herforingjaráðskort) 1:50.000

US Defence Mapping Agency DMA C761 1:50.000

Figure 2.1 Examples of topographic maps used as a basis for the data extraction in the southern lowlands. The Danish General Staff Maps were used for 1900 & 1950, and the DMA maps for the 1980-period.

The data representing the current situation of land use (2010 period) were provided by the relevant institutions and administrations (Table 2.2).

Table 2.2 Sources and types of electronic data used for the analysis in the southern lowlands.

Data provider	Type of data	date
National Land Survey Institute (NLSI)	Geographic data (IS_50V_2.3_ISN93, DEM_IS_50)	2010
	Corine Land Cover (CLC)	2000/2006
Agricultural University of Iceland (AUI)	Raster data Nytjaland (land cover)	Since 1999, ongoing
	Soil map of Iceland	2009
	Soil erosion map of Iceland	1997
	Ditch network	2010
National Property Registry (NPR)	Vacation homes	2009
National Power Company (LV)	Dams and reservoirs	2010
Transmission System Operator (TSE)	High voltage power lines	2010
National Energy Authority (NEA)	Power stations	2010
Iceland Forest Service (IFS)	Forest cover	2009
Environment Agency of Iceland (EA)	Protected areas	2010
Farmers Association of Iceland (FAI)	Annual hayfield conversions	1955-1989

2.2 Geographical Information System (GIS)

2.2.1 Data mapping

Data generation and mapping were performed with the ArcGIS Version 10.0 from ESRI. Electronic data were generated for each time period and category respectively. The maps were georeferenced prior to the data collection (Hillier, 2011), by using the Icelandic projected coordinate ISN1993_Lambert_Conformal_Conic as reference. A Digital Elevation Model (DEM) was used for area delineation and the surface analysis. Aerial photography was used for mapping (study area overview) and to verify the data about the ditch network obtained from DMA maps for the 1980 period, because of inconsistencies between data sources. For a small part at the northeastern margin of the study area, Atlas Maps (1:100.000) had to be used for data extraction as it exceeded the coverage by the Danish General Staff Maps. The first available Atlas Maps for this area were from 1937 and revised in 1971.

The data extracted were complimented by current day data if time specifications of the establishment were included in the attribute tables of the datasets, e.g. vacation home data. This allowed for temporal selection based on years of construction, and data extraction to be added to the time periods respectively. In cases of time variations of the maps from the periods determined, especially relevant for the 1980-period where maps were updated in 1988 and produced in 1990, the data extractable was adjusted accordingly, i.e. vacation homes existing by 1988 instead of 1980. It will still be referred to as 1980 time period.

2.2.2 Analysis and data processing

Data analysis and processing were performed with ArcGIS, utilizing the relevant overlay functions and the Spatial Analyst (Hillier, 2011). Land use and land cover were distinguished, as land cover is the physical surface characteristics of land, while land use describes its economic and social functions (Haines-Young, 2009). The forest data extracted for past developments include both natural birch forest and afforestations for timber production as the two categories could not be separated. The current data (2010 period) provided by the Forest Service allowed for the distinction, which was included in the analysis if applicable (Elmarsdóttir, Fjellberg et al., 2008).

Indicators

The indicators used for assessing the development in land use were the dimension of the land use and land cover types, the land conversion rate, impact and landscape fragmentation for the time periods respectively. Distribution and density were analyzed especially for the road system and vacation home development by using the line and point density functions of the Spatial Analyst. The extent of wetlands as the principal ecosystem type in the region in 1900, well identifiable on the Danish General Staff Maps, served as reference and indicator of the land conversion per land use category.

Land take

For the land take and conversion rate calculations, the land use categories represented as line or point features were processed by applying distance buffers (ArcGIS overlay function) in proportion to their actual size.

Information about the actual road widths was obtained from Jón Guðnason (1975), or if applicable, the road classification system by the Icelandic Road Administration (IRA, 2011d). To enable comparison between times, roads wide enough to facilitate all vehicle types were defined as drivable roads despite quality differences. Only drivable roads outside urban areas were included in the analysis. The road network within towns that were generated as polygon features as obtainable from maps, was clipped (ArcGIS overlay function) from the datasets. The average ditch width was determined as 2 m (Óskarsson, AUI, personal communication, November 16th, 2010) and the land influenced by power lines was calculated based on the security zone guidelines by the Transmission System Operator (TSO). The security zone depends on the voltage of the power lines (specified in the datasets) and is regulated by law, requiring at least 25 m for 66 kV, 35-40 m for 132 kV and 75-90 m for 220 kV, of which the average was used (TSO, 2010). For the power lines with 33 kV a 25 m security zone was determined, as there were no specifics in the guidelines. Vacation home data from NPR (Table 2.1) was provided by Ph.D. student and GIS tutor Martin Nouza, with the permission of the agency. This data gave information about the building's basal area, ranging from 5 m² to nearly 500 m², and the average used for calculations.

Impact

For investigating the impact of the land use types, i.e. drainage ditches, roads and settlements, a distance buffer was applied and its size determined based on literature and case study results. Extent and variables are defined further in the relevant chapters. To account for the cumulative effect of these categories, the zones of influence were a) intersected (ArcGIS overlay function) to determine the area that is simultaneously affected by more than one land use category, and b) merged (ArcGIS overlay function) to calculate the total area cumulatively affected in the periods respectively.

Case study: Þjórsárdalur valley

The *Þjórsárdalur* valley is one of the core areas for harnessing hydropower in Iceland. Electricity generated by hydropower is the most widely used form of renewable energy and produces the least amount of greenhouse gases of any energy source (Rabl, Spadaro et al., 2005). In contrast, sites are often located far away from population centers and the projects to be powered as is the case in the *Þjórsárdalur* valley. This requires a road network, housing and extensive power lines, which has turned the *Þjórsárdalur* valley into a highly developed area for the purpose of electricity generation and is special in the S-Iceland context. The area concerned was thus isolated and examined further to document the valley's development.

2.3 Data reliability

The DMA maps used for the 1980-period were only conditionally suitable for data generation. While data on built-up land were updated by the NLSI regularly and are considered reliable, data on the land cover and ditch network were neglected. The time and kind of information used that served as basis for creating these maps is largely unknown (Kristinsson, NLSI, personal communication, May, 10th 2011).

The wetland and land cover data extracted were thus complimented by other data sources, which is defined further in the relevant chapters. For the ditch network the time period was changed to 1970, supported by other sources.

There are significant differences of land cover area estimates and classification between data sources, e.g. forest cover. Little reliable data was available for agricultural land area (Bragason & Dýrmundsson, FAI, personal communication, June, 9th 2011) and there is a great difference between data published by FAI, and generated by CLC and *Nytjaland* (see also (Snæbjörnsson, Hjartardóttir et al., 2010)). One reason for the discrepancy probably is the inaccuracy of data obtained only by remote sensing. This method provides an overview but does not seem sufficient to categorize and specify vegetation cover.

Data about man-made structures as part of the Geodatabase IS_50V_2.3_ISN93, DEM_IS_50 released by NLSI in 2010 were generated from DMA maps representing the buildings existing in the 1980's (Guðbjörnsdóttir, NLSI, personal communication, September, 20th 2011). The actual number and purpose of buildings in 2010 was not available, which disabled numerical comparison and produced incorrect results of the impact analysis. It was also not practicable to calculate the land take of rural buildings owed to the variety of building types and outhouses. The size of rural residences is mostly expressed in m^3 and number of rooms, lacking information about basal area (SI, 1957, 1968, 2011b). Investigations at the State Archive and the online database of the NPR exceeded the time limit of this project. Information about the basal area of buildings in rural area was obtained from literature and the calculations approximates.

3 Results and discussion

3.1 Historical land use patterns and land conversion

3.1.1 Agricultural land use

Hayfields, grazing land and fertilizer use

The increase in agricultural production beyond subsistence correlated with the expansion of neighboring *Reykjavík* and the incipient urbanization process at the beginning of the 20th century (Júlíusson et al., 2005). To satisfy the demand for dairy products, more pastures and a higher hay yield were needed to sustain the rising number of milking cows. Between 1908 and 1957, the average size of hayfields had increased from 2,8 ha to 14,7 ha (Þorsteinsson, 1959), and the total hayfield area had expanded 15-fold between 1913 and 2010 (Figure 3.1) (AUI, 1999-2010; SI, 1913-1963; Sigurjónsson, 1970) & (Nýrækt Tún 1955-1989 [Newly-established Hayfields 1955-1989], compiled by Óttar Geirrson, FAI, 2005, unpublished data).

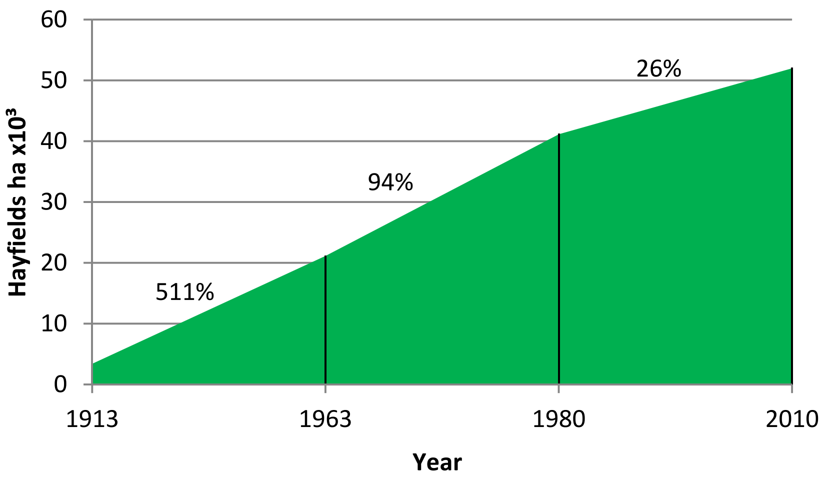


Figure 3.1 Approximate hayfield area (ha) in the southern lowlands in 1913-2010, including the %-increase between selected years. Source: SI, FAI & Nytjaland

Most hayfields were established in the 1960's (Figure 3.2) and the peak reached in 1964, where 1,936 ha of land were turned into hayfields in one year (Nýrækt Tún 1955-1989 [Newly-established Hayfields 1955-1989], compiled by Óttar Geirrson, FAI, 2005, unpublished Data). Past 1965, the emphasis was shifted towards the conversion of land into pastures to provide for the growing number of livestock (Geirsson, 1975). This is indicated by the declining trend of conversions into hayfields in the following decades (Figure 3.2). A total of 31,343 ha of land was converted into hayfields in 1955-1989 and an additional 6,566 ha were converted between 1989 and 2010 (AUI, 1999-2010).

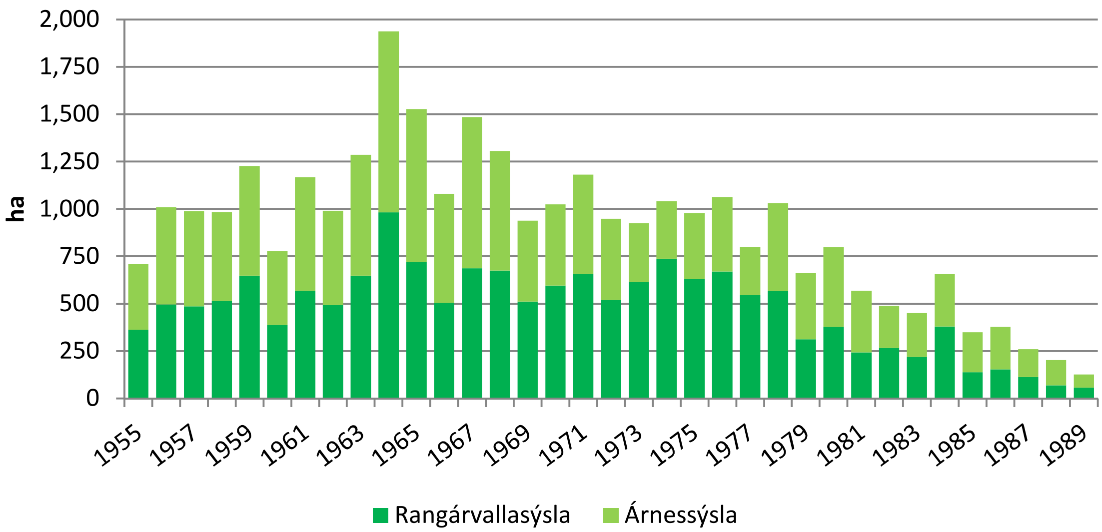


Figure 3.2 Annual hayfield conversions (ha) in the southern lowlands in 1955-1989. Source: Óttar Geirsson, FAI, 2005, unpublished data.

The livestock population in the region, i.e. sheep, cows and horses, fluctuated between 1900 and 2009, but the amount of cows and horses, requiring more hay and pasture land, grew steadily and had tripled by 2009 (Figure 3.3) (FAI, 2011; SI, 1967). The number of sheep peaked with a total of 91,752 winter-feeding animals in 1980 (SI, 1991). Year round free-range grazing was still practiced in the area at the time, but was slowly reduced to summer time only, enabled by higher hay yields and the availability of hay during winter time. Since the 1990's, free-range grazing is occasionally practiced with horses, whereas sheep are generally kept contained during the winter months (Dýrmundsson, FAI, personal communication, August, 22th 2011).

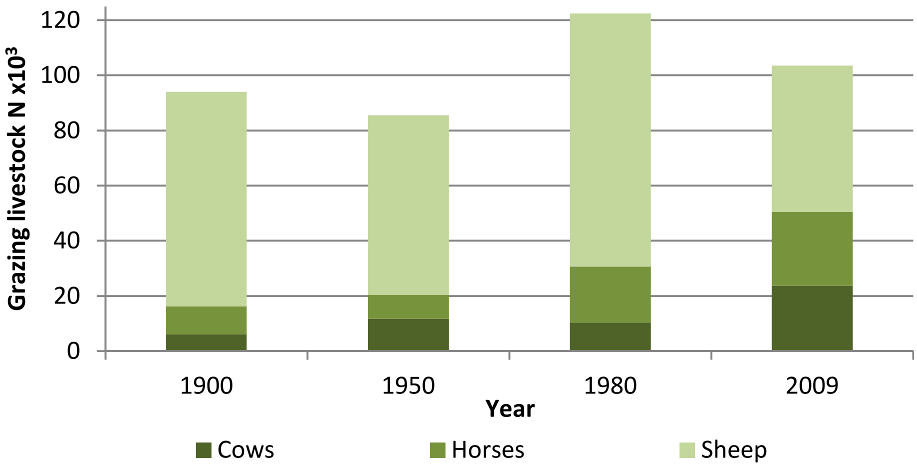


Figure 3.3 Grazing livestock (N) in the southern lowlands in 1900-2009. Source: SI & FAI

The use of artificial fertilizer was negligible until after the end of World War II (Figure 3.4). It then rose sharply and peaked at about 12,000 tones/yr around 1980, but subsequently declined to about 8-9,000 tones/yr (AUI, 1999-2010; FAI, 1985-2010).

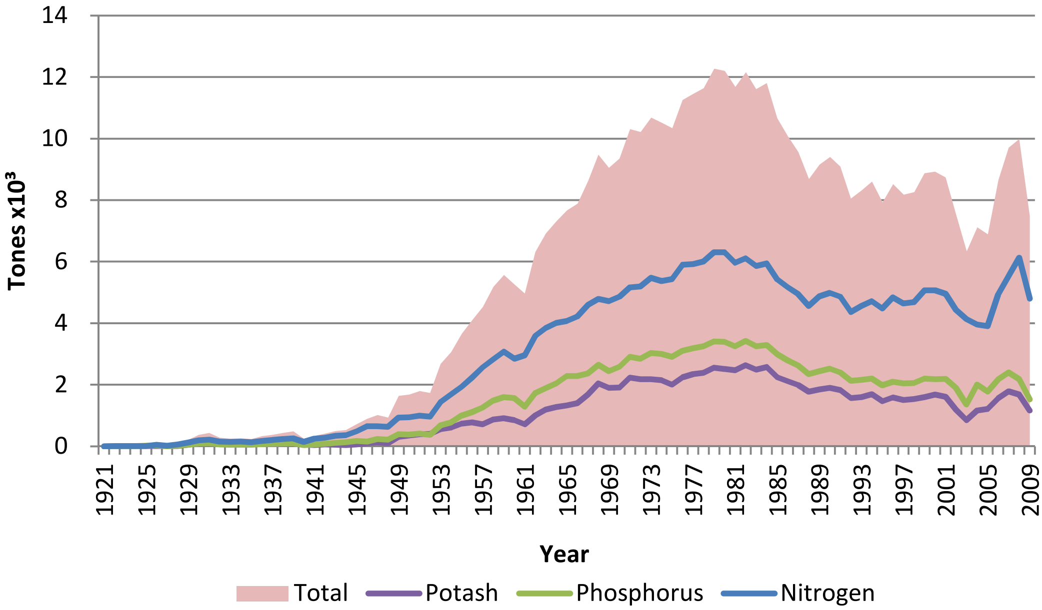


Figure 3.4 Approximate artificial fertilizer use (tones) in the southern lowlands in 1921-2009, averaging about 40% of the fertilizer used countrywide. Source: FAI

Irrigation period: Mid 19th to mid 20th century

The excavation of irrigation channels to flood wetland areas and increase their productivity was practiced after the mid-19th century until the 1940's (Geirsson, 1975; Jónsson, 1975; Sigurðsson, 1919). By 1853, 881 m of irrigation ditches had been dug in the two counties concerned (Bókmenntafélagið, 1855) and about 25 km excavated between 1899 and 1902 (Sigurðsson, 1919). The channels were connected to glacial rivers rich in mineral content (Þorsteinsson, 1959) and the meadows flooded in the spring and/or autumn months (AS, 1907). The flooding also reduced the formation of hummocks created by freeze and thaw cycles (Steindórsson, 1975), making the hay harvest by scythe much easier (Smith, 1995). The ditches were excavated manually until the arrival of trenchers pulled by horses in 1919 (AS, 1988; Þorsteinsson, 1959).

The largest irrigation network was in *Flói*, south of *Selfoss* (Plate 3.1), where some irrigation ditches had been dug by 1900 (Figure 3.6) (AS, 1903). The other core irrigation network, *Skeið* (Plate 3.1.), started to operate in 1923 and was followed by the expansion of the *Flói* irrigation system until 1927. Both systems flooded an area of about 14,062 ha (Jónsson, 1975) with water from the glacial river *Hvítá* (AS, 1907). The total length of irrigation channels excavated summed up to 325 km between 1913 and 1930 (Figure 3.5) (SI, 1913-1963). In the following years, irrigation practices declined and finally ceased in the late 1940's (Geirsson, 1975; SI, 1913-1963). The ditches excavated for irrigation purposes were included in the following calculations, based on the assumption that they also have draining effect on adjacent wetland area (Óskarsson, AUI, personal communication, May, 9th 2011).

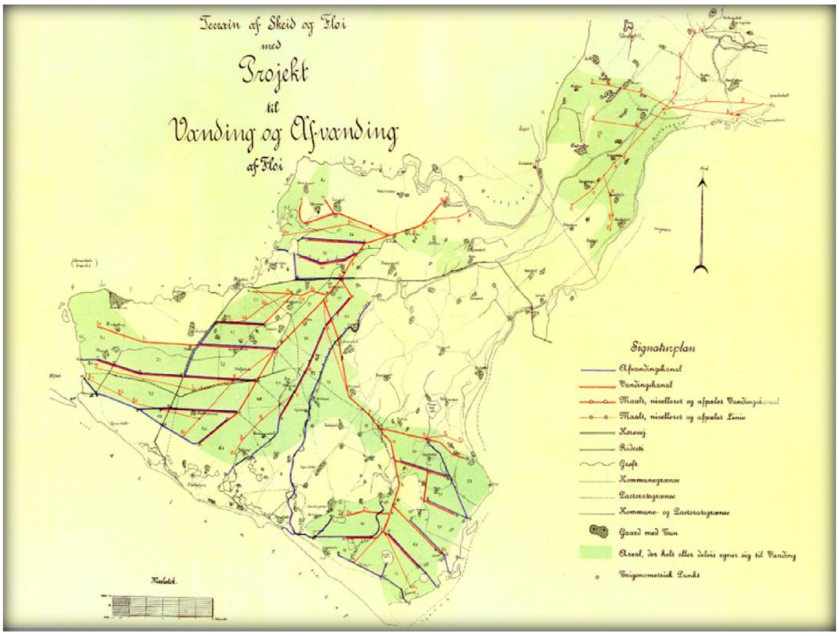


Plate 3.1 Irrigation systems of Flói and Skeið in the southern lowlands in the 1920's. The scheme illustrates the interplay of watering (blue) and draining (red) channels of the irrigation system (orange) at Flói. Illustration provided by Gísli Pálsson.

Drainage period

The shift from irrigation to wetland drainage was motivated by legislative measures and enabled by the introduction of mechanical equipment and fertilizer to the country (Júlíusson et al., 2005; Magnússon, 1998; Snæbjörnsson et al., 2010). While the southern lowlands comprised the largest continuous wetland areas nationwide, about 12% of total (Steindórsson, 1975), the proportion of ditches excavated in the region approximated ¼, or 24.6% (SI, 1913-1963) of the ditches dug countrywide (AUI, 2010). This percentage was used for calculating the periods where area-specific information was not obtainable (Figure 3.5). Most excavations took place in the 1960's, which correlated with the time of the highest hayfield conversion rates (compare Figure 3.2).

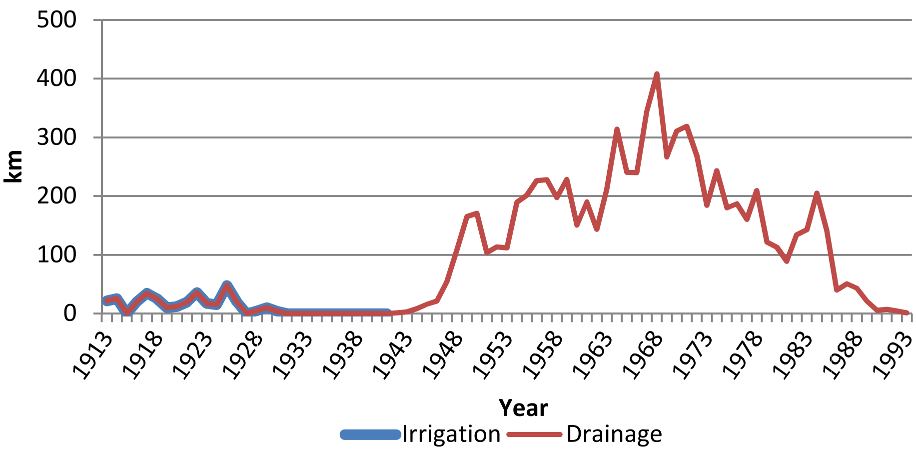


Figure 3.5 Irrigation channels and drainage ditch excavations (km) in the southern lowlands in 1913-1993, averaging 24.6% of the ditches dug countrywide in 1942-1993. Source: SI & AUI

For 1980, the data extracted from maps yielded a ditch length of 4,628 km. This was inconsistent with other data sources and corresponded to the calculated results for 1970, i.e. a decade earlier (Figure 3.6). Instead, the calculations produced a ditch length of 7,280 km in 1980 (Figure 3.5), which was more in line with current data. Compared to 1950 (456 km), the ditch network had expanded 16x by 1980 (calculated results).

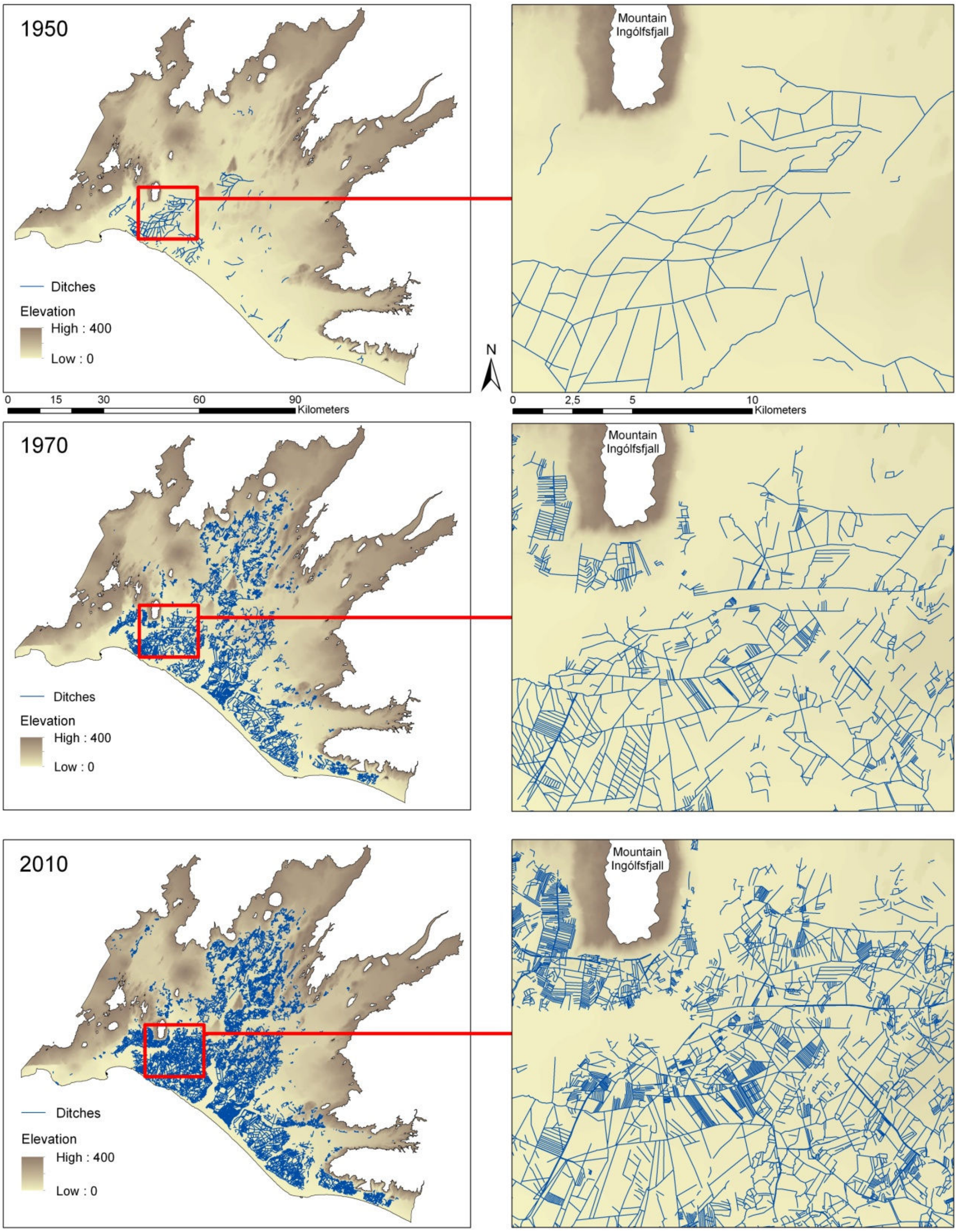


Figure 3.6 Ditch network in the southern lowlands in 1950-2010. The data generated from maps for the 1980-period corresponded to the calculated ditch length in 1970, i.e. one decade earlier.

Even though large-scale ditching had declined by 1993 (length 8,100 km) (Figure 3.5), the excavations in the southern lowlands continued, presenting a total ditch length of 9,050 km in 2010. This was an increase of 95% since 1970 (AUI, 1999-2010).

3.1.2 Buildings in rural areas

At the beginning of the 20th century, farmhouses and farm-related buildings were the principal building type, accounting for 89% of the buildings present (Table 3.1). The average size of traditional farmhouses made of turf was 70 m² (Helgason, 2004). Other building types that could be identified were churches, vicarages, guesthouses, and creameries for butter and cream production, totaling 73 buildings.

The following development showed a continuous decrease of agricultural buildings relative to the number of buildings present (Table 3.1), reflecting the shift from farming as main occupancy to other sources of income. The small creameries were replaced by two larger dairies in the forming towns *Selfoss* and *Hveragerði* in the 1930's (AS, 1988) and more service and recreational facilities added. These were post offices, variety stores, and schools, but also swimming pools, sports fields and golf courses. While the share of agricultural buildings decreased to 53.2% of buildings present in 1980 (Table 3.1), the total number of buildings in rural area increased 3x between 1900 and 1980. In 1980, the average basal area of residences built countrywide, was estimated with 182.2 m² (Jóhannsson & Sveinsson, 1986). Estimates for all rural residences, regardless their age, approximated 142 m² at the beginning of the 21st century (SI, 2004).

Table 3.1 Rural building development statistics in the southern lowlands in 1900-1980.

	1900	1950	1980	1900-1950	1950-1980	1900-1980
		N		*% change*		*Total %*
Buildings total	2,275	2,872	7,649	26.2	166.3	236.2
Agricultural buildings	2,031	2,304	4,072	13.4	77	100.5
Deserted buildings	174	295	627	69.5	112.5	260.3

The distribution of settlements was dispersed and generally located below 200 m a.s.l. in 1900-1950 (Figure 3.7), which is characteristic for the Icelandic settlement pattern (Júlíusson et al., 2005; Sveinbjarnardóttir, 2004; Valsson, 2003). By 1980, some buildings had been established in higher elevations and could be identified as ski huts or structures linked to power generation. While the location of farms remained mostly unchanged throughout time (Figure 3.7), the change in farming practices and modernization of farms between 1950 and 1980, where barns, cow- and sheep sheds were replaced or added (AS, 1988), resulted in an aggregation of several buildings for each farmstead.

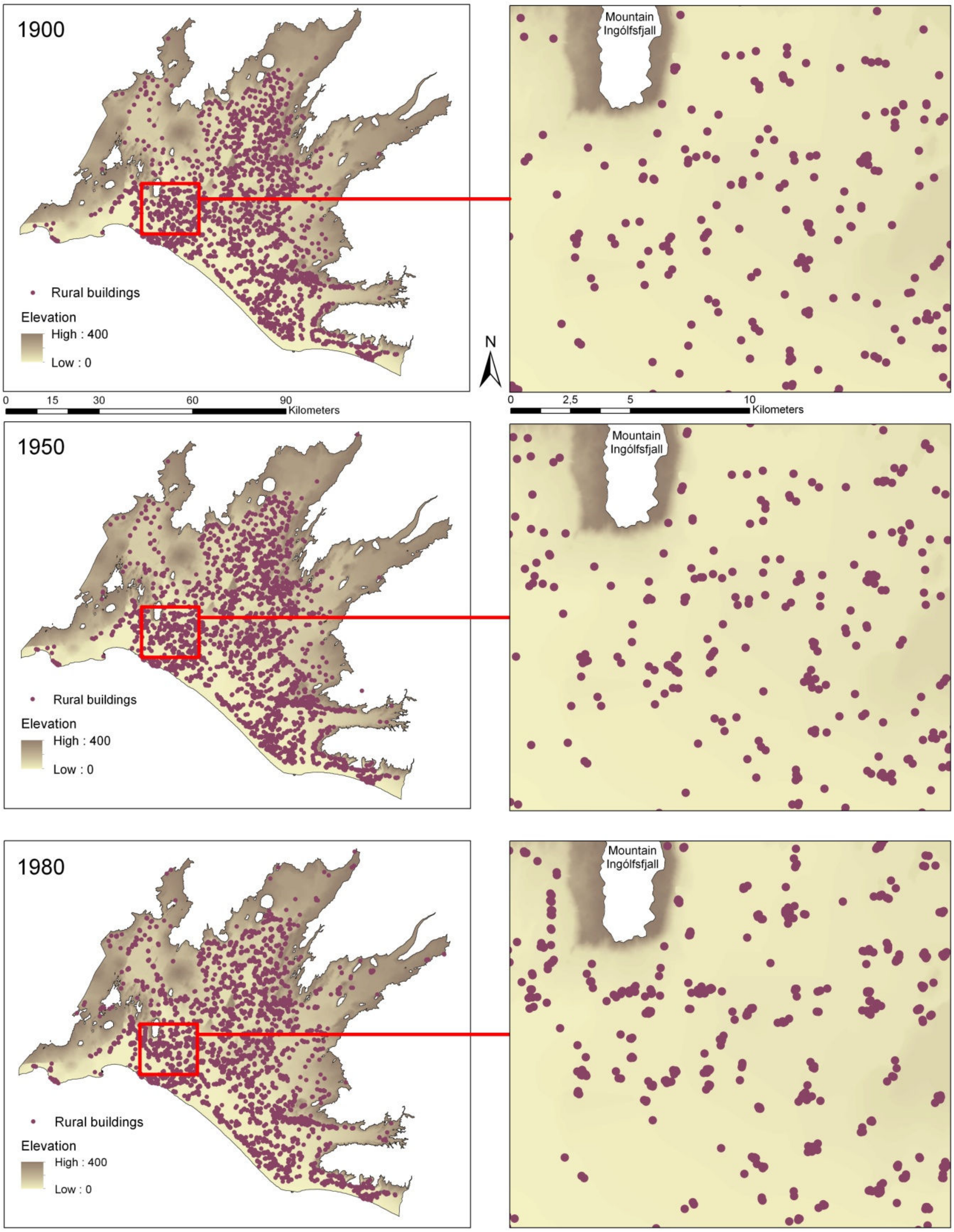


Figure 3.7 Rural building distribution in the southern lowlands in 1900-1980.

3.1.3 Transportation and roads

Paths, roads and bridges

In 1900, pathways such as horse tracks and walkways had connected most farmstead and only a few tracks were wide enough to facilitate horse wagons (Figure 3.8). These tracks connected the bridges across the rivers *Ölfusá* and *Þjórsá,* and indicated the increased communication of the region with the capital area (Júlíusson et al., 2005; Kristinsson, 1991; Valsson, 2003). They were specified with a standard width of 3.75 m (Guðnason, 1975) and had used about 148 ha land in 1900 (Table 3.2).

Past 1930, the roads were systematically widened to 4-5 m (Guðnason, 1975), forced by a growing car fleet and increasing demand for the transportation of people and goods (Kristinsson, 1991; Valsson, 2003). By 1950, the road length produced a 5x increase (Table 3.2) and by 1980, the road network was established and connected the main towns and farmsteads (Figure 3.8). In 1980, the total road length measured 3,601 km and covered 1,178 ha of land, which was an 8x increase since 1900 (Table 3.2). A considerable number of drivable tracks across the landscape without significant endpoint were extracted for 1980, suggesting a high vehicle fleet and increased tourist activities. This is consistent with the amount of registered passenger cars, which rose 14x nationwide between 1950 and 1980 (SI, 2011j).

Table 3.2 Road system development statistics in the southern lowlands in 1900-1980.

	1900	1950	1980	1900-1950	1950-1980	1900-1980
		km		*% change*		*Total %*
Total length	4,140	3,656	3,869	-11.7	6	-6.5
Pathways	3,745	1,634	268	-56.3	-83.6	-92.8
Drivable roads	395	2,022	3,601	412	78	811.6
Land take (ha)	148	869	1,178	487.2	35.5	696

In spite of another increase of passenger cars (141%) nationwide (SI, 2011j), the total road length had decreased by 4.4% between 1980 and 2010. This suggests that the 2010 data, producing a total road length of 3,444 km in the region, may have been incomplete not including all minor roads such as tracks. It could also reflect the potential of a well-defined road system to channel car traffic to be used as an effective measure against off-road driving (Thorsteinsson, 2006). In contrast, road improvements, i.e. widening and pavements, resulted in an increase of land take by 38.8% between 1980 and 2010. The total land area covered by roads, paved and unpaved was 16.3 km² in 2010. While unpaved roads can cause dust pollution, paved roads increase car traffic and affect the natural environment through soil degradation caused by sealing, changes in microclimates, erosion and increased water run-off (Coffin, 2007; Forman & Alexander, 1998; Jefferey et al., 2010).

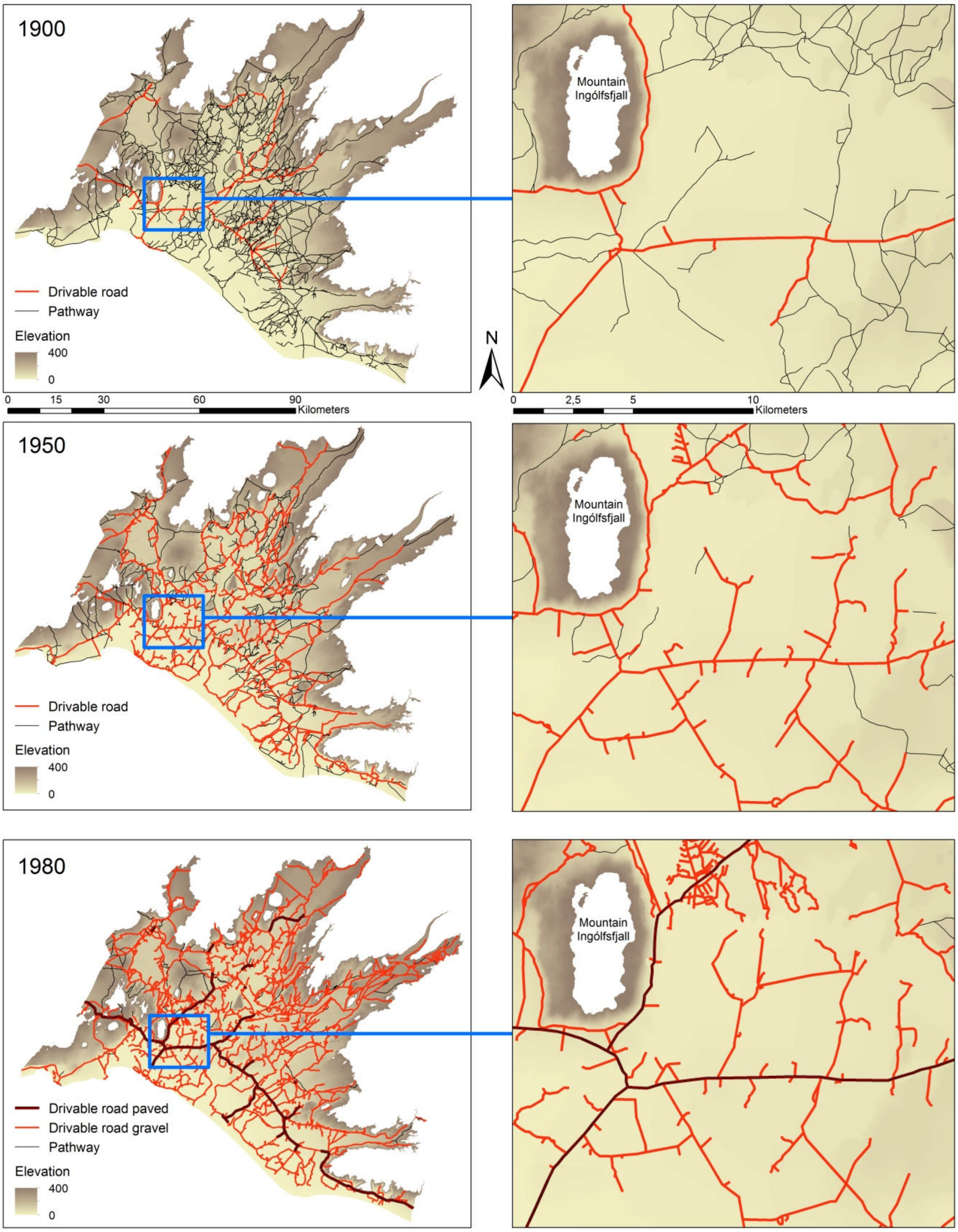


Figure 3.8 Road network distribution in the southern lowlands in 1900-1980. Pathways combine tracks not usable for any type of vehicle.

Road network density

The results of the density analysis are based on the road system and its spatial relationship in each period respectively. Red signifies the areas with highest road densities.

In 1900, the core areas, i.e. area of highest road density, describe the traffic junctions and their distribution remained largely unchanged throughout time (Figure 3.9). The road densities in 1980 and 2010 are comparable, which corresponds to the previous metrics. Though the accessibility of the region continued to progress until 2010 (Figure 3.9), presenting a more regular coverage by the road network in 2010. This is reflected in the less pronounced areas of highest road densities compared to the other time periods.

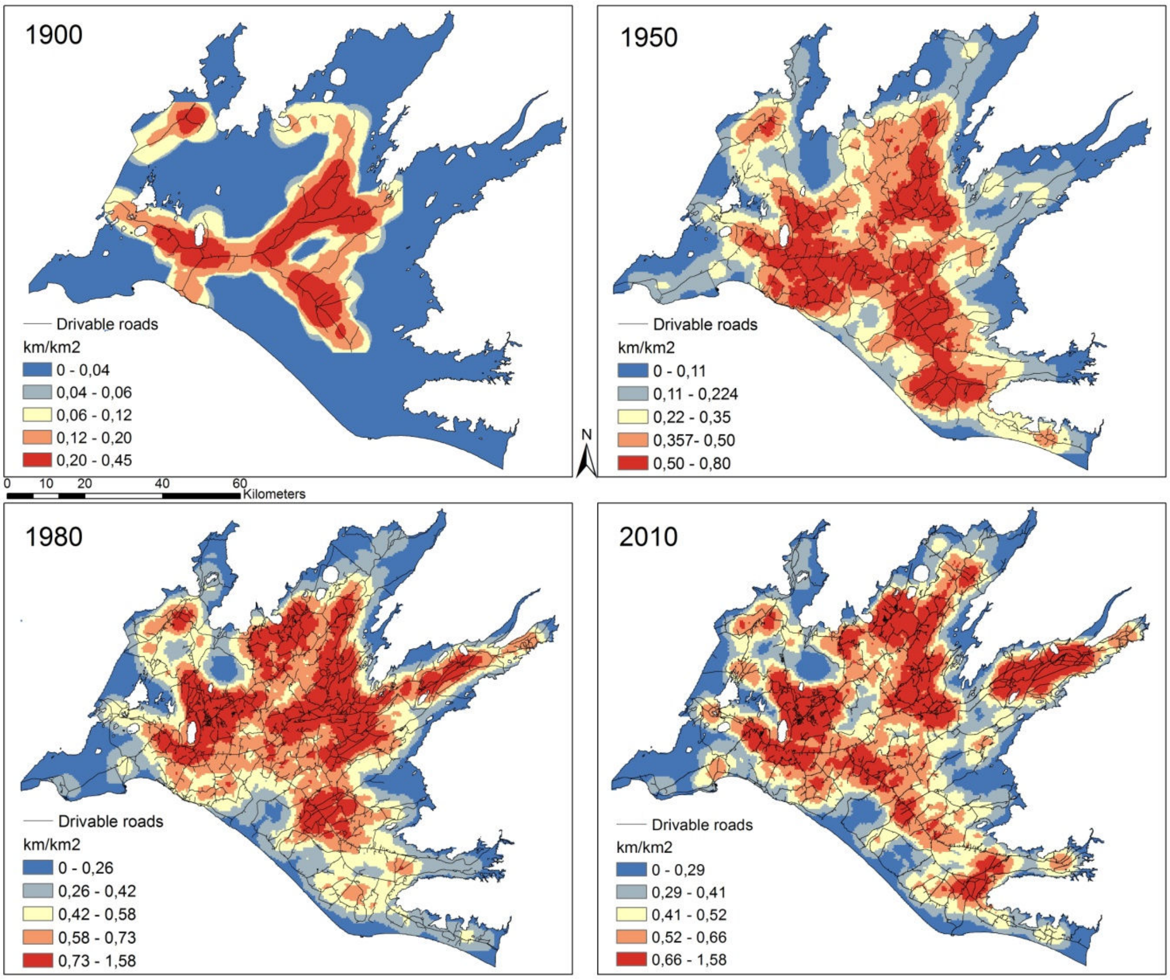


Figure 3.9 Road network density in the southern lowlands in 1900-2010. Note that the colors represent different absolute densities in different time periods.

3.1.4 Urbanization

Villages and towns

Like in the rest of the country, the region's urbanization was initiated by the growing population and the arrival of motorized fishing boats at the end of the 19th century (Jökulsson, 2000). This has led to the formation of little fishing villages that were scattered along the southern coast (Júlíusson et al., 2005; Valsson, 2003). In 1900, the only place with service infrastructure was *Eyrarbakki* at the south coast, which was an important trading center for centuries (Júlíusson et al., 2005). Another place with a higher population was the neighboring fishing town *Stokkseyri*. Together they occupied an area of about 45 ha at the time, mainly consisting of two-story homes made of wood (Ágústsson, 1998).

Selfoss, the biggest town and economic center today, had only been a farmstead at the time (Plate 3.2).

Rather unique is the village of *Þykkvibær* that was considered the oldest and only village in the country for 900-1000 years (Guðjónsson, Guðmundsson et al., 1983; Hansen, 1999; Óla, 1962). The place is located between the *Þjórsá* and *Hólsá* river estuaries that would regularly flood and change their course. It seems evident that the inhabitants, primarily engaging in fishing and later in animal husbandry, had to share the isolated, drier areas available. This may have resulted in the unusual dense settlement not present elsewhere (Óla, 1962).

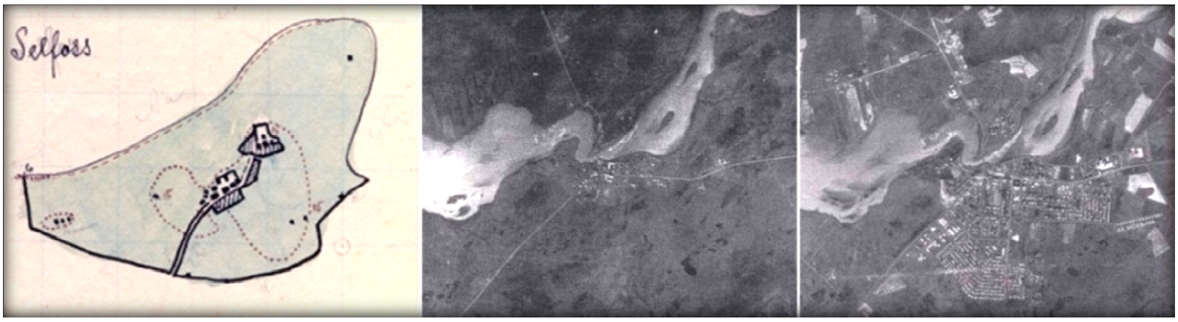


Plate 3.2 Selfoss in the southern lowlands in 1900, 1945 & 1984. Pictures published by NLSI, reproduced with permission of the agency.

While the importance of *Eyrarbakki* as the main trading center diminished with the closure of supply ship traffic in the 1940's (Kristinsson, 1991), *Selfoss* continued to grow and developed into the region's economic center. This development was especially favored by its location at the arterial road from *Reykjavík* eastwards, the foundation of the cooperative society (*Kaupfélag*), and the largest dairy in the country in 1930 (Kristinsson, 1991; Þorsteinsson, 1959). Simultaneously, more urban areas formed such as *Hveragerði*, based on its geothermal resources and greenhouse horticulture, and *Hella* and *Hvolsvöllur* to ensure supplies in the region's east (Valsson, 2003). The custom of establishing schools in places with access to geothermal heat (Valsson, 2003), i.e. *Laugarvatn*, *Reykholt* and *Flúðir,* encouraged the development further. Towns had occupied about 2.3 km² of land in 1950, and utilized 7.4 km² in 1980. Of the fishing villages established by the end of the 19th century, *Þorlákshöfn* was the only one to prevail. The harbor built in 1960 (Valsson, 2003) supported its growth into a town with fish processing industry. In 2010, towns with more than 50 residents covered about 12.3 km², which was a 27x increase since 1900.

Population trends

In 1900, 8.4% of the region's population (9,808 people) lived in the two towns existing *Eyrarbakki* and *Stokkseyri* (Table 3.3) (SI, 2011h, 2011i). By 1950, the total population had decreased to 8,121 people, whereas the percentage of people living in towns had increased to 43%.

Table 3.3 Population trends in towns in the southern lowlands in 1900-2010. Source: SI

	1900	1950	1980	2010
Árbæjarhverfi	..	..	..	57
Eyrarbakki	739	513	559	569
Flúðir	..	..	101	394
Hella	..	110	523	781
Hveragerði	..	514	1,254	2,316
Hvolsvöllur	..	91	532	860
Laugarás	..	..	100	119
Laugarvatn	..	..	144	169
Selfoss	..	967	3,409	6,512
Stokkseyri	83	427	484	445
Þorlákshöfn	..	131*	1,010	1,533
Borg í Grímsnesi	..	..	..	65
Sólheimar í Grímsnesi	..	..	..	85
Total	822	2,622	8,116	14,100

**in 1958 (Guðnadóttir, 2003)*

The turning point was in 1972, when more people lived in urbanized areas (Figure 3.10). While the rural population size stayed rather constant, the percentage of people living in towns rose to 73% in 2010 (SI, 2011e, 2011f, 2011h, 2011i).

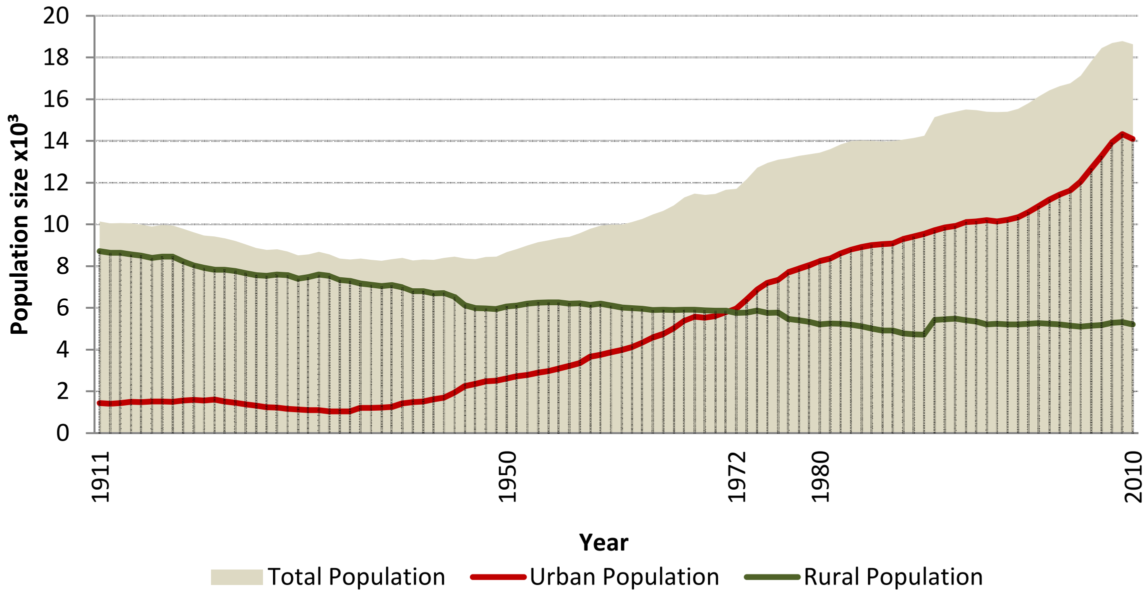


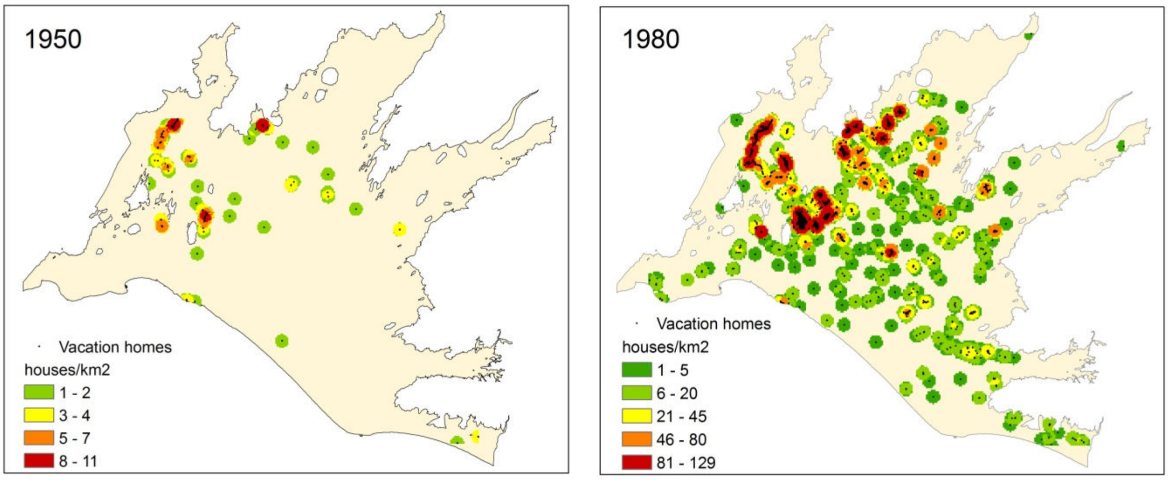
Figure 3.10 Rural versus urban population development in the southern lowlands in 1911-2010. No annual data was available on rural population sizes prior to 1911. Source: SI

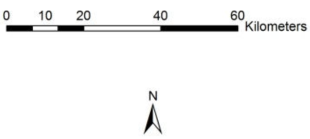
3.1.5 Recreation: Vacation homes

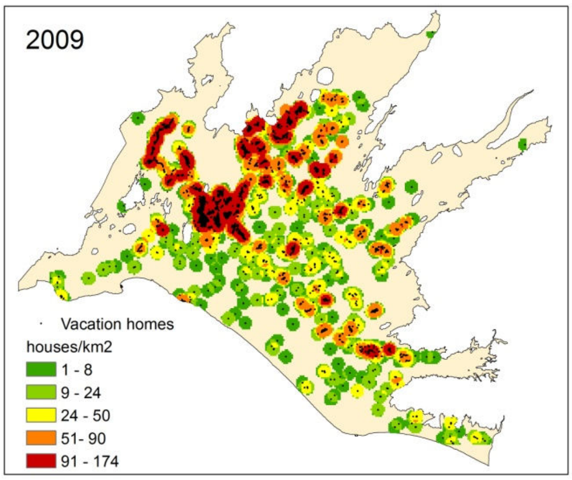
Vacation or second-home ownership became increasingly common in Iceland since the 1970's (Nouza, 2009), and vacation home areas, designated especially for vacation home development, turned into a new land use pattern. In 1900, 2 buildings were classified as second homes in the study area. In 2009, they totaled 5,148 buildings (Figure 3.11), with a calculated land take of 1.4 km², including roads. According to the preliminary results of a long-term study investigating second home ownership in the country, 71% of second-home owners are living in Reykjavik. The majority of owners asked in a survey about location preferences, listed the natural environment and the distance as main criteria (Nouza, 2010).

Vacation home density

Similar to the distribution of residences, the locations of vacation homes were rather sprawled (Figure 3.11). The core areas, highest density of houses per km², were in *Bláskógabyggð* and *Grímsnesi,* which remained mostly unchanged over the study period. The vacation home densities of these core areas, however, changed considerably averaging 9 houses per km² in 1950 but 132 houses per km² in 2009 (Figure 3.11). This is a 15x increase between years.







Statistics	1950	1980	2009	1950-1980	1980-2009	1950-2009
				Change %		Total %
Vacation homes (N)	96	2,590	5,148	2,598	98,7	5,262
Average size (m^2)	62.5	50	56	-20	12	-10
Land take (ha)	0.6	13	29	2,066	123	4,733

Figure 3.11 Vacation home distribution and density in the southern lowlands in 1950-2009, including the statistical summary of the development. Note that the colors represent different absolute densities for different time periods.

The municipal plans of nearly all municipalities concerned include further vacation home development. The calculation of already designated and planned vacation home area totaled nearly 20,462 ha (Table 3.4) and 40,924 vacation homes based on the minimum plot size of 0.5 ha. The municipalities *Hveragerði* and *Árborg* were excluded from the analysis. *Hveragerði* is a town district and the municipal plan for *Árborg* does not provide detailed information about the size of vacation home area (Bjarnadóttir & Ragnarsson, 2003).

Table 3.4 Vacation home area allocations in the southern lowlands, according to the municipal plans. The total area provides for 40,924 buildings considering a min. plot size of 0.5 ha. (Excluding Hveragerði as town district and Árborg due to lack of information).

Municipality	Vacation home area (ha)	Min. Plot Size ha	Validity	Reference
Ásahreppur	131	0.5	2022	(Gíslason, Jónsson et al., 2009)
Bláskógabyggð	734	0.75	2016	(Sigurðsson, Hermannsson et al., 2005)
Flóahreppur	431	0.5-2	2018	(Gíslason, Sveinsdóttir et al., 2008)
Grímsnes-Grafningshreppur	13,200	0.5	2020	(GOGG, 2009)
Hrunamannahreppur	488	0.5-2	2015	(Guðjónsson & Félagar, 2005a)
Ölfus*	199	0.5	2022	(Gíslason, Jónsson et al., 2011)
Rangárþing eystra	526	0.5-1	2015	(Guðjónsson & Félagar, 2005b)
Rangárþing ytra	3,335	0.5	2022	(Gíslason, Jónsson et al., 2010)
Skeiða-Gnúpverjahreppur	1,418	1	2016	(Landslag, 2006)
Total	20,462	..	..	..

**not yet approved*

3.1.6 Energy: Hydropower and geothermal development

Hydropower development

Hydropower generation in the region started at the river *Sog* in 1937 (FIEI, 2004; Valsson, 2003). A dam and hydropower plant was built in order to supply Reykjavík and the region's main urban areas with electricity (Figure 3.12). In the 1940's, a few windmills had been installed (Kristinsson, 1991), but the utilization of wind-power was never implemented seriously. Instead two more hydropower plants including dams were built at *Sog* in 1953 and 1959, to help powering the expanding *Reykjavík* and to supply the artificial fertilizer- and cement factories that were established on the west coast.

This marked the commencement of hydropower use for heavy industries (Júlíusson et al., 2005) and the beginning of a new land use pattern. In 1965, the national power company *Landsvirkjun* was founded explicitly for hydropower generation and to attract foreign investors with affordable energy prices. This resulted in the establishment of the power plant *Búrfell* at the *Þjórsá* river, in the region's northeast in 1972 (Figure 3.12). By 2010, 12 hydropower plants had been built, and *Sog* and *Þjórsá* are the main rivers harnessed.

Geothermal development

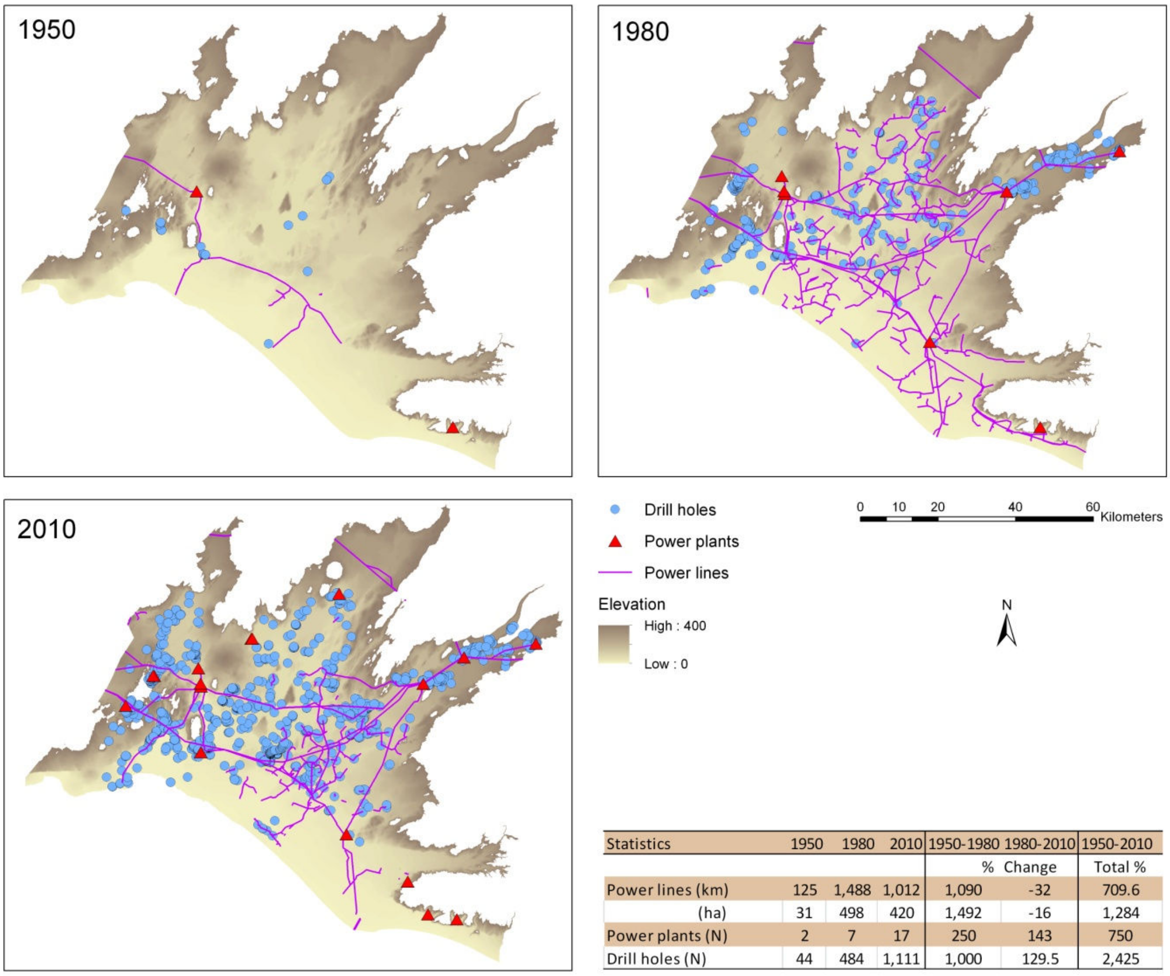
The first drilling for geothermal water in the area was at *Nesjavellir*, located in *Hengill*, which is the region's core geothermal area. The drillings were initiated by the land owner in 1946 and resulted in 5 exploitable holes by 1949. The hot water was used to heat the owner's home and to power a greenhouse at the site (RE, 2003). In 1964, the land was bought by the Reykjavík District Heating and research drillings performed in 1965-1972, which resulted in 17 holes suitable for exploitation. In 1990, the first geothermal power plant, *Nesjavellir*, was built at the site, where electricity was generated from the steam and used to heat up water to be transported in pipelines to the capital area (RE, 2003).

The construction of the 2nd geothermal power plant at *Hengill*, on *Hellisheiði*, was finished in 2010. The electricity generated will power another energy demanding industry located on the west coast and outside the region's boundaries. Boreholes[1] drilled for research and exploitation increasingly dotted the landscape (Figure 3.12), of which the ones in geothermal areas are especially visible due to steam release. Many of these holes have not been locked (Bragason, NEA, personal communication, September, 27th 2010), releasing steam and fumes continuously.

Power Lines

The first rural place in the country, to receive electricity from the public grid was the farm *Litla-Sandvík* in 1947, favored by its convenient location between the towns *Selfoss* and *Eyrarbakki* (FIEI, 2004). By 1980, the electricity supply of the local population was secured (Kjartansson, 2002) and the first high voltage power lines installed (Figure 3.12). These power lines spanned from *Búrfell* at the *Þjórsá river* across the region to supply the first aluminum factory established on the west coast. In the 1990's, great frost damage of low voltage power lines initiated their progressive replacement by underground cables (ISE, 2011). This resulted in a decrease of overall length of power lines and the area influenced between 1980 and 2010 (Figure 3.12). The number of high voltage power poles installed summed up to 1,845.

[1]Boreholes available until 2005/2006 obtained manually at (NEA, 2005/2006); the online database included only about 50% of drill holes that existed nationwide and consequently only ½ of the boreholes that actually existed in the study area at the time (Bragason, NEA, personal communication, September, 27th 2010).



Statistics	1950	1980	2010	1950-1980	1980-2010	1950-2010
				% Change		Total %
Power lines (km)	125	1,488	1,012	1,090	-32	709.6
(ha)	31	498	420	1,492	-16	1,284
Power plants (N)	2	7	17	250	143	750
Drill holes (N)	44	484	1,111	1,000	129.5	2,425

Figure 3.12 Power generation and electricity supply in the southern lowlands in 1950-2010, including the statistical summary of the development.

3.2 Land use impacts on natural and semi-natural habitats

3.2.1 Wetlands, drainage and conversion

In 1900, wetlands were the most common land cover type in the region, covering 1,152 km² or 18% of the study area (Figure 3.13). Because of the flat landscape, level-fens were a common wetland type. They stretched along the coastal region such as in *Flói,* south of *Selfoss,* and in *Landeyjar* further east but occurred also inland in *Skeið* (Steindórsson, 1975). The *Safamýri*, north of *Þykkvibær* (Plate 3.3), was a typical alluvial fen influenced by adjacent rivers and dominated by Lyngbye's sedge (*Carex lyngbyei*) (Jónsson, 1975), which is characteristic for alluvial fens in Iceland (Steindórsson, 1975). Both wetland types have no or very little hummock formation (Steindórsson, 1975) and were traditionally used for haymaking and livestock grazing (Jónsson, 1975; Þorsteinsson & Ólafsson, 1975).

Plate 3.3 Former and current wetland types Flói, Safamýri and Háfsós in the southern lowlands in 2010.

In 1950, the consequences of wetland drainage and cultivation practices had already been noticeable (Figure 3.13). For 1980, the wetland data obtainable from maps was complemented by the intersected wetland area of 1950 and CLC*2000* (see also chapter 2.3), based on the assumption that wetlands existing in 1950 and in 2000 must have also existed in 1980. This resulted in 68,299 ha of wetland area for the 1980 period, showing a 39.4% decrease since 1950.

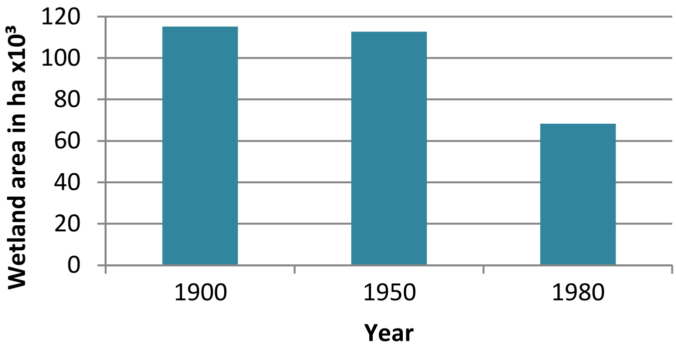


Figure 3.13 Wetland area in the southern lowlands in 1900-1980.

Wetland drainage

Wetland drainage is a long-term process and its effect may not be noticeable until years after the ditches had been excavated (Grootjans, Hunneman et al., 2005). To account for the long-term effect, the ditch networks in 1950, 1970 and 2010 were projected onto the wetlands existing in the previous time period. For instance, the ditch network present in 1970 was overlaid the wetland area of 1950. Three distance buffers were applied, 50 m, 100 m and 200 m based on the degree of draining effects (Gísladóttir, Metúsalemsson et al., 2007). They were measured from the edge of the ditch on either side, adding up to impact ranges of 100 m, 200 m and 400 m respectively. Only ditches and impact ranges within the wetland areas were used for the calculation, those located outside the areas classified as wetlands were excluded (clipped). This method was used to study the cumulative impact of ditching between time periods, obtain the estimated wetland area that was drained and the wetland area that remained. The expansion of the drainage system clearly correlates with the reduction or entire loss of wetlands in certain areas, for instance at *Ingólfsfjall* mountain (Figure 3.14).

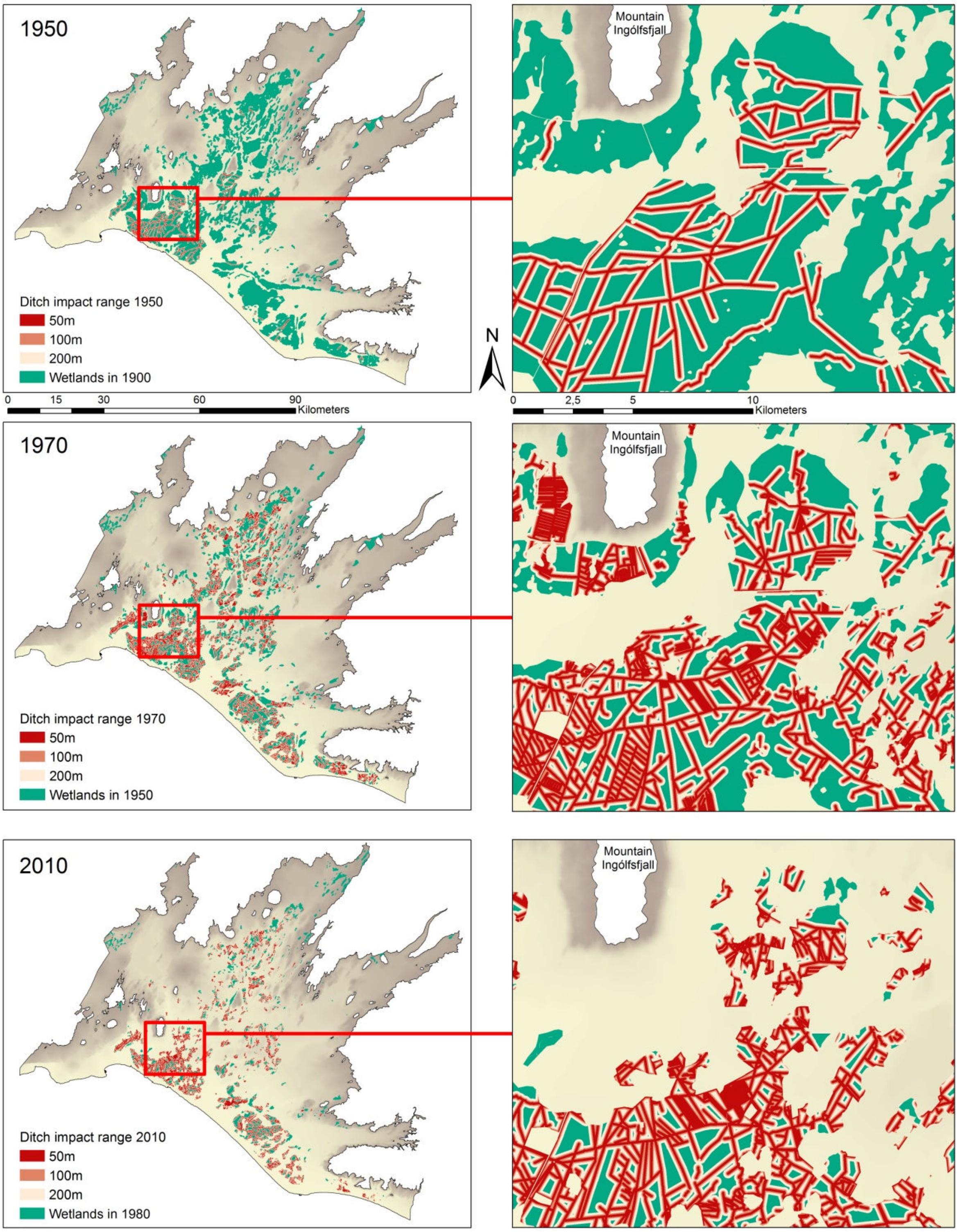
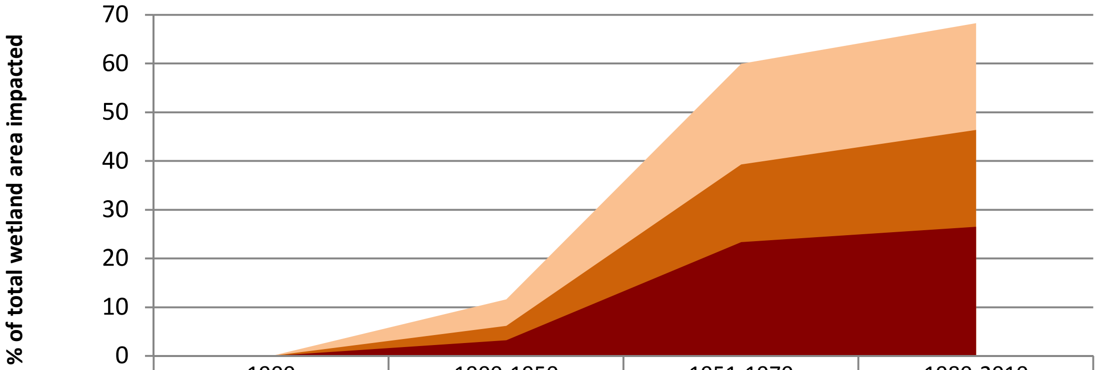


Figure 3.14 Wetland area reduction and drainage ditch impact correlation in the southern lowlands in 1950-2010. Only ditches located within wetland area of previous time periods were calculated and those outside eliminated to retrieve the actual impact range.

The impact range was then calculated with the total wetland area, to retrieve the percentage of wetlands that were cumulatively affected by the drainage networks in the periods 1900-1950, 1951-1970 and 1980-2010.

By 1970, draining had affected 60% or 67,541 ha of the wetlands that existed in 1950, considering the effect range of < 200 m (Figure 3.15). In 2010, 68.3% (46,651 ha) of the wetland area estimated for 1980 was cumulatively affected by ditching. Between 1970 and 2010, the total ditch length had nearly doubled, which implies a higher impact increase than demonstrated. This suggests that much of the ditches excavated between 1970 and 2010 may not have enhanced the draining effects but merely tightened the network. Supporting this, calculations based on the estimate that 7.3 km of ditches are needed to drain 1 km² of wetlands showed (Óskarsson, 1998), that the ditch length in 1970 (4,628 km) had the potential to drain 63,400 ha and the ditch length in 2010 (9,050 km) could drain 123,973 ha of wetland area. This is more wetland area than existed in the study area in 1900.



	1900	1900-1950	1951-1970	1980-2010
200m	0	11.6	60	68.3
100m	0	6.2	39.3	46.4
50m	0	3.2	23.4	26.5

Year

Figure 3.15 Estimated percent of total wetland area cumulatively impacted by ditching in the southern lowlands in 1900-2010. The table shows the % of total area affected for the different impact ranges respectively.

On average, drainage is most effective within 100 m distance from the ditches (Gísladóttir et al., 2007) (Óskarsson, AUI, personal communication, November 16th, 2010). Accordingly, 77,967 ha of wetland area present in 1900 have possibly been drained between 1900 and 2010, given the impact zone of < 100 m. This is a reduction of wetland area by 68% since 1900 (Figure 3.16). About 21,648 ha were located outside the draining effect range (distance > 200 m) and can be considered unaffected by ditching in 2010, which is 18.8% of the wetlands that existed in 1900.

The current wetland area estimate (*Nytjaland*) for the region is about 77,000 ha, showing a decrease of only 33% since 1900. While the wetland area calculated for 1980 may only be conditionally reliable, it nevertheless produced comparable results to a study performed on wetland drainage in this region in 1989-1991 (Þórhallsdóttir, Þórsson et al., 1998). According to that study that involved field research, 15% or 170 km² of wetland area existing in 1900 (estimated as 1,100 km²) were left in the 1990's. This suggests that the wetland area currently maintained may be overestimated and indicates the need for field research.

Nytjaland wetland data was nevertheless used for the subsequent analysis of road, building and cumulative impacts (chapters 3.2.5-3.2.7) for the 2010-period, as it is the official data currently available.

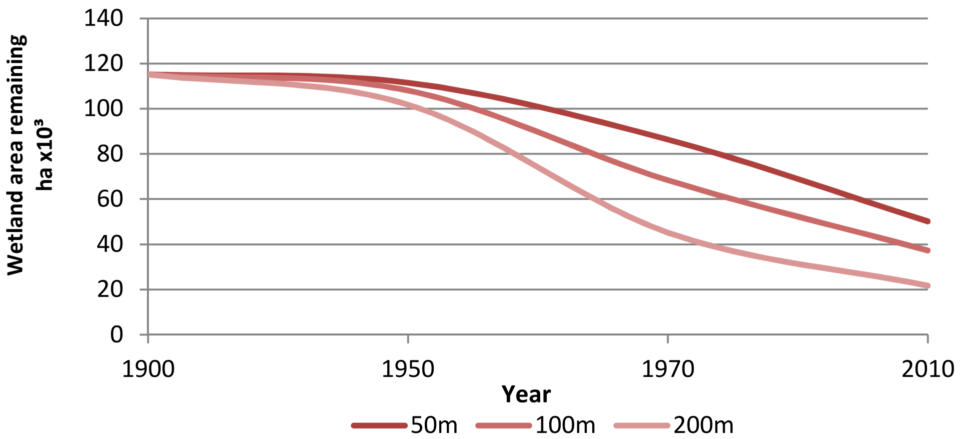


Figure 3.16 Estimated wetland area (ha) remaining in the southern lowlands in 1900-2010, calculated by subtracting the drainage zones of ditches from total wetland area. The different lines illustrate the different widths of effective drainage zones.

Wetland conversions 1900-2010

At least 208 km² of wetland area present in 1900 has been converted into another land use or land cover category in 2010, which is 26.6% of the area that was estimated to have been drained given the impact range of 100 m on either side of the ditches (Figure 3.16). The largest portion was converted into hayfields (based on *Nytjaland* data) amounting 183 km² or 23.5% of the drained wetland area. The conversion into other land use categories totaled 24.4 km², of which 17.7 km² turned into woodlands (Figure 3.17). The results don't include all wetland area converted. The incomplete building dataset for 2010 coupled with difficulties to determine the basal area of buildings in rural area prevented the estimation of wetland area that was changed into settlements. Only vacation homes could be included in the analysis (Figure 3.17).

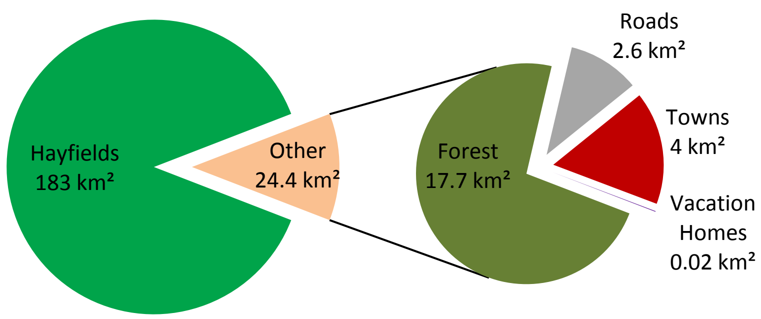


Figure 3.17 Minimum estimated wetland conversion per land use category in the southern lowlands in 1900-2010. Data incompleteness of the total number of buildings in rural area in 2010 prevented from calculating wetland area converted into settlements.

3.2.2 Woodlands and forests

By 1900, woodlands accounted for 105 km² or 1.65% of the study area (Figure 3.18) and were generally located in places of naturally drier conditions such as slopes or lava fields. The first afforestation trials had occurred in a fenced in plot at *Þingvellir* in 1899. A few imported species were used, i.e. white spruce (*Picea glauca*), mountain pine (*Pinus mugo*), balsam fir (*Abies balsamea*), gray alder (*Alnus incana*), common osier (*Salix viminalis*) and balsam poplar (*Populus balsamifera*), although with varying success (Bragason, 1995). The other woodlands existing at the time probably were representatives of the Icelandic native woodland, consisting mainly of downy birch (*Betula pubescens*), tea-leaved willow (*Salix phylicifolia*), wooly willow (*Salix lanata*) and possibly the hybrid *Betula nana x pubescens* (Blöndal, 1991; Kristinsson, 1995).

Until the late 1940's, most emphasis was put on the use of native species in afforestation measures and much of the seeds or seedlings used were derived from the 4 small tree nurseries existing in the country at the time (Gunnarsson et al., 2005; Pétursson, 1999). This may have been the reason for the only slight increase of woodlands by 1950 (Figure 3.18). For 1980, the criteria chosen for complimenting the woodland data obtainable from maps were time (*"plantings from the beginning until 1999")* and tree height (2-10 m) in the attribute table of the dataset (Traustason, 2009). By 2010, the woodland area (about 27,415 ha) (Traustason, 2009) accounted for 4.3% of the study area, which was an increase of 160% between 1950 and 2010.

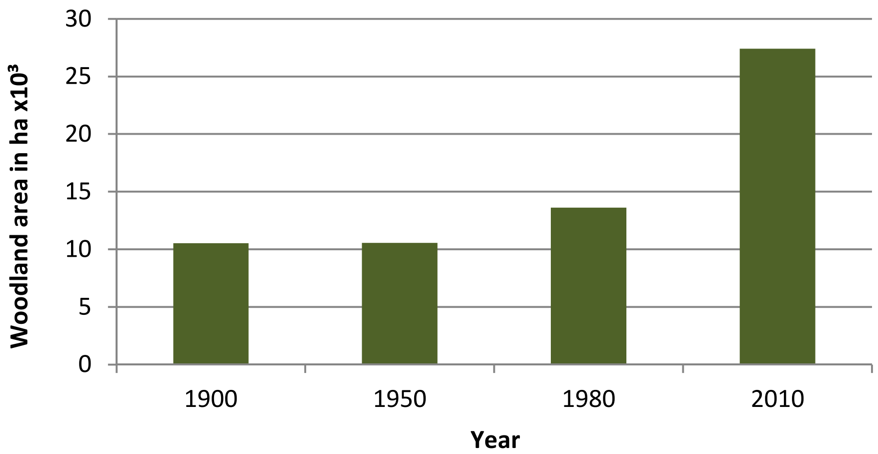


Figure 3.18 Woodland area in the southern lowlands in 1900-1950.

Since the establishment of the South Iceland regional afforestation program in 1998, about 10 million tree seedlings were planted primarily on privately owned land (Sls, 2001-2010). About 77% seedlings thereof were planted in the relevant municipalities (Table 3.5). Another afforestation initiative in the area was tree plantings as ecological restoration measures such as the *Heklaskógar* project, which aims to afforest about 90,000 ha of land (Aradóttir et al., 2005). Mitigation measures for environmental impact of industrial activities resulted in 28,000 tree plantings at the power station *Sog* and several thousand plants at *Kaldárhöfði* by LV in 1998-2003, together covering an area of 90 ha. Only 50% of the trees planted by LV were native species (Gunnarsdóttir, 2009). The ecological value of afforested areas depends in part on the tree species chosen and their density (Elmarsdóttir et al., 2008).

Dense stands of coniferous species don't allow much light to penetrate, which results in sparse understory growth, low species richness and lower decomposition rates (Arneberg, Nygaard et al., 2005; Elmarsdóttir & Magnússon, 2005).

Table 3.5 Forest and wind shelter plantations supported by the South Iceland Regional Afforestation Program in the southern lowlands in 1998-2010, according to the annual reports of 2001-2010. Source: Sls

Municipality	Forest ha	Tree seedlings planted	Wind Shelter Belts km	Tree seedlings planted
Bláskógabyggð	1,498	1,228,359	49.1	58,969
Flóahreppur	203	261,900	37.3	44,815
Grímsnes-Grafningshreppur	541	573,644	17	20,449
Hrunamannahreppur	404	579,806	7	8,405
Skeiða-Gnúpverjahreppur	855	846,223	87.3	104,772
Ölfus	503	442,800	29.7	35,670
Rangárþing eystra	1,230	1,375,802	213.8	256,595
Rangárþing ytra	2,004	2,421,197	380.9	457,110
Total	7,238	7,729,731	822.3	986,785

3.2.3 Case study: Hydropower development in the Þjórsárdalur valley

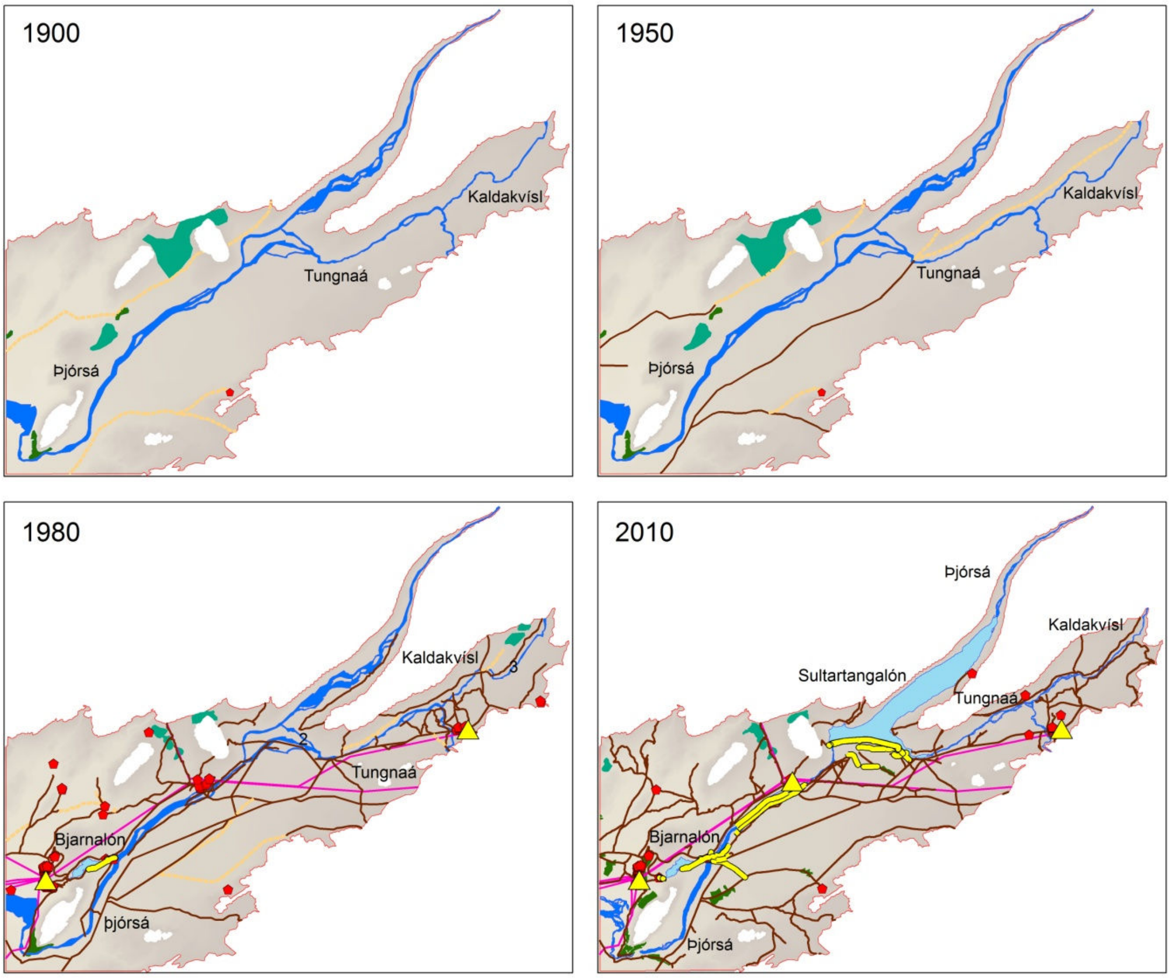
The area isolated for investigating the hydropower development in the Þjórsárdalur valley is 450 km² in size and included the valley and adjacent land area up to an elevation of 400 m a.s.l. at the northeastern margins of the study area. In 1900, the area was dominated by rivers (23 km²) and had little infrastructure, except horse tracks and a hut providing shelter for travelers (Figure 3.19). In 1950, the infrastructure was much the same with some road improvements as a consequence of the valley's high popularity as tourist destination (Kristinsson, 1991).

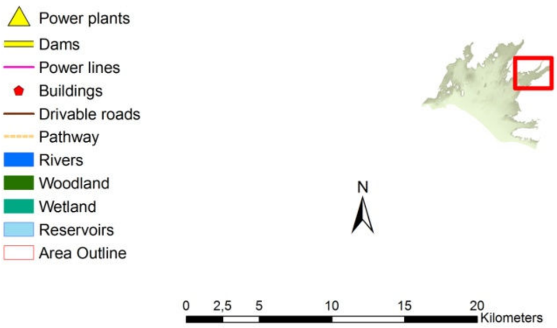
Ideas for harnessing the *Þjórsá river* were put forward by a Norwegian Engineer in 1915-1917 (LV, 2011a), but the construction of the dam and *Búrfell* power station didn't start until 1969, after the river had been rerouted and parts of it channeled (LV, 2011a). The associated intake reservoir, *Bjarnalón*, was filled in 1971, flooding an area of 123.8 ha (Plate 3.4). The construction of *Búrfell* was followed by the establishment of the *Hrauneyjafoss* power station in 1977-1981 (LV, 2011b). By the 1980's, the valley had been altered considerably by structures associated with the hydropower projects, including housing, power lines and a road network that extended by 231 km since 1950 (Figure 3.19). The land take by artificial area had caused a reduction of woodlands and wetlands in the area, that combined had decreased by 62.2%, from 1,139 ha in 1950 to 430 ha in 1980.

Plate 3.4 The reservoir Bjarnalón and the Búrfell power lines No. 1&3 in the southern lowlands. Line No. 3 stretches 118.5 km from the Búrfell power plant to an aluminum smelter on the West coast.

In 1997, the construction of the third power plant, *Sultartangi*, started, which was intended for supplying a second aluminum smelter on the west coast with electricity. The plant began operation in 2000, although the dam for the reservoir, 10.2 km in length, had been built 15 years earlier (LV, 2011c). A shallow valley at the junction of the two big rivers *Þjórsá* and *Tungnaá*, a tributary river, was impounded to create the reservoir *Sultartangalón* that covers about 20 km^2. About 6.6 km^2 of river area was taken by the reservoir. The damming of the rivers and subsequent alteration of hydrologic regimes, e.g. reduced water flow and sediment loads (Graf, 2006; Richter & Thomas, 2007) may have been the reason for further reduction of the river area, that measured 10.2 km^2 by 2010.

As a consequence of the hydropower development, the land area became increasingly fragmented and the land taken by roads, power lines, buildings (presuming an average basal area of 150 m^2), and reservoirs totaled 6.2% of the area in 2010 (Figure 3.19). Afforestation, partly as mitigation measures (Gunnarsdóttir, 2009) resulted in a 4x increase of woodlands that covered 1.1% of the area in 2010. In contrast, wetland area had decreased to 23.4% of the wetlands present prior to the development (1,011 ha) mainly caused by the expansion of the road infrastructure and power lines.





Statistics	1900	1950	1980	2010	1950-1980	1980-2010
					% Change	
Buildings (N)	1	1	87	57	8,600	-34
Power plants (N)	0	0	2	3	..	50
Dams (km)	0	0	2.2	32	..	1,332
Power lines (km)	0	0	68	90	..	32.3
(ha)	0	0	432	532	..	23
Drivable roads (km)	0	45	276	345	513.3	25
(ha)	0	18.7	68.4	156.4	265.7	129
Reservoir (ha)	0	0	124	2,102	..	1,595
Woodland (ha)	128	128	103	514	-19	399
Wetland (ha)	1,011	1,011	327	236.5	-68	-28

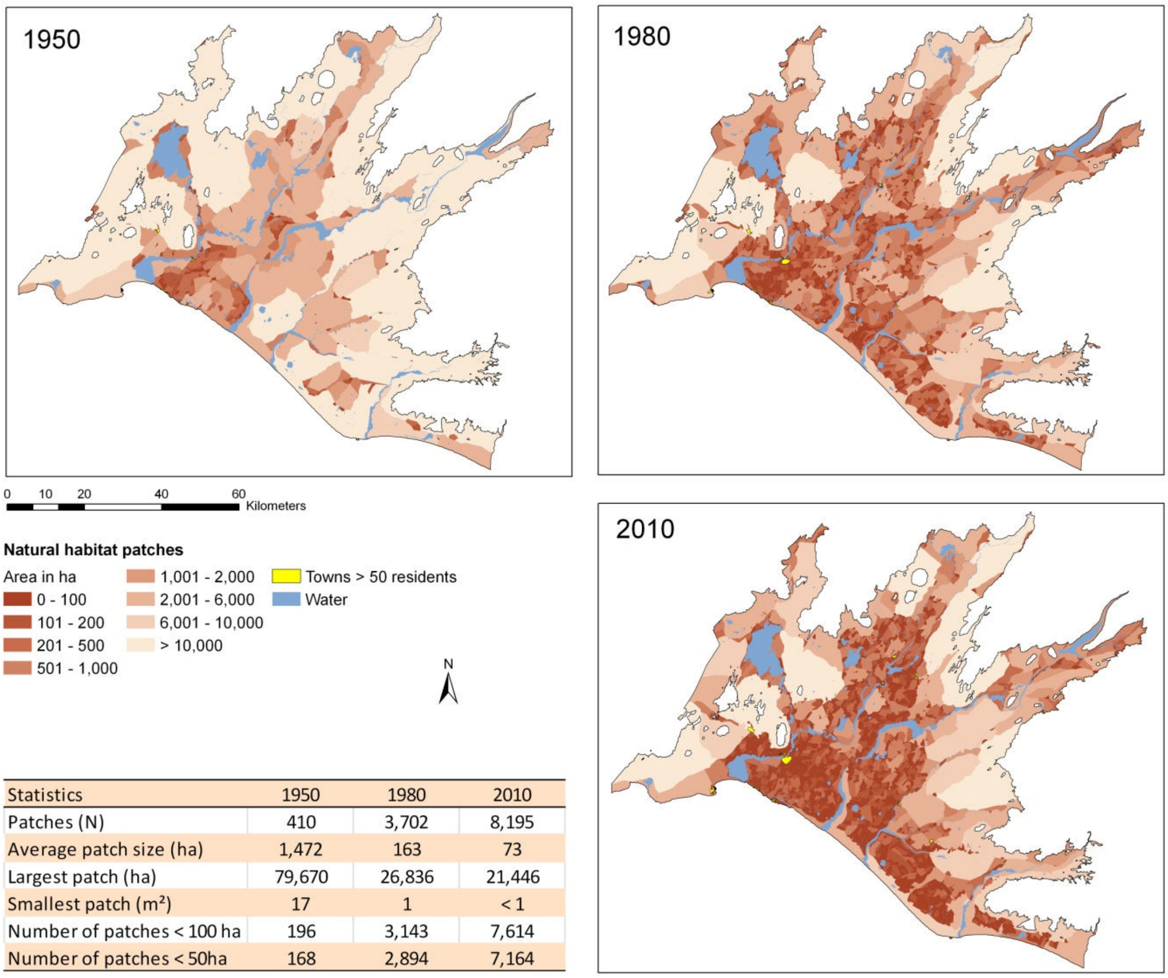
Figure 3.19 Case study: Hydropower development in the Þjórsárdalur valley in the southern lowlands in 1900-2010, including the statistical summary of the development.

3.2.4 Landscape fragmentation

The degree of landscape fragmentation was analyzed by extracting waterbodies as natural fragmentation elements, the road system, urban areas > 50 inhabitants and the ditch network from the land area. This enabled the acquisition of numbers and sizes of natural habitat patches between fragmenting elements. The ditch network was included in the analysis as it is a significant fragmenting element in the southern lowlands and creates barriers for plants and soil organisms. The size and degree of isolation of the remaining natural habitat fragment are generally the most important factors (Fahrig, 2003).

Between 1950 and 2010, the average size of natural habitat patches had decreased 20x (Figure 3.20), whereas the total number of patches increased 20x, being split apart by roads, ditches and towns with > 50 people in 2010. The size of the largest natural habitat area had shrunken by 582 km² down to 214 km² between 1950 and 2010. The response of natural habitats to fragmentation depends on the geographical position, ecosystem type and species (Ewers, Thorpe et al., 2007). The species that are unable to cross such barriers are confined to a number of small, isolated patches and exposed to a variety of disturbances, which reduces the probability for persistence (EEA & FOEN, 2011; Fahrig, 2003; Gu, Heikkilä et al., 2002).

The approach used seemed appropriate for investigations on a landscape level and to demonstrate the development. For larger scales to enable national or international comparison, the use of a matrix with predefined mesh size is considered more suitable, where the patches are quantified and the scale of isolation and connectivity of areas determined (EEA & FOEN, 2011; Girvetz, Thorne et al., 2008).



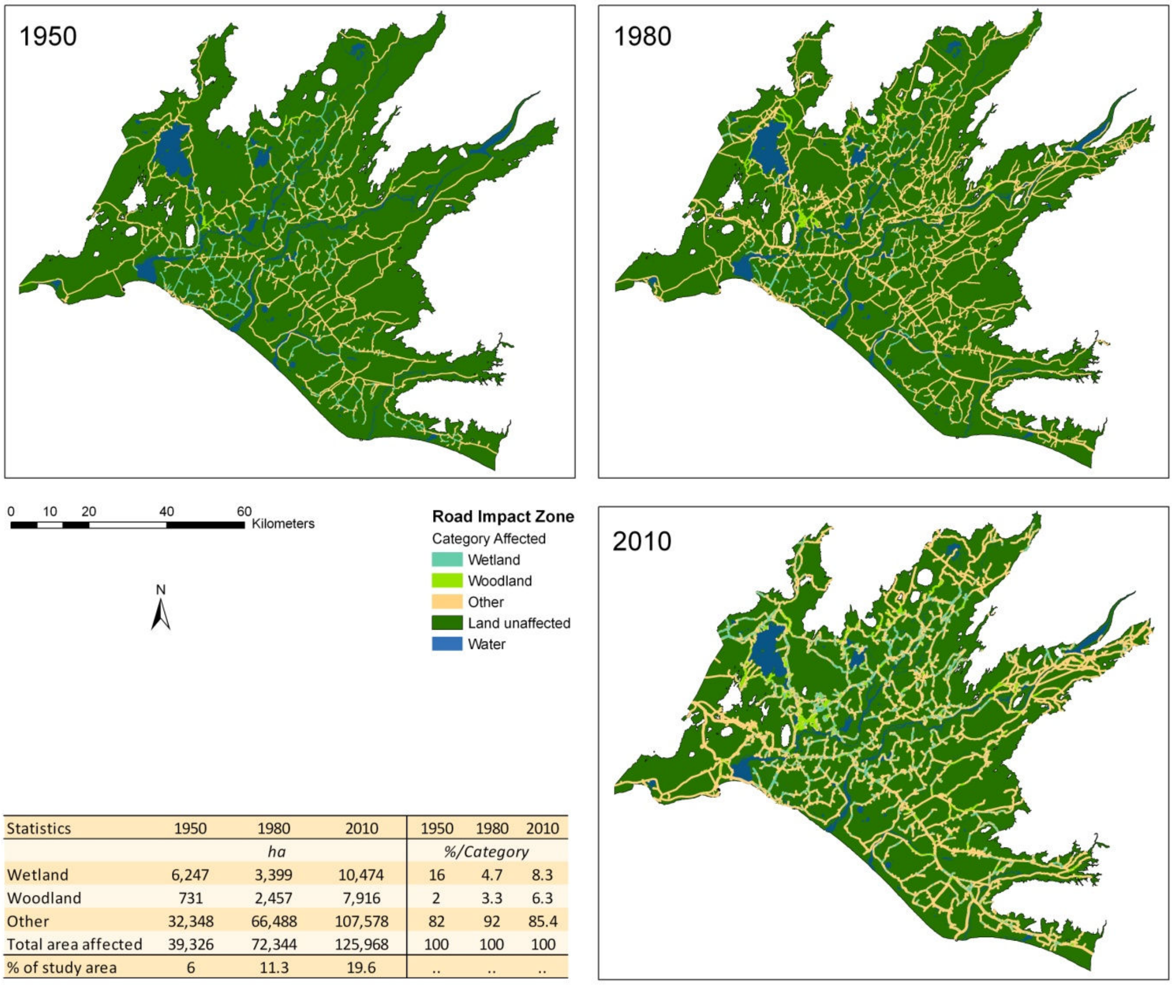
Statistics	1950	1980	2010
Patches (N)	410	3,702	8,195
Average patch size (ha)	1,472	163	73
Largest patch (ha)	79,670	26,836	21,446
Smallest patch (m²)	17	1	< 1
Number of patches < 100 ha	196	3,143	7,614
Number of patches < 50ha	168	2,894	7,164

Figure 3.20 Landscape fragmentation by roads, towns and drainage ditches as significant fragmenting elements in the southern lowlands in 1950-2010, including the statistical summary of the development. The area was progressively split into ever smaller natural habitat patches, being exposed to a variety of disturbances.

3.2.5 Impacts of Roads

The impacts of roads and car traffic on the natural environment, also called edge effects, are well-established and reach far beyond the actual land take. Such edge effects include alteration of the hydrology and microclimate, air pollution, eutrophication, noise disturbance and increased wildlife mortality (Benítez-López et al., 2010; Forman & Alexander, 1998; Hansen & Clevenger, 2005; Seiler, 2001). To include the majority of effects, distance buffers were applied measured from the edge of either side of the road (Figure 3.21). Noise disturbance from car traffic was included based on the findings that breeding of grassland birds was significantly affected by 5,000 cars per day within a distance of 100 m from roads, but affected more sensitive bird species up to several hundred meters from the road (Forman, 2000; Reijnen, Foppen et al., 1996). For 1950, a distance buffer of 100 m on either side was applied for all road types, while roads existing in 1980 and 2010 were divided into primary and secondary roads, based on the road classification system by the IRA (IRA, 2011c). In 1980, the impact was estimated with 200 m for primary roads and 100 m for secondary roads on either side, but was increased by 100 m for the categories respectively in 2010. This was based on higher traffic volumes, e.g. daily average of 19,818 cars on the road between *Selfoss* and *Eyrarbakki* in summer 2009 (IRA, 2011a, 2011b).

In 2010, about 19.6%, or 125, 968 ha of the southern lowland region was affected by roads, which was an increase of 74% since 1980 and 220% since 1950 (Figure 3.21).



Statistics	1950	1980	2010	1950	1980	2010
		ha			*%/Category*	
Wetland	6,247	3,399	10,474	16	4.7	8.3
Woodland	731	2,457	7,916	2	3.3	6.3
Other	32,348	66,488	107,578	82	92	85.4
Total area affected	39,326	72,344	125,968	100	100	100
% of study area	6	11.3	19.6	..	..	..

Figure 3.21 Road impact range and land cover affected in the southern lowlands in 1950-2010, including the statistical summary of the development. The impact range captures the main effects of roads and car traffic.

Apart from hayfields, native birch woodlands were impacted most by the road system in 2010, potentially affecting 32% of birch woodlands present in the study area (Table 3.6).

Table 3.6 Land cover categories (Nytjaland) potentially impacted by the road system in the southern lowlands in 2010

Categories	ha	% of total area
Wetlands	10,474	13.5
Native birch woodlands	5,039	32
Heathland	35,190	17.6
Grassland	10,773	22
Moss Land	8,930	14
Hayfields	24,187	46
Waterbodies	1,685	6
Sparsely vegetated land	11,689	17.3
Vegetation Cover 20-50%	15,123	18.3

3.2.6 Impact of urban and rural residential development

The impacts of settlements on the natural environment also reach beyond the land covered by construction. The ecological impacts that result from human activity are nutrient input, noise, mechanical stress, i.e. trampling or vehicle use causing soil compaction, and the introduction of non-native species (Blair, 2004; Clergeau, Croci et al., 2006; Hansen, Knight et al., 2005; Jefferey et al., 2010; McKinney, 2006). To capture the majority of effects, a distance buffer (radius) was applied taking into account building material, purpose, use frequency, and noise (Odell, Theobald et al., 2003; Theobald, Miller et al., 1997). A 100 m impact range was determined for buildings at the beginning of the 20th century, presuming a higher livestock grazing pressure on near-farm areas. From 1950 onwards, the impact range for residences was increased to 200 m, and a 100 m wide range determined for vacation homes and churches. For towns, a 300 m distance buffer was applied, and a 50 m buffer for abandoned farms and sheds. Between 1900 and 2010 the area influenced by settlement had increased 7-fold (Table 3.7), but would be more if all buildings in 2010 could have been included. At least 1,187 ha of native birch forest and 1,586 ha of wetland area were estimated affected in 2010.

Table 3.7 Minimum building impact range in the southern lowlands in 1900-2010, based on building material, purpose, use frequencies and noise. In 2010, the impact was probably greater than demonstrated (data incompleteness).

Building Effect Range	1900	1950	1980	2010
ha	3,966	18,382	24,922	26,723
% increase	..	363.5	35.6	5.5
% of Study Area	0.6%	2.9%	3.9%	4.2%

3.2.7 Cumulative impact and total impact range

The cumulative impacts describe the simultaneous effects, spatially and temporally, of more than one land use category in a landscape or on the same site (MacDonald, 2000). Here, the land area was determined, which was cumulatively affected by at least two land use types, including the impact ranges of roads, settlements (defined in chapters 3.2.5 & 3.2.6) and ditching (200 m both sides). In 1950, the dominating cumulative impact was from roads and settlements, whereas the cumulative impact of roads and ditching dominated in 1980 (Table 3.8). The land cumulatively affected by all categories, roads, ditches and construction, totaled 0.7% of the study area in 1980 and had increased by at least 184% in 2010 (building data incompleteness).

About 9 km² of wetland area was cumulatively impacted by all three land use categories in 2010 (Table 3.8). At least 9.7 km² of the native birch woodlands were cumulatively impacted by roads and buildings, which is 6.2% of native birch woodlands present in the study area in 2010.

Table 3.8 Cumulatively impact of the most common land use categories on adjacent wetland, woodland and other land area in the southern lowlands in 1950-2010. Table 3.9 summarizes other land cover classes for 2010.

Year	1950						
Category	Wetland	of total	Woodland	of total	Other land	Total area	
Impact Types	*ha*	*%*	*ha*	*%*	*ha*	*ha*	*%*
All Impacts	55	0.04	..	..	261	316	0.05
Road+Building	418	0.4	25	0.2	5,272	5,715	0.9
Road+Ditch	747	0.6	..	..	983	1,730	0.3
Ditch+Building	240	0.2	..	..	673	913	0.1

Year	1980						
Category	Wetland	of total	Woodland	of total	Other	Total area	
Impact Types	*ha*	*%*	*ha*	*%*	*ha*	*ha*	*%*
All Impacts	116	0.17	137	1	4,785	5,038	0.8
Road+Building	187	0.3	1,204	9	11,476	12,867	2
Road+Ditch	2,042	3	362	2.6	16,866	19,270	3
Ditch+Building	362	0.5	198	1.4	9,186	9,746	1.5

Year	2010						
Category	Wetland	of total	Woodland	of total	Other land	Total area	
Impact Types	*ha*	*%*	*ha*	*%*	*ha*	*ha*	*%*
All Impacts	882	1.1	656	2.4	12,724	14,262	2.2
Road+Building	1,193	1.5	2,762	10	18,398	22,353	3.5
Road+Ditch	7,283	9.5	1,707	6.2	42,769	51,759	8
Ditch+Building	1,094	1.4	723	2.6	14,267	16,084	2.5

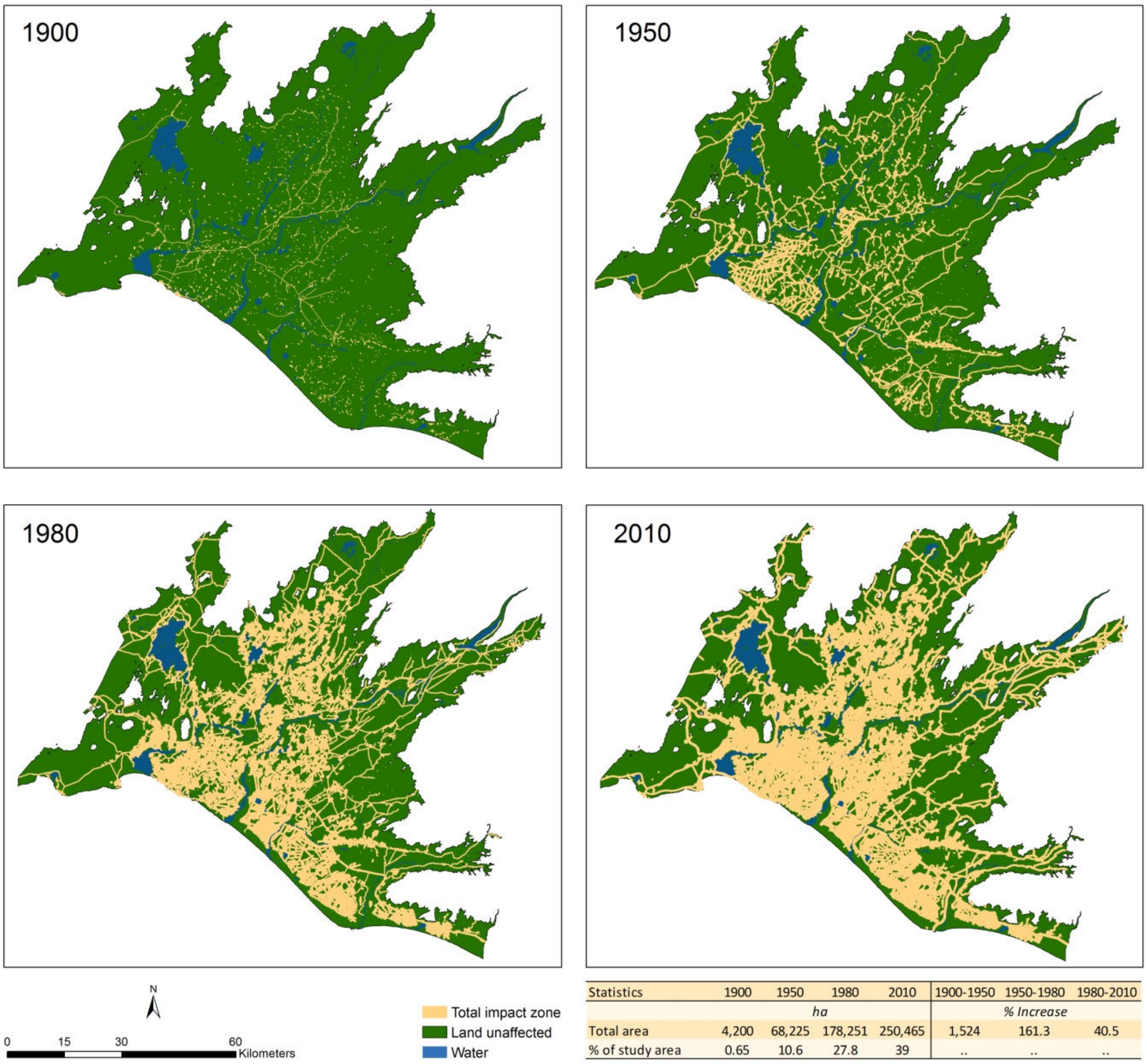
Of the other land cover categories, grassland was the vegetation type most affected relative to the total area, apart from hayfields (Table 3.9).

Table 3.9 Cumulative impact of the most common land use categories on other land cover classes (Nytjaland) in the southern lowlands in 2010, excluding wetlands and woodlands (summarized in Table 3.8).

Category	Grassland	of total	Heathland	of total	Moss	of total	Waterbodies	of total
Impact Types	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*
All Impacts	2,156	4.4	2,405	1.2	185	0.3	53	0.2
Road+Building	2,764	5.7	4,909	2.4	576	1	212	0.7
Road+Ditch	7,468	15.3	12,119	6	1,196	1.9	379	1.4
Ditch+Building	2,526	5.2	2,804	1.4	230	0.4	95	0.3

Category	Vegetation 20-50%	of total	Vegetation < 20%	of total	Hayfields	of total
Impact Types	*ha*	*%*	*ha*	*%*	*ha*	*%*
All Impacts	271	0.3	40	0.06	7,665	14.7
Road+Building	874	1	195	0.3	9,004	17.3
Road+Ditch	1,257	1.5	169	0.2	20,347	39
Ditch+Building	298	0.4	45	0.06	8,327	12.3

The total impact range was calculated by combining the impact ranges roads, buildings (as defined in chapters 3.2.5 & 3.2.6) and ditching (distance buffer 200 m on either side) and the actual land take by roads and ditches (2 m) in the time periods respectively. The total land area cumulatively affected by roads, settlements and ditching had increased 60x from 42 km² to 2,504 km² between 1900 and 2010 (Figure 3.22). Accordingly, at least 39% of the southern lowland area was affected either by ditching and/or development, i.e. roads, buildings and settlements, in 2010.



Statistics	1900	1950	1980	2010	1900-1950	1950-1980	1980-2010
	ha				% Increase		
Total area	4,200	68,225	178,251	250,465	1,524	161.3	40.5
% of study area	0.65	10.6	27.8	39	..	..	..

Figure 3.22 Total impact range of the road system, ditch network (< 200 m) and built-up land (as available for 2010) in the southern lowlands in 1900-2010, including the statistical summary of the development.

As continuation of the findings in chapter 3.2.1., the wetland area estimated not impacted by roads, ditches and settlements totaled 20,252 ha, spread in discontinuous patches across the region in 2010 (Figure 3.23). This is 17.6% of the wetland area in the southern lowlands in 1900, covering 3.2% of the study area in 2010. The inclusion of road and building impacts had reduced the remaining wetland area by another 1,396 ha.

For comparison, the calculations using current wetland area estimates (*Nytjaland*) resulted in 26,801 ha of unaffected wetlands, which is 23.3% of the 1900-wetlands and 4.1% of the study area. The inclusion of all buildings and their impacts in 2010 may have produced a greater reduction of wetlands respectively. In contrast, it was assumed that all ditches were maintained and had an equally high draining effect, which is probably not the case (Gísladóttir et al., 2007). The uncertainty about the draining potential of existing ditches and the discrepancy between results indicate the need for ground proofing.

The estimated area of unaffected native birch woodlands including birch afforestations summed up to 10,910 ha in 2010 (Figure 3.23), which was 1.7% of the study area.

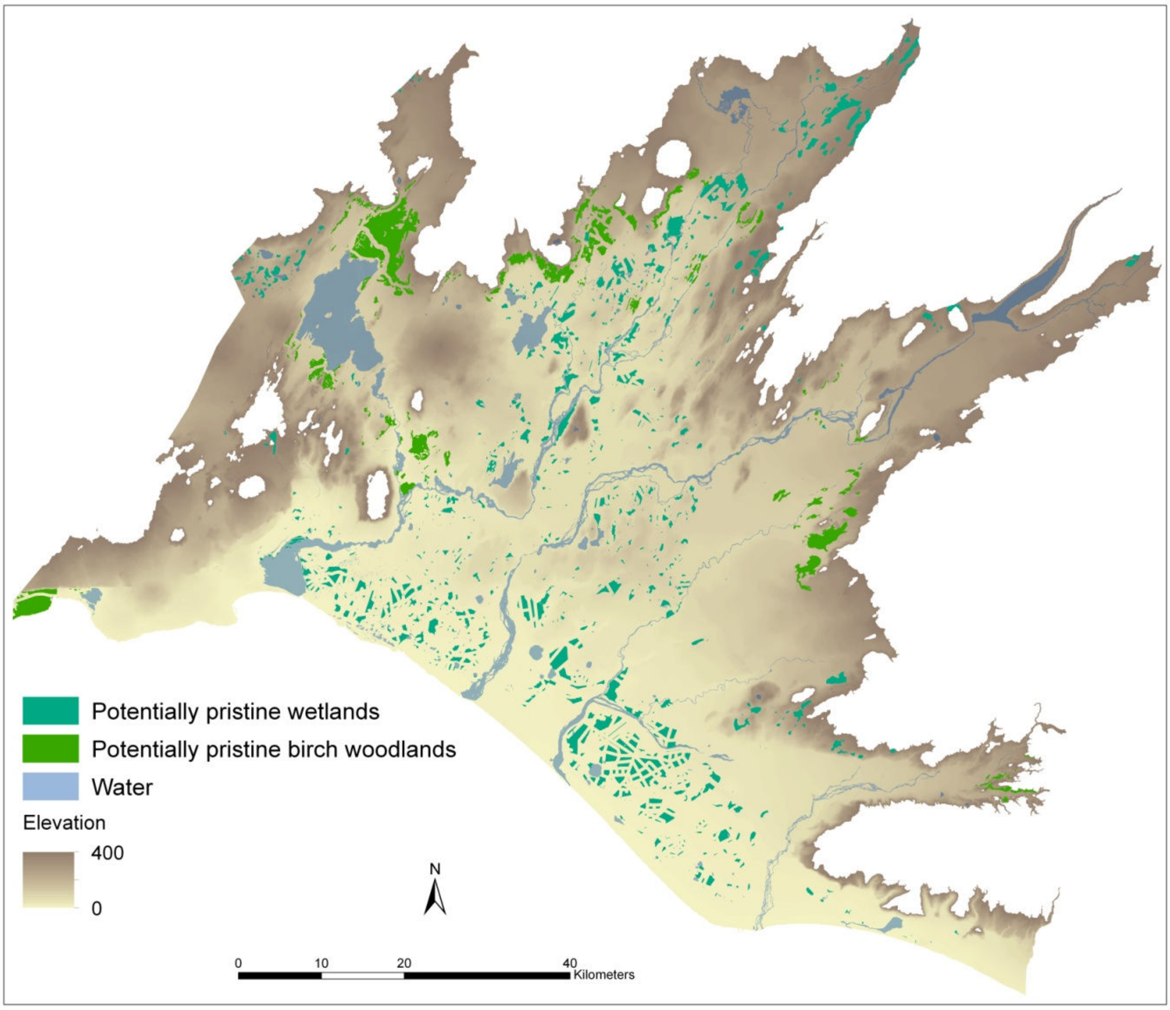


Figure 3.23 Estimated pristine wetlands and native birch woodlands not influenced by roads, ditches or settlements (as available) in the southern lowlands in 2010. The inclusion of all rural buildings would have resulted in fewer areas than illustrated.

A minimum of 4,236 ha of areas protected by legislation were potentially impacted by roads, ditching and rural buildings in 2010, which is 20% of what lies within the study area. The dominating impact, 83%, was from roads (Figure 3.24).

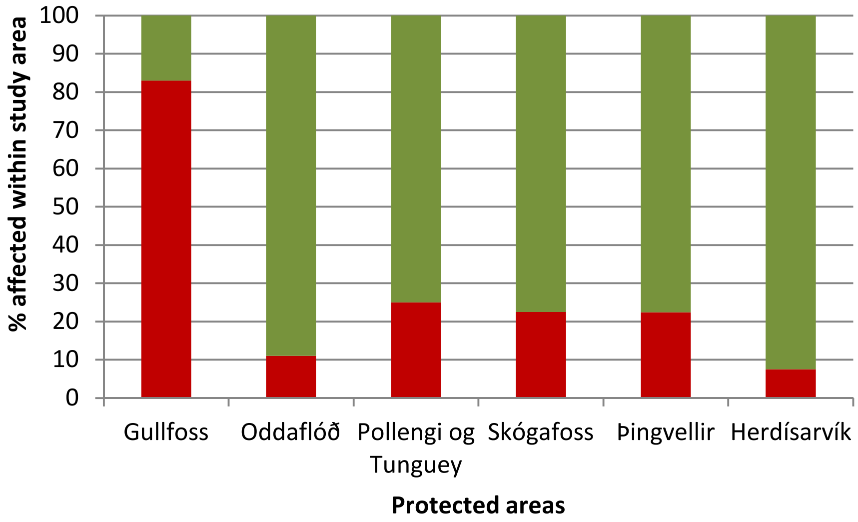


Figure 3.24 Protected areas within the study area that were estimated to be affected by roads, settlements and ditching in the southern lowlands in 2010. Red illustrates the proportion of each protected area that was affected.

3.3 Drivers of the land-use changes

3.3.1 Population growth and distribution

Population growth, as one of the main driving factors for land use intensification worldwide in the 20th century (Antrop, 2005; EEA, 2010c), is also applicable for Iceland, including the southern lowland region. There is a connection between the population growth since the latter half of the 19th century, the increase of agricultural production and the urbanization of the country (Júlíusson et al., 2005; Kristinsson, 1991; SI, 2011d). One phenomenon that influenced the region's development especially was the progressive migration of people across the nation to the capital area, followed by the growing demand for food supply, electricity, employment and recreation. The establishment of creameries in the region signifies the production increase and is symbolic for the shift towards market-oriented farming and specialization that caused the intensification of land use (Diðriksson, 1959; Geirsson, 1975; Jónsson, 1975; Kristinsson, 1991). Between 1900 and 2010, the land area used by agriculture and development increased by at least 21x, while the population size in the region doubled and grew exponentially in the capital area, from 8,221 people in 1900 to 200,907 in 2010 (Figure 3.25) (SI, 2011g, 2011h).

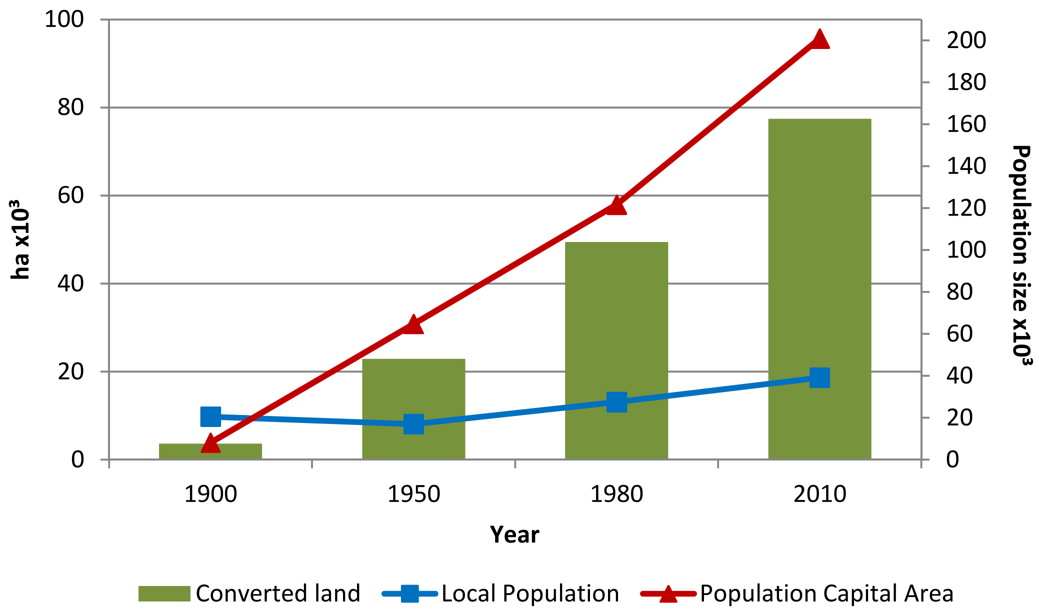


Figure 3.25 Population development, locally and in the capital area linked to the land use intensification in the southern lowlands in 1900-2010. Converted land includes roads, agricultural and built-up land, as available. Source: Population data, SI

3.3.2 Lifestyle and prosperity

Much of the land-use changes were likely driven by consumption and market demands, supporting urban expansion, the transformation and relocation of economic activity and sprawl (EC & EEA, 2006; Imhoff, 2004). Historically, the residential pattern has always been dispersed governed by subsistence farming and confined by natural conditions, with long distances between settlements (Sveinbjarnardóttir, 2004; Valsson, 2003).

The location of residences stayed largely unchanged over the period studied, despite the changing lifestyle and the decline of farmers (BSSL, 2011; Guðbjartsson, 1991; Snæbjörnsson et al., 2010). The increasing need for communication in a more market and consumer oriented society was served with the expansion of the road infrastructure. The strong regimes of car, land- and homeownership (NPR, 2006; Sveinsson, 2004) probably allowed for the dispersed residential pattern to prevail.

The extension of urban infrastructure across the region and the higher household spendings for commuting longer distances make urban sprawl an expensive form of urban development and livelihood (EC & EEA, 2006; Jónsdóttir, 2010). The yearly average expenditure of Icelandic households spent for transport was 30% in towns and 45% in rural areas in 2005-2009 (SI, 2010). This applied to all households outside the capital area and included the purchase of a vehicle and its operation. The proportion of homeownership rose from 63.9% in 1950 to 90% nationwide in 2006, and is considered among the highest in the world (NPR, 2006; Sveinsson, 2004).

3.3.3 Legislation

Planning

It was not until 1978 that all municipalities were obliged by law to establish a development plan beyond settlement borders. Until 1964, planning was limited to settlements with 200 residences and more, and reduced to 100 residents and/or 71 houses between 1964 and 1978 (SR, 1984). Since 1998, the obligation to establish development plans on municipal level nationwide was regulated with the Act of Planning No 73/1998. It stipulated that municipalities are responsible for developing and revising the municipal plans. The land management by municipalities was probably mainly based on local political and economic interests and the principal motivation for land partitioning was to secure local tax revenues. To stop or reverse rural depopulation measures were taken to satisfy the growing demand for coeval rural- and urban-living comfort (Jónsdóttir, 2010; Schuller, 1994). This is reflected in the vast areas allocated for vacation home development but also in the establishment of garden suburbs in the vicinity of *Selfoss*. The municipal plan of *Árborg* 2005-2025 has allocated 1.364 ha for such garden suburbs (Bjarnadóttir & Ragnarsson, 2003). They serve as incentives for people to stay in the region and commute (Búgarðabyggð, 2011) but also for people to move from the capital area as has been the trend since the turn of the 21st century (SI, 2011a).

The legislation has been revised and the Act of Planning No 123/2010 valid since January 2011. It reaffirms sustainability and the protection of the environment as code of conduct for development and provides for the establishment of a land use management plan within 2 years after Parliamentary elections (Alþingi, 2010b).

Agriculture

To increase agricultural production qualitatively and quantitatively, and secure the country's food supply, the Act on Land Tenure was passed in 1923 with the aim to increase hayfield area and hay yields. It included subsidies for land cultivation, fencing and drainage, but also hay and fertilizer barns. The following resolution on Agriculture and Construction No 7/1945 stipulated that haymaking may only be performed on land suitable for machinery use. It provided subsidies for ditching and the conversion of wetlands into hayfields and pastures, and for the flattening and removal of hummocks in meadows and grasslands. The Resolution also included incentives for the modernization and expansion of agricultural holdings (Alþingi, 1945). The Law on Animal Husbandry passed in 1931 and revised several times thereafter (Alþingi, 1997/1998) included subsidies for livestock numbers. It had thus considerable influence on livestock populations (Arnalds & Barkarson, 2003; Ólafsdóttir, 2001) and the extent of the land needed for grazing. The monitoring of livestock numbers has rested with the municipalities (Alþingi, 2002). The country's food supply was secured by 1960 and the aim shifted towards the export of agricultural produce in the following decades, which promoted the land use intensification further (Alþingi, 1997/1998). Past 1987, ditch excavation was no longer subsidized (Garðarsson et al., 2006), which led to the closing stages of large-scale wetland drainage. Instead, the restoration of wetlands was put on the agenda resulting in the establishment of an intergovernmental wetland committee with the aim to restore degraded wetlands in 1996-2005 (Garðarsson et al., 2006). During that time measures were performed such as the blocking of ditches in 5 selected wetland areas in the region.

Wetland drainage is still ongoing in some places, whereas much of the ditched wetlands have never been cultivated and are now primarily used for grazing or turned into fallow land (Hallsdóttir, Harðardóttir et al., 2010; Snæbjörnsson et al., 2010).

Forestry

In the attempt to stop the desertification process, the Act on Forestry and Protection against Soil Erosion was passed in 1907 (Arnalds, 2005) that later resulted in the two independent state institutions, the Soil Conservation Service and the Icelandic Forest Service. In the first decades of forestry, the priority was the preservation of remaining forest fragments and the promotion of native tree species reflected in the placement of the moratorium on alien tree species that was in effect 1912-1935 (Blöndal, 1991; Bragason, 1995). The shift towards the use of alien species was performed with the law on the governmental monopoly to import alien species No 78/1935 and the subsequent development governed by the Act on Afforestation No 3/1955, with the aim to increase the forest cover nationwide (Alþingi, 1935, 1955). The foundation of regional afforestation programs including financial incentives for the conversion of privately owned land into forest were decreed in 1984. This was followed by the Act No 93/1997 to inter alia promote southern forests especially (Alþingi, 1997). The reimbursement of 97% of the expenses of land conversion and the high activity of the Forestry Associations initiated the leap in forestry (Eysteinsson, 2009).

The aim of forest expansions has been reaffirmed by the Regional Afforestation Project Act of No 95/2006, decreeing that 5% of the country's lowland areas < 400 m a.s.l are to be covered by forests within 40 years (Alþingi, 2006). This translates to 32,076 ha in the study area and presents another increase of forest area by 17.4%. The location and species to be used are not stipulated but advised by the Forest Service, and are thus largely controlled by local stakeholders.

Land reclamation

In the first few decades, measures to stop erosion and reclaim the land concentrated particularly on the protection of local farmland. The exclusive top-down approach and conflicting policies such as the promotion of livestock numbers and unrestricted grazing resulted in little measurable success on landscape level (Arnalds & Runólfsson, 2007). Improvements took place with the Act on Land Reclamation No 17/1965 including financial incentives since 1975 (Alþingi, 2011), the use of fertilizer and alien species, and the program "Farmers Heal the Land" since 1990 (Arnalds & Runólfsson, 2007). Some of the species used became invasive, i.e. the Alaska lupine *(Lupinus nootkatensis),* which has also spread in parts of the study area, e.g. the *Þjórsár Valley* and *Geysir*. Officially recognized as invasive plant that threatens local ecosystems and biodiversity (Magnússon, 2006), the lupine is still used in land reclamation (IINH&LR, 2010), while programs exist to reduce its distribution in protected areas and the Mid-highlands (IINH&LR, 2011).

Global conventions

The country is member to 22 international conventions pertaining to the environment (EA, 2010), and the compliance is reflected by implementation in national legislation. Probably the most influential one in terms of land use is the United Nations Framework Convention on Climate Change (UNFCC) including the Kyoto Protocol.

This convention has transferred land reclamation, forest plantations and the restoration of wetlands into activities of international importance, which are used as instruments to control the national carbon budget (Hallsdóttir et al., 2010). Support and amplification of these activities, especially wetland restoration as carbon sinks, are to be expected in the future (ME, 2010; UNFCC, 2011). In contrast, incentives for compliance to the legally binding Convention of Biodiversity (CBD) have been underrepresented, especially on municipal levels. The threat to native ecosystems and biodiversity caused by land-use changes that may extend beyond a region's borders (BirdLife, 2001; Blair, 2004; EEA & FOEN, 2011; Gunnarsson, Gill et al., 2006; Hansen et al., 2005) has received little attention. This was confirmed by the Icelandic National Audit Office (INAO) in 2006, stating that the country's performance regarding the compliance to the CBD's aims and expectations had been insufficient (INAO, 2006). In 2008, an action plan was developed to increase and distribute knowledge about the country's biodiversity for its preservation. It also includes the restoration of wetland areas and natural birch forests (Alþingi, 2008). The nature conservation law is in the process of revision including tightened stipulations regarding the introduction and use of non-native species in forestry and land reclamation (Alþingi, 2010a), and is accordingly controversial. In view of past developments, improvements in biodiversity protection will presumably take place when financial incentives are put forth, similar to other legislations.

3.4 National and International context

3.4.1 National comparison

The southern lowland region accounts for 15% of the land area below 400 m a.s.l, which totals 43.100 km² (NLSI, 2011a), but contains 42.7% of hayfields and 43.7% of vacation homes existing nationwide (Figure 3.26). The percentage of land covered by hayfields is 8% in the study area, but hayfields cover 1.9% of land < 400 m a.s.l., distributed across the rest of the country. About 30% of the drainage ditches excavated countrywide are located in the area and the percentage of afforested areas accounts for ¼ of such areas in the country. In contrast, the region contains 1.1% of the total land area that is preserved by national legislation.

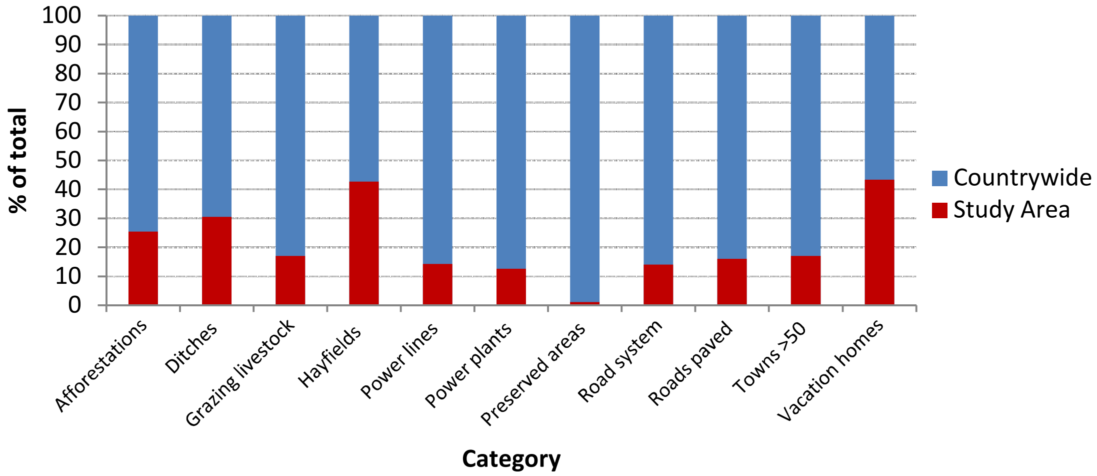


Figure 3.26 Share of land use types in the southern lowlands compared to absolute figures in 2010. The study area accounts for 15% of the total land area < 400 m a.s.l., clarifying the land use intensity compared to the rest of the country.

3.4.2 International context

Living standard, emissions and car ownership

Iceland's standard of living has been among the highest in the world. Since 1980, the country's GDP per capita generally ranged above the average of the European Union (EU), member countries of the Organization for Economic Co-operation and Development (OECD), and high-income OECD members as defined by the World Bank (Figure 3.27) (WB, 2011b). Despite the economic crisis in 2008, the living standard is still comparable to the high-income OECD member countries, with a GDP/capita of 39,678.84US$ in 2010. The country ranges with an employment rate of 80.4% among the highest in the world together with Norway, Switzerland and Sweden (Eurostat, 2011e) and has been ranked among the countries with the highest Human Development Index (HDI) worldwide (UNDP, 2011).

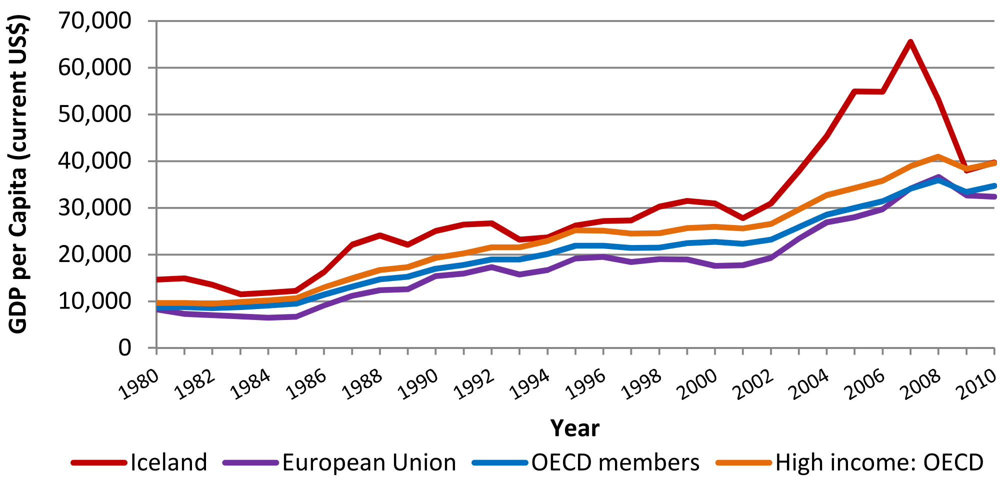


Figure 3.27 Gross Domestic Product (GDP) per capita in Iceland, the European Union and OECD member countries in 1980-2010. Source: WB

Comparing the greenhouse gas emissions (GHG) in $C0_2$ equivalents per capita between countries, Luxembourg and Iceland were the countries with the highest emissions in 2009 (Figure 3.28) (EEA, 2010b). The country ranks in 1st place in emissions originating from metal production, 3rd place from agriculture and 4th place from road transportation.

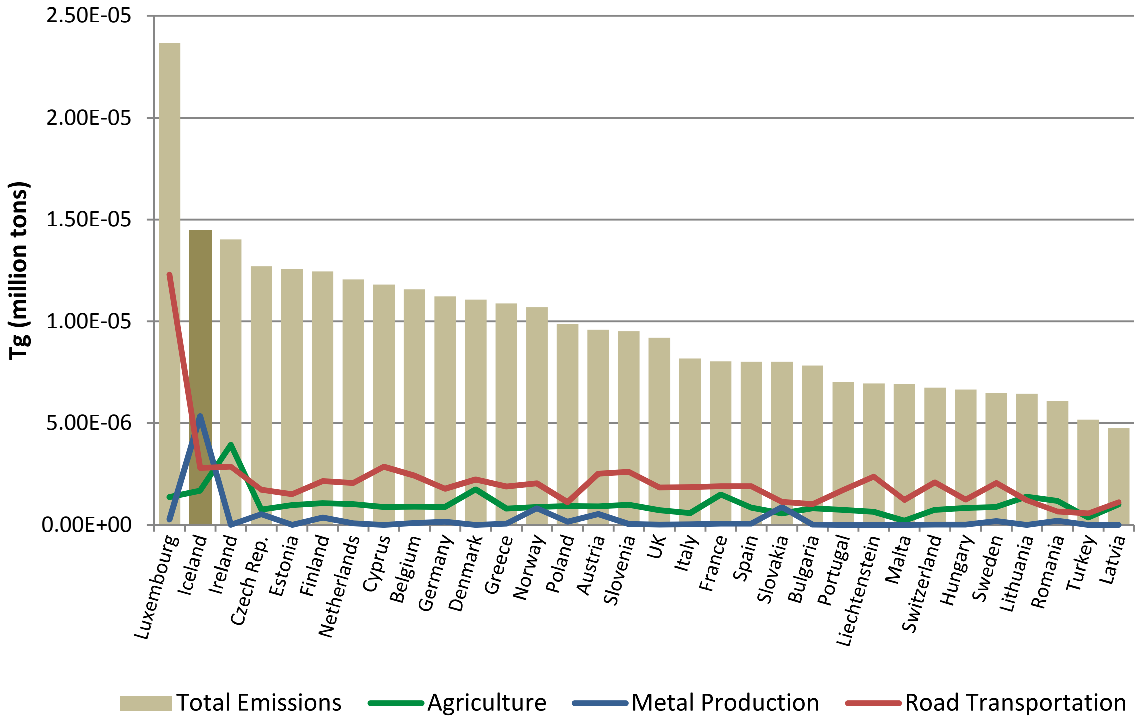


Figure 3.28 Greenhouse gas emissions ($C0_2$ equivalents per capita) in Europe in 2009, including total emissions and allotment by origin. Source: EEA

Iceland's passenger car ownership is among the highest in the world, and exceeded with 643 per 1,000 inhabitants the average of high-income OECD member countries (637 per 1,000) in 2009 (WB, 2011c). Of the European countries selected, Luxembourg maintained 1st place in 2009 (Figure 3.29), while the US ranked with 828 cars on 2nd place worldwide (Davis, Diegel et al., 2011; Eurostat, 2011c). Car ownership increased by 38% in Iceland between 1991 and 2009 (SI, 2011j). Among the countries compared, Germany is the only country where passenger car ownership decreased between 2001 and 2009 (Figure 3.29).

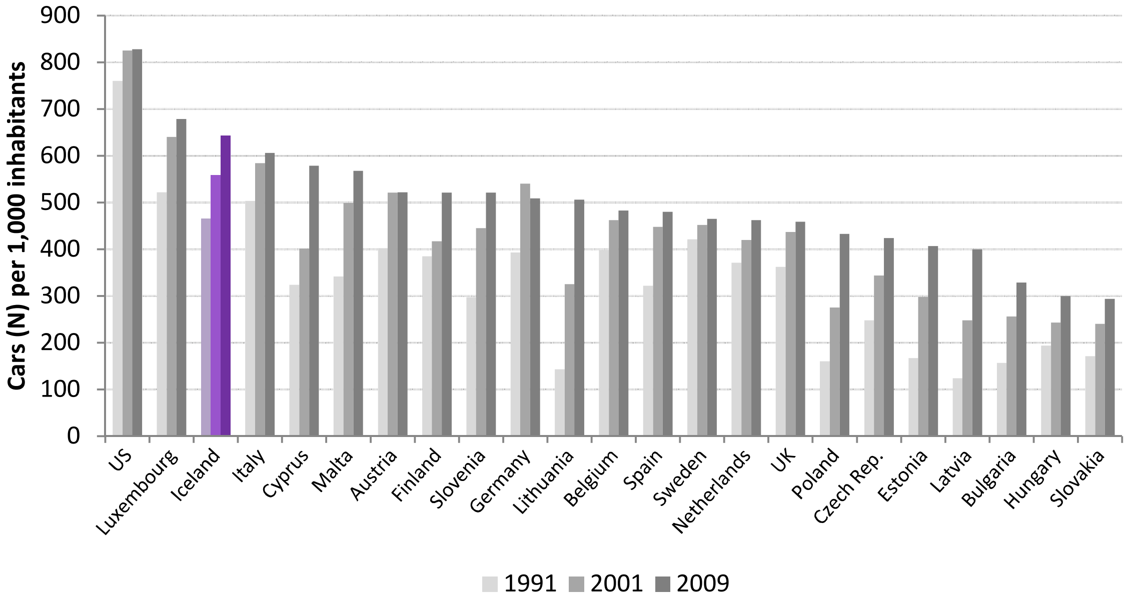


Figure 3.29 Passenger car ownership (N) per 1,000 inhabitants in 1991-2009, in selected European countries (based on data availability) including the US. Source: SI, Eurostat.

Land allocation: Artificial surfaces

The Icelandic road density is with 0.2 km/km² lowest among the European countries selected, where the road density averages of 2.1 km/km². In the study area, the road density is with 0.5 km/km² higher than the national average. The road length per capita is highest among those countries (average 18 m/capita) (Figure 3.30), ranging from 83 m/capita nationwide to 182 m/capita in the study area based on the population size in 2009 respectively (Eurostat, 2011b, 2011f; NLSI, 2010; SI, 2011d). The road lengths tend to be more in less populated countries, requiring a larger road network to connect settlements. Nevertheless, the Icelandic level of infrastructure is relatively high.

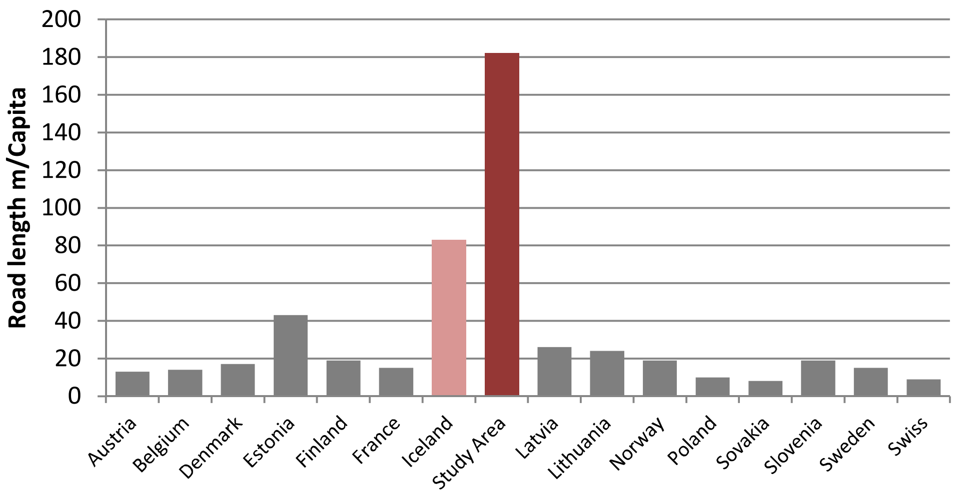


Figure 3.30 Road length (m/capita) in 2009, in selected European countries (based on data availability), Iceland and the study area. Source: SI, Eurostat, NLSI.

Based on *CLC 2000-2006,* artificial surfaces, i.e. urban area, road infrastructure, industrial and recreation areas have increased in all countries between 2000 and 2006 (Figure 3.31), though generally below 10%, except in Spain (15.4%) and Ireland (14%) (EEA, 2010a). In Norway, Sweden, Denmark and Finland, the increase of artificial surface area averaged 3%. The increase in Iceland was 19.7%, whereas the increase in the study area amounted 34.6% during that time period.

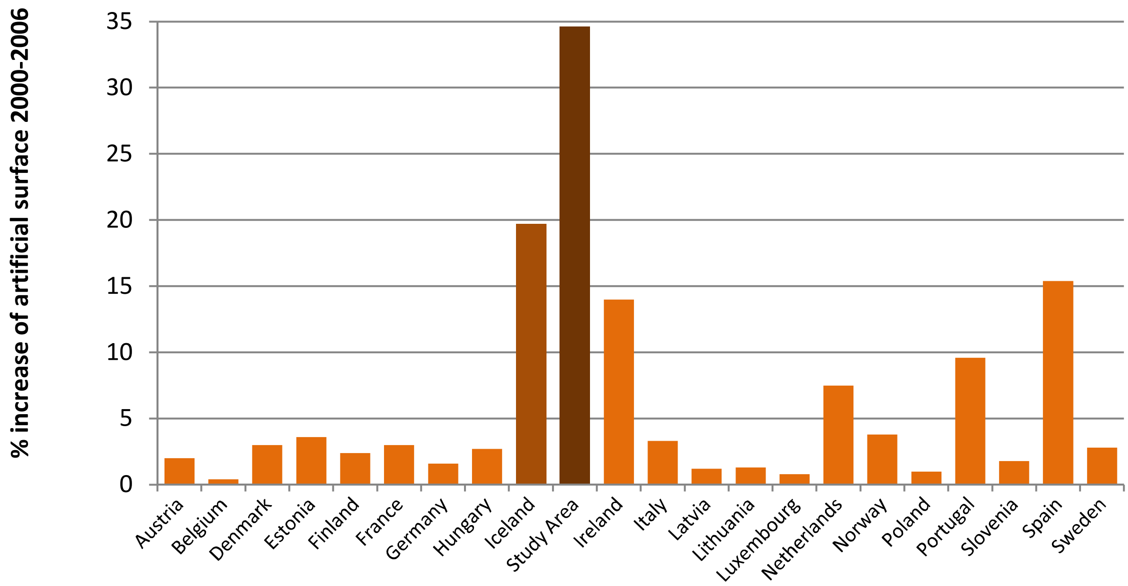


Figure 3.31 Change of artificial surface area (%) according to CLC2000-2006, in selected European countries (based on data availability), including settlements, roads, and industrial and recreation areas. Source: EEA

Agricultural land and farming practices

Agricultural land area, i.e. crop- and grassland, correlates with the latitudes of countries where data were available from and topography (Figure 3.32). It is significantly less in Nordic countries, while the mountainous landscape is the limiting factor in Austria despite the favorable latitudes. The general trend in Europe has been a decline of land area used for agriculture since the 1950's, except for Norway where the agricultural land area in 2009 is comparable with 1950 (Eurostat, 2011a). Iceland is the only country among the countries compared where agricultural land area has increased during that time period (FAI, 1985-2010; Snæbjörnsson et al., 2010).

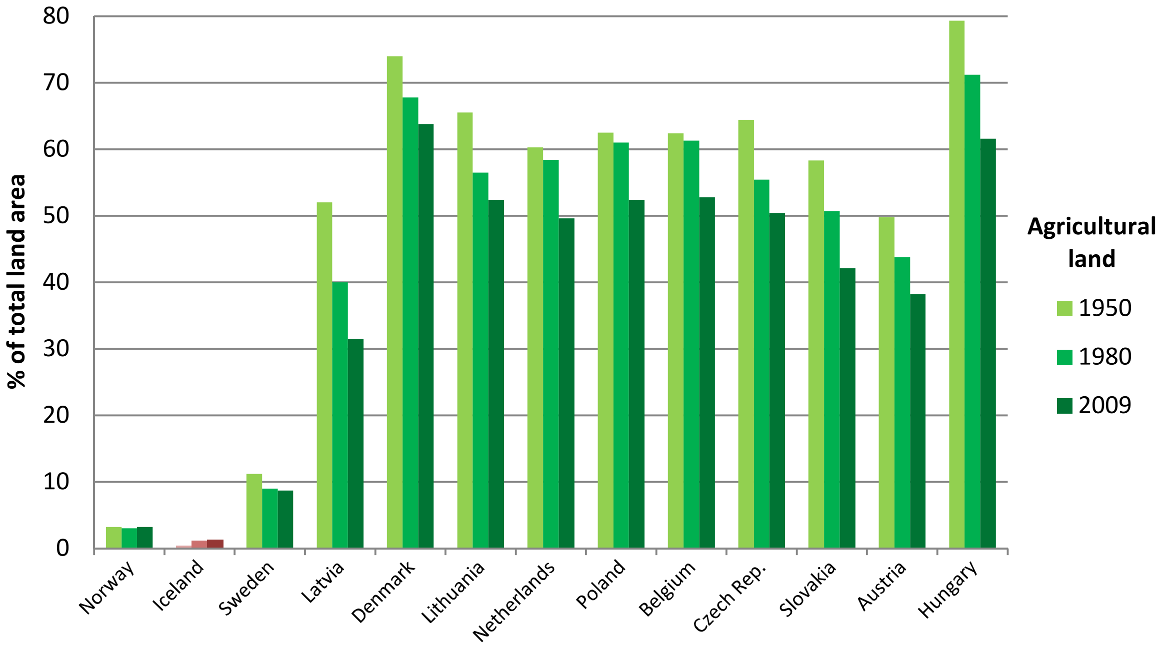


Figure 3.32 Proportion of agricultural land area in 1950-2009, in selected European countries (based on data availability). The countries are arranged by latitude from north (left) to south (right). Source: Eurostat, Land use Committee (2010) and FAI (2010) Reports.

Fertilizer use is an indicator of farming intensity. Over-fertilization can result in leakage of nutrients into the water cycle via groundwater and waterways, causing eutrophication of rivers, estuaries and coastal areas (Conley, Paerl et al., 2009; MA, 2005b). The ingestion of drinking water with high nitrate levels is linked to several cancers and reproductive problems in humans (Townsend, Howarth et al., 2003). In EU agricultures, it is estimated that half of the nitrogen in fertilizers and manure is lost to the environment. The costs associated with the effects of nitrogen on human health, ecosystems and global warming have been estimated at 70 to 320 billion € per year (Olesen, 2011). In Iceland, the amount of artificial fertilizer, i.e. nitrogen, phosphate and potash for grasslands, averaged 194 kg/ha in 2008 (Figure 3.33) (FAI, 1985-2010). Hay harvest occurs once, or maximum twice in favorable years. This may seem extensive in comparison with most countries, but with respect to the short vegetation period and natural conditions, this probably is the upper intensity limit for agriculture in these latitudes (Bragason & Dýrmundsson, FAI, personal communication, June, 9th 2011). Of the Nordic countries, only Norway has higher fertilizer consumption per unit area (Figure 3.33) (WB, 2011a).

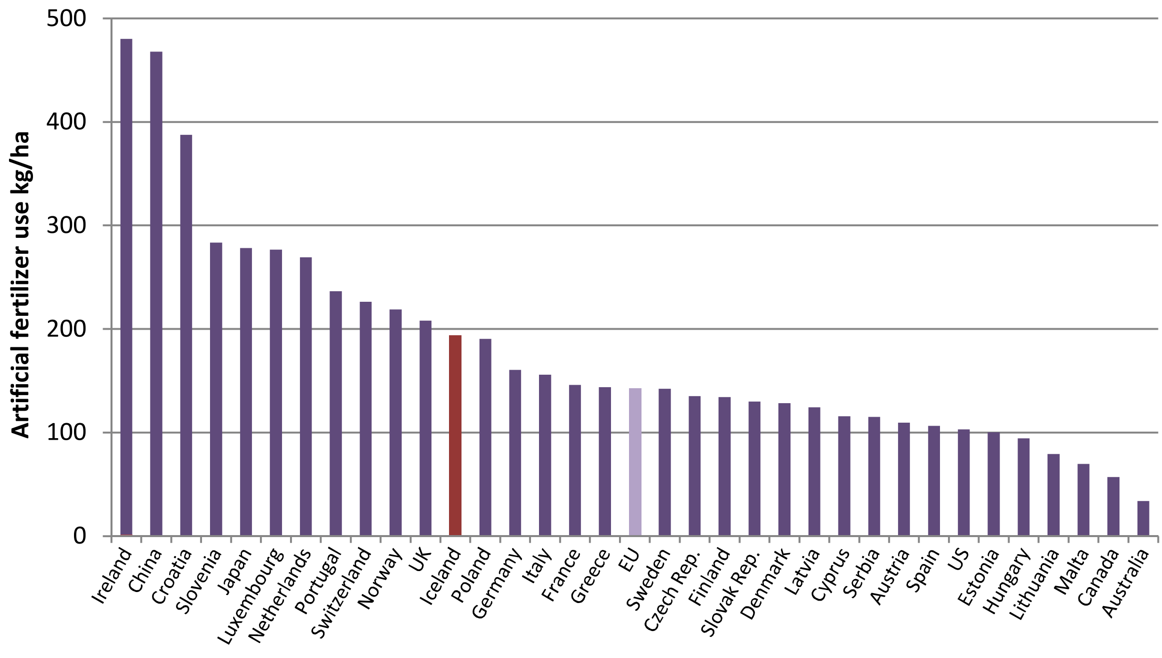


Figure 3.33 Artificial fertilizer use (kg/ha) in developed countries in 2008. Source: WB

In the context of sustainable development, there has been a general trend in Europe to reduce the intensity of agriculture and support organic farming, with respect to human health and the environment. In 2009, about ¼ of the world's organic agricultural land was in Europe and accounted for a global market share of 54% (Willer, Rohwedder et al., 2009). In the European Union (EU 27), 4.3% of agricultural land was managed organically, with the largest area, 13,308 km², in Spain. Italy had the highest number of organic producers, totaling 43,029 (Figure 3.34), but the percentage of agricultural land managed organically is highest in Liechtenstein and Austria (FiBl, 2011; Willer, 2009).

The share of organic farming in Iceland accounts for 0.4% of agricultural land area (Figure 3.34). Eleven of the 36 producers nationwide are located in the study area (Gunnarsson, Tún ehf., personal communication, June, 13th 2011). One of them, *Sólheimar*, has engaged in organic farming since the 1930's. The following comparably slow development in Iceland was also due to the missing financial support for the first years of transformation, which takes up to 5-10 years (Dýrmundsson, FAI, personal communication, June, 20th 2011). In 2011, special grants for the transformation phase and a parliamentary proposal were put forth to develop and support organic farming in Iceland similar to Norway (Dýrmundsson, 2011). This suggests that there will be measurable progress of organic farming in the future.

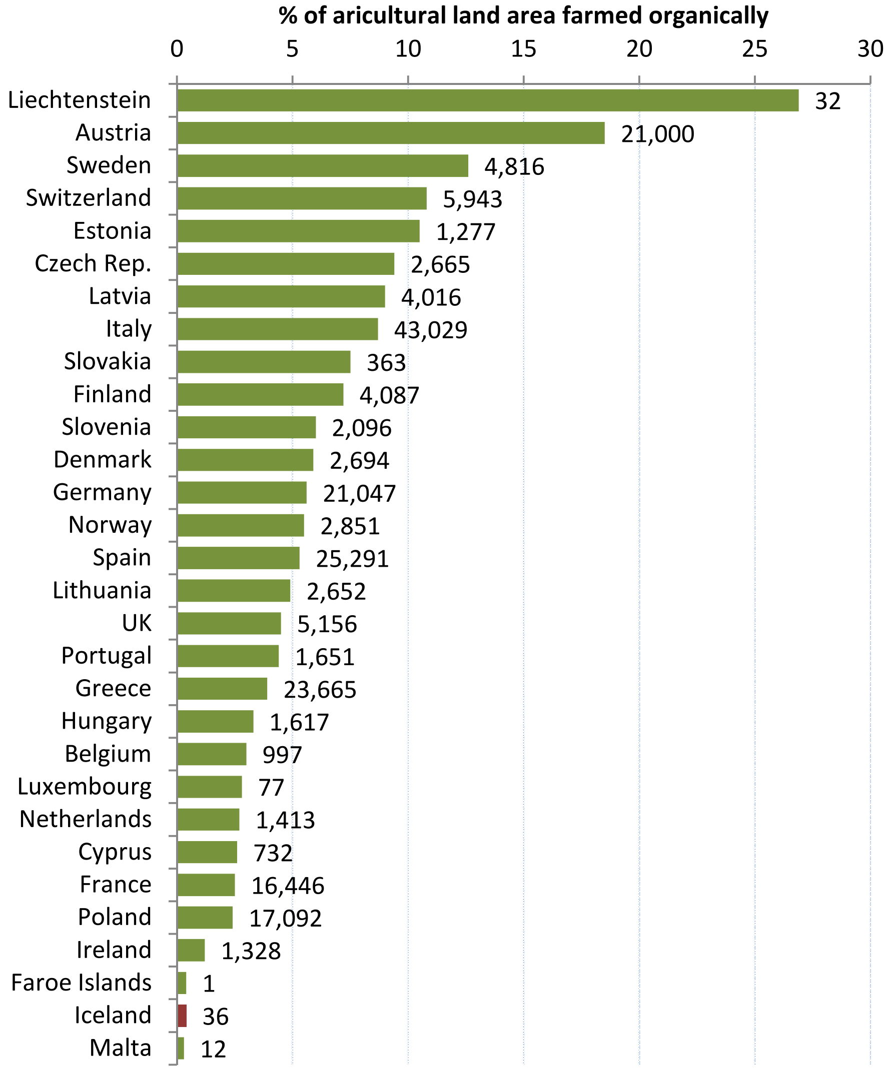


Figure 3.34 Organic Farming in Europe in 2009, including the number of producers in the countries respectively. Source: Research Institute for Organic Agriculture (FiBL)

Protected areas

Another measure to improve sustainability and decelerate biodiversity loss was the adoption of the Birds Directive 79/409/EEC and the complementing Habitats Directive 92/43/EEC by European Union governments in 1979 and 1992. These Directives were designed to protect the most seriously threatened bird species, and other species including their habitats (Europe, 1979/2009, 1992). Together they decree the designation of special areas for protection by the EU member states to establish a coherent network of protected areas across Europe, called Natura 2000. The Habitats Directive focuses on habitats that are typical for the geographic regions and serve as basis for the survival of associated species. It includes buffer zones surrounding the protected sites to prevent penetration of anthropogenic influences and together with regular monitoring ensures the quality and continuity of the protected sites. Area designations are entirely based on scientific criteria using the red list of endangered species as legal instrument for enforcement, and exclude current socio-economic interests, which differs considerably from the Icelandic nature conservation system (A. Jóhannsdóttir, HI, and M. O'Brian, Nature Unit DG Environment, presented at the conference "EU and the Environment" on October 25th 2011). Adjustments to the EU nature conservation strategy have been proposed by the working group for revision of Iceland's nature conservation legislation to improve its effectiveness (NEN, 2011).

Currently, about 20% of the European territory is protected by the Habitats Directive (Eurosite, Europarc et al., 2011). Comparing the terrestrial share between countries, Iceland ranks with 16% of area protected under national legislation on 5th place together with Greece (Figure 3.35) (Eurostat, 2011d; Jónsson Geirsson, 2010).

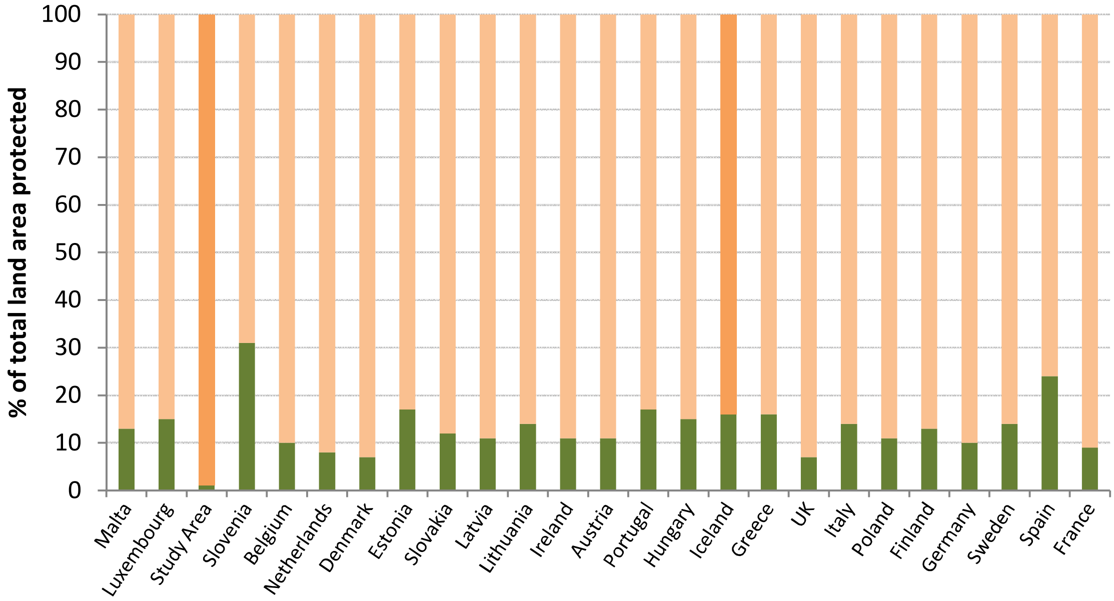


Figure 3.35 Protected terrestrial area under the Habitats Directive in the EU, and by national legislation in Iceland and the study area in 2010. Source: Eurostat, EA

Apart from legislation differences, factors such as population density and land use intensity need to be taken into account when countries are compared. Iceland has the lowest population density of the countries listed and much of the area protected is glacial and does not conflict with any land use categories. Malta for instance, which is 316 km² in size and only a fraction of the southern lowland region, has a population density of more than 1,300 people per km², but has nevertheless managed to designate 13% of terrestrial area for protection under the Habitats Directive, while 26% of the country is used by development and agriculture (EEA, 2010a; Eurostat, 2011f). Despite such achievements, biodiversity loss and ecosystem degradation is ongoing in Europe, driven by population growth and the limited awareness about biodiversity and its economic value as it is still being excluded in decision making. A new strategy has been developed, based on the vision that by 2050 "*EU biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided*" (EC, 2011).

4 Conclusion

This thesis presents a large scale analysis of environmental changes as consequence of the land use patterns in the southern lowlands from 1900 until 2010. Its objective was to quantify land use and land cover categories in selected time periods as possible, estimate their impacts, and place the developments in national and international context.

The time period covered by this study could essentially be divided into 5 transition stages that defined the land use regimes in the southern lowlands (Figure 4.1). The progressively intensifying trend of land use had caused significant alterations of the landscape, which has implications for increasing stress to the natural environment.

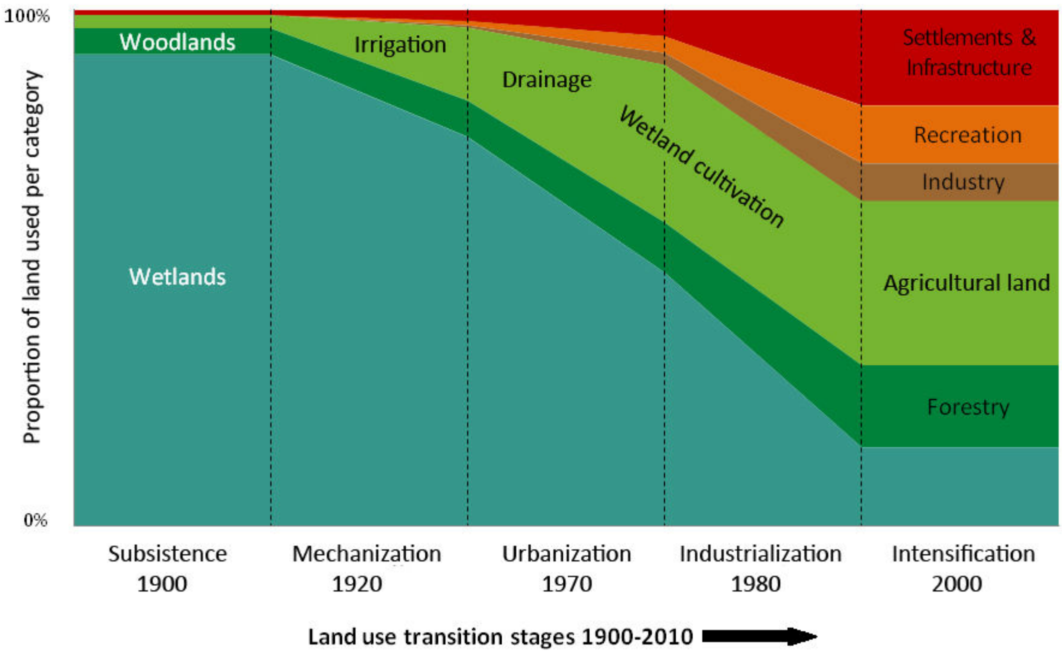


Figure 4.1 Schematic representation of land use transition stages including time approximates in the southern lowlands in 1900-2010. The scheme summarizes the landscape alterations and intensifying land use. Note that the land allocations are proportional and don't reflect absolute figures for the area outlined.

The effects of afforestations on species preferring open land are mostly local, whereas agriculture, urban development and roads are universally acknowledged to be the major causes for biodiversity loss and reduced ecosystem integrity (EEA, 2010c; Jongman, 2002; Ricketts & Imhoff, 2003). The disturbance by development is more permanent and often irreversible in character (McKinney, 2002), but impacts of agriculture depend much on intensity and local practices. Large-scale ditching to increase agricultural land has caused the great reduction and deterioration of the region's wetlands (Geirsson, 1975; Magnússon, 1998; Þórhallsdóttir et al., 1998; Þorleifsson, 1975) and there is evidence that the current wetland area is overestimated.

A recent study on drainage ditch density and draining capacity resulted in 5,873 km^2 of drained and disturbed wetland area nationwide, which is more than previously estimated (Gísladóttir, Guðmundsson et al., 2009). Field research is needed to investigate, which areas do in fact fulfill the criteria for being classified as wetlands to increase the reliability of data.

The region's landscape became increasingly fragmented into smaller natural habitat patches by roads, ditches and settlements. Having been of major international concern, landscape fragmentation has not received much attention in Iceland. Only one reference was found where fragmentation was addressed though in connection with agricultural land use suitability (Snæbjörnsson et al., 2010). The reason for this might be the low population density and large area remaining that is virtually undeveloped. In contrast, settlements are concentrated on low elevations that correlate with fertile vegetated areas, and thus important natural resources and ecosystems. Fragmentation may affect the ecosystem services in these areas, such as water- and soil-related services, but also services directly related to human well-being like recreation and education (Di Giulio et al., 2009; EEA & FOEN, 2011; Jefferey et al., 2010; Ólafsdóttir & Runnström, 2011).

Land use management on a local level affects the availability of natural resources on national and international scales. The promotion of certain land use types at the expense of others may accelerate the competition for the natural resources available, especially if there are inconsistencies in land management concepts and the trade-offs based on short-term socio-economic interests (Foley et al., 2005; Rodríguez & Beard, 2005; Smith, Gregory et al., 2010). The consequences of the intensifying land use are mostly unpredictable, as quantitative research is mainly performed selectively in context with single projects, and time series are lacking for most land use categories, except forestry, revegetation and hydro-power activities (Hallsdóttir et al., 2010).

The distance buffers representing the impact range of different land use types were equally applied regardless of the topography and response variables of ecosystems or species, which was an applicable method on landscape scale. However, the impacts from roads and settlements on the distribution and composition of avifauna are potentially greater than assumed and transfer across different levels of spatial organization (Biglin & Dupigny-Giroux, 2006; Blair, 2004; Forman et al., 2002). Including the local phenomena of habitat loss by wetland cultivation and afforestations as amplifying stress variables (Gunnarsson et al., 2006), the impacts from development are probably greater than demonstrated. This indicates the need for research on smaller scales including variables pertaining to the species and ecosystems concerned (Benítez-López et al., 2010; Forman, 2000; Forman & Deblinger, 2000; McKinney, 2002).

Environmental conditions at Iceland's latitudes will always be resource a limiting factor. Yet knowledge about the responses of existing ecosystem types, species and ecosystem functions to different land use patterns is necessary to predict availability, resilience and renewability of the country's natural resources in the future.

Recommendations

An obvious recommendation suggested by this study is a national land management plan that serves as a framework for land allocations on municipal levels.

This is already in progress (INPA, 2011) and will certainly be a useful instrument to guide local land use strategies.

Planning in the natural environment requires reliable data as a foundation for sensible land management. It is thus recommended to complement remote sensing land cover surveys by field research to increase the data quality and reduce area discrepancies between data sources.

The successful implementation of the Biodiversity Action Plan for compliance to the CBD regarding birch forest and wetland restoration (Alþingi, 2008) will depend on the involvement and cooperation of stakeholders, especially foresters and farmers, but also scientist. Incentives for land owners in soil reclamation contracts have proven to be successful (Runólfsson & Arnalds, 2004), and could be extended to other types of restoration and maintenance measures.

The wet meadows or *engjar* in the former irrigation areas *Flói* and *Skeið* represent a cultural landscape type that is unique to the southern lowland region. They could be designated and managed as natural and cultural heritage sites as they have a very high value for nature conservation and the preservation of the region's cultural heritage.

In order to explore the capacity and exploitation thresholds of natural resources, basic knowledge is needed about the function, capacity and interaction of Icelandic ecosystems and their services. This would prevent from utilization that exceeds resource replenishing rates as one of the main principles of sustainable development. To gain this essential knowledge, more research on land use patterns and ecosystem responses are needed.

The knowledge could be gained by:

- An ecosystem inventory, including the classification of all ecosystem types.
- Monitoring of ecosystem functions and research of their reaction to land use patterns.
- Assessment of the consequences of past management activities such as road construction, drainage and urban development on adjacent land, water bodies and organisms.

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