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Summary

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Sheep husbandry has been an important part of the agricultural system since the settlement of Norse man in Iceland, the Faroe Islands, Greenland and Norway. Besides shaping the landscape and it's biodiversity for centuries, sheep has played an important part in the development of the North-Atlantic culture and its economy which is also evident today.

In this report we present the results of an interdisciplinary study focusing on sheep management, resource economy as well as the ecological impact of sheep grazing in a long term perspective on Iceland, the Faroe Islands, Greenland and Norway. This comparative approach thus serves as a basis for discussing both the economic and ecological sustainability of sheep grazing in the North-Atlantic region and how this has varied over time due to both cultural and natural factors.

The report has a separate chapter for each country where the following topics are addressed: First a brief introduction to the natural history of the grazing land is given. Secondly, both present and former management is described with a focus on number of sheep, breeds, grazing season, supplementary feeding, law and other regulations. Thirdly, the resources provided by sheep husbandry, as well as the economical importance of this agricultural system, are presented in a historical perspective. Fourth, the ecological effects of sheep grazing includes both knowledge on the sheep grazing ecology (habitat and plant selection), effects on life history (production, mortality, diseases), the effects on plants, other animals as well as ecosystem effects.

Grazing by sheep mainly takes place in alpine and northern boreal vegetation in the NA-region. Winters are long and harsh, and provide a very limited amount of fodder for 5 to 6 months. The exception is the Faroe Islands and coastal parts of Iceland and Norway where feeding resources are available in the outlying land during the winter.

Number of sheep varies strongly on both a spatial and temporal scale also within each country. Environmental extreme events such as harsh winters (e.g. Greenland as late as the 1960ties), diseases, and eruptions (Iceland) had strong effects on sheep population densities, but also cultural factors (varying marked demands) were important.

Ancient Norse breeds dominated all over the regions until the 18th century. Breeding during the latest 200 years have in general caused the development of heavier and more productive animals, but also animals more selective on high quality and quantity fodder. Todays breeds on Iceland, Greenland and the Faroe Islands as well as Norwegian Spael are probably more related to the ancient Norse breed, as compared to the Norwegian White Sheep which represents a heavier and more productive breed, less able to use low quality fodder. There is also some variation in the length of the grazing season and use of supplemental fodder at present, which probably is related to climatic factors (the length of the plant growing season), the demands of the different breeds relative to litter production and annual animal growth rate.

Although sheep grazing in outlying land seems to be a strong prescriptive right all over the region, and strongly supported by governmental incentives, the need of regulating sheep densities to prevent overgrazing, have often been discussed. At present there are regulations enforcing indoor feeding during winter at Greenland, and reduced densities and length of the grazing season in Iceland from the 1980ties to prevent erosion.

The economic importance of sheep husbandry products has obviously decreased from being a vital part of the subsistent agricultural system, to a subsidised agricultural system with a limited importance for the national economy. The main products of sheep husbandry have also shifted from wool (and milk) to meat all over the region especially from the early 20th century. Nevertheless, the economical importance of sheep grazing at a local scale could be high, and sheep husbandry is probably important for the rural economy (and culture) in all countries. Also the consumption of sheep meet (the main sheep product today) is high, especially in the Faroe Islands and Iceland.

The ecological impacts of sheep grazing is indisputable, and sheep grazing are for example considered to be a main factor for preventing tree-recruitment and persistence in boreal parts of Iceland, Greenland and Norway. Although the sheep selection of habitats and plants as well as their impact on plants, animals and ecosystems are known in general (qualitative) terms, important knowledge on how different densities of different breeds effects the ecosystems with varying productivity is often not explicitly quantified. Overgrazing by sheep due to erosion is reported to be a problem on Iceland, the Faroe Islands and Greenland. In addition, overgrazing in terms of reducing populations of fodder species to the advantage of unpalatable resistant plant species is reported from several sites all over the region. Nevertheless, open semi-natural grassland are vulnerable habitats, and especially in Norway secondary succession in grassland habitats are considered to be a main threat to biodiversity. Sheep grazing is then one important factor for preventing this encroachment.

In this report we show that grazing intensity varies with different management factors especially the density of sheep, the breed, lenght of the grazing season, as well as the productivity of the grazing land. Moreover, choises made by the management have an impact on the animal productivity as well as erosion, tree- and shrub recruitment and persistence, and the palatability of plants in the grazing land. A common understanding of how sustainable grazing regimes could be defined is a prerequisite for a sustainable management. We argue that optimising animal productivity without providing negative effects on the environment in the grazing land, should be the ambitions for a sustainable sheep grazing regime both in an economical and ecological perspective. A more developed evidence-basis of the long term effects of different grazing regimes (varying density, breed, season and habitat productivity) involving both management and research in all countries in the North-Atlantic region would be important to underpin a management system for sustainable sheep grazing.

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Foreword

Sheep grazing is an important land use in the North-Atlantic region. This report presents an outline of presentations given at a workshop on the **Sustainable management of sheep grazing in the North-Atlantic region** in Trondheim on the 15 to 17 October 2007. Eleven participants (see picture below) from Greenland, Iceland, the Faroe Islands and Norway joined this interdisciplinary workshop, and the presentations focused on sheep grazing management, resource economy and ecology. We thank The North Atlantic Cooperation (NORA) for providing most of the financial support for both the workshop and the report. In addition we received grants from several institutions in each country. The Faroe Islands: The Faroese Museum of Natural History, Jardfeingi og Landbrugsfonden, Iceland: Islands lantbruksuniversitet, Framleiðnisjóður landbúnaðarins, Greenland: Norway: Statens landbruksforvaltning (SLF), Museum of Natural History and Archaeology, Norwegian University of Science and Technology (NTNU). Marc Daverdin at NTNU-VM, did an excellent job on the editing of this report.

Trondheim, October 2008
Gunnar Austrheim

Participants at the workshop (from right): Gunnar Austrheim, Borgþór Magnússon, Ingibjörg S. Jónsdóttir, Erla Olsen, Jon Feilberg, Atle Mysterud, Leif-Jarle Asheim, Anna Maria Fosaa, Anna Gudrún Thórhallsdóttir, Øystein Holand. Anders Skonhoft was not present when the picture was taken.

1. Introduction

Livestock are an important factor for biodiversity and other ecosystem services in all major regions of the world (Millennium Ecosystem Assessment 2005). The sustainability of such grazing systems is often questioned due to high stocking rates in several areas, but even low stocking rates and forest succession is considered a threat to biodiversity for semi-natural habitats such as in western-Europe.

In the North-Atlantic region, sheep husbandry has been important for the survival of man since the introduction of agriculture. Also today, sheep is by far the most important livestock in Iceland, the Faroe Islands, Greenland and Norway (Nordic Council of Ministers 2007). Although the economic importance of livestock grazing has decreased significantly all over the region, sheep grazing maintained by state subsidies, is from an ecological point of view an important land use with strong effects on landscape and plant community patterns in all countries (Hester et al. 2005). Although sustainable grazing is a superior aim for the management in each country, a common problem for the management is to define sustainable grazing regimes (Mysterud 2006). This is a complex issue related both to a limited knowledge on the ecological effects of sheep grazing, and also possibly a lack of common understanding on what the critical levels of sheep grazing are in different environments in this heterogeneous region. Moreover, sustainable management are dependent on laws and regulations; i.e. the ability to actually regulate the sheep grazing regimes in the region even if there are strong indications and a common understanding of unsustainable grazing regimes.

All NA countries (Iceland, the Faroe Islands, Greenland and Norway) are today part of a western economy driven by post-industrialised businesses, and were the society ability to succeed only to minor extent seems affected by the livestock management. Still, sheep grazing has undoubtedly a strong impact on important ecosystem services such as biodiversity, vegetation biomass quality and quantity, freshwater quality and quantity as well as the economy of rural societies were sheep grazing are locally important. Although such resources are prerequisites for the functioning of our modern society, mans ability to adapt to the environmental conditions were obviously more directly linked to the destiny of the society in historic and pre-historic times. Management of livestock was suggested as a main factor to explain why the Norse societies failed or succeeded at different areas in this region over time (Diamond 2005). Both the choice of livestock species (small ruminants vs. cattle and pig), the relative use of different habitats (upland vs. more productive lowland), grazing season (the use of winter grazing) and of course livestock densities were all critical factors for the sustainability of husbandry in an environment with spatial variation in plant productivity, vulnerability to soil erosion and catastrophes such as volcanic eruption and deceases. The ecological effects of livestock also varied with a changing climate which affected the various areas in the region differently, and probably was the ultimate reason for why the Norse society collapsed at Greenland at the 14th century during the little ice age.

The strong importance and long term management of sheep grazing in the NA region throughout the history of man, gives an unique possibility to examine the ecological effects of sheep grazing management and discuss sustainability in an ecosystem perspective as defined by Millenium Ecosystem Assessment. In this paper we will focus on four topics: (1) The natural environment in the North-Atlantic region which varies among areas and includes boreal forest (mainly Norway), semi-natural heathland and grassland, and alpine and arctic tundra. Strong latitudinal, longitudinal and altitudinal gradients in temperature, precipitation affects system productivity. Together with variations in bedrock and soil this sets up important constraints to biodiversity. The long term climatic variations as well as climatic variability (both seasonal and due to weather extremes) will also be discussed. (2) A historic overview of sheep grazing management in the NA region. In addition to sheep number, we will focus on breeding, management of grazing season and supplemental feeding. Further, the impact of more secondary management factors such as law and regulations as well as the economy of sheep husbandry including the basic products provided by the sheep (e.g. meat, wool, milk) and their contribution to the economy. Also the relative importance of state subsidises will be discussed. (3) Assess the ecological effects of sheep grazing based on both recent and historical data. This overview will be broad with a focus on sheep grazing ecology (habitat and plant selection, life history & deceases), plant effects (plant communities, plant functional groups and productivity), effects on other animals (mammals, birds and insects) and ecosystem effects (nutrient dynamics, erosion). (4) Based on an overview of the ecological effects of management environment interactions in all countries at different time stages, the sustainability of different management systems will be evaluated. Thus lessons from present and past grazing regimes may be used to prevent discontinuous and non-reversible processes in NA grazing systems in the future.

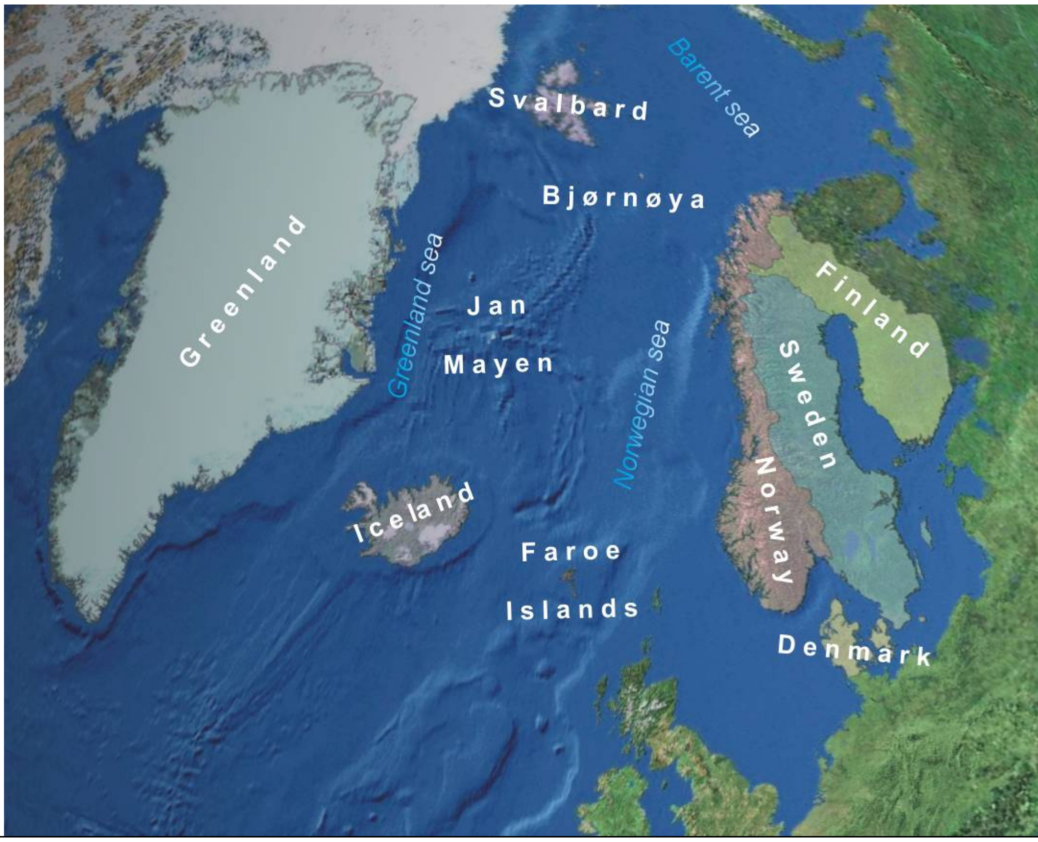


Fig. 1. The Nordic countries (Source: ArcGlobe).

2. The Faroe Islands

Gunnar Bjarnason, Anna Maria Fosaa and Erla Olsen

2.1. Introduction

The very first settlers that came to the Faroes likely brought with them sheep, and sheep has been the dominant herbivore on the islands since. The impact of grazing is visible on a broad scale, both when considering plant species, vegetation height and the extent of erosion. Controlled studies of the impact of grazing have not been conducted, though some information can be extracted from other vegetational studies.

2.2. Study site

The Faroe Islands is a treeless archipelago situated between 61^{o}20' and 62^{o}24' N and between 6^{o}15' and 7^{o}41' W in the warm North Atlantic Current. The nearest neighbour, the Shetland Islands, is 345 km to the southeast. The Faroe Islands consists of 18 islands separated by narrow straits with a total land area of 1400 km^2 of which 50% is 300 m a.s.l. or higher. The distance from north to south and from east to west is 113 km and 75 km respectively. The highest mountain peak is 882 m a.s.l. More than 90% of the land is uncultivated outfield.

2.2.1. Bedrock, quaternary deposits and soils

The Faroe Islands was formed by volcanic activity during the Tertiary, about 50-60 million years ago. From a geological point of view, the islands belong to the North Atlantic Basalt Area. Part of this area occurs in north-east Ireland, the west coast of Scotland, in south-east and north. During the last ice age, the Faroe Islands was covered with its own ice cap, distinct from the ice cap covering continental northern Europe. Possibly only the highest mountain peaks protruded from the ice, forming nunataks. These nunataks are thought to be refugia for some arctic plants, which were able to survive there. The majority of the present plant species invaded the islands after the ice disappeared about 10,000 years ago through the action of wind, ocean currents, birds, and later, by man. The soils are developed from fairly homogeneous, basalt parent material under humid and cool conditions. The time the processes have had to function is short on a geological timescale – about 10,000 years. The soils are continuously wet or moist and generally have a thick organic horizon. They are strongly acidic with high cation exchange capacities and low base saturation. The soils higher up are more minerogenic and with less vegetation cover. The soil here is less acidic and the vegetation forms grassland and grassy moors. These constitute the most important pastures for the thousands of grazing sheep.

2.2.2. Climate

The climate is highly oceanic with cool summers and mild winters. It is greatly influenced by the warm North Atlantic Current and by proximity to the common cyclone track in the North Atlantic region. Consequently, the climate is humid, variable, and windy. The location of the islands in the path of the warm North Atlantic Current makes the temperature more than 5^{o}C higher than it would have been without the oceanic heat transport (Seager et al., 2002). Air temperature observations from Tórshavn show a general warming from the beginning of regular observations in 1873 until around 1940. This was followed by a cooling until around 1980 and a warming since then. This development is somewhat similar to the changes in global mean temperature, but the cooling from 1940 to 1980 was much more pronounced in the Faroes than for the globe as a whole, while the subsequent warming has been weaker in the Faroes, perhaps due to reductions in the Atlantic water flow past the islands (Hansen *et al.,* 2001).

The warmest months are July and August with a mean temperature of 11^{o}C (lowland) and the coldest month is February, with a mean temperature of 4^{o}C (lowland). Precipitation reflects the topography of the islands with c. 1000 mm per year at the coast and more than 3000 mm in the central regions. Wind is one of the main factors affecting the vegetation both directly and by salt spray, which is carried inland. The growing degree days (GDD) has been calculated by summing the temperature excess over 5°C for all hourly observations in a year and dividing by 24 (Molau and Mølgaard, 1996). The mean GDD were 1036 for lowland sites, and ~ 450 GGD at high altitudes.

2.2.3. Vegetation

The islands are heavily grazed, and “natural” vegetation is thus rare. In the bottom of valleys, in depressions and other wet areas, mires have developed. The basis for the marsh vegetation is peat, which has played an important role for the Faroese population up to present. The cutting of peat was very common and artificial depressions have been formed in the terrain, which have promoted even larger areas of marsh vegetation. Due to the extreme oceanic climate, it is difficult to delimit plant associations. The differences are small compared to other countries and it is necessary to indicate a gradual transition from one association to another. Various methods and terms have been used to classify the vegetation of the Faroes (Fosaa, 2001). Because of the strong land use impact, “natural” vegetation can only be found in inaccessible places. *Racomitrium* heaths, some snow-bed vegetation in areas with late-lying snow, and fell-field vegetation dominate the alpine vegetation. *Calluna* heaths are common in the lowlands on most of the islands. The heath vegetation is very mixed with many grasses, herbs and mosses. The most dominant vegetation in the Faroe Islands is grassland vegetation, found from sea level to the mountain-top. Three types of mires are found in the Faroe Islands, topogenic, soligenic, and ombrogenic. Raised bogs are not found. Most parts of the Faroese coastline consist of more or less vertical cliffs with a few sand beaches and salt marshes. Sand dunes are found at one place only.

The Faroe Islands

2.3. History of sheep grazing management

The village was the central point in the traditional settlement. Included in the village were both cultivated infield and uncultivated outfield. The infield was – and still is – used for the production of winter fodder. The outfield was held in common, and used as pasture for both sheep and cattle throughout the year. From 1298 these pastures were regulated by the "Sheep Letter", a Norwegian document setting regulations for the Faroese agriculture. This letter also recommends the use of set stocking rates (Thomson *et al.*, 2005). Included in the rights to the land where rights to the bird-cliffs, peat and other natural resources.

The old tradition was to utilize the whole outfield, including the higher altitudes. Grazing at high altitudes was considered to improve the sheep health, both because the grass at high altitude was stronger and tougher, but also due to the walk uphill. Lambs from sheep that preferred low altitude were usually not allowed to breed. Sheep farmers also put an effort in improving the outfield in terms of drainage and preventing landslides.

Faroes sheep populations had considerable fluctuations from year to year during several centuries. These fluctuations continued until the 1920ties, when medicine came into common use. At the same time road construction facilitated the sheep management, and it has become increasingly more common to provide extra sheep food during the winter, especially in outfields that are directly accessible by car. There is no approved slaughterhouse in the

Faroes, so farmers and other sheep-keepers slaughter their sheep themselves. Most of the product is used by the farmers themselves and their family members, although some meat may be sold within the Faroes. Overall, the sheep management today is in many ways as in the old system, and thus mainly based upon an "in natura" economy and not so much driven by modern productivity.

2.3.1. Number of sheep

The number of breeding sheep is estimated to be around 70.000 (in 2004). On average, there are 57 ewes per km^2. There is a large variation in the number of ewes per hectare in the outfields, from less than one hectare per ewe till 7 hectares per ewe. However, it is difficult the get reliable data for the number of sheep, both because there are no official requirements for registration of the individual sheep, and also because the farmers slaughter their sheep themselves.

Table 1. Estimated number of ewes in the Faroe Islands.

Source	**Year**	**Estimated number of ewes**
Bjørk (1956/57)	Before 1600, "old sheep breed"	200.000
Svabo (1976)	1781/1782	75.000-100.000
Patursson (1919)	1870	100.000
Bjarnason (2004)	2004	70.000

2.3.2. Breeds

The Faroe sheep is a variant of the North European short-tailed sheep. The breed has been kept in isolation on the islands, and genetic influence from other breeds is considered to be minimal. The sheep are mostly white (~ 30%), black (~ 30%), grey (~ 30%), or brown/moorit (~ 10%) with a high frequency and variation of piebald animals as well as mouflon and other types of symmetric pigmentation. Most rams are horned and around 2/3 of the ewes are polled. There have been some recent imports of sheep to the Faroes, especially of Scottish Blackface. Other breeds were imported from Iceland, Sweden and Greenland.

2.3.3. Management: grazing season, supplemental feeding

The sheep graze the outfield the whole year as in former times, but some flocks are allowed to graze the infield during the winter, depending on whether the outfield and infield are adjoining pastures. Some shelters have always been provided, traditionally small open shelters/rough stonehouses. The last fifty years some relative large sheep-houses have been built, often in the vicinity of roads. The increasing use of fencing has also made it necessary to build new shelters for the sheep, because the fences delimit the access to the old shelters. There have been recent accidents where quite a lot of sheep died in bad winter-weather because no shelters were accessible.

2.3.4. Management: law and other regulations

Todays management is still based on the regulations given by the “Sheep Letter” from 1298. Although agricultural regulations were introduced in 1937, these regulations only confirmed the existing practice, but provide methods how to solve disputes between neighbours. No regulation of grazing pressure has been introduced. It is up to the farmers to decide how many sheep there should be in each outfield, as long as they manage to keep them within their own area. This can however be rather difficult to control.

2.3.5. Main products (meat, wool, milk)

Wool was the main product until c. 1900. Since then the value of the wool has decreased and is now negligible. The main product the last century has been meat, of which most is wind-dried and used as either ”hung meat” or ”dried meat”. There is no record of sheep milking after the thirteenth century (Thorsteinsson, 1977), but it might have been practiced by the first people who settled in the islands, as indicated by both archaeological artefacts, place-names and man-made structures that closed off areas (Arge, 2005).

2.3.6. Economy: subsidies, income

The only subsidies for sheep farmers is the VAT refunded. Most of the meat is used for own consumption, or sold privately. Hence refund is only paid for 150.000 kg meat per year, from an estimated breeding stock of 70.000 sheep. Marked price per kg is around 60 DKK (in year 2007).

2.4 Ecological effects of sheep grazing

2.4.1. Sheep grazing ecology

No published data are available. However, personal observations by Gunnar Bjarnason indicate that the ewes fight for their territories, and that it is an advantage to be horned. The weaker sheep ends up in wetter areas.

Habitat selection

In general the sheep is grazing lower altitudes during the winter, and goes a bit higher up during the summer, if the high altitudes were not grazed during the winter. There are especially two critical periods during the year: from September and till slaughter by the end of October the grazing pressure is often too high to feed the animals, and again from January till spring.Wet areas are avoided as long as possible, so typically the sheep graze the wet areas in the autumn.

Plant selection

The sheep are selective and e.g. prefer both flowers and leaves of *Agrostis capillaris* and *A. canina*. It is more common so see a *Festuca vivipara* in flower than *F. rubra,* which might indicate that the sheep prefers the flower of *F. rubra* (E. Olsen, pers. observ.). Some plant species are not grazed before late autumn. These include *Juncus squarrosus* and *Deschampsia* *cespitosa* (Gunnar Bjarnason, pers. observ.). There are no observations of grazed *Nardus stricta.*

Life history (Productivity, mortality (predators), annual growth)

The wool is double coated; the greasy fleece weight is around 1 kg. Adult wither height of rams is 80-85 cm and 70-80 cm of the ewes. The live weight of rams and ewes is 75-85 kg and 40-50 kg respectively. The mean litter size is 0.8 lambs at birth and 0.7-0.8 at the time they are weaned. This low litter size is expected to be due to the strains on the ewes from November to May/June, both in terms of food and weather conditions. Mean carcass weight of lambs is 12.5 kg when slaughtered at the age of 5 months, but weight may vary considerably. There is no predation on adult sheep, but weak newborn lambs can be attacked by birds of prey, such as raven.

Diseases

The following sheep parasites have been found in the Faroe Islands: Nematodes in the abomasums (*Teledorsagia circumcincuta, T. trifurcata, T. davtiani* and *Trichostrongylus axei)*, nematodes in the small intestine *(Trichostrongylus vitrinus, Nematodirus battus*, and *N. filicollis)*, nematodes in the large intestine (*Chabertia ovina, Oesophagostomum venulosum*, and *Trichuris ovis)*, nematodes in the lungs (*Dictyocaulus filaria* and *Muellerius capillaries*), cestodes in the small intestine (*Moniezia expansa)*, cestodes in the abdominal cavidy (*Cysticercus tenuicollis* (*Taenia hydatigena*)), coccidia in the small intestine (*Eimeria* spp), flukes in the liver (*Fasciola hepatica*), and ectoparasites (*Bovicola ovis* and *Melophagus ovinus)*. There are significant reasons to believe that *Psoroptes ovis* is also present. It is anticipated that these parasites would have a great impact on the health of the sheep in the Faroe Islands, if proper management and medication were not provided (Hanusson, 2001). Around 20 cases of *Narthecium ossifragum*-associated photosensitization are diagnosed every year, and the problem is considered of minor importance (Flåøyen *et al.*, 1993). The most important other diseases are scrapies and Johne's disease.

2.4.2. Effects on plants

A short term experimental grazing study showed that five plant species changed their abundance significantly after 4 years (Fig. 2; Fosaa and Olsen, 2007). At low altitude (70 m a.s.l.) *Nardus stricta* (which had the highest abundance in grazed plots) decreased in sheep exclosures while more palatable grasses like *Agrostis capillaris* and *A. canina* increased in exclosures ($p < 0.01$) as did the sedge *Carex panacea*. Herb species like *Potentilla erecta* increased their abundance in ungrazed plots significantly ($p < 0.01$) and the same trend was seen for *Narthecium ossifragum* although these changes were not significant.

At high altitude (600 m a.s.l.), *Agrostis canina* increased in ungrazed plots (as compared to grazed plots; $p < 0.05$) while *Euphrasia* sp., had a significantly higher abundance in grazed plots ($p < 0.05$). In ungrazed plots, an unsignificant increase in the abundance of *Deschampsia cespitosa*, *Bistorta vivipara*, and *Salix herbacea* was observed while the abundance of *Festuca rubra* showed a non-significant increase in grazed plots.

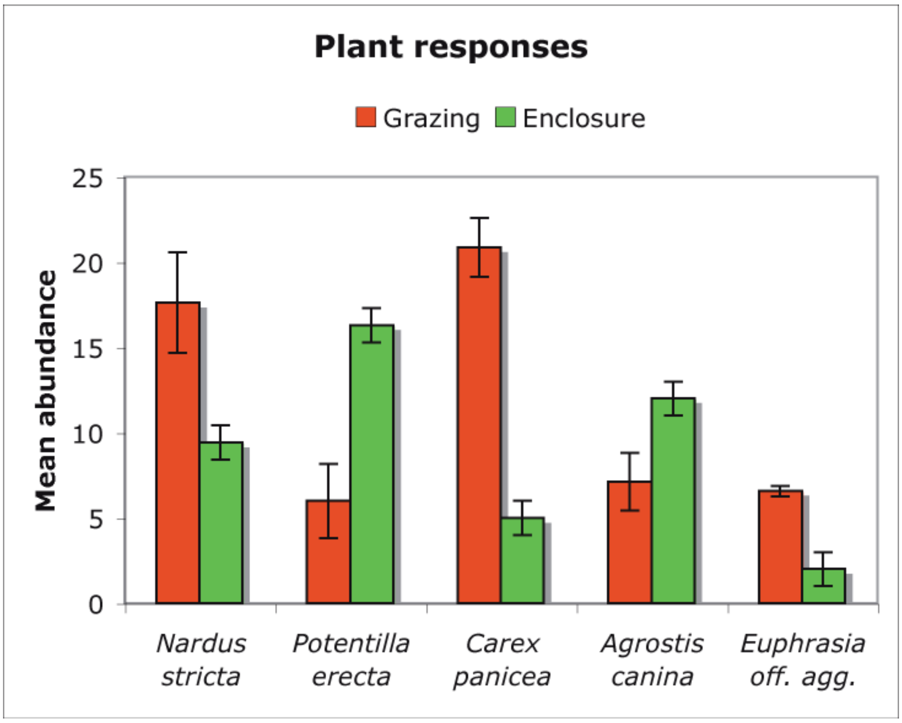


Fig. 2. Mean abundance of plant species with significant response to grazing, in grazed and ungrazed plots. *Nardus sticta, Potentilla erecta* and *Carex panicea* had significant responses at low altitude only, while *Agrostis canina* and *Euphrasia sp*. had significant results at high altitude only. Bars indicate ±SE.

Plant community

The plant community types in the Faroes have been divided into six main categories, starting from high altitudes with alpine vegetation, continuing into lower areas, which are divided into five categories: heath vegetation, grass vegetation, mire vegetation, freshwater vegetation and finally coastal vegetation (Fosaa, 2001).

Thirtysix community types have been categorized into alpine vegetation, heath vegetation and grass vegetation. In addition to this, thirty community types were categorized into mire vegetation, freshwater vegetation and coastal vegetation.

Only limited information is available from the Faroe Islands on the effect of grazing on the vegetation. An attempt to compare the grazing indicators, *Nardus stricta* and *Carex panicea* with the number of sheep did not show a significant relationship.

Plant functional groups

Fosaa and Olsen (2007) grouped the plant species in the following functional groups: graminoids, herbs, mosses, and lichens (Fig. 3). At 70 m a.s.l., the abundance of graminoids was lower in ungrazed plots than in grazed plots. The same was the case for mosses, but the opposite was the case for the herbs. The abundance of lichens was in general very low. At 600 m a.s.l., graminoids and mosses had a higher abundance in ungrazed plots than in grazed plots. For the other functional types, only small differences were found between grazed and ungrazed plots. None of the changes in abundance of the functional types were significant.

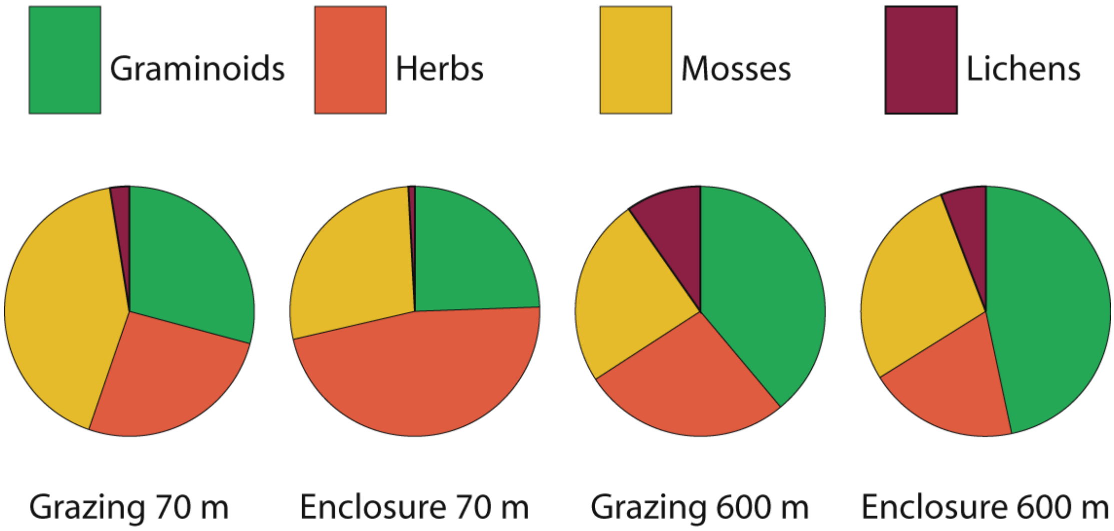


Fig. 3. The abundance of the four functional groups graminoids, herbs, mosses and lichens in grazed and ungrazed plots at 600 m a.s.l. and 70 m a.s.l.

Biomass, productivity

After four years, Fosaa and Olsen (2007) also found grazing effects on the vegetation biomass. In sheep exclosures, the mean increase in vegetation cover at the alpine site (600 m a.s.l.) was 14% and the mean length of the highest grass leaf increased 25%, from 4.4 to 5.5 cm ($p < 0.05$; Fig. 4). At the lowland site (70 m a.s.l.), the difference was even more profound as the vegetation cover inside the exclosure increased with 17% and the mean length of the highest grass leaf had increased with 62% (from 14.5 to 23.5 cm; $p < 0.05$; Fig. 4).

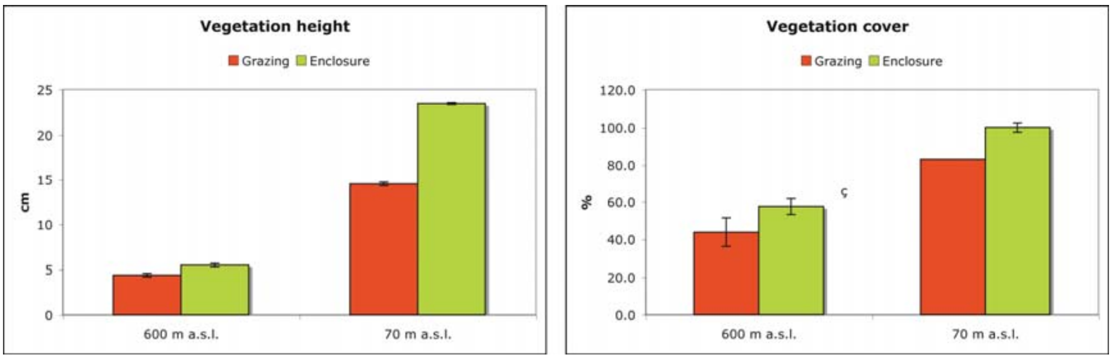


Fig. 4. Mean vegetation height in cm (a) and percent cover (b) in grazed and ungrazed plots at 600 m a.s.l. and 70 m a.s.l. Error bars indicate ± SE.

2.4.3. Ecosystem effects

Sheep grazing & nutrient dynamics (chemical, physical and biological properties of the soil)

In general, the Faroese soils are poor of available nutrients, but nutrients and organic matter typically increase downslope, and the soils also become more acid at low altitude. The extractable phosphate (Olsen-P) and total nitrogen varied between 10-25 ppm and 0.2-1.5% respectively. Both P and N were highly positively correlated with the loss on ignition (LOI). LOI was in the range of 10-55% (Olsen and Fosaa, 2002). Fosaa and Olsen (2007) also measured the water-soluble phosphate and soil moisture content at grazed and ungrazed plots and found no significant response to grazing. On the other hand the roots of the palatable grass *Agrostis capillaris* were finer in grazed plots at high altitude than in ungrazed plots at high altitude ($p < 0.01$), while there was no significant difference in the roots from low altitude (Fig. 5). The percental arbuscular mycorrhizal colonisation in the roots from grazed *Agrostis capillaris* tended to be greater in roots from grazed plots than in roots from in ungrazed plots, though not significantly ($p = 0.084$; Fig. 5).

Thus the response of grazing was more root growth and greater root colonisation. Both these factors indicate a greater nutrient demand in plants, probably used for regrowth, when plants are grazed.

Erosion

The vegetation cover is decreasing with altitude, from on average 85% at low altitudes to less than 50% at higher altitudes (Fosaa *et al*., 2006a). According to Fosaa *et al.* (2006b) the eroded areas, which mainly are found at high altitude, account for almost 10% of the total land area. The erosion is more profound in the outfields than in the infields, and Mortensen (2006) estimated the eroded part of a typical Faroese outfield to be close to 25%.

Mammals, birds, insects

The sheep is the main mammal on the islands, and it is likely that other life-forms are affected by the dominance of sheep. However, no studies of sheep grazing effects on animals have been conducted. In total 54 bird species nest regularly in the Faroes, but in general the bird-life is in decline, and several bird species are considered vulnerable. Of other terrestrial mammals in the outfield there is the hare, introduced 100 years ago, and the rat (and possible mouse). No recent registration of the Faroes animal species exists, but the estimated number of insect species are ≥1000. In addition to this there are a lot of invertebrates, many never registered (Hansen, 2006).

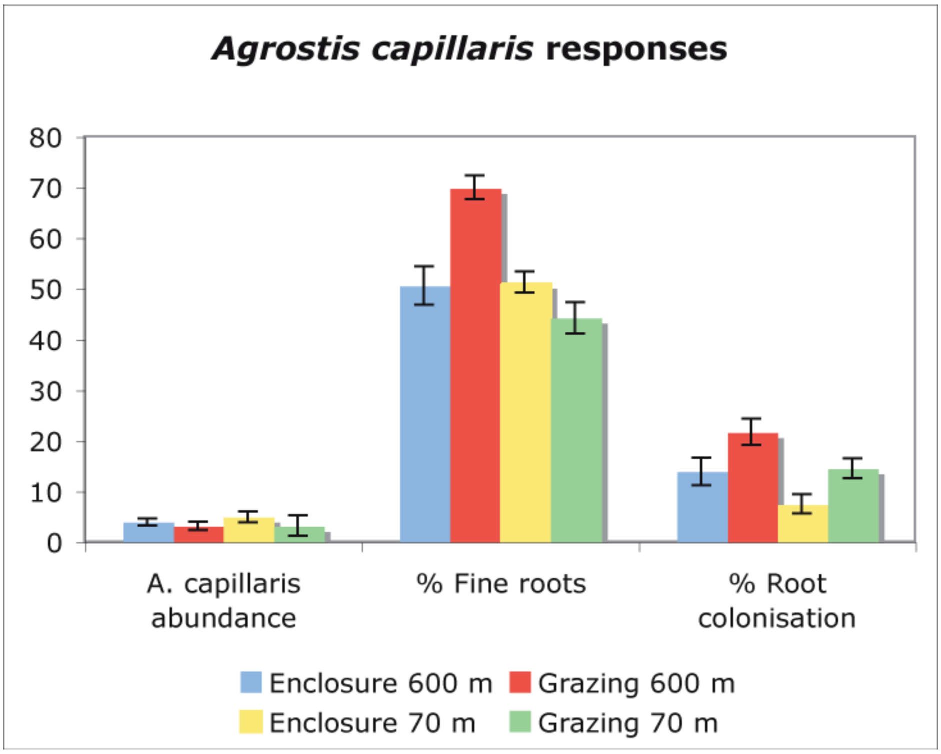


Fig. 5. Mean responses of the plant species *Agrostis capillaris*: the abundance, the percent fine roots and the percent root length colonisation by arbuscular mycorrhizal fungi in grazed and ungrazed plots at 600 m a.s.l. and 70 m a.s.l. Bars indicate ±SE.

2.5. Sustainable management in an ecological and economic perspective

In total, the sheep grazing impact has increased in the Faroes during the latest decades due to three main changes in management. Firstly, feeding the animal during winter together with minerals, vaccines and medicine has decreased the death rate, both of adult sheep and lambs, and thus the mean number of sheep is considerable higher than previously. Secondly, due to the changed practice with feeding etc., but also due to the selection of larger animals for the meat production, the sheep are larger today and therefore require more fodder for their maintenance. The traditional livestock at the Faroes were small. That applies both to sheep, cattle and horses. Finally, the number of cattle is decreasing, and there is a trend to increase the number of sheep as a compensation.

The sheep management in the Faroes is mainly based upon an "in natura" economy, and there is no official registration of the contribution to the national household. The sheep number is high, and the impact of the high grazing pressure is visible in many places, for example as changed vegetation. Moreover, the area of the land affected by erosion has been estimated to be 10-25%. Though it has not been documented that the erosion is due to a too high grazing pressure, it is questionable whether the current sheep management in the Faroes is sustainable.

3. Iceland

Anna Gudrún Thórhallsdóttir, Ingibjörg S. Jónsdóttir and Borgþór Magnússon

3.1. Introduction

When the first Norse settlers came to Iceland they entered a pristine land. Sheep has been the main livestock in Iceland since the time of the Norse settlement in 874.

3.2. Study site

Iceland has a land area of 103.000 km^2. It is situated between 63° 24' - 66° 32'N and 13° 32' - 24° 28' W. There are several islands at the coastline, the biggest are Heimaey (13.5 km^2, in Westman island chain) off the southern coast, Hrisey in Eyjafjord northern Iceland, and Grimsey, which is on the Arctic circle, off the northern coast. Highlands and mountain areas are extensive in Iceland. All the central part of the island is highland area. The highest peak, Hvannadalshnjukur, 2119 m a.s., is found in the southernmost part of the Vatnajökull glacier (8.300 km^2). Glaciers cover about 11% of Iceland and lakes and rivers 1.5%.

Greenland is the closest landmass to Iceland, the shortest distance between the countries being approximately 290 km to the northwest. The Faroe islands are 410 km to the southeast, Scotland 790 km to the southeast, Norway 970 km to the east and Jan Mayen 1760 km to the northeast.

Iceland is geologically young. It is located on the Mid Atlantic Ridge. Plate tectonics, seafloor-spreading, hotspot and volcanism are key words regarding the geological processes in Iceland. The North-Atlantic Ocean began opening about 60 million years ago. During that time span the North-American plate and the Eurasian plate has moved east and westwards, approximately by 1 cm a year in each direction. This process is still lasting today. Iceland is the longest ridge segment and largest landmass exposed anywhere along the Mid-Oceanic ridge system, due to a hot spot that is located near the ridge in Iceland. The main zone of volcanic activity goes through Iceland from the southwest to northeast. In this zone bedrock and sediments from the Holocene and Late Quaternary (< 0.7 m yrs) are dominant. To the west and east of this zone the bedrock is older, from the Tertiary. The oldest bedrock in Iceland dates at about 3.1 million years. Due to Iceland's locality over the Mid-Atlantic Ridge, basalt is the dominant rock type in the region.

Iceland is one of the most active volcanic countries in the world. There are about 200 post-glacial volcanoes, at least 30 of which have erupted since the country was settled in the 9^{th} century A.D. On average there is an eruption every fifth year. Nearly every type of volcanic activity found in the world is represented in Iceland, the most common being fissure eruptions. The most famous Icelandic volcano is Hekla in the southern part of the country, which has erupted 19 times in history. One of the most severe eruptions in Iceland was the

Lakagigar eruption in 1783. A 30 km fissure opened with about 100 separate craters. The lava flow from the eruption covered 565 km^2. The gases and ash poisoned grasslands, causing tremendous havoc to the countryside. The resulting damage to the farmland brought widespread famine to Iceland resulting in the deaths of livestock and tens of thousands of people through starvation. It is believed that the eruption had a cooling effect on climate in the northern hemisphere, due to fine particles that were spread long distances in the atmosphere. Due to the frequent volcanic eruptions in Iceland, soil sediments are relatively thick and rich in volcanic ash layers. Many of these layers are of known age and distribution within the country. They can be used to date soils of different depths.

The climate of Iceland is oceanic, with high humidity and frequency of strong winds. Due to the influence of the North Atlantic Drift, the climate is much milder than might be expected considering the northerly location of Iceland. Thus winters are relatively mild and summers are cool. The mean annual temperature for Reykjavik (1961 – 2000) is 4,4 °C and mean annual precipitation 807 mm. The average January temperature is –0.4 °C and for July, 10.7 °C. The annual precipitation is highest in the southeast part. The south-eastern slopes of Vatnajökull receive over > 4000 mm of annual precipitation. The driest areas in Iceland are, on the other hand, in the highlands to the north of Vatnajökull, with < 400 mm of annual precipitation. The longest continuous air temperature records in Iceland are from the meteorological station in Stykkisholmur in western Iceland, going back to 1823. They show a variation in mean annual temperature of 0.9 – 5.5 °C. The records show definite long term climatic trends. The coldest period was between 1860 and 1890 but warmest between 1930 and 1960. A strong warming trend has also occurred in the last 10 years.

The flora and fauna of Iceland is rather poor, due to the isolation of the island and short time from the Ice Age, when Iceland was probably completely covered by glaciers. There may have been periods with pockets of ice free areas (e.g. mountain peaks and volcanic or geothermal areas) with some plant and animal life. However, indications are that most of the present biota of Iceland is postglacial.

The flora of Iceland includes about 480 species of vascular plants. About 97% of these species are also found growing in Norway, 87% in the British Isles, whereas only about 60% are found in Greenland. The character of the Icelandic flora is therefore distinctly North European or Scandinavian. About half of the Icelandic species are boreal species, having their main area of distribution in the conifer region of the northern hemisphere. On the other hand, only about one third of the species are arctic-alpine species, with their main distribution in the treeless areas north of the Arctic Circle and in mountains of regions farther south; the rest of the species being coastal plants and other groups of species with wider distribution, like fresh-water plants and weeds. Grasses and sedges are the most common vascular plants in Iceland, the Sedge Family being far the biggest family comprising 53 species. The bryophyte flora of Iceland includes about 600 species. It is more of a temperate character than arctic. Some bryophytes are extremely common and conspicuous in the landscape, like *Racomitrium lanuginosum* and *R. ericoides,* which cover extensive areas in lava fields and stony areas, both in the lowlands and in the highlands. Over 600 species of lichens have been found in Iceland. The lichen flora is of a Scandinavian character. The upper level of continuous vegetation cover in Iceland is generally at the 600 – 700 m level and birch-shrub woodland extends to 250 – 350 m on the average.

Iceland was settled between 874 and 930 A.D., by Norsemen from Scandinavia and Celts from the British Isles. Around the year 1100 it is estimated that the population was 70 -

80.000. It was to decline during cool periods and when violent volcanic eruptions and famine struck the country. In the eighteenth century the population declined below 40.000. The present population in Iceland is around 300.000. Over 90% live in towns and villages.

The present nakedness and lack of trees in Iceland is largely due to man and his livestock. When Iceland was settled 1100 years ago, most of the lowlands, or about 35% of the total area of the country were covered with Birch (*Betula pubescanes)* wood and shrub and willow (*Salix)* cover was also high. After the settlement, the woods were cut for fuel and housing. In addition, heavy grazing by livestock (sheep, cattle, horses) damaged the vegetation and caused disturbance so that the wood and shrub (the chief protectors of the easily eroded volcanic soils of Iceland) were gradually destroyed and soil erosion started. This became more and more serious with the result that in extensive areas all upland soil was blown away. About half of the land area below 400 m level, which was without doubt formerly covered by vegetation, is more or less bare and only small areas of the extensive wood and shrub-land still remain.

Vegetation of lowland and highland areas in Iceland is under strong influence from utilization by cultivation and livestock grazing. Most of the extensive lowland wetlands were affected by draining in the last century and very few of them remain intact. Most of the wetlands are base rich, with a relatively high pH, and may be classified as sedge fens. In the lowlands, grasslands, modified wetlands and heath-lands are the dominant vegetation types at present. In the highlands, barren areas, heath-lands and wetlands are most extensive.

Livestock numbers in Iceland were relatively low and limited by climatic conditions and frequency of volcanic eruptions, determining the size of the human population as well. After 1800, livestock numbers start to increase, especially the sheep stock. The number of winterfed sheep peaked at 900.000 in 1977. With so many sheep in the country, severe overgrazing occurred in many areas. Since that time the numbers have decreased by half. On the other hand, the number of horses has almost doubled during the same time, which has led to considerable overgrazing in many lowland pastures. At present there are about 80.000 horses in the country. The numbers of cattle has remained rather stable during the last 30 years, with about 30.000 milking cows. The cattle mainly graze on cultivated land and have limited effects on other pastures.

Traditional farming has declined in Iceland in the last 50 years. Fewer and fewer people live in the rural areas. This has caused changes in land-use. Some traditional farming areas have very limited livestock left. Afforestation programs have been introduced by the government and also there are extensive land reclamation programs in the country. Introduced species, e.g. Larch, Spruce, Pine and Nootka lupine are used extensively in these programs, which has been a matter of debate. The Nootka lupine was introduced to Iceland in 1945. It may be considered as the first introduced plant species that has started to grow and spread out of control in Iceland in areas where sheep grazing has ceased.

Iceland

3.3. History of sheep grazing and management in Iceland

In the first centuries of Icelandic history, wool was the most important product of the sheep and wool cloth (vadmal) was the main currency in Icelandic foreign trade. So important was the wool cloth in the Icelandic economy, that its value was determined in the Icelandic book of law from the early 12th century, as 6 alin equal to 1 eyri of silver or 120 alin as 100 cow units (Gragas, 11th century). In the early 14th century, export of wool cloth from Iceland decreased, and fish products took over as the main currency in Icelandic foreign trade (Thorkell Johannesson, 1943). This change in production and export of wool cloth did not only occur in Iceland. In the early 14th century, the international trade in cheap cloth collapsed, and cloth exports from Britain also declined (Rorke, 2006). In 1329 Magnus Eiriksson, king of Norway made a declaration on how the wool cloth should be made, in response to complains about lowering quality of the wool cloth (Thorkell Johannesson, 1943). Better quality cloth took arise in exports from England in the middle of the 14th century, but for Iceland, wool cloth exports became history. Knitted woollens, socks and mittens however became an important product in export trade in Iceland soon after Icelanders learned to knit in the last part of the 15th century. Although knitted woollens were an important currency from the 16-19th century, fish products were the most important export from Iceland in this period. (Knitting woollens is first mentioned in Icelandic trade documents in 1581, and in 1624 Icelanders exported 72.231 pair of socks and 12.232 pair of mittens. In 1764, the numbers were 252.495 for socks and 59.309 for mittens!).

For more than 400 years, while wool was the main currency in Icelandic economy, the main aim for sheep husbandry was kept as to maximize wool quantity and quality. In the first centuries after settlement, c. 25% of the land was covered with forest (birch and willows) and sheep had to be kept out of the forest to prevent damage to the wool. From the sagas it seems that in these first centuries, at least part of the sheep were kept in pastures (tun) by the farm to ensure good quality wool. Most of the sheep though grazed free roaming in extensive common pastures during the summer and closer to the farm during the winter (Thoroddsen 1919). Wethers give more wool and are more able to torerate winter grazing as compared to lactating ewes. Wethers were therefore much more numerous in earlier times to ensure wool quantity, and could reach 50% of the sheep numbers in each stand (Thoroddsen 1919; Thorhallsdottir & Thorsteinsson 2005). The change in the importance of the wool in the 14th century and worsening of the climate from the late 13th century and repeated epidemics led to a change in farming practices in Iceland. Many small farms, often located in the highlands, were abandoned and more people moved to the cost to make a living from the sea. Further, during this period, export from Iceland changed dramatically and in the middle of the 13th century, dry fish and fish liver oil took over as the main export good from Iceland (Thorsteinsson & Grimsdottir 1989). This change must have led to a change in farming practices, with decreasing sheep numbers and less grazing pressure, especially in the inland (Thorhallsdottir 1991). From the 14th -17th century, the number and importance of cattle seems to have decreased, and the importance of sheep, especially for milk, increased (Thoroddsen 1919). There are, however, no documentations on the number of animals from this period. Lactating ewes must be kept under daily control in the lactation period during the summer. Thus, these were kept under controlled grazing during the summer, either from the farm or the summer farm in the mountains and only the wethers and lambs were allowed free roaming grazing. The first actual count of number of farm animals in Iceland was done in 1703-1712 upon the request of the Danish king. Of the 279.000 sheep counted, 111.000 (40%) were wethers and other non-lactating animals. As farming practices seem to have been largely unchanged during the 15-17th century, the proportion of lactating ewes to non-lactating animals in the flock in 1703 is likely to reflect the combination of the sheep population for that period and the management practices (Thorhallsdottir 1991). The counting of farm animals from 1760 gives just the total number, but in 1785 there are 51.236 lactating ewes and 13.223 non-lactating ewes in the country, or 26% wethers ect. Countings throughout the 18th century, reveal the same relationship between lactating ewes and wethers; 75:25. During this period, the management system is well documented. Lambs were born in the infield in late May and were allowed to go with their mothers for 3-4 weeks. Between 24 June and 2 July, lambs were separated from their mothers and they were kept home for one week before they were driven to the mountain pasture, along with older and dry ewes. No more than 1 dry ewe was allowed to go with every 10 lambs (Jonsbok 1281). The ewes were milked until late October (veturnætur 23-24 October; Thoroddsen 1919). On most farms, ewes and wethers were housed or at least kept in enclosures by the farm at night during the winter, and grazed during the day. Supplement hay was provided in the evening when available, but in may years, there became shortage of hay and loss of animals due to starvation, a painful experience for most farmers year after year, especially in the cold 18th century.

Industrialization and growing cities in Britain in the latter part of the 18th century led to a change in the Icelandic farming system, especially sheep management. Around 1880, British salesmen started to come to Iceland to buy sheep. In the beginning, these were transported alive to Britain and slaughtered there to supply growing cities in Britain with meat, mutton and lamb. Soon however, sheep were slaughtered in Iceland and salted meat exported in barrels. The importance of meat, especially lamb changed rapidly. Now the most important factor in the management became a good growth of the lambs and the importance of the ewes milk declined rapidly. Lambs now, for the first time in centuries, started to go with their mothers during the summer and milking of the ewes was brought to an end. Good grazing land became very valuable and farming communities bought good grazing land in the highlands, mostly from churches and bigger farms. By 1920, hardly any farms kept their ewes for milking, and all were now producing lambs for slaughtering. At the same time, cultivation of the infields increased and in the 1940-ies, draining of the wetlands for cultivation changed the possibilities for producing winter forage for the sheep flock dramatically and thus the possibilities for increasing the numbers of sheep on the farms.

3.3.2. Number of sheep

There is no available date on number of livestock in Iceland until early 17th century. However, annuals and registrations from churches as early as from the 11th century and various written decrees and judgements cast a light on size of the sheep flock in different settings throughout the history. From the 11-14th century, the size of the sheep flock owned by larger churches was often 100-150 ewes (i.e. Reykholt-church 1185: 150; Garðakirkja-church 1220: 108), and prosperous farmers would keep 2-300 on each farm they owned (Guðmundur ríki – Gudmund the rich 1446: 288 at Kaldaðanes, 347 at Brjánslæk and 216 at Felli í Kollafirði). In the year 1374 there were 963 sheep at the bishop's settlement at Holar, the second biggest farm in Iceland at that time (Thorvaldur Thoroddsen 1919). From those data it seems that the number of sheep in Iceland from the settlement in the 9th century till the 14th century must have been higher than in the 17th century, when the first census on livestock numbers was taken and probably more like the numbers seen in the late 18th-19th century.

The first census on livestock numbers in Iceland was taken in 1703. In 1703, sheep numbers in Iceland were 280.000, of which 169.000 lactating ewes and 111.000 wethers. In 1770, after import of sheep from England that brought in foreign sheep diseases, the population declined to 140.000, due to deaths and systematic slaughtering to prevent spread of the diseases. In 1784 the lowest sheep numbers were reached, following one of if not the biggest eruption in historic times on earth which occurred at Laki in S-Iceland in 1783. The numbers of surviving livestock from that catastrophe were; 49.600 sheep, 9.800 cattle and 8.700 horses (Hagskinna – Icelandic historical statistics 1997).

Table 2: Number of sheep in Iceland

Year	Number of ewes
1703	280.000
1760	357.000
▪ 1784	49.600
▪ 1800	304.000
▪ 1802	133.200
▪ 1820	260.100
▪ 1853	516.800
▪ 1896	594.900
▪ 1918	644.900
▪ 1933	728.500
▪ 1949	401.800
▪ 1977	896.100
▪ 2000	458.500
▪ 2006	455.656

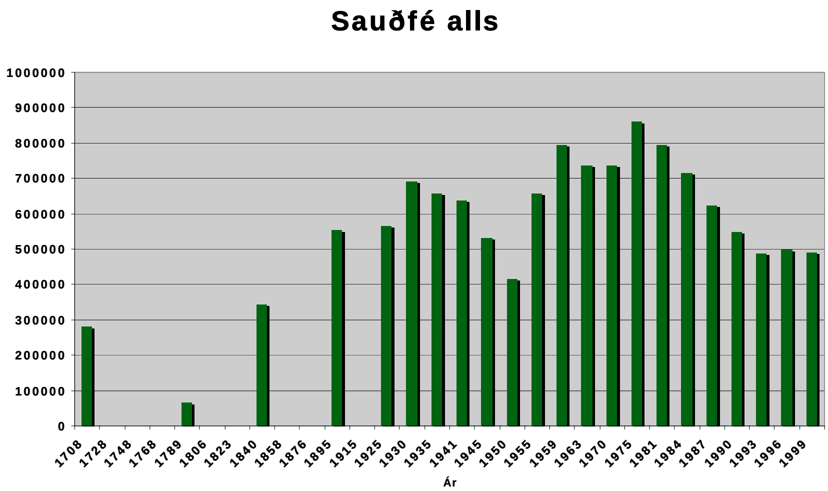


Figure 6. Number of ewes in Iceland – from 1708-1999

After the catastrophe in 1784, sheep numbers increased again in the 1790-ies. However, very cold years in the first decade of the 18th century (1801 and 1802) lead to a decline in numbers again. From around 1840, sheep numbers increased, and were only cut down temporally in very cold years throughout the whole 18th century. In the first part of the 19th century, sheep numbers continued to grow (Hagskinna – Icelandic historical statistics 1997). In 1933, karakul sheep were imported into Iceland from Germany. These sheep brought three different diseases with them into the Icelandic sheep population, diseases that the Icelandic sheep were highly susceptible to (Stefán Aðalsteinsson 1981). To prevent spread of these diseases, the country was divided into sections during 1937-1950, and all interactions, contacts and exchanges of sheep, feed ect., were banned between the sections. Systematic slaughtering within the sections followed, and a new stand of sheep from disease-free sections then brought in. In the 1950-ies, sheep numbers grew again, until reaching the maximum of

960.000 in 1978. Due to closing of foreign markets for Icelandic lamb and mutton and general overgrazing of the grazing areas, a quota system was initiated in the sheep industry in Iceland in 1983, and farmers were forced to cut down on the numbers of sheep. In 1990, sheep numbers were down to 549.000. Since 2000, sheep numbers have been fairly stable; between, 450.000 and 470.000.

3.3.2. Breeds

The native Icelandic sheep was brought to Iceland by the Norse settlers in late 9th century. DNA analysis have shown that Icelandic sheep are closest to the old Norwegian short tail breeds, Spael, Old Spael and Grey Trönder (see fig. 7; Tapio et al. 2005). Relation to the Faeroe Island sheep and Greeland sheep can be explained with recent inbreeding of Icelandic sheep into these breeds (Tapio et.al 2005). In the 18th and 19th century, a few individuals of foreign breeds were imported to Iceland for breeding purposes. This import, however, brought foreign diseases into the Icelandic sheep population which caused both considerable deaths and vast slaughtering to prevent spread of the diseases (see number of sheep). Today the influence of foreign breeds is generally considered to be minimal. However, it has been pointed out that in certain parts of the country, especially in N-West Iceland (Westfjords), were the majority of both ewes and rams are white and pooled, an influence of Cheviot sheep can be seen today (Sturlaugsdottir 2008). In all other parts of the country, about 70% of the Icelandic sheep, rams and ewes, are horned (Eythorsdottir pers.com.). Today, the majority of Icelandic sheep are white. In a study by Dyrmundsson and Adalsteinsson in 1980, 84% were white and 16% multicolour, including all different kinds of colours and patterns (Eythorsdottir pers.com). Earlier, before intensive breeding programs for better wool production for the wool industry in the middle of the 20th century, a larger part of the population was multicoloured.

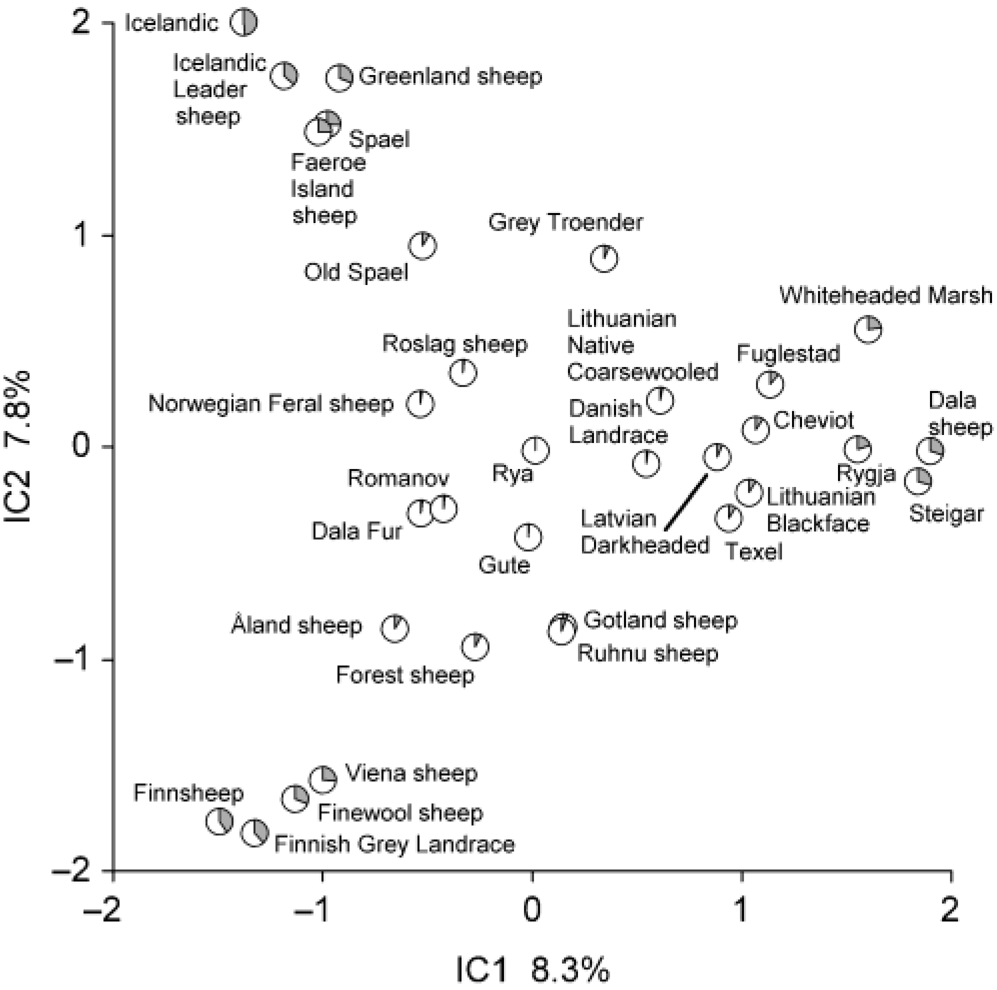


Fig. 7 Plot of two-component solution of ICA for the northern European sheep breeds. The location of the pie diagrams indicates the breed values. In each pie diagram, the dark proportion equals the proportion of the allele frequency variance within the population explained by the two components. For each population, the sum of the variation explained by IC1 and IC2 is identical to the variation that would be explained by the first two PCs together. The most important information for the centrally located breeds is that they do not belong to the three surrounding groups. The breeds with IC1 ≈ 0.5 have intermediate or variable tail-length being intermediates between Northern Short-tailed (IC1 < 0.3) and modern long-tailed breeds (IC1 > 0.75; see text), but they are often categorized into the Northern Short-tailed breed group (Tapio et al. 2005)

3.3.3. Management: grazing season, supplemental feeding

For the last 50 years, or from the middle of the 20th century, Icelandic sheep management has changed little – as the main change occurred earlier (see 3.1). Lambs are born in early May. Today, most lambs are born indoors but a few decades ago lambs were still born outdoors in pastures close by the barn. After a few days indoors, ewes and lambs are moved outdoors to cultivated pastures around the farm. In most years, the infields (cultivated pastures) have started growing so there is grazing for the animals but supplemental feed (hay and concentrates) are now provided by all farmers. Wethers and non-breeding animals are usually moved outdoors as soon as the weather allows and will graze mostly outfields around the farm in May and June. As the plants in the outfields start to grow, farmers will open the gates from the infields and the ewes and lambs can move to larger areas around the farm. In some parts of the country, these outfields are not fenced and the sheep can move freely into extensive mountain areas for summer grazing. In other areas, especially areas that lie to the main inland, the summer grazing areas are Commons belonging to certain communities. These Commons have their own laws and regulations and the date for the start of the grazing season is usually decided by the board of the Commons, often in agreement with the Soil Conservation Service. Farmers in communities having Commons will gather their sheep from their outfields in late June-early Jul and drive their flock up to the Commons. Until the 60-ies, many farmers would move their sheep with horses but today, trucks are used and the driving can take many days for a flock of 500 or more. The sheep will graze freely in these open outfields or Commons during in July and August, in areas that can be hundreds of km^2. In early to middle of September, the sheep are gathered from their summer grazing areas. In smaller and steeper areas the sheep are gathered by walking shepherds. In all larger areas and in the Commons, the sheep are gathered on horseback with the help of dogs. In the largest Commons, these gatherings can take up to 10 days for 10-20 people. The sheep are driven down to the community gathering place, the "rétt", which is usually a wheel formed fence structure – where each farm has its own section in the "weel". All sheep have ear markings, both the traditional ones (ear cuttings) and plastic numbers. Each farmer gathers his/her sheep from the flock and drives it to the farm. There the slaughter lambs are separated from the main flock. The rest of the flock graze on infields or/and outfields until November when most farmers start housing their flock. The sheep are kept indoors in sheep barns until spring and fed on hay or silage, often with the addition of concentrates during the breeding season around Christmas time and again during lamming in May.

3.3.4. Management: law and other regulations

In Icelands first lawbook; Gragas, there are many law and regulations on the use of land for grazing, including the number of sheep that could be grazed on a particular land and the length of the grazing season. Farmers that violated these regulations were punished with heavy charges. These verdicts indicate the importance of grazing land at that time. Payments were made for the use of the land to the owners, which were in the first centuries usually bigger farms that had claimed the land after the settlement. Gradually though, the church managed to gain ownership over a big part of these farms and claimed the payments for their use (Thorvaldur Thoroddsen 1919). In the late 19th century, during the changes that took place in sheep management in Iceland at that time (see section 3 above), most communities bought their common summer grazing land from the church or farms to create a common summer grazing land for the farmers in the community – the Commons. The change of the ownership of the land mostly happened between 1880 and 1900, followed by changes in the regulations regarding the use of the land. All farms in a given community were given access to the common grazing land and could drive their sheep, and usually also horses, to the Commons (afréttir). The price for the use was no longer a certain payment, rather a part of the direct cost for using the land which was mainly gathering the sheep again in the fall. Each farmer had to take his/her part in this cost, according to the number of sheep that the farmer drove on the land, either by providing so many man with horses or pay the cost of getting man and horses from outside. As time progressed, all Commons got their regulations written down and today these regulations are agreed on by the Ministry of Fisheries and Agriculture (Fjallskilareglugerðir). In the late 1960-ies, many people began to have concerns about overgrazing on the summer grazing areas, which in fact cover most of Icelandic inland and mountain areas in other parts of the country. Increasing numbers of sheep during the 20th century, combined with colder climate starting from the middle of the 1960-ies, resulted in heavy overgrazing in many parts of the country. At the same time, consumption of lamb and mutton decreased in Iceland and export of lamb meat became difficult, leading to an overproduction and accumulation of lamb and mutton meat. In the early 80-ies, quota system in sheep farming was initiated and sheep farmers were forced to cut down on their production by 30% in the first run, and more in the following years (see 3.1). At the same time, The Soil Conservation Service started working closer with individual farmers and farming communities, trying to regulate sheep numbers on the summer ranges and not least, regulate the timing of the start of the grazing season. Today, overgrazing by sheep in Iceland is still considered to exist in some areas, while there is an agreement that the condition of most of the summer grazing land has improved considerably in later years, due to decreased number of sheep, shorter grazing season and probably not at least, warmer climate in the last decades (Thorhallsdottir 2003).

3.3.5. Main products (meat, wool, milk)

For the first part of Icelandic history, wool was the most important product from the sheep (see 3 above). In the 14th century, the importance of wool declined and it is likely that Icelanders start to milk the ewes around the same time. In the 18th and 19th century, most ewes are milked and sheep milk is one of the most important products in Icelandic agriculture. In the latter part of the 19th century, markets open for meat in Great Britain and British salesmen start coming to Iceland to by sheep for slaughtering. In the beginning, sheep were sold live to Britain but soon they are slaughtered in Iceland and salted mutton in barrels sold to Britain. Since the 1920-ies, meat has been far the most important product from the sheep industry in Iceland. Between 1960 and1980, there was a blooming in the wool industry in Iceland and wool price was high. However, for the last decades, wool price has been very low in Iceland as elsewhere, and many farmers will even not bother to shear their sheep. If they do so, it is for the welfare of the sheep and to throw away the wool.

3.3.6. Economy: subsidies, income

For centuries, the sheep farmer was the Icelander and sheep was the main production animal. As no villages, not to say towns were found in Iceland until early 18th century. Bigger farms had cows as well as sheep, poorer farmers had only sheep. Sheep farming has never been profitable, but after introduction of the quota system in the 80-ies, the income of sheep farmers decreased considerably and many stopped farming. Others bought quota to be able to increase their production to make better living of the farm, despite the cost of the quota. Subsidies for sheep production were linked to the quota in the 80-ies and therefore subsidies were linked to the production. In 2000, this link was removed and today farmers receive subsidies according to the amount of quota they hold, even though they don’t have sheep to fulfil the quota – they only have to have a minimum of 50% of the sheep stand they receive subsidies for. The quota – or the right to receive subsidies can be sold and bought, but the quota must be signed to a *legal* farm (lögbýli) and there must be at least 50% real sheep behind the quota on that farm. Following the changes in 2000, farmers that show a special good farming practices, including responsible use of the land, are given special credit. For farmers that have quota for all their sheep, and the “Good farming practice” credit, the subsidies can today cover up to 40% of the farmers income from the sheep production. For other farmers however, the percentage of subsidies can be considerably lower.

3.4. Ecological effects of sheep grazing

Iceland is a volcanic island. Large areas are frequently covered by ash and tephra which severely affects the vegetation or completely suffocates it. The soils are volcanic andosols and thus susceptible to wind and water erosion. In spite of these detrimental natural forces, Iceland was widely covered by mountain birch (*Betula pubescence*) forests and woodlands up to 200-600 m altitude by the time of Norse settlement eleven hundred years ago according to written sources as well as paleological documentation (e.g. Landnáma, Hallsdóttir 1995). By that time waterfowls were the largest herbivores in the country, but the Norse settlers introduced livestock to the pristine ecosystems of Iceland. Large areas of forest and woodlands were cleared for grazing. The extensive deforestation that followed the settlement was also due to various other utilizations of the woodlands such as wood fuel, charcoal, and timber for construction. However, livestock grazing prevented regeneration of the woodlands, sheep in particular, thus dramatically speeded up the process of vegetation degradation followed by soil erosion and sand encroachment (Thórarinsson 1961).

By the turn of the 20th century, soil erosion had become Iceland's major environmental problem. Huge quantity of soil had been lost, leaving large previously vegetated areas deserted (Arnalds et al. 2001). Even though much has been achieved in halting soil erosion and subsequent sand encroachment during the last century, land degradation continues to be a serious problem in Iceland. A major cause, added to the natural causes, is the high grazing pressure during the 20th century, reaching its maximum during the late 1970´s (section 3.1).

In the light of the Icelandic grazing history, there are surprisingly few published studies available on the effect of sheep grazing on plants and vegetation in Iceland. One reason is that the effects of sheep grazing are so extensive that it is difficult to find unaffected areas to use as an ungrazed reference. Ungrazed islands in lakes may serve this purpose, provided that breeding birds, such as geese, do have a great effect on the island systems (Jónsdóttir 1984) and a few areas that have been protected long enough time as to allow recovery from intensive grazing (Jónsdóttir 1991). Several grazing experiments have been conducted where sheep grazing pressure is controlled, but only a few publications focus on the effects of grazing on plants and ecosystems (e.g. Thorsteinsson, I. 1986, Jónsdóttir 1991, Magnússon and Magnússon 1992). One study involved simulated grazing experiments (e.g. Jónsdóttir and Callaghan 1989). The main findings from these studies are summarised below in sections 4.2 and 4.3.

3.4.1. Sheep grazing ecology

Habitat selection

Few studies focus on habitat selection of Icelandic sheep. In the summer of 1982, habitat selection of free roaming sheep, grazing extensive common grazing areas in the highland of northwest Iceland was recorded (Thorhallsdottir and Thorsteinsson 1993). Observations were taken for three days in July (24 hrs) and September (9-21 hrs) from two ridges revealing a 200 ha mosaic grazing area. Before starting the observations, accurate vegetation mapping was done of the area. Sheep were counted in each vegetation community every hour and their activity recorded; grazing, lying or walking. Preference index for the different vegetation communities was then calculated (see further in Thorhallsdottir and Thorsteinsson 1993).

In July, sheep showed the highest preference for the mires (dominating species: *Carex bigelowii, Eriophorum angustifolium, Salix phylicifolia)* and to a much lesser degree, the dry heath land (dominating species: *Betula nana, Kobresia myosuroides, Graminae.* No preference was shown for the fens. However, in September the preference had changed dramatically. Far the most preferences was then for the fens (dominating species: *Carex rostrata, C. rariflora, Eriophorum angustifolium*) and the preference for the mires was reduced by more than half from July. On a daily basis, the grazing of the wetlands, mires and fens, took place from just before dawn (in July around 4 in the morning; in September around 7) and all the sheep had moved out of the wetlands by 16 in the afternoon, both in July and September (Thorhallsdottir and Thorsteinsson 1993). The same grazing pattern on a daily basis was observed in a study in east Iceland in the summer of 1980 (Thorhallsdottir and Thorsteinsson 1993).

Plant selection

Sheep are highly selective in their plant selection. Several studies have been conducted on plant selection of Icelandic sheep and different methodology used. Thorsteinsson and Olafsson (1965; 1967) and Thorhallsdottir (1982) used oesophageal fistulated sheep, Thorhallsdottir (1981) used analysis of rumen contents of sacrificed animals, and Thorhallsdottir (1981) and Jonsdottir (1989) analysed faecal samples for plant remains.

In the study of Thorhallsdottir (1981), 14 sheep were sacrificed (shot) in a free range grazing in the highlands of east Iceland, 7 in July and 7 in September and rumen and faecal samples taken from each animal for analysis of plant reamains. In the study of Thorhallsdottir (1982), oesophageal fistulated sheep were grazed in 5 enclosures in east of Iceland, each with different plant communities once a week for the whole grazing season. The five plant communities were birch forest, larch forest plantation, species rich dry grassland and two highland enclosures with mixed communities, fens, mires and grass/sedge tussocks.

Both studies gave in general the same result. The main plant species selected were *Festuca* sp. *Agrostis* sp., *Poa* sp., *Calamagrostis neglecta, Carex bigelowii, Salix callicarpea, Bistorta vivipara, Equisetum* sp. and *Galium* sp. There were however, distinct seasonal changes in the plants selected. *F.rubra* was selected earlier in the season and *C. neglecta* later in the season. *Salix* sp. was, in both studies, highly selected for in early to mid season while sedges were much more selected later in the season. *Equisetum* sp. were only consumed early and *Vaccinium uliginosum* only later. Sheep were opportunistic in their selection of forbs and many forbs were taken according to their availability, when in season, like *Rubus saxatillis, Rhinanthus minor, Gentiana campestris*. It was notable however, that the difference in plant selection between individuals in both studies was considerable, which stresses the importance of plasticity in diet selection (Thorhallsdottir et al. 1987; Thorhallsdottir et al. 1990a,b,c; Provenza and Balph 1988).

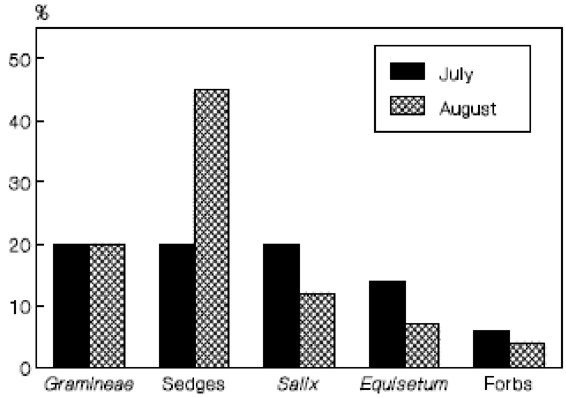


Figure 14. Results of rumen content analysis from 14 sheep (n=7) sacrificed in east Iceland 1980 (Thórhallsdóttir, 1981).

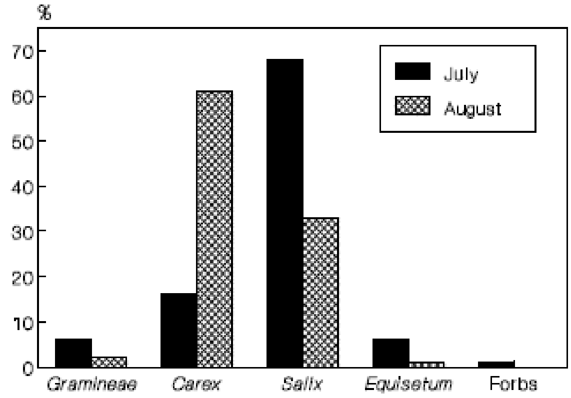


Figure 15. Results of feacal content analysis from 14 sheep (n=7) sacrificed in east Iceland 1980 (Thórhallsdóttir, 1981).

Figure 8. Results from sheep plant selection studies in east part of Iceland in 1980 (see Thorhallsdottir 1981)

Calculated estimated preference (Jacobs 1974) for the different plant species and plant groups showed that sheep were more selective in July than in August (Fig. 8; Thorhallsdottir 1981). Grasses were highly preferred, followed by *Salix* sp. and *Carex* sp. In August estimated changed and the overall estimated preference was close to zero, indicating less selective grazing (Fig. 8).

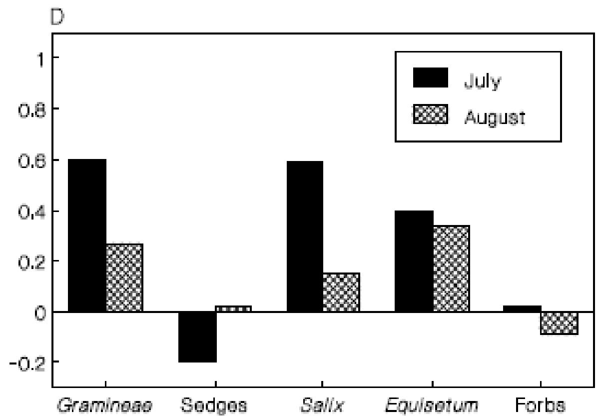


Figure 16. Estimated preference index (D) from results of rumen content analysis and plant composition on offer in east Iceland in 1980 (Thórhallsdóttir, 1981).

Fig. 9

Life history (Productivity, mortality)

Live weight of Icelandic ewse is today 60-70 kg and has grown in the last decades. Today, most sheep in Iceland have their first lambs as yearlings. In their first lamming season, average productivity is 1-1.2 lambs/ewe while ewes 2 years and older have on the average 1.8

lambs/ewe. Mortality is nil or hardly any during grazing in the summer (1-2%). The only wild predator in Iceland is the arctic fox which can take young or/and weak lambs, although minimal. Lambs are slaughtered after 130-140 days and in the last few years the average slaughter weight has been 15.5 kg, giving on average 26.3 kg/ewe/year.

3.4.2. Effects on plants

Plant species differ both in palatability (see section 3.4.1) as well as sensitivity to grazing (Thorsteinsson 1980). Many broad leaved dicotyledon herbs are both palatable and extremely sensitive to grazing due to the exposure of the phososynthetic tissue and meristems and these species usually disappear under heavy grazing. Other palatable plants, such as many graminoid species, are more tolerant to grazing. The grazing tolerant palatable species have attracted great research attention, especially because they raise the question of co-evolution with grazing animals. An example of a palatable, grazing tolerant species that is very common in Iceland is *Carex bigelowii*, (Jónsdóttir 1991).

Carex bigelowii is a clonal sedge with physiological integrated ramets. These traits together with the graminoid growth form enhance its tolerance to grazing as demonstrated in clipping and labelling experiments in Iceland (Jónsdóttir and Callaghan 1989). The apical meristem is well protected from the grazing animals by the leaf rosette of vegetative ramets which reduces the risk of damage by grazing. Vegetative production of daughter ramets from axillary buds situated on the belowground rhizomes, well out of reach from the grazing animals, ensure recruitment under grazing pressure and thus provide an efficient way to bypass the risky process sexual reproduction and seedling establishment. The longlived ramet connections prolong physiological integration among ramets and enable ungrazed ramets to subsidise damaged (grazed) ramets with carbohydrates and nutrients. Such compensation speeds up recovery from grazing (Jónsdóttir and Callaghan 1989). However, even the most tolerant plant species are eventually negatively affected by continuous grazing. In the case of *C. bigelowii* individual ramets were bigger at sites where grazing had been excluded for 10-14 years than at grazed sites (Jónsdóttir 1991).

Compensation for grazing can also be considered at a population and community level. Under grazing, *C. bigelowii* suffered less competition from grazing and trampling sensitive species, resulting in denser populations of smaller ramets at the grazed sites compared with the grazing protected sites. This in turn led to higher biomass of *C. bigelowii* per unit area at grazed sites than at ungrazed sites (Jónsdóttir 1991).

Plant community

There is large variation in climate among the different regions in Icleand, but also between the potentially forested lowlands and the treeless alpine tundra in the central highlands (section 3.2). Broadly, the potential tree line of the mountain birch marks the limit between the lowlands and the highlands. Sheep grazing has strongly affected plant communities both in the lowlands and the highlands as can be seen from a few grazing protected sites. Areas of variable sizes in urban areas and around settlements have been protected from grazing in recent years and we are now experiencing vegetation change within these areas. Furthermore, during the last few decades the number of sheep in Iceland has dropped considerable (see section 3.3.1) causing changes in the vegetation over wider areas. However, climate has also become warmer during the same time which makes it difficult to disentangle the single effect of a relaxed grazing pressure (Magnússon et al. 2006).

Lowlands

The most obvious effect of grazing on plant communities in the lowlands is the absence of forests. Scattered remains of birch woodlands are found in sheltered fjords and valleys. Broad leaved herbs such as *Geranium sylvaticum, Alchemilla vulgaris, Rubus saxatilis*, *Geum rivale* and *Rhodiola rosea* dominate the forest floor where the soils are relatively fertile. These species disappear even under relatively mild grazing and other less palatable species take over like grasses and various dwarf-shrub species such as *Vaccinium myosuroides*, *V. oliginosum* and *Betula nana*. On less fertile soils un-palatable species of sedges and rushes like *Kobresia myosuroides* and *Juncus trifidus* dominate and in drier soils and more exposed areas *Empetrum nigrum, Calluna vulgaris* and *Dryas octopetala* become more pronounced. Willow thickets have probably also been more common than they are today in areas with high soil moisture and in wetlands as well. Interestingly, the contribution of mosses in lowland plant communities sometimes decreases when areas are protected from grazing (e.g. Thorsteinsson 1972). The reason is that pleurocarp mosses are sensitive to tampling, but they are also poor competitors in ungrazed woodlands and many acrocarp moss species are dependent on suitable microsites created by small disturbances by grazing animals.

The overall consequence of centuries of heavy grazing in the lowlands is decreased contrasts between different plant communities within landscapes, i.e. decreased beta diversity, and disrupted vegetation cover and even totally destroyed vegetation in many places followed by sever soil erosion, especially on exposed ridges and steep slopes.

Highlands

The fragile tundra vegetation in the highlands of Iceland is even more sensitive to grazing than the lowland vegetation due to short growing season, and the relatively simple vegetation and soil structure. Grazing pressure in these areas increased when milk production was no longer the main product by sheep and it reached a maximum during the last century (see section 3.3). The highlands serve as summer grazing commons for sheep (afréttur) and today they are grazed usually from mid-late June to early-mid September. Large highland areas are almost completely devoid of vegetation. Some areas are “natural deserts”, i.e. have not been vegetated in historical time, either due to volcanic activities or jökulhlaups (glacial flooding due to sudden burst of ice dams). Some of these areas are in rain shadows thus experiencing low precipitation (< 600 mm), which retards the rate of succession after natural disasters. Other areas were vegetated before the settlement but became degraded and desertified due to grazing. The extent of areas degraded by human activities is still debated and will be addressed in more detail in section 3.4.3.

There are even fewer areas available in the highlands where grazing has been excluded for long enough time than in the lowlands. To assess the potential condition of un-grazed vegetation, we therefore need to take advantage of naturally protected areas such as lake islands, or areas surrounded by glacial rivers. A drumlin (an elongated whale-shaped hill formed by glacial action) situated in Lómatjarnir, one of the lakes in the Audkuluheidi heathlands, North Iceland at 430 m elevation, provided an unusual opportunity to study the potential ungrazed plant communities in different topographical settings (Jónsdóttir 1984).

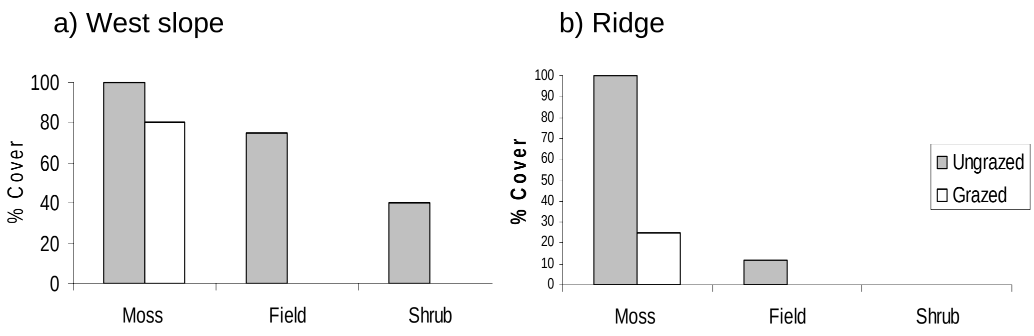


Fig. 10 Percentatge cover of different vegetation layers in ungrazed and grazed highland heath vegetation at Lómatjarnir, Audkúluheidi on a) west facing slopes b) ridges (reproduced from Jónsdóttir 1984).

The vegetation of this island was analysed along topographical gradients and compared with vegetation gradients across similar topographical zones in the surroundings. The results suggested that in all topographic zones there would be much greater vegetation cover and more complex vegetation structure (more vegetation layers) without grazing (Fig. 10). The willows *Salix lanata* and *S. arctica* would be much more conspicious in the vegetataion across several topograpyhical zones. Today these species are present in some vegetation types, but only as small, creeping individuals. *Salix phylicifolia* and broad leaved dicot herbs such as *Geranium sylvaticum, Alchemilla vulgaris* and *Rhodiola rosea* and *Equisetum pratensis* would be found in sheltered places where snow accumulates in winter, thus improving soil moisture in summer. These species are almost completely absent from the grazed areas today. Exposed ridges would be covered by continuous moss and lichen mats. Today ridges are often severely eroded. Finally, erosions spots (bare soil patches in otherwise continuous vegetation, *sensu* Arnalds et al. 2001) so common in the highland heaths today would occur at less frequency (Jónsdóttir 1984).

On a plot basis (50x50 cm) species richness, reflecting alpha diversity, was much greater at the most favourable sites in the grazed areas than at comparable sites in the ungrazed areas (west facing slopes) while there was no difference in more exposed sites (Jónsdóttir 1984). Grazing and trampling by sheep opened up larger number of microsites enabeling more species to get established, especially various species of acrocarp mosses and lichens, but also small dicot herbs. Indeed, this process contributes greatly to the reduction of diversity at larger scales. As in the lowlands, the overall consequence of heavy grazing on plant communities in the highlands is decreased beta diversity. In addition extensive vegetation destruction and soil erosion has taken place in the highlands (Steindórsson 1994).

The highland plant communities take a long time to recover from centuries of sheep grazing. In a grazing experiment at Audkuluheidi, the exclusion of sheep for twelve years had negligible effect on species richness and plant community composition (Magnússon and Magnússon 1992, see section below). Accordingly, fencing off a dwarf shrub heath in the same area did not have any measurable effect after five years (Jónsdóttir et al. 2005), but today, thirteen years later, *Salix lanata*, *S. arctica* and *Betual nana* have become more pronounced (I. Jónsdóttir pers. observ).

Highland grazing trial – viðbót

In 1987 a study of vegetation and plant preferences of sheep were carried out in a grazing experiment on Audkuluheidi northern Iceland (Magnússon and Magnússon 1992). The experimental site was at 470 m a.s.l. and had heathland as the dominant vegetation type with *Racometrium lanuginosum, Betula nana* and *Empetrum nigrum* as the dominant species. The grazing experiment had started at the site in 1975 and was still in operation. In the study in 1987 a comparison was made of sections with light, moderate and intense grazing. The average carcass weight of twin lambs was 13.8, 12.7 and 11.7 kg in the lightly, moderately and intensely grazed sections respectively, over the experimental period 1975-1987.

The plant community was very rich in species with 67 vascular plants, 100 bryophytes and 39 lichens recorded at the site. Over 60 species were on the average found in a 100 m^2 study plot. Grazing did not affect species richness considerably during the time of the experiment.

Bryophytes were of greatest significane in the vegetation and had about 50% cover in the sections, while shrubs covered around 20%, lichens 10-20%, dicot herbs 10%, sedges 5-10% and grasses 2-3%. Bare ground was in the ragen of 5 – 20% and was most extensive in plots with shallow soil. The moss *Racometrium lanuginosum* was the dominant plant species and reached over 30% average cover in most sections. The sheep grazing had not exerted great influence on the vegetation cover during the experimental time, except in the intensely grazed section where the cover of *R. lanuginosum* was reduced by half (Figure11), shrub cover (mainly *Betula nana)* had decreased considerably and extent of bare ground had increased.

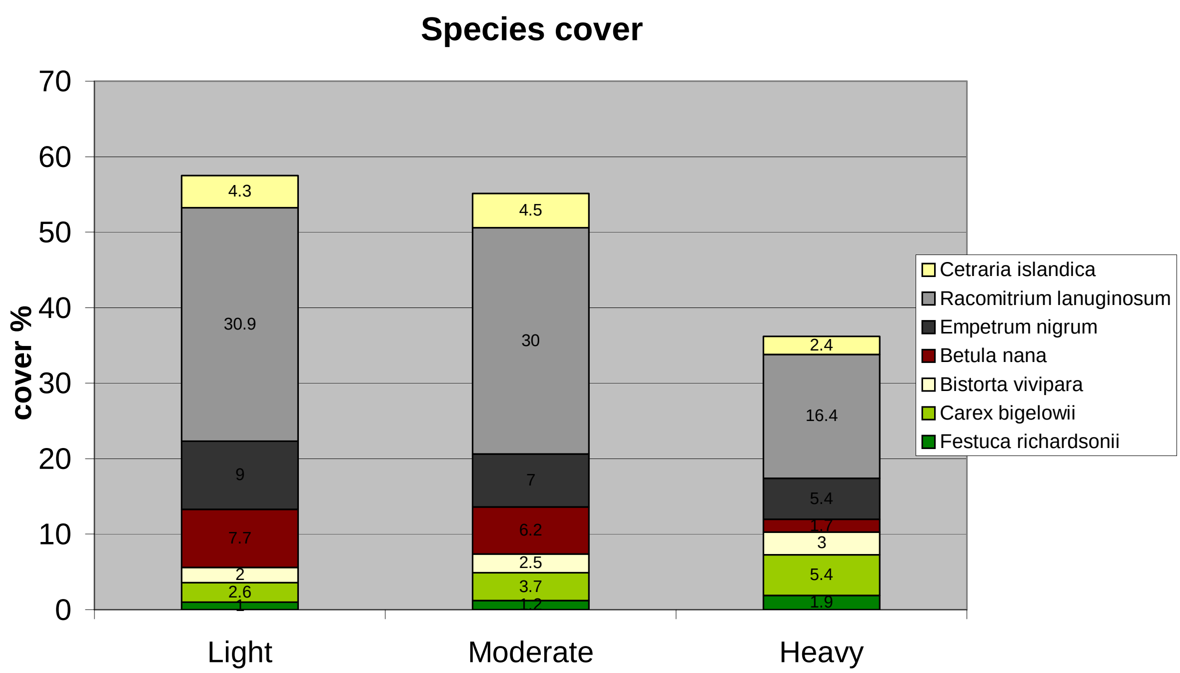


Fig. 11. Average cover of dominant plant species in a sheep grazing trial on Audkuluheidi in 1987, following 13 years of grazing under different grazing intensities.

The sheep were stongly selective in their choice of diet during the summer and about half of the vascular plant species showed signs of having been grazed. Grasses and sedges were most frequently grazed but shrubs the least. The most preferred species at light grazing were *Carex vaginata, Bartsia alpine, Salix callicarpaea, Poa pratensis* and *Agrostis vinealis*, while the least preferred species were *Thalictrum alpinum, Empetrum nigrum, Equisetum vaginatum, Silene acaulis* and *Cerastium alpinum.* With increasing grazing intensity the selectivity was reduced and the sheep shifted their grazing to species which were little or not grazed at light grazing intensity. In the intensively grazed section, the sheep grazed *Betula nana* considerably leading to the reduction of its cover. The abundance of individual species in the plant community and the study of diet selection indicated that *Salix callicarpaea, Carex bigelowii, Bistorta vivipara* and *Armeria maritime* were the most important grazing plants of the range, making up a considerable proportion of the food of the sheep.

Rangeland recovery?- viðbót

A recent study of vegetation in permanent plots set up during 1997-1998 in lowland and highland ranges of horses and sheep in Iceland and resampled in 2005 indicates a considerable improvement in vegetation and range condition Iceland in recent years. This may be attributed to decrease livestock numbers and grazing pressure and climatic warming. A significant decrease in extent of bare ground and cover of mosses had occurred while the average cover of grasses and sedges and all vascular plants had increased significantly (Fig. 12; Magnússon et al. 2006).

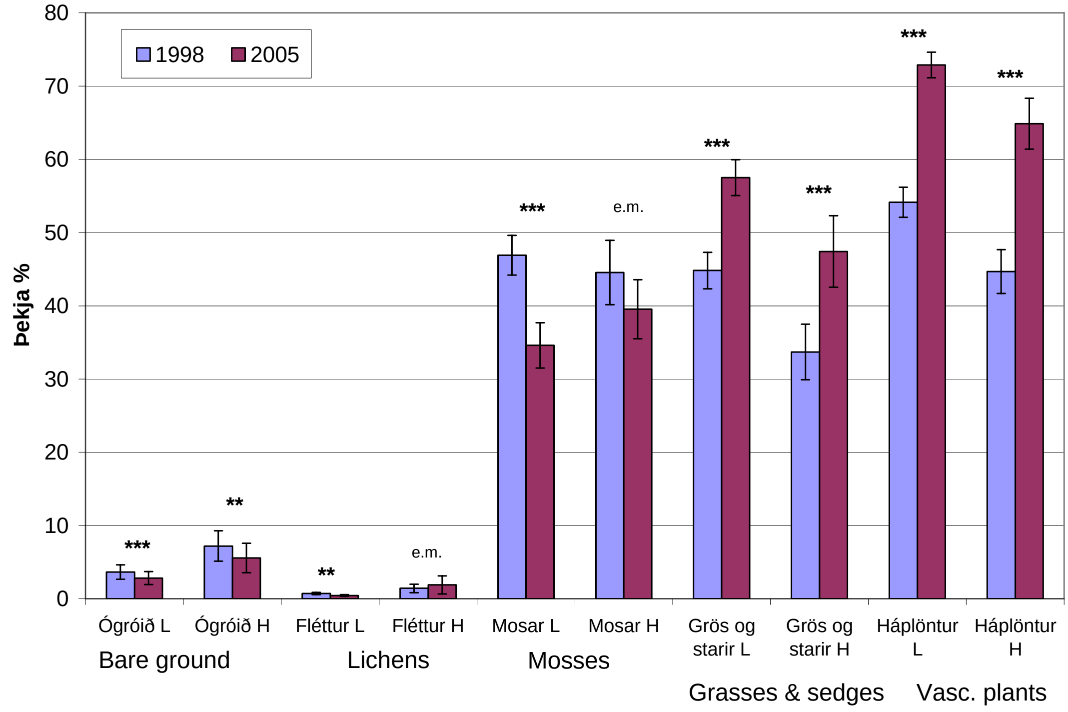


Fig.12. Average cover of bare ground and different plant groups in 100 permanent plots set up in lowland (L) and highland (H) pastures during 1997-1998 and revisited in 2005.

Plant functional groups

By using growth forms to indicate functional groups, it becomes obvious that in the lowlands deciduous trees (mountain birch) and shrubs and broad leaved dicot herbs (forbes) give way for increased abundance of growth forms like deciduous and evergreen dwarf-shrubs, rushes, sedges and grasses. In the highlands we see similar patterns. Again there is not much data available but the study from Lómatjarnir at the Audkúluheidi heathlands provides some support for this trend (Fig. 13).

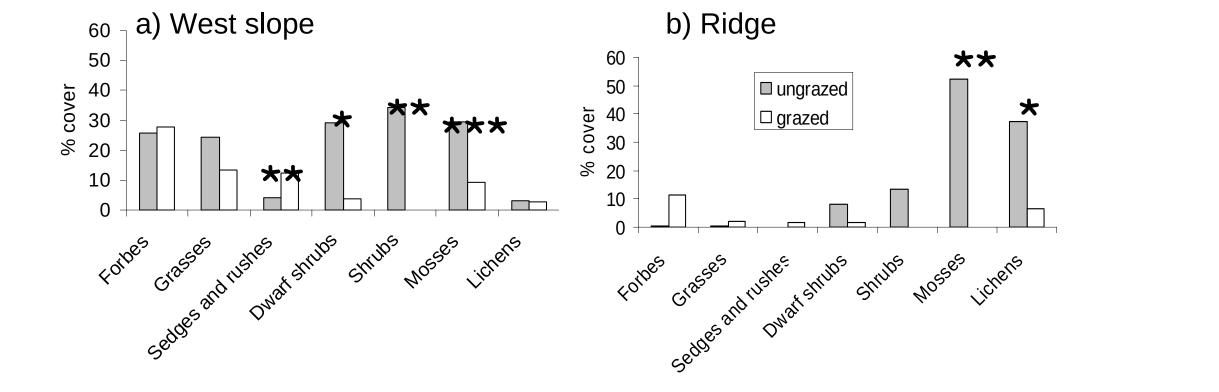


Fig. 13 Percentage cover of different growth forms in grazed and ungrazed vegetation at Lómatjarnir. Audkúluheidi (from Jónsdóttir 1984), a) on west facing slope (ungrazed: n = 48; grazed: n = 72), b) on exposed ridge (ungrazed: n= 35; grazed: n = 34).

Biomass, productivity

Extensive biomass studies have been done for different vegetation types in both the lowlands and the highlands (Thorsteinsson 1980). Above ground biomass varies greatly from only a few kg ha^{-1} in semi-bogs to 2063 kg ha^{-1} in the most productive woodlands in the lowlands, and from 14 kg ha^{-1} in fens to 1352 kg ha^{-1} in herb meadows in the highlands (Thorsteinsson 1980). However, there is not much information available on the effects of grazing on biomass and productivity, but the large potential effect of sheep grazing on biomass was clearly reflected in the data on the vegetation cover and structure in the Lómatjarnir study (Jónsóttir 1984). Because of the slow rate of recovery from grazing no difference in cover or structure was found in the grazing experiments at Audkúluheidi in response to relaxed grazing (Magnússon and Magnússon 1992).

3.4.3 Ecosystem effects

Centuries of heavy grazing have had great effects on Icelandic ecosystems. In the lowlands the transition from forests and woodlands to open grasslands, dwarf-shrub and moss heaths has had great consequences for both the biological and physical components of the ecosystem and probably contributed to decreased biodiversity at least on a landscape scale, both in terms of flora and fauna as well as trophic interactions and food web structures. In the highlands the transition from diverse ecosystems to more homogenous heathlands has probably had similar consequences. Soil properties have most likely radically changed both in terms of structure and chemical composition although it may be difficult to separate direct effects of grazing from indirect through soil erosion and accumulation of wind born soil particles in the remaining vegetation. The grazing effects on soil properties are probably the main reason for the slow recovery of grazed ecosystems after excluding grazing.

Sheep grazing & nutrient dynamics (chemical, physical and biological properties of the soil)

Grazing in general may have positive effect on soil properties resulting in increased productivity of the ecosystems through increased turnover rate of nutrients. However, heavy grazing by domestic animals leads to a net removal of energy and matter from the grazing areas. Under continuous heavy grazing such net removal will eventually result in impoverished organic matter and nutrient contents. Trampling by large animals such as sheep may also affect the structure and other physical properties of the soils, i.e. make it more compact, reduce water holding capacity. All this may negatively affect the soil fauna and micro-flora. Because recovery of the soil properties after exclusion of grazing is a very slow process it is difficult to demonstrate all these effects of grazing on the soils in grazing experiments (Magnússon and Magnússon 1992). However, this was reflected in soil differences between the grazing protected island in Lómatjarnir and its surroundings (Table 13).

Table 3. Soil characteristics in ungrazed and grazed areas at Lómatjarnir, Audkúluheidi. Range is given if more than one value is included (reproduced from Jónsdóttir 1994).

	pH (0.01M $CaCl_2$)	*Field capacity (%)*	*Organic matter (% loss on ignition)*	*Total N (%)*
West facing slope				
Ungrazed	4.7 – 4.9	67 - 69	27 -32	0.57 – 0.86
Grazed	4.9 – 5.8	51 - 49	13 - 18	0.24 – 0.44
Ridge				
Ungrazed	5.4	51	20	0.24
Grazed	6.1	21	5.7	0.13

Vegetation cover/Erosion

Based on written sources as well as palaelogical studies we know that the vegetation cover and the birch woodlands were considerable more extensive at the time of the settlement (Landnam) 1100 years ago than today (Hallsdóttir 1995). Roughly estimated, up to 2/3 of the land surface were vegetated and birch woodland covered up to ¼ of the surface area. The Norse settlers brought with them agricultural practises developed in Scandinavia and other parts of Europe which did not suit the fragile ecosystems in Iceland and their erosion susceptible volcanic soils. Heavy livestock grazing opened up the vegetation cover, thus giving way to both wind and water erosion. Dust storm particles accumulated in the remaining vegetation leading to soil thickening which eventually dried out the vegetation (Thórarinsson 1961). The degradation process was accelerated by climate cooling soon after the settlement. Regeneration of the cleared birch woodlands was prevented by the grazing animals and when the protecting cover of the woodlands disappeared, the vegetation became less resilient to natural catastrophes.

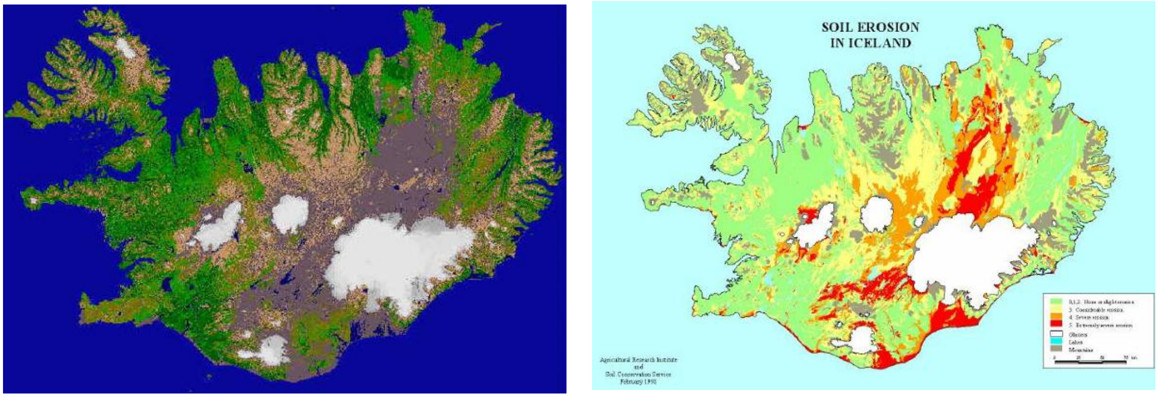


Fig. 14 Left: The extent of vegetated land in Iceland produced from Landsat 5 stellite image (ESA/LMÍ 1993). Right: Yellow to red colours = different severity of erosion; green = little or no erosion; grey = mountains; blue = lakes; white = glaciers (Arnalds et al. 2001).

Today about 25% of the land has continuous vegetation cover and woodlands cover only 1%. Erosion of variable form and degree is found in both vegetated and desertified land or in more than 70% of the land (Fig. 14; Arnalds et al. 2001). Even though much has been achieved in halting the degradation and soil erosion processes as well as in land restoration, many degraded areas are still being grazed by livestock.

Mammals, birds, insects

The terrestrial and limnic fauna of Iceland is relatively poor. The Arctic fox is the only land mammal that was present at the time when the country was settled by man. The field-mouse, which is widespread, came with the settlers 1100 years ago. Reindeer were first introduced to Iceland in 1770. A small population exists in the eastern highlands. Mink was brought to Iceland in 1931 for fur-farming. Within few years, it escaped and it has spread and naturalized around the country, causing considerable damage to bird-life.

There are over 70 native bird species that breed in Iceland. Sea birds, waterfowl and waders are the most common indigenous birds. Over 240 species of birds are known to have visited Iceland in one time or another. Iceland is one of the major breeding ground of waterfowls in Europe, and Lake Mývatn is renowned for its abundance of waterfowl.

The insect-fauna of Iceland is rather sparse compared with more southerly lying countries. About 1300 species have been spotted. Most species originate from Europe, only a few from North America.

4. Greenland

Jon Feilberg and Kenneth Høegh

4.1. Introduction

Sheep grazing was an important part of the agricultural system in south Greenland for the Norse settles (985 – c.1450) as well as for the modern husbandry (from 1924 and forward). The areas indicated on fig. 15 are the major sheep farming districts.

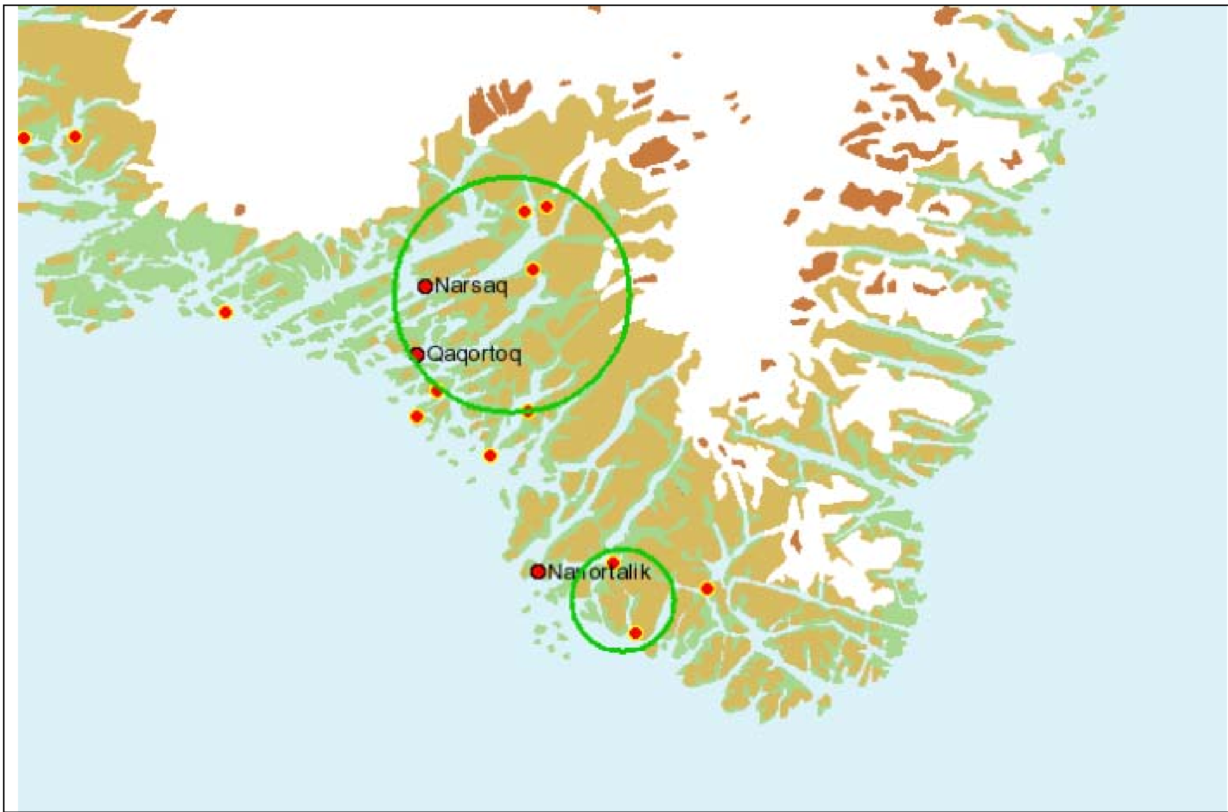


Fig. 15. The two centres of sheep farming in Southern Greenland.

4.2. Study sites

Southern part of Greenland belongs to the northern boreal and alpine vegetation region (Hallanaro and Pylvanainen 2001). Mean annual temperature in the sheep farming area is 0-2.5 º C, while mean annual precipitation do not exceed 700-1100 mm per year. Total number of growing days (≥5º C) is estimated to 100-150 days.

4.2.1. Geology

Two major complexes dominate South Greenland; the Archaean gneiss complex in the northwestern part, and the Ketilidian mobile belt in the rest of South Greenland. Bridgwater *et al.* (1976) summarized the former as follows: "Between 80 and 90% of the Archaean complex consists of granitoid quartzo-feldspathic gneisses, of which major parts appear to have been derived from acid or intermediate igneous rocks. They are intercalated with units of amphibolite, which appear to be mainly derived from metavolcanics, a minor amount of metasedimentary gneisses, and concordant units of metaanorthosite and associated meta-basic igneous rocks characterised by very calcic plagioclase. These units range from a few centimeters to a few kilometers in thickness".

Allaart (1976) summarized as follows: "The Ketilidian mobile belt comprises gneisses, granites and metamorphosed supracrustal rocks and is characterised by the occurrence of numerous late, intrusive granite plutons covering large areas- … The mobile belt can be subdivided into several zones from the northern margin towards the south: (1) The northern border zone in the northern part of which Ketilidian sediments and volcanic rocks overlie Archaean gneisses and supracrustal rocks uncorformably. Towards the south these are progressively involved in Ketilidian metamorphism and deformation. (2) A complex body of granites, diorites and gneissose granites (Julianehab granite) in which a central zone of late intrusive granites can be distinguished. (3) An intricately folded zone of granites, gneisses and migmatised Proterozoic or earlier sediments and volcanic rocks with amphibolite facies mineralogy. (4) A flat-laying, slightly domed, migmatic complex of high-grade . . . metasediments and metavolcanic rocks, early Ketilidian granite sheets and numerous late Ketilidian granite intrusions". In several areas the Ketilidian mobile belt is intruded by alkaline plugs and dykes from the Gardar period. The common rocks are syenites, granites, dolerites, gabbros and sandstones. The Ilimaussaq intrusion is remarkable by its low contents of Ca and high contents of Na, K and many exotic elements.

During the Quaternary, South Greenland was heavily glaciated, even though restricted areas may have remained unglaciated (Weidick 1976). The ice-cover ceased ca 9500 ^{14}C years ago (Fredskild 1973). The upper marine limit ranges from 25 to 60 m a.s.l. (Weidick 1976, Fredskild 1973).

4.2.2. Soil

The South Greenland soils range from Syrosem through Ranker and Brown soils to Podsols (Larsen 1977). Brown soils are most widespread and occur in rather densely vegetated areas. Syrosem soils are widespread too, but developed in areas with open and scattered vegetation. Ranker soils are found where the vegetation constitutes just a continuous cover, while Podsols are developed under dense vegetation, particularly in areas with high precipitation (Hansen 1969). Topsoils have pH 4-7 (Hansen 1969, Larsen 1977), the highest values from the inland.

Severe soil erosion is seen in a few areas in South Greenland. The only substantial eroded area (c. 10 km^2) is situated near Igaliku Kujalleq. Fredskild (1988) suggests that the Norse settlers could be responsible for initiating this erosion. Beginning erosion is widespread near the sheep farms, which is only natural. However, more severe erosion is seen near farms, which used winter grazing. Micro erosion (fig. 20) occurs in most parts of South Greenland (Feilberg 2004).

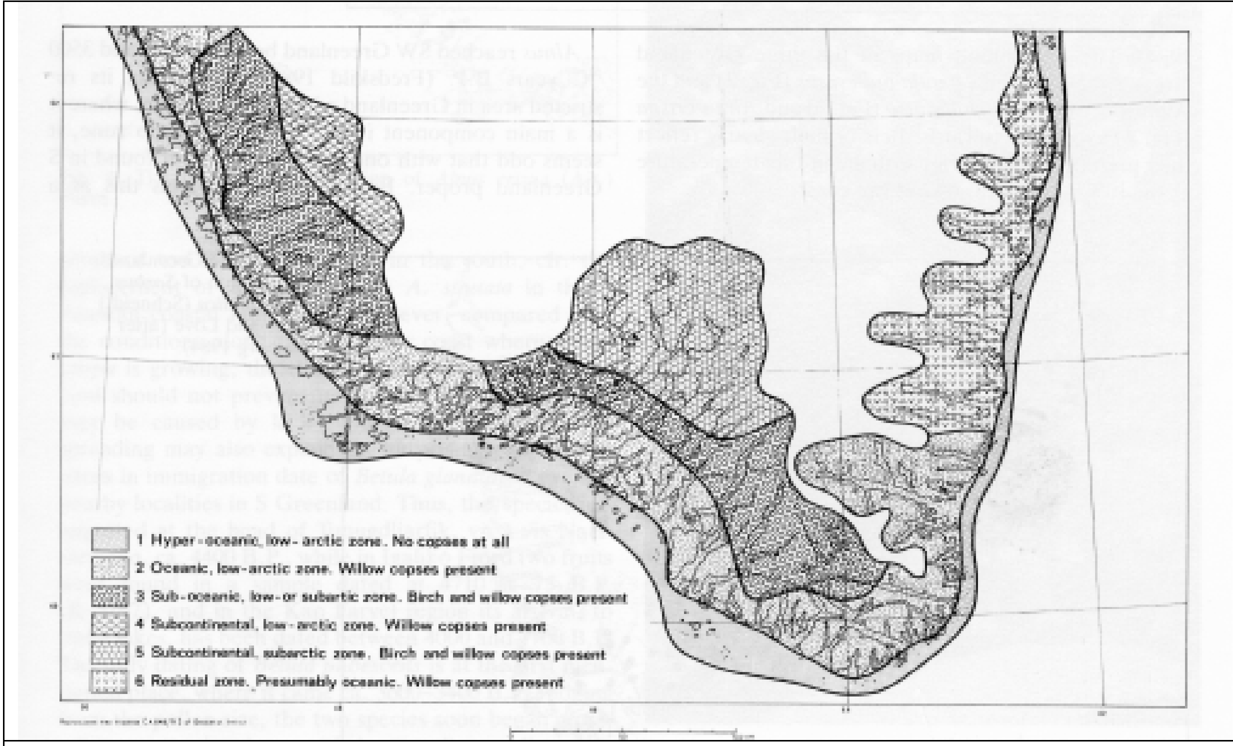


Fig. 16. Vegetation zones of South Greenland (Feilberg 1984).

4.2.3. Vegetation

Dwarf-shrub heath is the most widespread plant community, dominated by one or more of the following dwarf-shrubs: *Betula glandulosa* (inland), *Vaccinium uliginosum* (intermediate), *Empetrum nigrum* (coastal) and prostrate forms of *Salix glauca* (all over).

Willow copses cover fairly large areas in the lowlands, particularly slopes with abundant snow-cover during winter. The ground vegetation may be dominated by ferns, grasses, or forbs like *Ranunculus acer* and *Lathyrus japonicus.* In the inner parts of the fiords the highest copses reach about 2 meters, *Sorbus groenlandica* is rather frequent, either isolated or scattered in the copses, and *Alnus crispa* is found in the western part of the province. *Betula pubeseens* constitutes open woodlands or thickets on the most favorable places. The highest birch stems reach 10 meters (Feilberg & Folving 1990), but generally the height ranges between 2 and 5 meters. The stems are polycormic and tortuous.

Herb-slopes are most luxuriant in the inner parts of the coastal areas, below high rock walls. Typical herb-slope plants are *Angelica archangelica, Epilobium angustifolium, Alchemilla glomerulans,* and *Plantanthera hyperborea.*

In the coastal parts of South Greenland, heaths are commonly dominated by mosses (especially *Racomitrium lanuginosum),* lichens (especially *Cladonia* sp.), or *Juncus trifidus.*

Near Kap Farvel, *Nardus stricta* may dominate heaths on the well-drained areas, while *Juncus squarrosus* dominates heaths in more damp areas.

Grassland-slopes are frequent in the inner parts of fiords. *Anthoxanthum odoratum* and *Deschampsia flexuosa* are dominating, often with *Alchemilla alpina* as subdominant.

Heaths with *Kobresia myosuroides* are found on horizontal or slightly sloping, well-drained soil in more continental areas, e.g. near Narssarssuaq.

In the alpine areas, here defined as areas above the altitudinal limit of willow copse, fell-fields are widespread, variable, and forming transitions to most other vegetation types. Common taxa are *Luzula confusa* and *Silene acaulis.* In gravelly and rocky areas, along rivers and brooks, *Epilobium latifolium* and *Saxifraga aizoides* are frequent.

Snow-patches are widespread, particularly in the alpine areas. Dominants are *Salix herbacea, Harrimanella hypnoides, Carex bigelowii* or mosses.

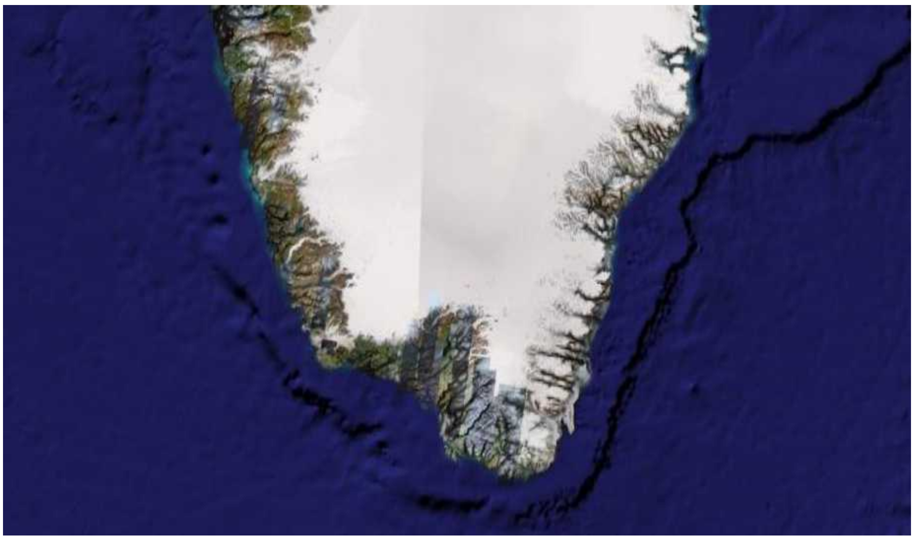
Fens are frequent, but cover limited areas due to the topography. *Carex rariflora* and species of *Sphagnum* are the most frequent dominants followed by *Eriophorum angustifolium* and *E. scheuchzeri.*

Seashore vegetation is generally poor, due to the prevalence of rocky coasts. Salt marshes and sandy beaches are confined to the heads of inlets and fiords. *Plantago maritima* and *Carex glareosa,* however, are found almost everywhere along the coast.

Freshwater vegetation is most vigorous in shallow ponds and brooklets, as great lakes and rivers in general are almost free of vascular plants. *Sparganium hyperboreum* and *Hippuris vulgaris* are among the most common hydrophytes.

3.4.4. Land use

Cultivated land comprises a minor proportion of South Greenland (< 0,1 %) and most of it is used for fodder production (winter fodder mainly) in the animal husbandry (Nordic Council of Ministers 2007). However, most of the vegetated area could be classified as outlying fields.



Due to the huge icecap, the climate of Greenland is extremely variable

4.3 Sheep grazing management: past and present

South Greenland was exposed to two separated agricultural periods of agriculture, a long period of Norse settlements (985 A.C. – 1450 A.C) and a short period of modern sheep farming (after 1925). In addition, a few domestic animals were kept at the colonies from in the 18th and 19th century. Details of management in the Norse period are little known, however archaeological findings indicate, that the Norse settlement in South Greenland (Østerbygd) consisted of about 200 farms (Krogh, 1982). A typical Norse farm included a living house, a stable/barn laying in a fenced and intensively cultivated home field and some small buildings in the outfield. Some of the bigger farms had irrigation-systems too. They kept horses, cattle, pigs, sheep, goats and cats (Krogh, 1982). The small huts in the outfields indicate that the shepherds followed the livestock in the fields, so that the total vegetated landscape was utilized. The sagas also mention, some big forests, and it is likely that several valleys and lowlands with favorable climate were forested at the beginning of the colonization (Fredskild & Ødum 1990).

Besides farming, Norse settlers were fishermen and hunters as well, so they were only partly dependent of agriculture (Krogh, 1982).

The modern grazing management in a bigger scale began in 1915 (Friis, P. Rasmussen, R.O. 1984). In the period 1915 – 1970 the management was based on extensively all year around grazing, with small supplements of winter fodder (hay) and sometimes stabling. The sheep were collected once a year for shearing and slaughtering.

This management appeared to be successful, and the number of ewes increased from 250 (1915) to 45.000 (1966). Due to heavy snow and strong frost in the winter 1966/67, 50 % of the ewes died this winter. That was a catastrophe. A similar situation came in the winter of 1971/72, and the number of ewes settled on about 20.000.

In 1982, a new plan for sheep management was presented (Egede 1982). The number of sheep-farms (32 at that time) should be doubled, and new stables, roads, harbours and bridges were planned. Moreover, the management should be based on seven months of stabling and 5 months grazing on the outlying fields.

4.3.1. Number of sheep

The grazing land was calculated to 242.937 ha, corresponding to 56.000-80.000 ewes (Egede 1982). Sheep density is thus set to be between 0.23 and 0.33 per ha.

Tab. 4. Number of ewes in South Greenland 1915-2006.

Source	Year	Number of ewes
Laursen & Ørnsholt 1979	1915	250
Laursen & Ørnsholt 1979	1936	10.000
Thorkelsson 2003	1996	14.635
Greenland Agr. Advisory Service	2006	17.016

4.3.2. Breeds

The Greenland Sheep is a race within the North Atlantic Short Tailed Sheep; originating mainly from Iceland and the Faroe Islands. The first introduction was from the Faroe Islands, when the Greenlandic priest Jens Chemnitz imported 9 ewe-lambs and 2 rams from the Faeroe Islands in 1906, supplemented with another import in 1908 with fewer animals - while the Danish colonial administration imported 172 sheep from Iceland in 1915 to the new agricultural station. There were a few animals imported around 1900 of Scottish or English origin that may have had an influence of the present Greenland Sheep. In the 1930's further more some rams were imported by the agricultural station from Iceland, and again in 1957 the sheep farmer Mr. Abel Kristiansen imported 2 rams of "Spealsau" from Norway.

Today the Greenland Sheep is to be considered a race of its own, though it resembles very much the Icelandic sheep.

4.3.3. Management: grazing season, supplemental feeding

The grazing season is from May 1st until October 31st (plus/minus 2 weeks, depending on conditions), and supplemental feeding consisting of home grown silage and hay, Greenland fishmeal and imported concentrate grain. The feeding season is from early November until May – again depending on conditions.

4.3.4. Management: law and other regulations

Greenland Agriculture is regulated though the home rule law of Agriculture (law no. 5, 2nd May 1996), and grazing, grazing areas and stocking rates are regulated by law no.8, 22nd Sept. 2000.

4.3.5. Main products (meat, wool, milk)

More than 80% of the income in Greenland agriculture is from sheep farming, around 20 mill. DKK. Meat production provides 98%, and wool 2% . There is no milk production from sheep in Greenland.

4.3.6. Economy: subsidies, income

There is a subsidy on meat production with 20 DKK per kg slaughtered lamb. The ewe subsidy is around 140 DKK per ewe per year. The subsidies for sheep farming are totally around 10 mill. DKK (2008).

4.4. Ecological effects of sheep grazing

4.4.1. Sheep grazing ecology

Habitat selection

No published data is available. Sheep seem to prefer plant communities in the following rank (the most visited areas first): meadows and grasslands, heathlands, saltmarshes, bogs and marshlands (J. Feilberg & K. Høegh pers. observ.).

Plant selection

No published data is available. In Greenland sheep seem to prefer herbs, before graminoids and woody species (J. Feilberg, pers. observ.). The Greenland sheep prefer *Agrostis, Poa*, *Anthoxanthum* and *Festuca* species (Thorsteinsson, I. 1983). In summer grazing on *Salix glauca, Lathyrus japonicus, Angelica archangelica, Eplobium* and *Rhinatus* species are observed (J. Feilberg, pers. observ.). Some plant species are not grazed before late autumn. These include *Juncus squarrosus*, *Nardus stricta* and *Carex* species. *Ranunculus acris* and *Alchemilla alpine* appears to be avoided by sheep. (J. Feilberg, pers. observ.).

Life history (Productivity, mortality)

There is a big difference in weight and litter size between the farms. Ewes weigh between 60 – 70 kg, while body mass of lams varies between 30-45 kg. Litter size varies from 1.2 lambs per ewe, to 1.8 lambs per ewe – with a country average around 1.5 lambs per ewe. The slaughter weight is from 12-20 kg, with an average of around 15 kg pr. carcass. Lamb loss is from 2%-10%, depending on grazing area. Predators are mainly the white-tailed eagle, the arctic fox and the raven – (the polar bear is a very rare predator).

Diseases

None of the serious sheep diseases occur in Greenland.

4.4.2. Effects on plants

Everywhere in the sheep districts of Greenland the effect of grazing on the trees and shrubs can be observed. Even at moderate stocking rates, damages on the woody species can be observed. A field site was identified near the bottom of Tunulliarfik fiord, close to the settlement of Narsarsuaq, with cooperation with a local sheep farmer who grazed sheep out in the birch areas around his farm all year. Fencing treatments included an area with free grazing area near the farm (summer + winter grazing), an area with free grazing (summer only), and a protected area (no grazing). About twenty birch trees were marked within each of the three 'treatment' areas. One branch per tree within browse range of the sheep was selected for study and all dead shoots were removed from it in summer 2001. All branches were resurveyed one year later (summer 2002) and the damage to any shoots on the branch was recorded on a scale from 0 (no damage) to 9 (severe damage) and grouped as damage caused by either mammals (sheep & hares), insects, physical and other (frost, etc).

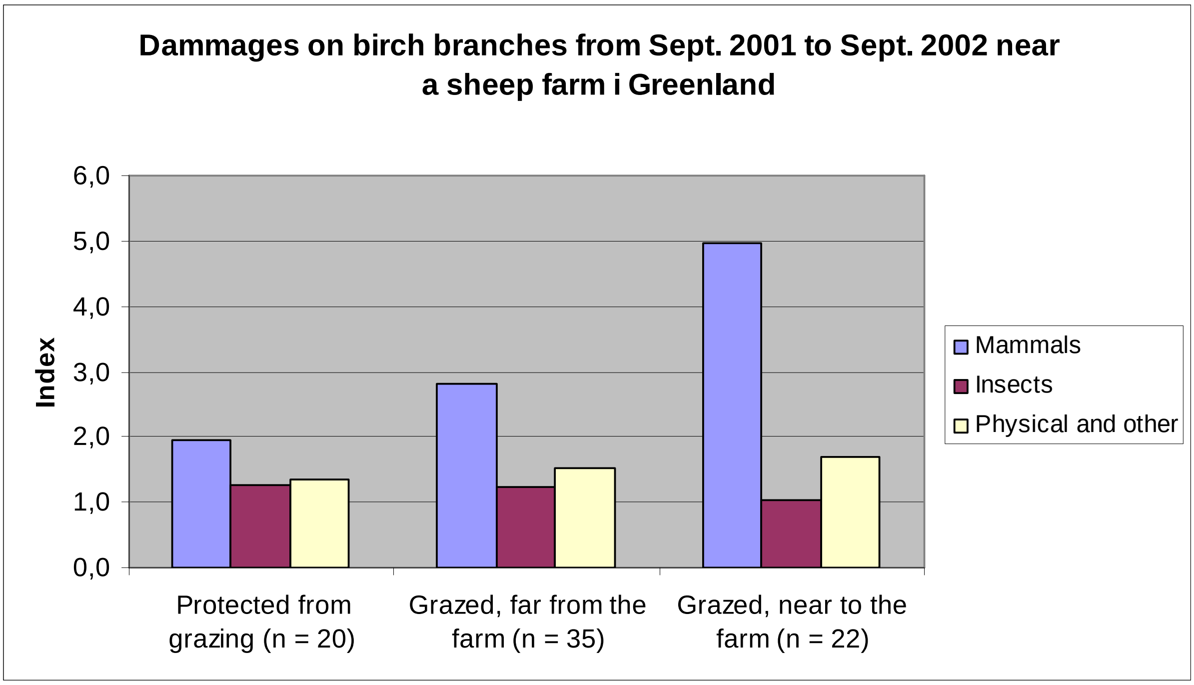


Fig. 17. Damage on branches of *Betula pubescens* caused from September 2001 – September 2002 in Qinngua, South Greenland. The damage is measured on an index (0 = no damage, 9 = severe damage) and grouped into three categories: mammals, insects and physical & other.

The effect of all year around grazing near the farm is obvious compared with the protected area and with the more distant summer-grazed area. The braches grazed by mammals inside the protected area are due to a small number of arctic hares, and should be considered as a sort of ”background grazing”.

Plant community

In order to monitor the impact of sheep on the vegetation in the outfield, a number of permanent plots were established. From 1984 to 2004 about 100 field sites were placed widespread in the sheep-farming district of South Greenland. There are two major categories; 1) reference areas (inside a fence) and 2) control areas (not fenced). The vegetation was described, photo-recorded, measured by qualitative and quantitative methods and – for some of them – the aerial shoot production (ASP) was measured. Most of the stations were re-investigated – a least one time, and some of them were investigated five times in the period. All results indicate, that forest, copse and heath change towards grassy communities as a result of sheep grazing.

Plant functional groups

An example of the impact of sheep grazing on four functional plant groups is shown below. Plot 39 was fenced in 1984/85 whereas plot 38 was grazed all the time. Grazing pressure of plot 38 peaked in 1986-1988, and now resembles the fenced area.

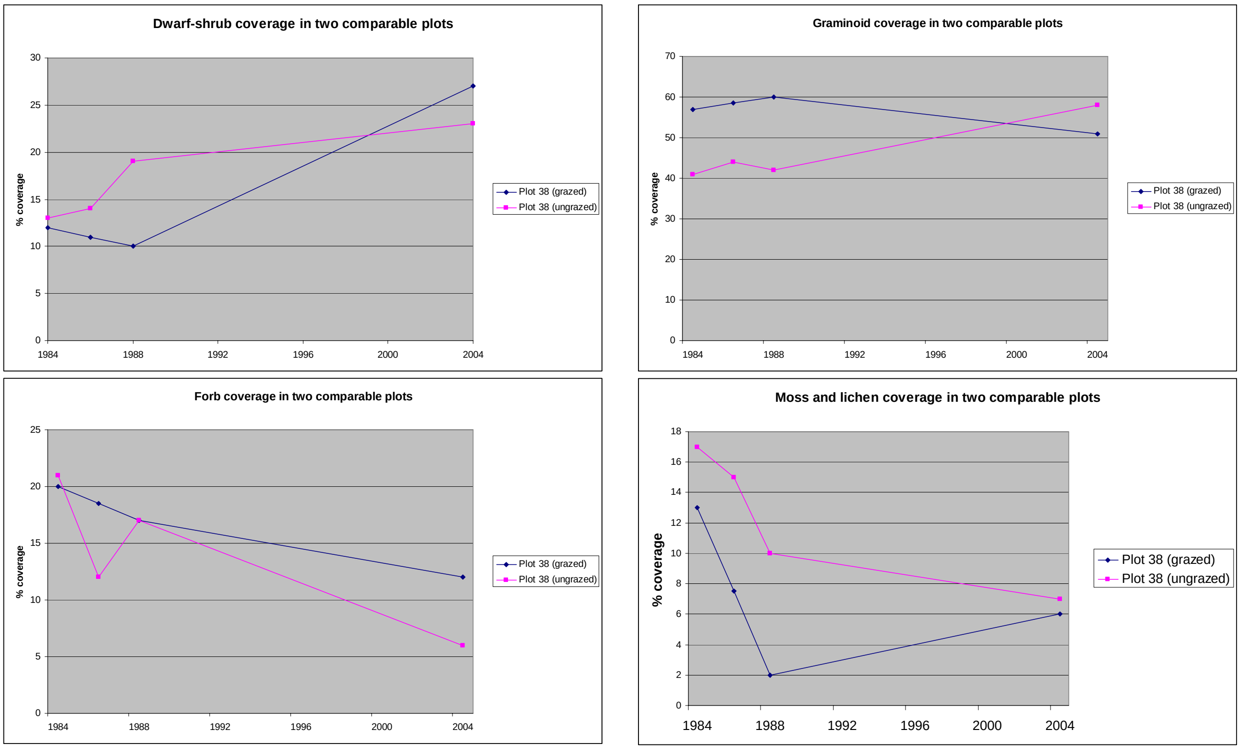


Fig. 18. Plant cover measured over 20 years in four functional groups on a grazed area (blue line) and on a nearby ungrazed area (lilac). (Feilberg, 2004).

Biomass, productivity

ASP (aerial shoot production) was recorded in five plots. Only ASP from the ground layer was considered. The plots were investigated three years. ASP was higher in the fenced (ungrazed plots), and herbs were more vulnerable to sheep grazing than graminoids.

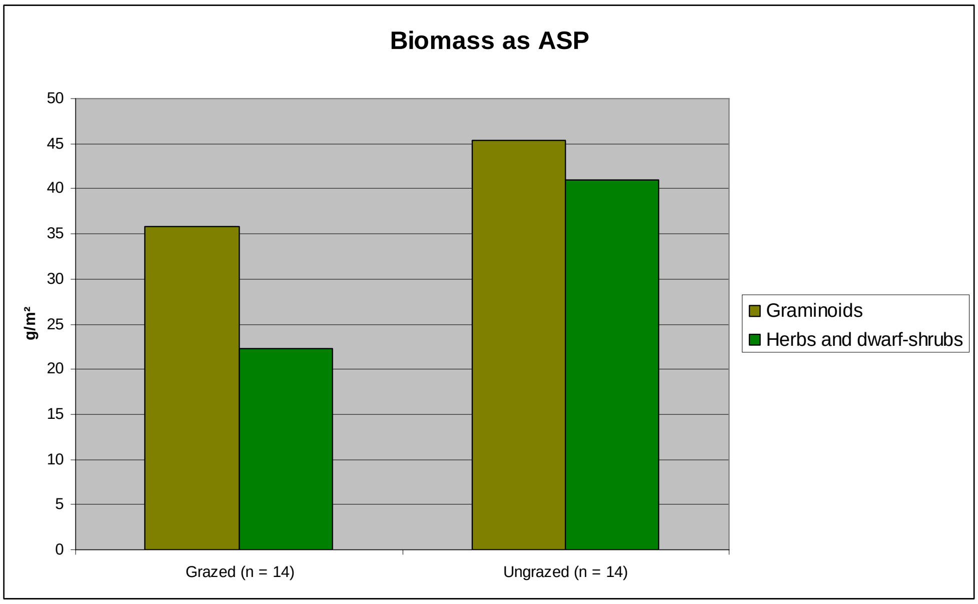


Fig. 19. Biomass measured as Annual Shoot Production (ASP) for two functional groups, graminoids, herbs and dwarf-shrubs. (Feilberg 1984) .

4.4.3. Ecosystem effects

Sheep grazing & nutrient dynamics (chemical, physical and biological properties of the soil)

No published data are available on this subject from South Greenland. For an outline of soil see section 4.2.2.

Vegetation cover/erosion

An area of c. 10-15 km² near Igaliku Kujalleq, and some small areas near Narsarssuaq are all suffering from heavy erosion. However, heavily eroded areas cover < 1% of the sheep district in South Greenland. Almost everywhere there are signs of micro erosion, which can develop to real erosion. An example from two comparable sites, one with no micro erosion and another nearby with pronounced micro erosion in a 20-years period is seen in fig. 20.

Fig. 20. Comparable rocks. The rock to the left (plot 39) has been protected from grazing animals since 1984, the rock to the right (plot 38) has been exposed to grazing animals for the same period. The weak red line indicates the limit of vegetation in 1984.

Mammals, birds, insects

The sheep is the main mammal in the grazing area of South Greenland. Modern sheep farming affects most levels of the terrestrial ecosystems, which include two mammals, 30 breeding birds and some 500 insects. It is presumed, that the predators, arctic fox, white-tailed eagle and raven are favoured by the sheep farming. Greater numbers of predators on the other hand affect their natural prey negatively. However, no published data are available.

5. Norway

Gunnar Austrheim, Atle Mysterud, Geir Steinheim and Øystein Holand

5.1. Introduction

Most of the Norwegian land area could be classified as outlying fields (c 90% of the total Norwegian land area; Statistics Norway 2003). Cultivated infields comprises a minor proportion of Norway (3.2%), and most of it (1.9%) is used for fodder production (winter fodder mainly) in the animal husbandry (Nordic Council of Ministers 2007). Sheep is the most important livestock herbivore in terms of metabolic biomass, and most all Norwegian municipalities had sheep grazing in 1999 (Fig. 21; Austrheim et al. 2008b) but most sheep (c. 75%) graze in the northern boreal and alpine region in Norway (Moen 1998), which covers > 60% of the total land area. Moreover c. 80% of all sheep grazing occurred south of Northern-Norway (i.e. south of the counties of Nordland, Troms and Finnmark). This presentation of sheep grazing in Norway will thus focus on the Norwegian mountain region in southern Norway.

5.2. Study sites

5.2.1. The environment of the Norwegian mountain region

Mean annual precipitation is high, especially in the western part of the Norwegian mountain ridge (between 2000 – 5000 mm per yr) and are normally not lower than c.1000 mm in the least humid parts of the region. The annual fodder production is mainly limited by the temperature, and the number of growing days (> 5º C) in the alpine region, normally do not exceed 130 days. In comparison, the lowland parts of Southern Norway have a growing season of up to 220 days.

5.2.2. Geology and soil

Boreal and alpine areas include both nutrient poor Precambrian bedrock resistant to weathering (southern Norway and eastern part of the Finnmark county) and more easy weathering and base-rich bedrock from Kambro-Silur (Central Norway and further north mostly; Moen 1998). Soil productivity thus varies between acidic mineral soils poor in nutrients and more base-rich soils which in general have a positive effect on plant productivity.

5.2.3. Vegetation

Alpine vegetation (above the subalpine tree-line) could be classified as 1) low alpine, 2) middle alpine and 3) high alpine (Moen 1998). The low alpine zone is delimited by well developed *Vaccinium myrtillus* dwarf-shrubs in the upper part (1300 m a.s.l. at Dovre, Central-Norway). The upper boundary of the middle alpine zone is defined by the occurrence of continuous vascular plant vegetation (1700 m a.s.l. at Dovre). High alpine vegetation is thus dominated by mosses and lichens. Alpine plant communities are further structured by the length of the growing season along the ridge, lee-side and snow-bed gradient. While ridge communities include vegetation with a thin and unstable snow-cover, the snow cover increases along the gradient so that snow-bed plants have a short growing season with a high degree of disturbance due to solifluction. Mires and bogs cover vast areas in the low alpine zone, but peat thickness is thin and decreases with altitude. The alpine species pool is dominated by dwarf-shrubs, graminoids, mosses and lichens, and a large number of herbs at base-rich sites. Although, herb diversity is high in base-rich alpine vegetation, the biomass proportion is low. While the vegetated land cover of Norway includes a broad variation of different vegetation types from nemorale, boreal and alpine vegetation zones. A large proportion of the northern boreal and also alpine vegetation in the whole NA region could be classified as semi-natural, as open areas to a large extent are induced by land use such as livestock grazing, collection of winter fodder and fuel-wood. As many as 45% of all red-listed species in alpine areas have their main distribution in semi-natural habitats (Austrheim et al. 2007a). Semi-natural habitats in the northern boreal and alpine region are characterized by a dominance of graminoids and herbs in the field layer. The relative importance of sheep grazing for inducing and maintaining these semi-natural habitats is difficult to estimate, but tree recruitment (birch mostly) is currently causing a tree-line elevation and a denser subalpine forest, while willow-shrubs cause a decrease of semi-natural habitats above the forest-tundra ecotone. Climate change is expected to strengthen these secondary successional processes in the years to come.

Sheep grazing in the low alpine zone at c. 1200 m a.s.l. in Hol, Southern Norway (Photo; Atle Mysterud).

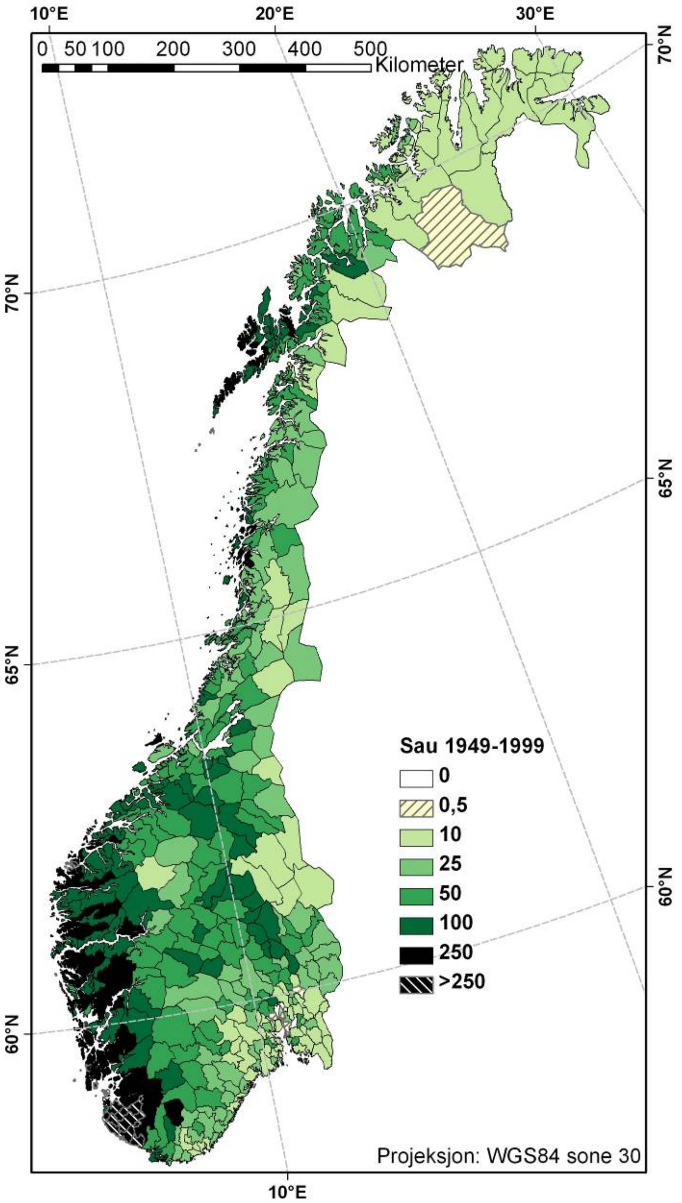


Fig. 21 Mean metabolic biomass for sheep (kg per km^2) in Norwegian municipalities for 6 time stages during 1949-1999 (from Austrheim et al. 2008b).

5.3. History of sheep grazing management

Agriculture and livestock keeping as a way to secure a livelihood was introduced in Norway during the middle Neolithic B (2600-2200 BC), and was widely adopted during the late Neolithic period (2200-1700 BC; Hjelle et al. 2006). As in most of the world, sheep and goats were the first livestock species to reach importance (Clutton-Brock 1987; Hjelle et al. 2006).

The sheep was clearly important in Norway in the period from the Viking age (starting around 900 AC) and up to the onset of "Svartedauden" (the Black Death) which ravaged Norway 1349-1350; this is confirmed by written sources and archaeological findings. The double-fleeced wool of the Nordic short-tailed sheep now played an interesting indirect role in fisheries, sea journeys and warfare. For hundreds of years Norwegian boats used sails weaved from wool, where the coarse outer fleece was used for basic fabric (*renning*), and the very fine, inner fibres for woof (*veft*) (Drabløs 1997; Lightfoot 1993). Also, most people dressed almost exclusively in wool fabrics, and wool was clearly the most important product the sheep had to offer in this period. For the making of sails and fisherman's clothes, wool from 2-3 year old wethers and dry ewes gave the best fabrics (longer fibres). These animals also produced a lot of the important kidney fat used for consumption and as lamp fuel (Drabløs 1997).

During the 17th through the 19th centuries, wool was still of great importance, and the kidney fat collected prices almost as high as butter. Farmers thus still kept some wethers and dry ewes. As in the previous periods, it was common to milk ewes for production of cheese or butter (Drabløs 1995). Due to the high content of fat and proteins, sheep-milk products were especially valuable as food for children. Sheep body growth seems to have been poor, partly because the presence of large predators necessitated herding during the day and keeping in corrals during the night (= high parasite loads). The winter period was also hard on the animals, and sheep were often kept in damp, warm buildings with very poor feeding (Drabløs 1997). During this period import of "exotic" breeds started, with society's dignitaries (priests, civil cervants, etc.) as initiators. The foreign breeds had a hard time gaining popularity, not least because the single-layer fleece (cross-bred) was unsuitable for some of the traditional craft traditions (Drabløs 1997), especially the "stamping" or "toving" (mechanic filtering) of wet wool fibres

5.3.1. Number of sheep and sheep farms

During the 19th century, numbers of sheep and lambs in summer reached almost 3 mill. animals (Mysterud & Mysterud 1995), but it declined during the last of this century. The number of sheep then increased all through the 20th century (Fig. 22), but may have reached a maximum in 2005. From the 1960's, the increase in the sheep population happened despite a rapid decline in the number of farms keeping sheep (Fig. 23); in 1969 approx. 69.000 farms, in 2007 only 15.500. The parallel increase in flock size thus more than compensated for farmers quitting on sheep – or quitting farming altogether. In 2005, Norwegian sheep farms stocked on average 63 ewes (young and adult) in winter.

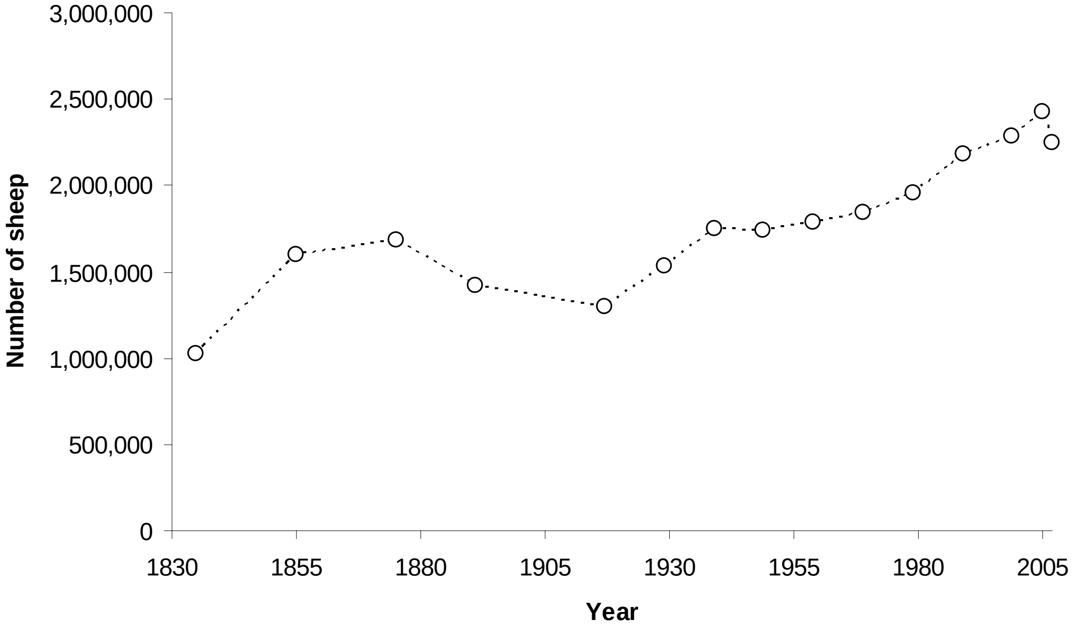


Figure 22. Number of sheep and lambs in Norway during <u>summer</u>, 1835-2007. Data from Statistics Norway. Note that all statics from the 19th century were recorded at 31. Desember, while later recordings were at 30. September (1917) or the 1 or 20 of June (the rest of the 20th century. Thus counts from the 19th century do not include lambs slaughtered in the autumn.

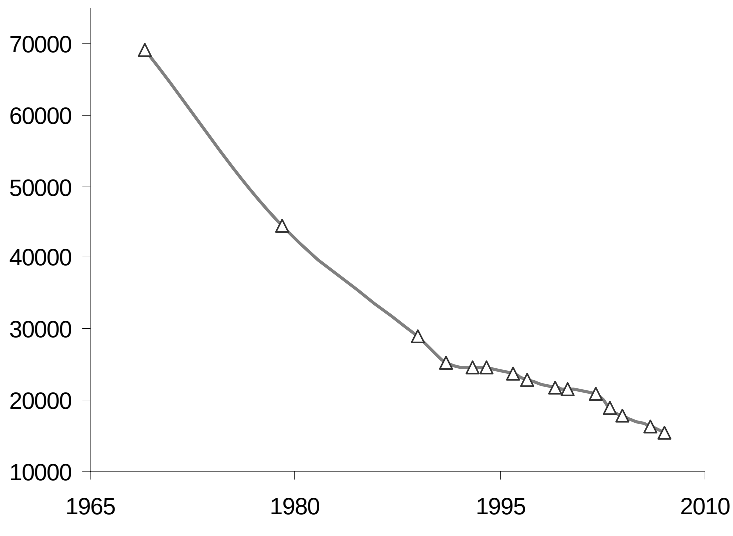


Figure 23. Number of Norwegian farms keeping sheep 1969 – 2006. Data from Statistics Norway

5.3.2. Breeds and breeding

Originally, Norwegian sheep were of the old Nordic, short-tailed and double-fleeced type. Imports of breeds, especially English and Spanish, are documented from the mid-eighteenth century and onwards (Nedkvitne 1955), but have probably taken place a lot further back.

A few breeds of the short-tailed type have prevailed, but today the majority of Norwegian sheep are of a modern cross-bred type, with strong influences from British sheep (Trodahl 1998). In this report we lump the breeds Dala, Rygja, Steigar and Norwegian White into "Norwegian White Sheep", as these breeds are closely related (see Fig. /) . Every year the short-tailed breeds decline in numbers, and may be at risk of being reduced to conservation status rather being a part of the commercial livestock production. For images and short descriptions of these and other breeds, see Oklahoma State University's (2008) web page: http://www.ansi.okstate.edu/breeds/sheep/.

In 2007 the Norwegian sheep population consisted of the following (Table 5, short-tailed breeds marked with *):

Table 5. The percentages of different sheep breeds in Norway in 2006. Data are based on the Sheep recording System (Løvik & Hansen 2007), which includes 1/3 of all Norwegian sheep.

Breed	Percentage of population
Norwegian White Sheep	81.5
Spael Sheep*	13.1
Cheviot	1.6
Norwegian Fur Sheep*	1.0
Other breeds	2.8

A modern and organized sheep breeding scheme was developed during the 1960's and was implemented throughout the 70's. The basis of the scheme was ram circles, where sheep farmers in an area cooperate to test promising male lambs in an efficient way, i.e. giving a suitable number of young rams enough offspring (rule: each ram tested had to be mated to at least 30 ewes). Rams could thus be evaluated as 1 ½ years olds, and the best ones would later be evaluated also based on their daughters' production of lambs. From the beginning, the basis for selection was production *across* breeds, only the short-tailed sheep were treated separately, whilst the cross-bred breeds were taken as one, large breeding population.

Today the ram circles (now approx. 125 circles) are still an important basis for the breeding programme, testing around 2000 rams per year. The multi-trait breeding goal consists of many production and health traits which are assigned economic weights to calculate an overall breeding index. Now the production results of all sheep that are registered in the Norwegian Sheep Recording System are used, not only the test rams and their offspring. Today approximately 30% of all Norwegian sheep are registered in this system. Best linear unbiased predictions are used for calculating genetic values and indices.

From the 1980's the use of artificial insemination (AI) for sheep has increased, and in 2007 a total of 28400 doses of semen were sold through the AI system. Thus, some rams will spread their genes across a wide variety of environments – north and south, mountain and lowlands. What might be the consequences of this?

The main breeding goal, as stated by the Norwegian Sheep and Goat Breeders' Association, is (translated by the authors) to develop a sheep that is "**able to utilise the natural resources in the best possible way**". This sheep has "an average of two lambs per adult ewe in autumn", "best possible growth potential of lambs, and lambs ready for slaughter directly from rangeland pastures", and other defined sub-goals for carcass quality, fat, maternal ability, wool quantity/quality, and, the sheep should have a "conformation of body that enables the sheep to utilise rangeland pastures; strong legs and good udders".

5.3.3. Management: grazing season, supplemental feeding

Keeping sheep outside around the year, with little or no supplemental feeding, is an option in coastal areas. An increasing number of flocks are today managed like this; they are often kept on islands, using sheep of the old Norwegian type, and producing niche products marketed as meat from "Villsau" or "*wild sheep*". The sheep survive the winter foraging on heathers (mainly *Calluna vulgaris*), woody plants, and sea-weeds.. This kind of extensive management is very likely to have been common back to the Viking age and earlier, it may well be the way sheep were kept back in the Bronze Age. The practice, in its "pure" form, may be seen as a stage between hunting and livestock keeping: the animals are left to fend for themselves, Man drops by to collect animals for slaughtering.

Today the majority of sheep are kept on pastures (generally) from May to October, and inside, with feeding, the rest of the year. Keeping sheep housed during winter has long traditions in Norway, and was common at least back to the seventeenth century (Drabløs 1997). Especially in inland areas, feeding during winter was necessary,.

About 93% of Norway is rangelands not fit for agricultural purposes apart from grazing. The typical sheep farm in today's Norway is deeply dependent upon the use of rangeland pastures during summer (mainly mountain and forest pastures). Ewes (also 7-8 months olds) are mated in early winter, and give birth while still housed. Feeding during winter is aimed at optimising litter size and vitality of dams and lambs, and roughage (silage, some hay) is supplemented with concentrates.

Animals are sheared before lambing. If the timing of mating - and the spring - is right, ewes and lambs are put on fenced spring pastures for one or two weeks after lambing. After a few weeks the ewes and lambs are moved to the rangeland pastures, and released to roam freely without interference from fence or shepherd for (on average) 95 days (Skurdal 1997). The time sheep spend on rangeland pastures was reduced during the 20th century; in 1949 the average rangeland period was 116 (Otnes 1976). Further, a study based on 61% of all Norwegian sheep in 1992 give an average rangeland period of 95 days, ranging between counties from 92 to 135 days (Skurdal 1997). The farmer will normally (in areas without large predators) check on his animals a couple of times per week. No supplement feeding in summer, but some mineral licks will be distributed in the (often communal) grazing area.

The breeding stock will stay on autumn pastures until winter approaches and plant growth is slowing down. They are then housed, and mated in early winter.

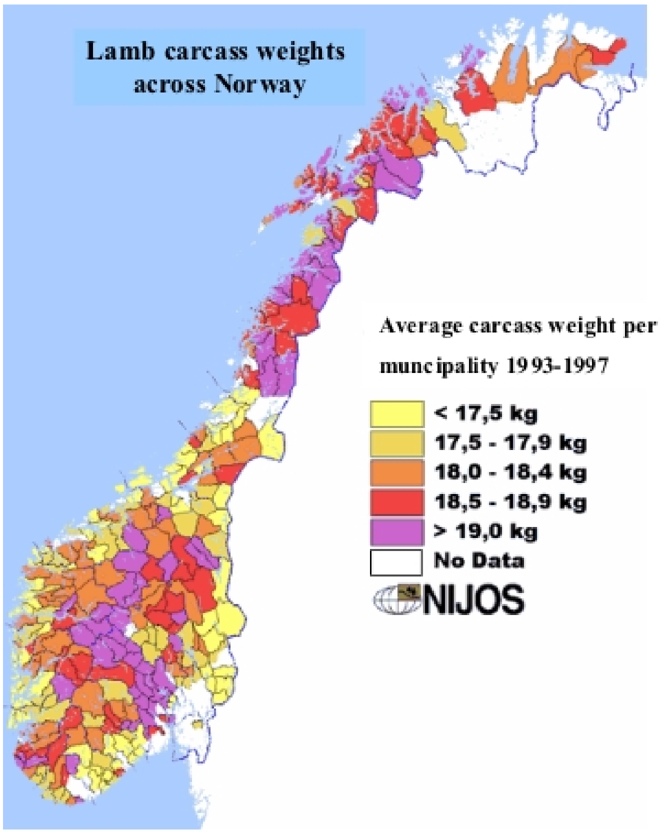


Figure 24. Lamb carcass weights 1993-1997, means per muncipality. From Steinheim & Tauball (1998)

In autumn the sheep are collected, often using herding dogs, and sorted into animals for slaughter and animals for breeding stock. Typically, one third of the year's ewe lambs are recruited for breeding, along with a few ram lambs that will be tested as potential sires. The lambs on average weigh 42.5 kg in autumn, and the slaughtered lambs will on average give carcasses weighing ≈18.5 kg (for regional variation, see Fig. 24). Some lambs are sent to the slaughterhouse directly from the rangeland, others are given a period to finish on cultivated autumn pastures, often with some concentrate supplements. A schematic representation of the year on a typical Norwegian sheep farm is given below (Fig. 25)

The breeding stock will stay on autumn pastures until late autumn when plant growth is slowing. They are then housed, and mated in early winter.

5.3.4. Management: law and other regulations

The Norwegian sheep production is in general very well organized. Today more than 85% of the sheep farmers are members of "Norsk sau og

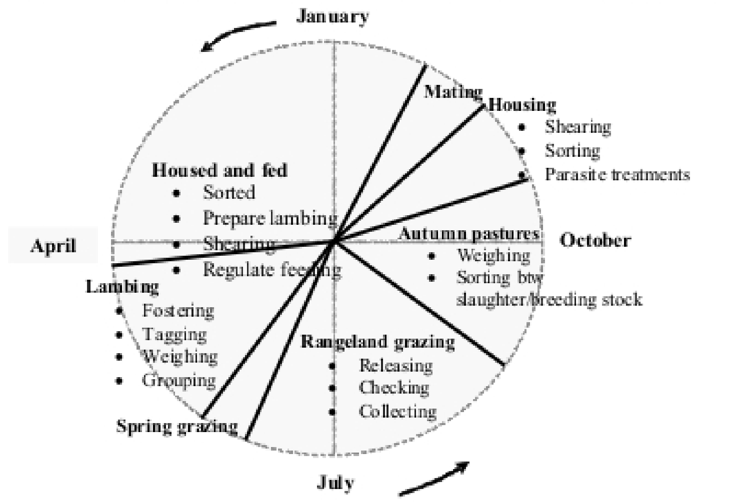


Figure 3. Sheep farm yearly cycle, drawn from Hellebergshaugen & Maurtvedt (1998)

geit" (*Association of Norwegian Sheep and Goat Farmers*) (Aunsmo 1997). This organization administrates the breeding scheme and gives advice to farmers through direct communication and through various courses on breeding, feeding, welfare, etc. A third of all sheep farms register all their animals in the Sheep Recording Scheme which is the basis for the national breeding scheme and gives data for calculating breeding indices (see above).

The cooperation between farmers for utilising grazing areas efficiently has long traditions, but a national rangeland grazing system was not up and running until around 1970 (Drabløs 1997). The main goal of this system, "Organisert beitebruk" (*Organized Grazing*), is to reduce losses of animals grazing on rangeland pastures. Sheep farmers using the same grazing area form a "beitelag" (*grazing area society*), and receive funding to implement various tasks, such as organizing checking on animals and collecting animals in autumn. Also, building of bridges, fences along dangerous drops, fences for collecting and sorting animals, etc. is supported through the system. Today more than 900 grazing areas all over Norway are organized in the system, and approx. 80% of all sheep flocks are registered here. The units register the number of sheep of different breeds, sex and age that graze in outlying land, and detailed data on animals lost (or found dead) during the rangeland season. Information from this system (including maps showing carcass weights and summer mortality per unit), linked with other databases, can be found at www.skogoglandskap.no/kart/beitebrukskart_og_statistikk. This digital system, "Informasjonssystem for beite i utmark" (*System for information on rangeland grazing*), is administrated by the Norwegian Forest and Landscape Institute.

Around 1260 the king Magnus Lagabøter mentions rangeland grazing in his laws (Hagland & Sandnes 1994; Nedkvitne et al. 1995). Today several specific laws have relevance for grazing livestock, and in addition we have regulations based on these laws (Nedkvitne et al. 1995) (Tab. 3.7). A few central points, picked from the various sources:

- if a farm has traditional rights to graze animals in an area owned by the State (a lot is owned by the State, especially in northern Norway), the farmer is allowed to graze as many animals as he/she can provide with feed during winter
- Any farmer grazing livestock is responsible for keeping his animals away from areas where they aren't allowed to graze

- It is not allowed to keep male animals born before 15 April on pastures where they may come into contact with animals owned by an other farmer
- Animals with contagious diseases can not be put on communal pastures
- The owner has a duty to ensure that sick or injured animals get care, and that all animals are collected from the pastures before onset of winter
- A farmer may kill predators that are in the process of attacking her/his animals, regardless of protection status of the predator
- Free-ranging animals must be monitored at least twice a week in areas with high risks of predators, injury or diseases.

The "right to graze" has been challenged in recent years. The Norwegian Food Safety Authority, suggested to prohibit sheep grazing in an area where severe attacks on sheep by large predators are occurring – or are likely to occur based on animal welfare concerns. Such a case was taken to the court system, where the sheep farmers were ruled to have the right to graze their animals even under such problematic circumstances.

5.3.5. Main products

Sale of lambs for slaughter is the main source of income for Norwegian sheep farms. Since 1996 Norway has used the EUROP classification system for carcasses, and slaughtered lambs are generally of reasonable quality according to this system (Fig. 26). Wool contribute with approx. 15% of the total income of a typical sheep farm (Lien & Trodahl 1998).

There is a trend towards product diversification in brand names, based on locality and natural environment characteristics, and the Norwegian sheep industry have several established and emerging brands, such as "Lofoten-lam", "Hallingskarvet-lam", "Høgfjellslam frå Nord-Gudbrandsdalen". Some 2% of lambs slaughtered in 2007 were defined as produce from organic farming; this is way below the present government's goal of 15% organic by year 2015, but still an increase from the 0.3% of 1996 (data from M. Røe, Animalia).

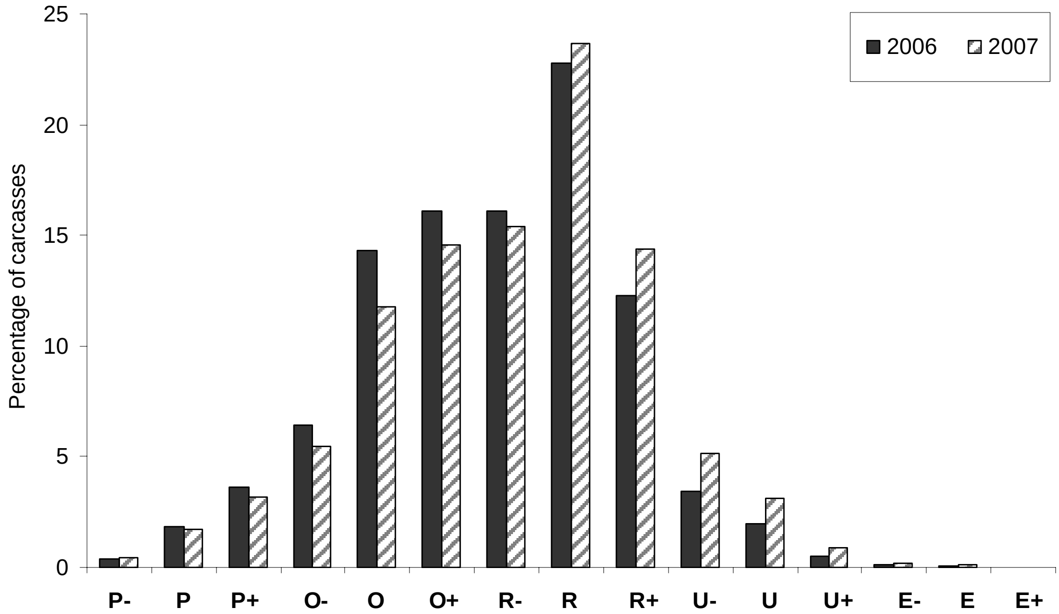


Figure 26. EUROP classification of Norwegian lamb carcasses in 2006 and 2007

The rangeland pastures, and the young age (on average ≈150 days) at which lambs are slaughtered results in Norwegian lamb meat being of a high quality (this year the world championship for chefs use Norwegian lamb as one of the main raw materials.

5.3.6 Economy: subsidies, outlook

Sheep farmers, as all Norwegian farmers, receive several different subsidises based on production, area use, region, flock size, etc. We will not go into details, but focus on some important points.

The main policy for deciding the farmer income is determined and revised in the yearly "Agricultural Settlement" (*Jordbruksoppgjøret*). Here the farmers' organisations and the Norwegian state negotiate subsidises seen in context with factors such as international trade agreements, general trends of income in Norway and agricultural policy goals. The negotiations are conducted much in the same way as when labour employers' organisations negotiate wages.

Sheep farming has generally generated less income per year than most other agricultural productions. In 2007 the Settlement resulted in a substantial increase in subsidises, but the sheep is still the poor cousin of the livestock species.

Today, the most important subsidy in sheep farming is given as "subsidy per sheep in winter" or adult breeding stock sheep. This is a structural measure and with increasing flock size the subsidy per animal is reduced. In 2007, 88% of all Norwegian sheep farms had less than 76 adult animals in winter, and thus received the highest rate per sheep. Following steps of reduced returns, an increase of flock size to above 200 does not generate any increase in subsidises (Statens landbruksforvaltning 2008). The system is under debate, and an increase of maximum subsidy-generating flock size to 300, along with a less steep ladder of reduced subsidies per flock size interval, has recently (April 2008) been suggested by the Norwegian Agricultural Authorities (Statens landbruksforvaltning 2008). This change, if implemented, will presumably affect the structure of the industry resulting in fewer and larger flocks.

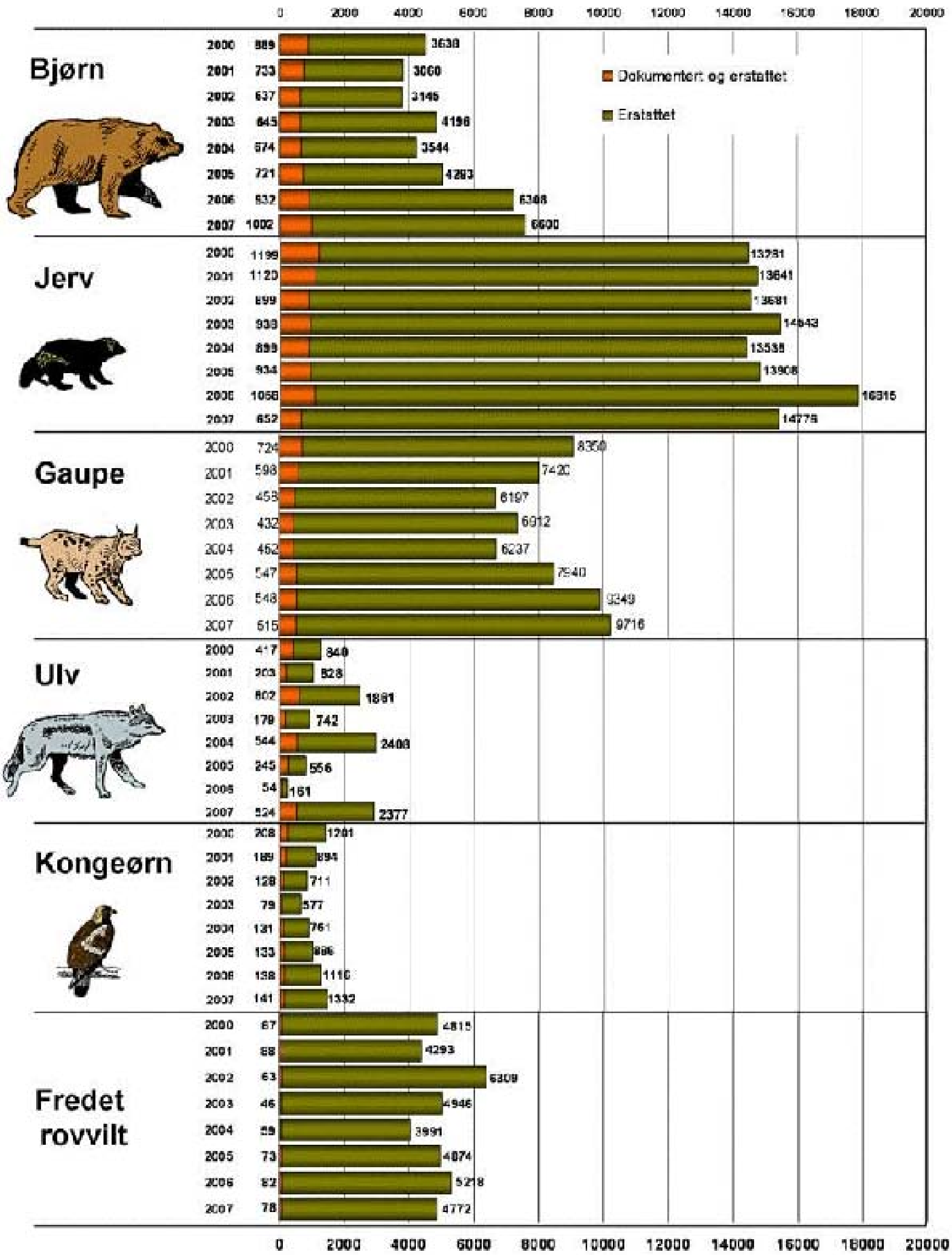


Figure 27. Sheep and lambs compensated 2000 - 2007 as killed by the different protected predators; documented and "probable" cases. Adapted from DN (2008) online: www.dirnat.no/content.ap?thisId=500033805

5.4. Ecological effects of sheep grazing

5.4.1. Sheep grazing ecology

Habitat and plant selection

Sheep is defined as a grazer which prefer herbs > graminoids > woody species although the relative amount of woody species in the diet of free-ranging sheep differ between breeds (i.e. Norwegian White Sheep; 26 % and Norwegian Spael; 25-50 %; Table 6). Thus, sheep prefer graminoids and herb-dominated vegetation types in lee-side and snow-bed communities when foraging, but more exposed ridge-habitats while resting (Kausrud et al. 2006). Density dependent effects on foraging ecology are less examined, but selection ratio was found to be higher at low densities of sheep as compared to high densities (Mobæk et al. In press), and lambs were heavier at low grazing pressure as compared to high grazing (Mysterud and Austrheim 2005). Habitat productivity in outlying land also affect sheep growth rate, and weight gains for lambs during summer grazing in Hol (productive site) were higher as compared to Setesdal-Vesthei (low productive site).

Life history

Average body mass of Norwegian White Sheep (NWS, the main Norwegian sheep breed, cf. Table 6) is 83 kg for ewes and 43 kg for lambs (carcass 19.2 kg). NWS normally reproduce the first year with an average litter size of 1.5. Litter size at ≥ 2 years is 2.0. Mortality is 4.2% and 22.9% for ewes and lambs respectively. The main cause of lamb losses are predation (75%) before disease (22%), while 3% died of other causes (Table 6; Animalia 2007, Steinheim et al. 2008a, Steinheim et al. 2008b).

Norwegian Speal (13.1% of the Norwegian sheep population) have a lower body mass as compared to NWS. Ewes weigh 65 kg while the weight of lambs is 41.2 kg (carcass 17.8 kg). However, litter size and mortality during the grazing season corresponds with life history data for NWS (Table 6; Animalia 2007, Steinheim et al. 2008a, Steinheim et al. 2008b).

5.4.2. Effects of sheep grazing on plants, animals and ecosystems

Sheep, like other herbivores, can strongly affect plant communities by favouring resistant and tolerant plants, while less tolerant and selected species decreases (Crawley 1997, Hester et al. 2006). However, the impact on plant communities depends on environmental factors such as productivity as well as sheep density. Studies from a productive and species rich alpine environment in Norway (Hol) showed only modest effects of grazing on plant community patterns on a short term scale. Tall competitive herbs decreased, while a few graminoids increased as expected at high grazing (80 sheep per km^2 grazable area) in contrast to ungrazed controls. Plants in plots with low sheep grazing (25 sheep per km^2 grazable area) were found to be almost unaffected. Plant species that decreased at high grazing generally increased in controls and *vice versa* suggesting a response to enhanced grazing and succession respectively (Austrheim et al. 2008a). Grazing frequency of the palatable herbs also increased significantly from low to high grazing, but the grazing frequency was < 40 % at high grazing (Evju et al. 2006) which is considered low according to international standards (Holechek 1999).

In contrast, the cessation of sheep grazing in a species poor alpine system of low productivity (Setesdal Vesthei) caused a rapid shift in graminoid dominance after 5 years. The highly selected *Deschampsia flexuosa* increased while the resistant *Nardus stricta* decreased after 7 years (Austrheim et al. 2007b, G.Austrheim unpublished). Densities in 2006 which varied between 44 and 88 per km^2 grazable area (which probably were relatively stable for the latest 150-200 yrs) were also higher than the densities recommended for optimal meat production (Rekdal and Angeloff 2007).

Sheep grazing are found to affect various groups of organisms, but the directions of responses differ between target animals and sheep density. The study in a productive low-alpine environment in Hol, has revealed a short-term (4-yr) negative effect of both high and low grazing vs. no grazing on the diversity of plant eating beetles (Mysterud and Austrheim 2005), while the diversity of nesting birds increased at high grazing vs. no grazing (Loe et al. 2007). Population growth rate of field vole decreased at high grazing as compared to low grazing (Steen et al. 2005).

Herbivores may have strong effects on ecosystem structure and function. These effects are mainly considered to be mediated by grazing impacts on plants, and although few grazing effects on plant community patterns and species abundances are found at the productive site in Hol, sheep grazing probably affect ecosystem functioning through a change of plant quality, structure and biomass (Evju et al. 2006) on a short term (up to 4 years). How different densities will affects ecosystem properties on a longer term is a more open question.

6 The economy of sheep management in the North-Atlantic region

Leif Jarle Asheim & Anders Skonhoft

Within the Nordic farming system with its distinction between the indoors season and the outdoors grazing (except for the Faroe Islands), the farmers face several investment decision problems. One problem is to find the optimal size of a farm; that is, the capacity to keep animals indoors during the winter season. Another problem is the so-called replacement problem, i.e., to find the optimal categories, or year classes, of adult females, as fertility (as well as mortality) varies over the life cycle. A third problem is, for a given farm capacity, to find the capacity utilization that gives the optimal number of animals to be fed and kept indoors during the winter season. A corollary of this problem is to find the optimal number of lambs to be slaughtered before the winter season. All these problems are influenced by what type of products the farmers aim to produce, and meat only production give different answers compared to a production scheme involving wool together with meat. Economic factors, like the winter fodder costs and the meat price, as well as the summer grazing conditions influence the various investment decisions outcome as well. The prices and costs are heavily influenced by the various supporting schemes for the farmers.

The Organization for Economic Co-operation and Development (OECD) computes Producer and Consumer Support Estimates for its member states which include Norway and Iceland. The webpage (www.oecd.org/document/59/0,3343,en_2825_494504_39551355_1_1_1_1,00.html) contains the databank which has numbers from 1986 to 2006 together with an explanation of the calculation principles. Sheep meat support is quite high in both Norway and Iceland as well as in the EU when compared to the main exporters of sheep meat, Australia and New Zealand, which abolished most of their agricultural support in the early 1980s. However, the Norwegian sheep meat subsidies are not high when compared with other agricultural commodities. In 2004-06 producer single commodity transfers (SCT) by commodity was low for sheep meat (5%), but 34% for eggs, between 40-60% for common wheat, barley, oats, milk, and pig meat, and around 60-70% for poultry and wool. (http://www.oecd.org/dataoecd/14/0/39579647.pdf).

Island has always exported a surplus of sheep-meat, while the Norwegian consumption has exceeded production since 2003 (according to OECD). Sheep meat consumption is around 22 kg per capita in Island, 33 kg in the Faroe Island and 5.8 kg in Norway (Dýrmundsson, 2004). In Island domestic sheep meat consumption per capita decreased from 47 kg in 1978 whereas in Norway it has increased, albeit slightly, during the last 25 years. It is clear that sheep meat consumption per capita in the EU has been fairly stable over the last 40 years (EAAP, Publication No.108, 2003). Sheep meat consumption may continue to decline, especially in competition with pig and poultry meat in countries with traditionally strong demand for lamb. On the other hand, ethnic changes in the population may lead to increased demand for sheep and goat meat in some of the countries, especially in those with large numbers of Muslim immigrants (Dýrmundsson, 2006). At the Faroe Islands, 90-100% of the export was products from sheep in the 18th century. In the 19th century the relative importance had decreased to 60%, while only 3% of the export income in the 20th century was associated with sheep (Bjørk 1956/57). At present, most of the products from sheep husbandry are used by the farmers themselves.

For centuries, sheep farming has contributed substantially to the grassland-based agricultural production in Northern European countries (Dýrmundsson, 2006). However, sheep farming in Europe has been under great economic pressure facing an ever increasing international market competition, basically due to cheap lamb meat import from New Zealand. In addition to the pressures of trade liberation and international competition, technical evolution in production and greater emphasis on processing and distribution, substantial changes are also taking place in consumer demand. The primary producers share of the consumers expenditure are declining as relative food prices are declining and have been doing so under great political pressure for decades (Dýrmundsson, 2006). On the other hand recent increases in oil and other energy prices are affecting fertilizer prices and feed used by non-grazing animals face more competition due to e.g. use of corn for ethanol. Increased prices for feed may well be followed by a renewed interest in grassland based agricultural production in the region and in particular for use of unfertilized outfield range pastures which are mostly utilized by the sheep.

7. Conclusions

At present, sheep is by far the most important grazer in the Faroe Islands, Iceland and Norway, as well as in the south-western coastal zone at Greenland. Moreover, sheep grazing has prehistoric traditions, and sheep most likely were the main livestock at all times in all countries and thus the main strategy for converting plants from the vast non-arable outlying land to food for humans. However, sheep grazing management and the ecological effects and economical importance of sheep grazing has varied over time and between countries, and in this report we present an overview of the spatio-temporal variation in management factors such as number of sheep, breeds, grazing season, supplemental feeding, law and other regulations, main products and the economical importance of sheep, and the ecological impacts of sheep grazing on the sheep itself, plants and the ecosystem for each country. Finally, these cultural and natural factors are used as a basis to evaluate whether sheep grazing management could be considered sustainable both in an ecological and economic perspective.

7.1. Variation in management

The common breeds used at present at the Faroe Islands, Iceland and Greenland differ from the main Norwegian breed (Norwegian white sheep; NWS), which is both heavier and produces more lambs as compared to Faroese, Iceland and Greenland breeds (Table 6 and Fig. 7). Ewes of NWS are also heavier than Norwegian Spael (NS), and although litter size does not differ NWS are found to be more dependent on high quality herb and graminoids fodder, while Norwegian Spael selects a higher percentage of woody species in the diet. All breeds except the NWS are probably strongly related to the ancient breed used exclusively all over the region until the 18th century.

Table 6. Sheep grazing ecology**.** Grazing ecology and some key life history parameters of domestic sheep in the Nordic countries. Habitat rank = from most to least selected separated on two main types of activity (grazing vs. resting); "use" = proportion of time spent in habitat; "Selection index": use/availability. See text for references.

	Foraging ecology		Life history		
	Habitat rank (use %; selection index)	Diet (%)	Body mass (autumn; kg)	Litter size	Mortality (grazing season; %)
Norwegian White Sheep (NWS)	Grazing: Meadows (26.6; 2.8)> Snowbed (30.1; 2.2)> Lichen heath (8.1; 0.5)≥ Bog/fen (4.7; 0.9)≥ Dwarf shrub heath (30.6; 0.6). Resting: Lichen heath> Dward shrub heath> Meadows> Snowbed> Bog/fen Method: dobservation	Forbs: 22.2 Grasses: 50.8 Woody: 26.2 Other: 0.8 Method: Microhistological analysis of faecal samples	Ewes: 83.0 Lambs: 43.0 (carcass 19.2 kg)	Age 1: 1.5 Age ≥2: 2.0	Ewes: 4.2 Lambs: 22.9 Cause (lambs; % of losses): Predation: 75 Disease: 22 Other: 3
Norwegian spæl	n.a.	Woody plants 30-50%	Ewes: 65 kg Lambs: 41.2 kg (carcass 17.8 kg)	≈ same as NWS	≈ same as NWS
Icelandic sheep	n.a.	n.a.	Ewes: 60-70 kg Lambs: 15.5 kg (carcass)	Age 1: 1.0-1.2 Age ≥2: 1.8	1-2%
Sheep from the Faroe Islands	n.a.	n.a.	Rams 75-85 kg Ewes 40-50 kg Lambs 30-40 kg (12.5 carcass).	0.8	Very variable, but low now. Main reason is weather conditions, often in combination with insufficient food supply.
Sheep from Greenland	n.a.	n.a.	Ewes: 60 - 70 kg Lambs: 35 kg (15 kg carcass)	1.5	2-10 % on lambs

Sheep number varies strongly both among and within countries (e.g. fig from Norway) at present. Sheep number also varied on a temporal scale and especially on Iceland the population fluctuated due to both diseases (1770), eruption (1784) and a systematic slaughtering in the 20^{th} century to limit overgrazing. Extreme weather events have also caused declines in population densities as exemplified by the 50% reduction of ewes in Greenland during the harsh winter in 1966/67.

The length of the grazing season and the amount of supplemental feeding is a third factor which affects the actual grazing intensity (i.e. the total grazing pressure exerted in a given landscape). At present, winter grazing is only practiced in the Faroe Islands and mainly on infields, while sheep in Iceland, Greenland and Norway are feed indoors mainly on hey/silage and partly grains especially during the breeding season (Table 7). Winter grazing on outfields occur in some (coastal) areas with a mild winter climate using mostly old breeds, but were probably the most important management all over the region in former times.

Table 7. Sheep breeds in the North-Atlantic region. See text for references.

	10th century	15th century	18th century	19th century	Early 20th century	Year 2007
Greenland	Ancient breed	Die out of the Nordic farming culture and their sheep breed	Reintroduction of agriculture, cattle and goats		Reintroduction of sheep from Iceland the Faroes	Greenland variant North European short-tailed sheep.
Iceland	breed brought in by the Norse settlers	Icelandic sheep	Icelandic sheep	Icelandic sheep	Icelandic sheep	Icelandic sheep
Faroe Islands	Ancient breed		Import from Shetland/Orkney and Iceland?		Scottish Blackface. Also import from Iceland, Sweden and Greenland.	Faroese variant of the North European short-tailed sheep.
Norway	Ancient breeds.		Ancient breeds. Introduction of British and Spanish breeds	Imported breeds	Imported breeds	80 % Norwegian white sheep, 13.1 % Spael

While wool (and partly milk) was the main products from sheep farming in former times, the importance of meat production gradually increased from the 19th century in all countries, and meat is the main product in the region at present (Table 8). The economical importance of sheep management (relative to other incomes) may be high at a local scale all over the region, but varies among countries at the national scale. However, there is a large variation in sheep meat consumption per inhabitant within the region being for Norway only 26% and 18% of the consumption in Iceland and the Faroe Islands respectively (Dyrmundsson 2004).

Table 8. Main products from sheep in the North-Atlantic region. See text for references.

	10th century	15th century	18th century	19th century	Early 20th century	Year 2007 (present)
Greenland	?	-	-	-	Meat	Meat
Iceland		Wool & Milk	Wool & Milk	Wool & Milk	Meat	Meat
Faroe Islands		?	Wool	Wool	Meat	Meat
Norway	Wool & Milk	Wool & Milk	Wool & Milk	Wool & Meat	Meat	Meat

7.2. Ecological effects of sheep grazing

Several studies have examined the ecological effects of sheep grazing at different sites in all countries, but the complex nature of these study systems makes it difficult to directly compare the ecological effects of sheep grazing among sites. First, the methods used to identify the ecological effects (and to disentangle management effects from variations in the natural environment) vary between studies. Secondly, sheep management clearly has varied among the North-Atlantic countries, due to several factors (breed, number, grazing season and supplemental feeding), and third, environmental conditions varies between the Faroe Islands (strongly oceanic), Iceland (easily erodible eruptive deposits), Greenland (short growing season with limited production) and Norwegian alpine land (short growing season with limited production), as well as within each country. However, separate studies of grazing effects on plants in each country support the general assumption that heavy grazing cause an increase of graminoids while herbs and woody species are decreasing. There are also some indications of an increase of grazing resistant species (i.e. Nardus stricta) while less tolerant (and grazer selected) species decreases at high sheep densities (e.g. Norway; Setesdal, the Faroe Islands).

7.3. Sustainable management of sheep grazing

Although sustainability has been the main aim for the sheep grazing management in all North-Atlantic countries, the concept is vaughly defined, and it's thus difficult to judge whether this aim has been reached. In this report we have addressed four different aspects of sustainability from an ecological (and economic) perspective.

(1) Animal productivity (weight gained per unit time grazed in outlying land) is used for estimating cervides productivity, but sheep weights from the start and the end of the outlying grazing season is often not available since measures of sheep weights often includes the periods when sheep graze at infields (which provides an opportunity for weight gain after grazing in low productive outfields). However, studies from Iceland and Norway clearly show that sheep productivity depends both on density (Icelandic highland; Audkuluheidi, Norwegian low-alpine land; low densities vs. high densities) and habitat productivity (Norway; productive vs. low productive habitats). Thus, animal productivity will decrease if densities reach a level when the availability of fodder plants could not be sustained. This

knowledge of factors affecting sheep productivity is important from a management point of view, and provides a basis for a more production optimal distribution of sheep in the outfields. More data from different sites in the region is however needed to get more details on how sheep productivity is linked to both density and habitat productivity.

(2) Sustainable production of forage plants. Several case studies in this report indicate that high sheep densities increase the densities of non-palatable resistant species (e.g. *Nardus stricta*) to the detriment of palatable forage plants. Although most forage plants are tolerant (e.g. *Deschampsia flexuosa*) high grazing over a longer time scale would decrease forage quality and quantity not only for the livestock, but also most likely for other vertebrate and invertebrate herbivores. More data on plant dynamics relative to net densities of sheep are needed to optimise management.

(3) Erosion. High densities of sheep may also contribute to erosion effects especially in interaction with extreme weather events and in areas with more easily erodible soils (e.g. Iceland). In this report, erosion events correlate with high grazing at the Faroe Islands (higher altitudes), Greenland (mainly one site) and Iceland. Especially on Iceland, where erosion of varying severity has been recorded at 70% of the land area, and although erosion is reported to decrease, some degraded areas are still grazed. More studies are needed to examine the specific effects of grazing on erosion. Erosion also occurs at a local scale close to salt-stones and where sheep are gathered in folds, but this is more difficult to avoid.

(4) Biodiversity. Studies from the North-Atlantic region have so far examined grazing effects on biodiversity on a short term, and the effects vary from positive (bird species diversity) to negative (beetles, spiders) and none (vascular plants). In addition long-term effects on biodiversity are expected to differ from short-term effects, and biodiversity may thus be a difficult parameter to use for the management. Another aspect is the effect of cessation of grazing which contributes to encroachment in former semi-natural habitats and loss of species-rich grasslands and heath-lands. Most species in semi-natural habitats are depending on grazing and/or other land uses to limit encroachment, but it is still an open question which grazing regime that should be applied to maintain semi-natural grasslands without overexploiting high quality fodder such as herbs and other ecosystem components (e.g. wildlife).

In this report, we show that sheep grazing intensity at different sites in the North-Atlantic region varies due to different management factors; the size (breed) and number of sheep, and the length of the grazing season. All factors could be manipulated to improve the management according to the above aspects of sustainability, but the sustainability of different grazing levels are to a large extent site specific, due to the strong environmental variation between different sites in the region. This overview of the site specific ecological effects of different grazing regimes indicate how the environment will respond to different management regimes, and will thus hopefully serve to underpin a sustainable management of outlying sheep grazing land. Secondly, we hope that this report will contribute to a more common understanding of how sustainable sheep grazing should be defined. At present, sustainability is vaguely defined and there are also few examples of an active regulation of sheep populations in any country. Thirdly, we believe there is a need of a further development of the evidence-basis on long term grazing effects on fodder quality and quantity in outlying habitats and an improved communication between research and management to underpin the sustainable management of sheep grazing in the long term.

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Rapportserien

«Norges teknisk-naturvitenskapelige universitet, Vitenskapsmuseet Rapport zoologisk serie» er en videreføring av »Vitenskapsmuseet Rapport Zoologisk Serie» og presenterer stoff fra de zoologiske fagområdene ved Vitenskapsmuseet. Serien bringer i hovedsak arbeider fra oppdragsprosjekter og andre undersøkelser og forskning ved Seksjon for Naturhistorie. Serien er ikke periodisk og antall numre varierer pr. år. Serien startet i 1974 og det finnes parallelle botaniske og arkeologiske rapportserier ved Vitenskapsmuseet. Mindre arbeider og utredninger som av ulike grunner trenger en rask publisering og distribusjon presenteres i en egen notatserie: »Norges teknisk-naturvitenskapelige universitet, Vitenskapsmuseet Zoologisk notat».

Til forfatterne

Manuskripter
Manuskripter bør leveres som papirutskrift og som tekstfil i Word. Vitenskapelige slekts- og artsnavn kursiveres. Manuskripter til rapportserien skal skrives på norsk, unntatt abstract (se nedenfor). Unntaksvis, og etter avtale med redaktøren, kan manuskripter på engelsk bli tatt inn i serien. Tekstfilen(e) skal inneholde en ren «brødtekst», dvs. med færrest mulig formateringskoder. Hovedoverskrifter skal skrives med store bokstaver, de øvrige overskrifter med små bokstaver. Manuskriptet skal omfatte:

1. Eget ark med manuskriptets tittel og forfatterens/forfatternes navn. Tittelen bør være kort og inneholde viktige henvisningsord.
2. Et referat på norsk på maksimum 200 ord. Referatet innledes med bibliografisk referanse og avsluttes med forfatterens/forfatternes navn og adresse(r).
3. Et abstract på engelsk som er en oversettelse av det norske referatet.

Manuskriptet bør for øvrig inneholde:

4. Et forord som ikke overstiger en trykkside. Forordet kan gi bakgrunnen for arbeidet det rapporteres fra, opplysninger om eventuell oppdragsgiver og prosjekt- og programtilknytning, økonomisk og annen støtte, institusjoner og enkeltpersoner som bør takkes osv.
5. En innledning som gjør rede for den faglige problemstillingen og arbeidsgangen i undersøkelsen.
6. En innholdsfortegnelse som viser stoffets inndeling i kapitler og underkapitler.
7. Et sammendrag av innholdet. Sammendraget bør ikke overstige 3 % av det øvrige manuskriptet. I spesielle tilfeller kan det i tillegg også tas med et «summary» på engelsk.
8. Tabeller og figurer leveres på separate ark og skrives i egne filer. I teksten henvises de til som «Tabell 1», «Figur 1» osv.

Litteraturhenvisninger
En oversikt over litteratur som det er henvist til i manuskriptteksten samles bakerst i manuskriptet under overskriften «Litteratur». Henvisninger i teksten gis som Haftorn (1971), Arnekleiv & Haug (1996) eller, dersom det er flere enn to forfattere, som Sæther *et al.* (1981). Om det blir vist til flere arbeider, angis det som «som flere forfattere rapporterer (Haftorn 1971, Thingstad *et al.* 1995, Arnekleiv & Haug 1996,)», dvs. forfatterne nevnes i kronologisk orden, uten komma mellom navn og årstall. Litteraturlisten ordnes i alfabetisk rekkefølge: det norske alfabetet følges: aa = å (utenom for nederlandske, finske og etniske navn), ö = ø osv. Flere arbeid av samme forfatter i samme år angis ved a, b, osv. (Elven 1978a, b). Ved lik alfabetisk prioritet går to forfattere foran tre eller flere («*et al.*»).

Eksempler:

Tidsskrift/serie
Slagsvold, T. 1977. Bird song activity in relation to breeding cycle, spring weather, and environmental phenology. – Ornis Scand. 8: 197-222.

Arnekleiv, J.V. & Haug, A. 1996. Fiskebiologiske undersøkelser i Holmvatnet og Rundtuvvatnet, Rana kommune, Nordland, 1995. – Vitenskapsmuseet Rapp. Zool. Ser. 1996, 3: 1-22.

Kapittel
Nilsson, S.G. & Ericson, L. 1992. Conservation of plants and animal populations in theory and practice. s. 71-112 i Hansson, L. (red.). Ecological principles of nature conservation. – Elsevier Appl. Sci., London.

Monografi/bok
Urke, H. A. 2001. Utvikling av sjøtoleranse og vandringsåtferd hos Atlantisk laks (*Salmo salar* L.) med og utan oppdrettsbakgrunn. – Cand.scient. oppgave i akvakultur. Norges teknisk-naturvitenskapelige universitet, Zoologisk institutt. 79 s. Upubl.

Haftorn, S. 1971. Norges Fugler. – Universitetsforlaget, Oslo. 862 s.

Illustrasjoner
Figurer (i form av fotografier, tegninger osv.) leveres separat, på egne ark, dvs. de skal ikke inkluderes eller monteres i brødteksten. På papirutskriften av manuskriptet skal det i venstre marg angis hvor i teksten figurene ønskes plassert. Strekfigurer, kartutsnitt o.l. figurer skal være trykkeferdige fra forfatterens hånd. Skal rapporten inneholde fargebilder, bør også disse leveres som jpg-filer.

Opplag
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