Geographical and management related factors affecting lambs of outwintered sheep along the west coast of Norway

A BASELINE STUDY IN THE RESEARCH PROJECT
FERAL SHEEP IN COASTAL HEATHS – DEVELOPING A SUSTAINABLE LOCAL INDUSTRY IN VULNERABLE CULTURAL LANDSCAPES

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Front page: *Ovis brachyuran borealis* females and lamb on Tungodden, July 2007. Eva Kittelsen.

Preface

The work presented in this thesis is part of the research project *Feral Sheep in coastal heaths – developing a sustainable local industry in vulnerable cultural landscapes* funded by The Research Council of Norway's AREAL programme. The Feral Sheep project is lead by Ann Norderhaug at the Norwegian Institute for Agricultural and Environmental Research (Bioforsk), and is conducted by a project team with members from the Norwegian Agricultural Economics Research Institute (NILF), the Norwegian School of Veterinary Science (VETHS), the Norwegian University of Life Sciences (UMB), and the University of Bergen (UIB). Research design and data collection was done in close collaboration with the Feral Sheep project team, and all data presented in this thesis will be used in different ways as part of the Feral Sheep project.

I have a long list of people to thank. Firstly, I would like to thank my supervisors Vigdis Vandvik and Anne Lucas for giving me ideas, guidance and encouragement in the work process. Brooke Wilkerson has been indispensable, especially through the great mapping job she did and the many valuable tips and ideas she had, and she deserves the greatest rewards.

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- Eva Kittelsen -

Contents

Abstract

The Ancient Norse breed of outwintered sheep (ANBOS/Feral sheep) are the traditional sheep of Norwegian coastal heathlands, an open semi-natural landscape now threatened by regrowth due to cessation of management. One of the main challenges for the ANBOS industry is the low slaughter weights achieved in some herds, and the aim of my MSc project is to provide a baseline study of the relationships between geographic and management-related variables and the weights of ANBOS lambs in different herds along the Norwegian coast. My study will be crucial for identifying possible causal factors behind the between-population variability in lamb weights, and it provides an important first step towards the aims of the Feral Sheep project, namely to develop efficient farming practices that mitigate the economic and animal welfare problems linked to the poor lamb growth and low weights observed in some herds. The 13 localities included in the study were situated along a 500 km latitudinal gradient on the western coast of Norway. Each locality was grazed by an ANBOS herd. On each site, through land cover mapping, and through interviews with sheep owners, data was compiled that could possibly explain differences in lamb weights. Linear regressions and t-tests were used for the statistical analysis, with the compiled data as predictor variables, and with lamb growth rates and slaughter weights obtained from Bioforsk as explanatory variables. ANBOS lamb weights increased with the percentage of grass on the pastures, and decreased with increasing annual precipitation and discharge. Although there were considerable differences in management practices between herds, no management-related variables were found to be important for lambs growth and weights. Summer fodder is an important compartment of sheep diets, but summer fodder may be sampled and analyzed at different assumptions, and my data indicate that the availability of summer fodder is more important than any other variable for explaining lamb weights. However, lamb weights were collected in the summer season, so in order to be able to explain temporal patterns, the Feral Sheep project should aim at collecting data that enables comparison of winter and summer grazing and habitat use.

1 Introduction

1.1 BACKGROUND

Coastal heathlands stretch along the west coast of Europe from Portugal to Lofoten in Norway. Norway harbours the northern third of the European coastal heathlands, and here an oceanic climate with mild winters and cool summers has given rise to a farming system with all-year grazing by the Ancient Norse breed of outwintered sheep, (*Ovis brachyura borealis*) (Kaland 1974), hereafter named ANBOS. This indigenous sheep of traditional coastal heathlands in Norway plays an important part in the management of these landscapes by keeping them open and free of shrub and forest vegetation.

***Figure 1**: Heather, Calluna vulgaris. Photo: Eva Kittelsen*

Another inhabitant of the coastal heathlands which plays a central role in the system is heather, *Calluna vulgaris* (fig. 1), an evergreen Ericaceous plant dominant in coastal heathlands, which provides winter fodder for ANBOS. Heather occurs in successional stages of differing fodder quality from pioneer via building and mature to degenerate (Gimingham 1975). The degenerate stage is particularly vulnerable to invasion by trees and shrubs, but grazing by ANBOS, together with management practices such as cutting and burning, prevents the heather from reaching this stage. Rather, the heather remains young and edible to the animals. During summer, the sheep prefer grass, which dominates in areas that have been recently burnt or where grazing pressure is high. Therefore, a mosaic of heaths and grass dominated areas is regarded as the optimal pasture for ANBOS.

Sheep have been subject to extensive breeding over the last century. The most common sheep breed in Norway is "Norsk kvitsau", which belong to the "crossbred" type characterized by a long tail and with one layer of wool (Norsk Sau og Geit [NSG] 2008). The other type is the "landrase" or short-tailed type with short tail and two layers of wool. ANBOS is one of the short-tailed breeds. These have a smaller digestive system than the long-tailed breeds (Stenheim *et al.* 2003), and they graze more selectively and to a larger extent on woody species (Steinheim *et al.* 2005). Human domestication have made sheep more generalized grazers (Schwartz and Ellis 1981), while ANBOS still has many ancient traits, such as the characteristic selective grazing mentioned above and strong herd instincts. ANBOS is the most ancient sheep breed in Norway, and apart from the Soay sheep in Great Britain, it is the most ancient in Europe. ANBOS is friskier and sturdier than other domestic breeds; it is smaller and has fewer offspring, and therefore produces less meat.

ANBOS (fig.2) was the common sheep breed in Norway until the mid 1800s, when crossing with foreign breeds started (Christiansen 2005). Demands for efficiency in farming increased in the 20th century, and the number of ANBOS decreased as larger and more productive sheep were bred. The use of heathlands decreased as the modern agriculture developed, as summer pastures in the mountains were preferred for the new sheep breeds and livestock was kept indoors and fed during winter rather than being outwintered on the coastal heathland. During the 1950s and the 1960s there were less than 500 ANBOS animals in Norway (Domestic Animal Diversity Information System [DAD-IS] 2008). As a result of the decreased management, large areas of former heathlands are now in different stages of secondary succession towards forest, and coastal heathlands are now listed as a threatened vegetation type on the national scale (Fremstad and Moen A. (eds.) 2001). At the European scale, the coastal heathlands are also listed as a critically threatened habitat type (The Habitats Directive 1992), but in contrast to the Norwegian situation, the most severe threats to the heathlands further south are habitat loss, nitrogen deposition and overgrazing (Grant and Armstrong 1993). One third of the European coastline harbouring this landscape occurrs in Norway, so conservation of the coastal heathlands is an important responsibility for Norway.

Figure 2: *Ram of the Ancient Norse breed of Outwintered Sheep. Photo: Eva Kittelsen*

The last decades has seen an increase in the ANBOS population (DAD-IS 2008). This is probably related to increased knowledge about and interest for the heathland agroecosystem, and change in consumer preference towards organic food, healthy food, products that reflect sustainable resource use and products with a cultural (hi)story. Today, there are around 30 000

ANBOS in Norway (Fjærli 2005), and the number is increasing. Traditional coastal heathlands farming capitalizes on resources that would otherwise not be used, and it has a great cultural value in the traditional setting. The meat production from coastal heathlands was approved by the Slow Food Foundation for Biodiversity as a "Prestidium" in 2006 (Slow Food Foundation for Biodiversity 2008), which means the production is recognized as sustainable and based upon important local traditions. Developing the ANBOS industry can therefore help preserve not only the heathland ecosystem but also cultural history in the form of food traditions, agriculture traditions, landscape resources and genetic resources.

1.2 THE FERAL SHEEP[1] PROJECT

The research project *Feral Sheep in coastal heaths – developing a sustainable industry in a vulnerable landscape* (hereafter referred to as the Feral Sheep project) funded by The Research Council of Norway's AREAL programme (2007-2010) aims to increase the understanding of the ANBOS industry and agroecosystem through crossdisciplinary research involving a veterinary, ecological, economic, and consumer/market perspectives. The results of the Feral Sheep project will be used to develop and advance an industry that has its core in sustainable traditions of small-scale use and local knowledge that has functioned, survived and evolved over several thousand years (Kaland 1974).

One challenge in maintaining a functioning ANBOS farming industry is the high variation of lamb weights within the species. Geographical differences in ANBOS lamb slaughter weights have been reported from slaughter houses in Norway; ANBOS lambs seem to be smaller than average in western Norway (Velle *et al.* 2005). The reasons for these differences are unclear, and since neighbouring sites can have significantly different mean weights (Velle and Waldeland 2006), the factors influencing weights may operate on a very local scales.

The The aim of the work package in the Feral Sheep project that my master thesis is part of is to identify potential causal factors behind the variation in slaughter weights between ANBOS herds in order to prescribe management actions to secure sufficient lamb growth under different climatic and environmental conditions. This is important both in an animal welfare perspective, and in the economy of the ANBOS farming industry, which is fundamental for the continued management of coastal heathlands.

[1] *Feral Sheep* is a direct translation of the commonly used term *Villsau* in Norwegian. Moreover, refer to Appendix C for a discussion of terminology of the ANBOS.

1.3 OBJECTIVES

Coastal heathlands are scarce and unproductive habitats that are usually not covered by national inventories of vegetation mapping such as the Norwegian monitoring programme for agricultural landscapes (Fjellstad *et al.* 2004) or the land cover mapping used in the Economic Maps (Bjørdal 2007), and they are not separated in the grazing map database provided by the Norwegian Institute of Forest and Landscape and the departments of agriculture of the County Governors (2008). Coarse-scaled maps of the potential extent of the heathlands (Op. cit. DiemontHaaland and Kaland 2002), but are not ground-truthed or updated. Because of the rapid loss of coastal heathlands, today's actual extent is not clear, and there is a need for quantifying knowledge on the spatial distribution of these landscapes. Another issue is that existing maps do not comprise the variation within coastal heathlands. In addition to a lack of spatial data on their habitats, little is known about the ANBOS` grazing preferences, and mapping their habitat and its composition is a first step in obtaining such information, which is an important issue in order to secure animal welfare in the growing ANBOS industry. Knowledge based on surveys and mapping is important in order to implement and localize good management practices including the continued traditional use of coastal heathlands.

The aim of my study was to quantify the pasture resources available to different ANBOS herds as basal data for the Feral Sheep project, and to use this information to indicate causal factors behind variability in lamb growth between herds. This broad exploratory approach is needed as a foundation for a research project in an area where little previous work has been done, and my work will contribute baseline knowledge about the system and also generate hypotheses that can later be investigated experimentally. The study focused on 13 ANBOS herds which were selected as study herds by the Feral Sheep project. Manual vegetation mapping through field registering is time-consuming when large areas are to be covered. Heathlands are also extremely heterogeneous habitats, and applying automatic remote sensing methods for classifying these habitats are a complex procedure (Wardley *et al.* 1987). I therefore chose aerial photography interpretation, which should be a suitable alternative mapping method for quantifying not only the extent of heathland vegetation, but also the quality of the heathlands as ANBOS pastures.

Work packages included in my Masters thesis include:

1. creation of land cover maps that were specifically designed to enable distinguishing and quantifying the extent of different coastal heathland habitats and successional stages that could potentially be of importance as resources for the ANBOS,
2. assemblage of other geographic information on the pastures available to each sheep herd, including area and physical and climatic variables
3. interviews with sheep owners to collect information on the management of the pastures and how the different sheep herds are kept,
4. evaluation of the collected data (1-3) and extraction of variables for further analyses (6),
5. exploratory data analyses of differences in lamb weights among localities,
6. exploratory data analyses of relationships between lamb weight data (5) and the assembled geographical and management data (1-4) to identify potentially important causal factors,
7. evaluation of the applicability of the GIS methods used – both for creating vegetation maps (1) and for analyzing the data (6), and
8. making recommendations, based on my findings (1-7), for further data collection and experiments in the project.

2 Materials & Methods

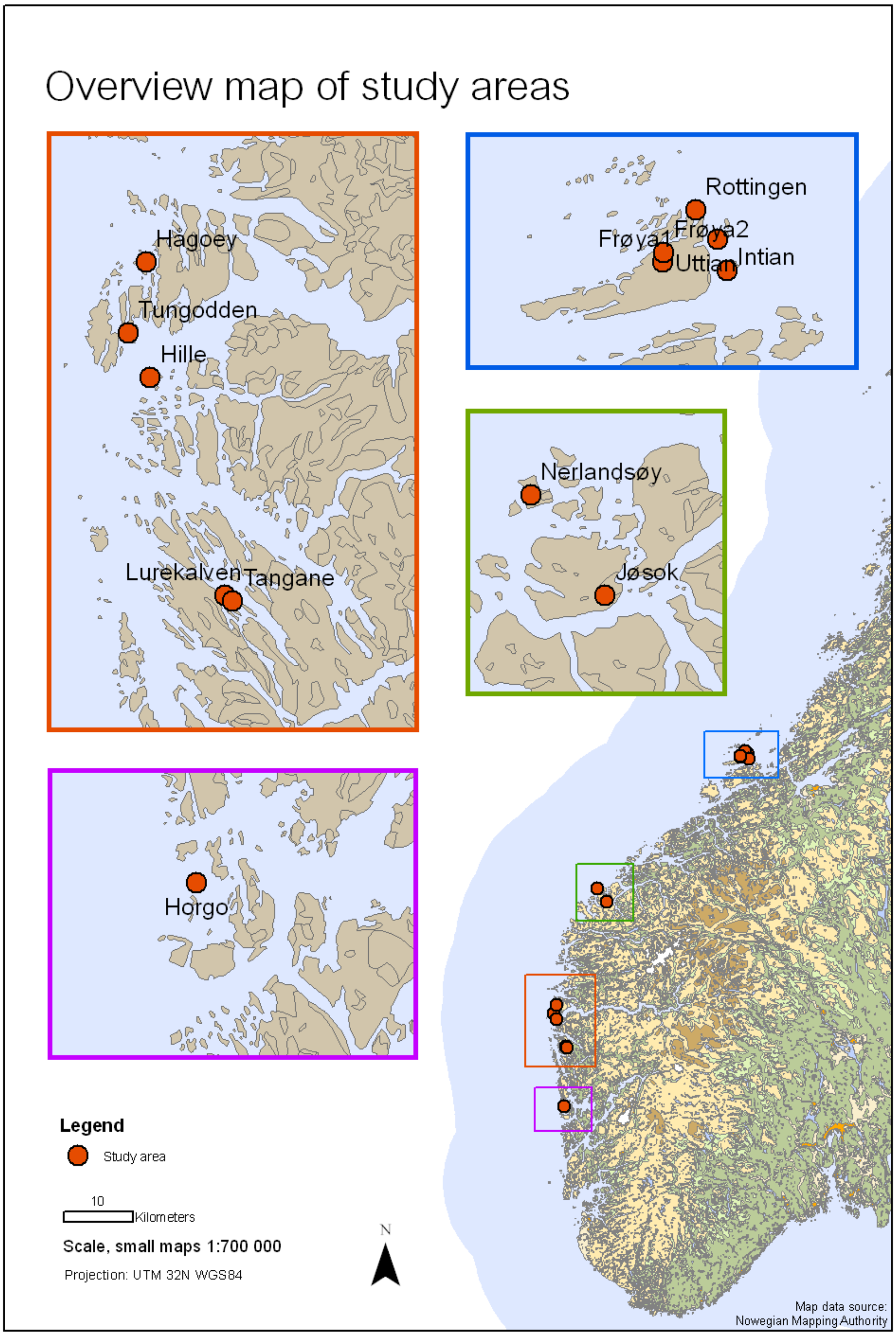
2.1. STUDY SITES AND SHEEP HERDS

The selection of herds for the study was done by the Feral Sheep project following criteria that should be met in order for the location to reflect traditional uses of coastal heathlands:

- The sheep should be *Ovis brachyura borealis*, and not mixed with other breeds.
- The sheep should be outwintered.
- The study sites should be located in the oceanic climate zone.
- The vegetation/landscape type should be heathland outfields and not infield areas.
- The amount of additional fodder should be minimal. In order to find out what there is about the pasture that causes low weights among lambs, any additional fodder would cause uncertainty in the analysis.
- The herd should graze in one area as much as possible. If the herd is not kept in one place, the variables connected to the pasture would be difficult to identify.

Based on these criteria, 13 herds of ancient ANBOS in western Norway were selected for study by the Feral Sheep project. For each herd, the study site is defined as the areas available to the herd. The delineation of a sheep populations' pasture (and hence a study site) is different from site to site. Some of the studied herds are isolated on islands, other within fenced areas, or in some cases, use only particular areas although they roam freely. The study period is the time affecting the growth of lambs, which is considered to be from winter 2006 (at conception) to autumn 2007 (when lambs are slaughtered). In practice, it was difficult to meet the last three criteria, and they are therefore not true for all localities.

Figure 3 shows an overview map of all localities in the study.



Eva Kittelsen, MSc thesis, University of Bergen, 2008

Figure 3: Localities

All study sites were located in the highly oceanic section (O3) in the *Vegetation section map of Norway* (Moen *et al.* 1999a). Horgo, Hille, Tungodden, Hågøy and Nerlandsøy were located in the Sub-section with mild winters (O3t), while the remaining were located in the Humid subsection (O3h).

According to Moens *Vegetation zone map of Norway* (1999b), Horgo, Tangane, Lurekalven, Tungodden and Hågøy is located in the Boreonemoral vegetation zone, Jøsok is both in the Boreonemoral and the Alpine vegetation zone, Nerlandsøy in the Boreonemoral zone and all localities in Frøya municipality are located in the Southern boreal vegetation zone.

2.1.1 Horgo

Horgo is one of the 667 islands that constitute Austevoll municipality in the county of Rogaland. Horgo is cut off from the mainland, and has no roads and no inhabitants, but it has a single cottage and some boat houses which are in use. There is a joint ownership of the ANBOS herd here, which consists of about 100-120 sheep on the island. The herd is free roaming on the island, but excluded from one house and its surroundings by fences. Six of the animals are rams, which are grazing with the rest of the herd all year round. Around 110 lambs were born in 2007. The lambing was at the beginning of April. Horgo has a long history of grazing by ANBOS along with heather burning, dating back at least 50 years, and *Ovis aries* (Norsk kvitsau), cattle and horses were kept on infields until the early 1960s. The area available to the sheep is 200 ha. No other domestic animals exist on the island today, and no wild herbivores are common.

2.1.2 Lurekalven

Lurekalven is an island northwest of the island Lygra in Lindås municipality, north in Hordaland county. There is no connection to the mainland, and no roads, constructions or inhabitants. A grass area that used to be the infield of a farm from medieval times is present. The area available to the sheep is about 1 km^2. The island is long and narrow, stretching southeast - northwest. The area available to the sheep is around 100 ha.

2.1.3 Tangane

Tangane is the northwestern part of the island Lygra in Lindås municipality, north in Hordaland county. Lygra is accessible by road from the mainland, and the area called

Tangane is located at the tip of the island, enclosed by a fence southwest to northeast across the island. The same owners as on Lurekalven own the sheep here. There are trails for recreation through the pasture. The area available to the sheep is about 40 ha.

2.1.4 Hille

Hille is an island in Gulen municipality, in the southern part of Sogn og Fjordane county. The production is Debio certified. Two families are living on the island all year round. The herd has one owner but is socially divided in two groups that according to the owner use the landscape quite differently in that one herd keeps to a higher extent to infield pastures, while the other prefers the more scarce outfields. Since their grazing grounds overlap and cannot be mapped, they are treated as one herd, and the area as one study site. The area available to the sheep is 350 ha. No other animals are usually present on the study area.

2.1.5 Tungodden

Tungodden (fig. 4) is a peninsula south in Gulen municipality, Sogn og Fjordane county. There is a joint ownership of the Old Norwegian sheep herd at Tungodden. On the northern border of the grazing area, a fence and a small lake delimits the flock from the main island. The ANBOS farming started here with 60 individuals in 2005, and is still building up. In 2007, 120 adults were grazing on the island, with 80 lambs born from 25th April. On Tungodden, the males are kept separated from the flock during autumn and are set out in early December. The area available to the sheep is around 320 ha, and has a small area of previous infield. No other animals graze here, except some wild Red deer (*Cervus elaphus*).

Figure 4: *The herd at Tungodden beeing gathered in July 2007. Photo: Eva Kittelsen*

2.1.6 Hågøy

Hågøy is an island in Gulen municipality, Sogn og Fjordane county. The stock is owned by the same group who owns the sheep at Tungodden. The ANBOS farming started here in 2001, and for the last two years it has had a stable size of 140 adults all year and around 70 lambs during the summer season. The lambs were born from 10th April. The males are grazing with the flock all year. The area available to the sheep is around 210 ha and is entirely composed of outfield areas. No other grazing animals are present here.

2.1.7 Jøsok

Two owners have sheep which share the same area at Jøsok, and the sheep are thus considered as one herd in the study. Jøsok is situated at the south-eastern part of the island Gurskøy. The herd roams freely on the whole island, but uses only a certain inland area, which is thus considered as the study area. The herd consists of 80 females with lambs. Gurskøy covers both Sande and Herøy municipality in Møre og Romsdal county, but the study area is in Herøy municipality. The study site is around 615 ha. No other domestic animals are present in the outfields of the island, but Red deer (*C. elaphus*) are common.

2.1.8 Nerlandsøy

Nerlandsøy is located in Herøy municipality, Møre og Romsdal county. The herd was established in 2002, and has built up from an initial 20 females; in the study period it consisted of 45 ewes, 2 rams and 65 lambs born from 16th April. The whole island except the inhabited areas, which are fenced out, is available to the sheep, but they do not utilize the whole island. Delimiting the study area was done based on GPS data from collars on some of the sheep, provided by the owner through Telespor (Telespor AS 2008). The area which is mainly utilized is around 780 ha. No other domestic animals graze the study area, but Red deer (*C. elaphus*) are common.

2.1.9 Intian

The island Intian is located east of mainland Frøya in Frøya municipality, Sør-Trøndelag County. There is no road to this island. No one lives there today, although it was previously inhabited, and some houses on the island are frequently used for recreation. Sheep, cattle and horses were kept on the island in earlier times. The herd consisted of 56 ewes and 62 lambs in the study period. Lambs were born from 25th April. The rams are not grazing with the rest of the herd. The herd is moved between three different enclosures, of which the total area available to the sheep is about 40 ha, and consists mainly of infield areas. No other animals graze on the island today.

2.1.10 Uttian

Uttian is located east of mainland Frøya in Frøya municipality, Sør-Trøndelag County. Two persons own the herd. There is a road from the main island of Frøya to Uttian, which means the island is easily accessible from the mainland. A fence across the island separates the herd from the inhabited areas in the summer, but in the winter the fence is taken down. The herd stays away from the developed parts also in the winter. Up until 2007 the rams have been with the rest of the herd. The herd has built from 15-20 animals 15 years ago at Værøya, an adjacent smaller island. Three or four years ago, when it consisted of 20 adults and 15-20 lambs, the herd was moved to Uttian, and had in 2007 built up to 102 sheep that had 95 lambs, starting from the end of February. Up until 15-20 years ago, Norsk kvitsau and cattle were kept in the infield areas of the island, but no other animal graze here today. The area utilized by the sheep is around 140 ha.

2.1.11 Mainland Frøya

Two herds share the same area at the main island Frøya in Frøya municipality, Sør-Trøndelag county. The area is delimited by water and fences. The two herds came to the area at different times, are socially segregated and thus use different areas of the available area, but they are not separated by fences. They have been treated as two herds and the area as two localities. No other domestic animals graze in the study areas, but Red deer (*C. elaphus*) are common. ANBOS farming has not been practiced in the areas before, but another breed, the Fro sheep, were common on Frøya up until 1960-80. Cattle and horses were also kept.

The herd grazing the southern parts consists of 86 adults with lambs that were born from 17th April. Rams are not kept with the herd after mating, but taken away quite soon, in January. The herd has been under establishment, and has increased from 20 individuals 5 years ago to 86 individuals in 2007. The area available to the sheep is around 240 ha. This study site is called Frøya1 in the text and figures.

The herd grazing on the northern parts was established in 1991, and build up to approximately 60 ewes in 2004, which it has remained at since. In 2007 there were 62 ewes. Lambing started 15th April, and 66 lambs were born. The area available to the sheep is about 100 ha. This study site is called Frøya2 in the study.

2.1.12 Rottingen

Rottingen is an island north of mainland Frøya in Frøya municipality, Sør-Trøndelag County. No one lives there, but the family of the owner has a house there and spends weekends and holidays on the island. The herd has grazed the island since 1968, and in the same area the breed Cheviot was kept from 1957 to 1987. Before this both sheep, cattle and horses were kept, while the use paused from 1953 until the father of the current owner bought the place. The farming product (meat) produced on Rottingen today has been Debio certified since 1994. In 2007, the herd consisted of 141 adult outwintered ewes and 184 lambs during the summer season. The 8 rams are with the herd only until early summer. Lambing was in late April to early May. The area available to the sheep is 130 ha. No other animals graze on the island today.

2.2 DATA COMPILATION

Spatial and non-spatial datasets were used to extract explanatory variables. The spatial data was put in a Geographical Information System (GIS). ArcGIS 9.1 ArcMap (ESRI Inc. 1999-2005a), along with ArcCatalog (ESRI Inc. 1999-2005b) was used to create vegetation maps, as well as for the delineation of all spatial data when extracting variables for statistical analyses.

2.2.1 Existing data

Existing data on different variables were collected from external sources. The N50 Kartdata series (Dokken 2006) was provided by Statens Kartverk through Norge digitalt[2] (2008). These maps were used as basemaps for georeferencing and as inset maps in my display maps. This dataset was also used as a template in the process of clipping out the exact study sites, and for extracting latitude values. In the latter operation it was the mid point of each polygon (study site) which is the value given.

Data on discharge were provided by the Norwegian Water and Energy Department (Norges Vassdrags- og Energidirektorat [NVE] 2002). This was a point shapefile containing median annual discharge estimated from topographic and precipitation data from the last climatic normal period (1961-90). Uncertainty is estimated by NVE to be +/– 20 %. These data were made in a different projection than the other datasets, but I have used the same method for extraction, along with new sets of basemaps from Arealdekke N50 data downloaded from the Norwegian Forest and Landscape Institute (Skog og landskap 2008). This is the same dataset as in N50 Kartdata series from Statens Kartverk.

All spatial datasets were vector data, except the airphotos used to develop vegetation maps, which were raster data.

Nonspatial data on precipitation and temperatures were downloaded from Eklima hosted by the Norwegian Metereological Institute (2008). Data was downloaded from 10 different weather stations. Five different stations were used for each dataset in order to get data that best represented the 13 localities. Criteria for choosing the weather station was that it was functioning through the study period, that it was close to the locality, and if not, that it represented the locality climatically (i.e. considering elevation and distance from coast). The stations used are listed in Table I in Appendix B, along with altitude information. For each locality, data on temperature, precipitation from 2007, and precipitation from the last climatic

[2] Norge digitalt is a national cooperation project on geographical data sharing.

normal period may not be from the same station. Data from the same meteorological station may be used for several localities. For example, the same meteorological station has been employed for all localities in Frøya municipality. Figure I in Appendix B shows monthly precipitation normals for five weather stations.

Detailed references to all data used in the study are listed in Appendix D.

2.2.2 Generated data

Some data was not available in an extent or format suitable for the need of the current project, and needed to be generated.

2.2.2.1 Land cover mapping

The vegetation dataset created consisted of maps and database attribute values. In contrast to the other datasets, the vegetation dataset was made manually in this study because vegetation maps in an appropriate scale and thematic scope did not exist for the study areas. Methods used by other institutions are usually developed to cover other needs, and one of the aims of my project was therefore to develop mapping methods specifically designed to meet needs of the Feral Sheep project. Vector data was chosen over raster for the vegetation maps because of the ease of drawing polygons over the aerial photographs, and of extracting numerical data from the attribute table of vector data and relate it to each patch and class. The resulting map is a polygon shapefile.

Mapping land cover was done in the GIS by manually drawing polygons in a new shapefile over orthophotos, which were used a visual basis for manual interpretation. For each island, a separate shapefile was made. Mapping was done by Brooke Wilkerson and Eva Kittelsen in 2007 and 2008.

Aerial photographs

Vegetation maps were made based on aerial photographs in TIFF formats (Ritter and Ruth 2000), obtained from TerraTec AS (2008), The University of Bergen and Norge digitalt (Norge digitalt 2008).

True colour photographs (RGB) were used. Colour infrared (CIR) photos were available for some locations, but for consistency, one set of images were chosen. CIR photos can be valuable in mapping vegetation, as the infrared radiation is absorbed by water which makes it possible to distinguish different kinds of vegetation based on their moisture content. However, colour images are easier to interpret as the colours of the different features are more obvious to the interpreter, and for this reason the IR photos would require more field work than colour photos, according to Fjellstad (2004). When working with large areas, such as in the current study, extensive field work would be demanding considering time efficiency and available funds. Having features that are obvious to interpret is especially important to an inexperienced interpreter.

The scales of the different aerial photographs ranged from 1:6000 to 1:20 000, but with the same original ground resolution, 0.20 m.

Georeferencing

Orthophotos (georeferenced aerial photographs) were available for Hågøy, Tungodden and Jøsok through Norge Digitalt (Statens Kartverk 2007). Aerial photographs for Tangane and Lurekalven were available through the University of Bergen, and for Intian, Uttian, Rottingen, Frøya1 and Frøya2 through TerraTec AS (TerraTec AS 2008).

The aerial photographs were georeferenced to the N50 Arealdekke_pol dataset, provided by Statens Kartverk (2007). Cell sizes may change during the process of rectification, so all images do not have the same spatial resolution. The dates as well as the years of photography are other features that differ among each set of images. The study sites were also of different sizes, and different numbers of photos were necessary to cover each site. A list of these details related to each study site is given in Table II, Appendix B. The properties of the photographs were the same for all photos within each study site.

Field work

Field work was done in order to learn how to interpret the aerial photographs (training) before starting the mapping process, and later to validate the mapping accuracy. Both during the training and the validation field work, a GPS of the type GARMIN eTrex Vista with the projection UTM 32V was used in the field to record the location of the field surveys. GPS points were later imported to ArcMap as a layer. Training field work was carried out at Tangane and Lurekalven in June and July 2007, at Hågøy in July 2007, and at Rottingen and Uttian in December 2007. The study sites to perform the training on were chosen based on availability of aerial photographs at the time, need for training of interpreting the current set of photos, and on logistic bases. Validation field work was done at Tungodden in April 2008. This study site was chosen because training had not been performed at this site.

Aerial photograph interpretation training

The aerial photograph interpretation training was done by comparing vegetation types in the field with their signatures in the aerial photographs, using the GPS points collected in the field along with othophotos as two layers in ArcMap when back in the computer lab.

Two hundred and forty four training points were collected at four study sites. Training points were typically chosen in the middle of areas where large patches of one vegetation type appeared, and where characteristic landmarks where present, such as turf houses, inlets or large boulders. These points were both located in the aerial photographs beforehand and in the field. Aerial photographs were available before the field season (growing season) for two study sites only (Tangane and Lurekalven). Some training therefore had to be done without the aerial photographs available at the time (Hågøy), or after the field season (Rottingen and Uttian).

Mapping criteria

Criteria which were considered for the selection of classes in the land cover maps were that the classes should:

- be consistent among islands
- reflect nutritional demands of sheep
- be possible to interpret from the aerial photographs available

It would also be desirable to have classes that were compatible with standard classification systems, but this was difficult to meet while still maintaining the other criteria, and was not regarded as important as the criteria listed above.

The minimum area for mapping features was set to $300m^2$, and the minimum width was approximately 2 m. The background for choosing this mapping resolution was that it captures much of the variation in the coastal heathland vegetation while at the same time it was reasonable in terms of workload. The lower coverage limit of one vegetation type was 50% in an area this size. If a vegetation patch was smaller than this, it was included in the surrounding patches, evenly distributed or to the type it had most in common with regarding fodder value (e.g. Dry heather would rather be assigned to the class Mire than to the class Rock).

Different criteria were used to delimit each vegetation class in the aerial photographs. These were based on:

- "expert knowledge" of the coastal heathland system and the specific areas in question, including assumptions of distribution patterns based on the ecology of the vegetation type, plant phenology, field surveys and interviews
- signature properties of the vegetation type, namely texture and colour
- elevation, slope and landscape structure as seen in aerial photographs and in elevation data

- Bare rock
- Burnt heather
- Grass and pioneer vegetation
- Mire
- Damp heath
- Dry heather
- Degenerative heather
- Forest and shrub
- Bracken
- Water
- Developed areas

Table 1. *List of criteria for distinguishing the different vegetation classes and for delineating features in aerial photographs*

Vegetation class	Argument for separating class	Most important features for distinguishing feature
Bare rock	No fodder value.	Appeared very bright compared to all other land cover types
Burnt heather	Relatively low biomass and therefore low fodder value first year after fire.	Grey to brown signature. Smooth texture.
Grass and pioneer vegetation	Valuable as summer fodder.	Green signature. No drainage pattern.
Mire	Assumed to be of low fodder value, but young graminoids might be valuable early in the growing season.	Green, yellow or brown signature. Drainage patterns. Appears in flat areas.
Damp heath	Potentially important as winter fodder	Dark brown signature. Rather coarse texture. Appears in flat areas and close to mires.
Dry heather	Important as winter fodder.	Dark brown signature. Rather coarse texture. Appears on hilltops, often close to rock.
Degenerative heather	Low fodder value, but may have tree and shrub species that are edible, especially moist degenerative heath.	Areas of Dry heather or Wet heather that have occurences of single trees. Coarse texture.
Forest and shrub	Low fodder value, but may have tree and shrub species that are edible. Potentially important as shelter.	Different shades of green. Coarse texture.
Bracken	Low fodder value. Takes over valuable summer fodder areas.	Bright green.
Water	May be important as drinking sources.	Dark blue signature. Flat features. Crisp boundaries.
Developed areas	No fodder value.	Recognisable urban features (houses, roads etc.).

This classification scheme assigns vegetation containing *Calluna vulgaris* to different classes depending on the successional stage of *C. vulgaris* (Gimingham 1975) and on soil moisture. Table 2 shows how the different stages are classified in my scheme.

Table 2. Classification decisions for heather stages for dry and damp heath

Stage	Dry heather	Damp heath
Young	Grass and pioneer vegetation	Mire
Building phase	Grass and pioneer vegetation	Mire
	Dry heather	Damp heath
Mature	Dry heather	Damp heath
Degenerative	Degenerative heather	Forest and shrub

Map validation

Field validation points for accuracy estimation of the maps were chosen based on a stratified random sampling scheme. Four random points in each feature class were selected on one of the study localities for field verification. Also, each class was classified into four quartiles of the polygon area, with one validatation point in each group. Polygons larger than 10 000 m^2 were excluded, in order to equalize the classes` size distributions. There were nine classes (including water and bare rock), and hence a total of 36 points (9 x 4) were validated. The points were selected using a grid of 100 m squares, where the point was placed in the best location (furthest from polygon border) within the randomly selected square. In the field, I went to the particular point and decided what vegetation type was dominant in an area similar to the mapping criteria, using the same classification scheme as in the vegetation maps. The results were compared to the vegetation maps.

Figure 5: *Ram being weighed at Lurekalven in August 2007.*

2.2.2.2 Interviews

Interviews and a qualitative approach were used to map the farming practice differences among the sheep populations in the study. It is important to take local knowledge into account when studying features that has to do with land-use. Farmers may have knowledge descended from centuries of farming practice, and may help explain some of the problems I have been concerned with.

A semi-structured interview was used. The interviews were done over telephone or in person. The questions were replicated; I asked about each topic in relation to the general condition (last ~10 years) and to the situation the last year (which would directly affect the lambs in the study).

In order to as correctly as possible map out the study sites to extract information (when clipping the datasets) on the correct grazing grounds I asked the sheep owners about borders and fences on the study sites.

I also asked about different issues related to the sheep herds and to the management. This included questions about the size of the herd, the time of lambing, and the number of lambs. The farmers were asked whether they give additional fodder to the sheep, whether parts of the grazing areas consist of infield or old infields, whether they lime the pastures and whether they practice heather burning. In order to get an image of the grazing pressure, the farmers were asked whether other animals graze in the study area, including wild animals. I also asked how often the herds were gathered, to get an impression of the degree of overseeing of the herd.

In order to correct the data for small lambs that were not slaughtered, I asked how many were kept over winter or used in their own household.

The results from this dataset were used to estimate reliability of and make decisions about other datasets and the analyses of these, such as in the mapping process (e.g. farmers told me which areas had been burnt) and to interpret results. Parts of the interviews were also used directly as predictor variables in the main analysis.

2.2.2.3 Sheep weight data

Data on lamb weights collected (fig. 5) by the Bioforsk partner in the Feral Sheep project are used as a proxy for flock health in my study. Data were weights of lambs (live weights collected by Bioforsk in the spring and in the autumn) and slaughter weights (obtained from the slaughterhouses and/or farmers by Bioforsk). Growth rate in grams per day was calculated from the live weights using the equation

$$\frac{W_2 - W_1}{T_2 - T_1} \qquad \textit{Equation 1}$$

where W_1 and W_2 are weights in grams at T_1, time 1 (spring) and T_2, time 2 (autumn).

A linear formula for growth rate was chosen for simplicity and because this probably best reflects growth or juvenile ruminants over the time span in question (cf. Wild *et al.* 1994). This method of measuring growth rate is widely used, but other, more complex models have also proved suitable in describing growth-age relationships (Op.cit. Brown 1970, Bathaei and Leroy 1996).

The dates of weighing were not the same for all localities.

Slaughter weight is the carcass weight of the dead animal where skin is taken away. The weights were used raw with the unit kilograms. The dates of slaughter were not the same for all localities. Table IV in Appendix B shows dates of weighing and slaughter for the different localities.

2.2.3 Predictor variables extracted from the datasets

Different variables were extracted from my datasets. An overview of these is given in Table 3, along with information on the units used for each.

Table 3. *Variables extracted from the datasets*

Dataset	Variable	Units
Lamb weights	Growth rates (rams)	Grams per day
Slaughter weights	Slaughter weights (rams)	Kilograms
Vegetation maps	Grazing pressure : available grass areas per fodder unit consumed (see below)	-
	Grazing pressure : available heather areas per fodder unit consumed (see below)	-
	Percent grass areas	% cover
	Percent heather areas	% cover
	Patch sizes of Grass and pioneer vegetation	Square meters
	Patch sizes of Dry heather	Square meters
Temperature	Mean winter (January) temperature	Degrees Celsius
	Mean summer (July) temperature	Degrees Celsius
Precipitation	Annual precipitation	Millimetres
	Precipitation during the summer season (May-August)	Millimetres
Discharge	Discharge	Millimetres per year
N50	Latitude	UTM coordinates
Interviews	Grain feed given	True/false
	Hay given	True/false
	The occurrence of infields on the pasture or in the herd's diet	True/false

The grazing pressure was calculated for each vegetation class on each study site, using the equation

$$\frac{\text{Area}}{0.85\,\text{f.u.} * \text{n ewes} + 0.60\,\text{f.u.}(\text{n rams} + \text{n lambs})} \qquad \textit{Equation 2}$$

where *Area* is the total area of the particular vegetation class in m^2 based on map attribute values, *n ewes, n rams* and *n lambs* are numbers of animals on the study site as recorded in the interviews, *f.u.* is fodder units; factors are specific to ANBOS and are based on literature on animal grazing consumption for different animal breeds, sexes and ages (Op. cit. Kaland 1979). Separate variables were made for different land cover classes.

From the precipitation datasets, an assemblage of total precipitation through the season based on observations from 2007, and mean annual precipitation based on climatic normals (from 1961-90), were extracted and tested as variables.

Parts of the interviews were used directly as predictor variables. All these variables were factors with two levels, such as former infield present or absent within the study area. The extent of these former infield areas was sometimes difficult to quantify, and the areas were not delimited as a separate class in the vegetation map dataset (they would generally be classified as part of the grassland). I did not investigate whether these infields had previously been fertilised and for how long they had been unmanaged. The many differences in management methods of the different herds, the few observations, as well as the qualitative nature of the data (based on interviews) made it difficult to create a numerical scale, and these variables were therefore used as factors with the two levels *true* and *false.*

Data available and unavailable for the different localities are summarised in Table V in appendix B.

2. 3 Analyses

Statistical analyses were done in R.2.4.0 (The R Development Core Team 2006).

2.3.1 GIS operations

The study sites were delineated based on the N50 Kartdata and information from

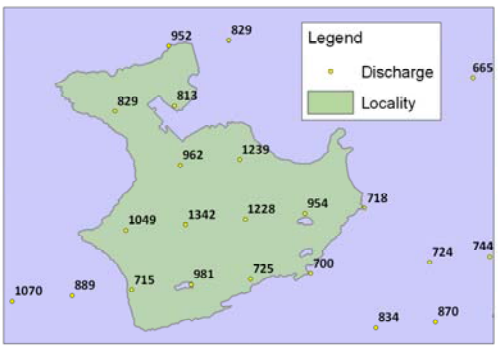


Figure 6: *Variables were extracted in ArcGIS by statistics for each locality. Here, Discharge is averaged over Nerlandsøy.*

interviews. Using the resulting map extents, values of the existing spatial datasets were calculated for each study site using a clip operation with a template file or through simple statistical calculations (fig. 6) within the template. The vegetation dataset was made in a smaller (cartographic) scale than the N50 Kartdata, and is thus more detailed. It was not extracted from an existing dataset, but rather mapped manually for the exact relevant area. The area and perimeter of each patch of the different feature classes (i.e. for polygon datasets) was calculated. This was done for the datasets bedrock and vegetation. Database attribute values were extracted from the polygon datasets and used to collect relevant variables for further statistical analyses.

2.3.2 Statistical tests performed on weight data

Differences between localities and between sexes in the growth rate and slaughter weight datasets were explored through various statistical tests. Shapiro-Wilk tests of non-normality were performed to test if the data were normally distributed. If possible, datasets with non-Gaussian distributions were log-transformed to achieve normality before further analyses. Heterogeneity of variance in growth rates and slaughter weights between localities and between sexes was tested using Levene tests. In datasets where factors of two levels were compared, Students t-tests (t-test) were preferred, but the non-parametric Wilcoxon Rank Sum test3 (Wilcoxon test) was used if non-normal distributions or heterogeneity of variances among groups occurred. Analyses of Variance (ANOVA) and the non-parametric Kruskal-Wallis tests were used for datasets where factors of more than two levels were compared for the populations with Gaussian and non-Gaussian distributions, respectively. The Kruskal Wallis test was also used when heterogeneity of variance among levels occured. Datasets with too few observations to perform reliable analyses or with heterogeneous variance among levels were omitted from post-hoc tests and exploratory analyses (Ch. 2.3.3.). The post-hoc Tukey Honest Significant Difference tests (Tukey HSD) were used to compare growth rates and slaughter weights of lambs among locality pairs. Correlations are tested using Pearson`s Product Moment Correlation test.

[3] Also known as and confused with the Mann-Whitney test.

2.3.3 Exploring relationships between explanatory variables and weight

The exploratory analyses are done with animal live growth rate and slaughter weight as response variables, and all other variables as explanatory variables. Some explanatory variables are continuous, and some are factors with two levels. Hence, the appropriate analyses are regressions and Students t-tests, respectively. The spatial data were extracted from the GIS for the statistical analyses. For each study site, the mean values were computed. This applies to both weight data and geographic variables. Hence, each study site was one observation in the analyses. Interactions between the variables may exist, but I do not have sufficient numbers of observations in my dataset to test more complex models. Each of the variables extracted from the data were therefore plotted and tested separately. Regression plots are shown with a simple regression line to visualize the main trend, and t-tests are visualized through boxplots.

3 Results

3.1 LAND COVER

The land cover maps created are shown in Appendix A. Each map shows the extent of the area grazed by an ANBOS herd in the study. Appendix A also gives information about the geodatabase modelling, which is essential for data management and further development.

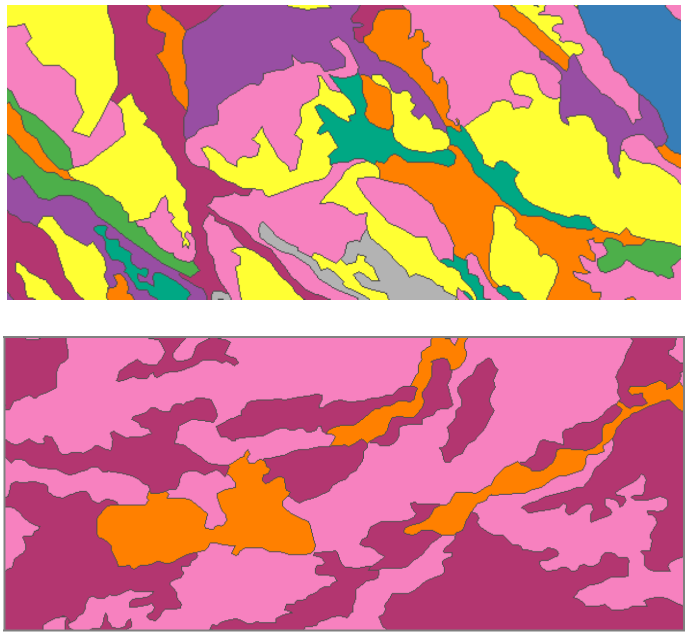


Figure7 : *Two map extents of similar scale (1: 3000), showing differences in heterogeneity of land cover types.* ***Upper:*** *Lurekalven shows high heterogeneity.* ***Lower:*** *Jøsok shows rather low heterogeneity.*

Land cover distribution patterns are not spatially analyzed in this study. However, through a visual inspection of the land cover maps in Appendix A, it is evident that the variability of the land cover type on the different pastures is high. Some study sites have a high heterogeneity of patches; many classes appear intergraded among each other, while others have lower heterogeneity with fewer classes dominating in large areas (fig. 7). Some patches look complex, with multiple convoluted edges, other have rounder, simpler shapes. In some sites the patches obviously follow topographic structures, having long, narrow patches or filling valley spaces around rock outcrops. This is especially evident in the classes Mire, Damp heath, and at Tungodden for Grass and pioneer vegetation.

The proportional composition of land cover classes differ between the study sites, as can be seen from Figure 8. The most obvious difference is the proportion of rock, which is more than 50% of the land surface at Tungodden, and only 0.3% at Jøsok.

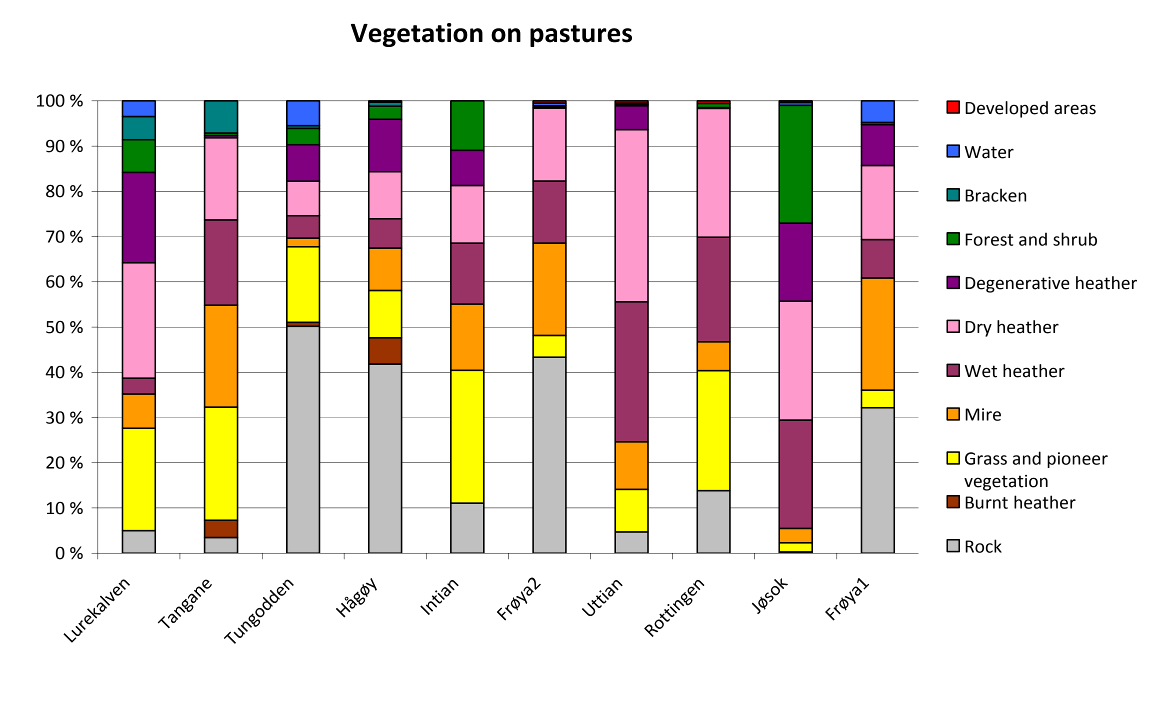


Figure 8. Proportional land cover classes on each study site mapped. Detailed proportion values of the classes are shown in Table VII in Appendix B.

Not all land cover classes occur on all study sites. Developed areas appear only at Jøsok, Frøya2, Uttian and Rottingen. Water appears on all sites except Tangane, Intian and Rottingen. The remaining classes appear on all sites. Burnt heather was only mapped at Tangane, Tungodden and Hågøy. Except for Lurekalven, which is also regularly burnt, this is consistent with information from the interviews. Heather burning is also practiced at Horgo and Hille, which are study sites that have not been mapped (see Table V in Appendix B). Bracken was present at Tangane, Lurekalven, Tungodden and Hågøy, but at no other sites. At Horgo and Hille, I also observed Bracken areas that would probably meet the mapping criteria. These results show a 100% overlap of localities where the classes Burnt heather and Bracken appears, and at the same time. In addition, these are all the southernmost localities.

3.1.1 Map accuracy

The field validation showed that the total map accuracy was 86.1%, and the accuracy of the actual vegetation classes (excluding rock and water) was 82.1%. When each class was considered separately, the accuracy was 100% for the classes Water, Rock, Mire, Burnt heather, Damp heath, and Degenerative heather, 75% for Dry heather and 50% for Grass and pioneer vegetation and for Forest.

Table 4. *Map accuracy. Green indicates accordance between aerial photograph interpretation and field survey, while red indicates disagreement.*

Classes as interpreted from aerial photographs	1st quartile of polygon size	2nd quartile of polygon size	3rd quartile of polygon size	4th quartile of polygon size
Water	green	green	green	green
Rock	green	green	green	green
Mire	green	green	green	green
Burnt heather	green	green	green	green
Damp heath	green	green	green	green
Degenerative heather	green	green	green	green
Dry heather	green	green	red	green
Grass and pioneer vegetation	red	green	red	green
Forest and shrub	green	green	red	red

At five validation points, the field survey vegetation definition was not in accordance with the aerial photography definition. It was generally the relatively large patches of each class that were misinterpreted. Table 4 shows accordance and disagreement between aerial photograph interpretations and field surveys for all validation points.

At the site where the vegetation was defined as Dry heather in the aerial photography, it was interpreted as burnt heather in the field survey. This patch was within the third quartile of patch sizes. Two sites where Grass and pioneer vegetation was expected, Damp heath was found in one case (first area quartile), and Dry heather in the other sites (third area quartile). One site was classified as Forest and shrub in the aerial photographs, but as Degenerative heather in the field survey (third area quartile). Large amounts of last years *Pteridium aquilinum* was found at one validation point where Forest and shrub (fourth area quartile) was expected.

3.2 SHEEP WEIGHT DATA

3.2.1 Live weights

3.2.1.1 Rams

The ram growth rates were normally distributed (*Shapiro-Wilk test, p=0.42*). The number of observations for each locality is shown in Table V in Appendix B.

Variance of ram lamb weights within each locality was not significantly different among localities (*Levene test, p=0.39*), but a suspicious outlier was taken out; a ram at Jøsok had a negative growth rate of -44 g/day. The ram was not slaughtered, and is healthy according to the owner.

Rams in at least one of the localities had growth rates different from the rest (*ANOVA, p<0.001*) (fig. 9), and a Tukey HSD-test was done to test for differences between pairs of herds. The result is visualized in Table 5, which shows that there is no particular segregation growth rate level between herds with large and small mean growth rate; the transition is rather smooth. However, the herd with the highest growth rate, Intian, has significantly higher growth rates than the the seven lowest herds in the rank, and there is a group of intermediate-to high growth rate herds (Rottingen to Tungodden) that do not differ form each other, but which all differ from the lowest growth rate herds.

The two groups of animals in the herd owned by two different persons and sharing the same grazing area at Jøsok did not have significantly different growth rates (*ANOVA, p=0.12*). At Jøsok, the newborn lambs were also weighed. Growth rates were not correlated with birth weights (*Pearson's product-moment correlation test, p=0.35, correlation coefficient=0.18, n=70*).

3.2.1.2 Ewes

Variance of ewe growth rates was significantly different among the localities (*Levene test, p=0.036*), making comparison of mean values inappropriate. This dataset is therefore not used in further analyses, except in comparisons of sexes.

Table 5. *Comparison of mean growth rates between localities (Tukey HSD test). Green indicates significant differences (α level = 0.05), while red indicates no significant difference between pairs. Localities are ordered from low to high values. This means that when two localities differ, the one listed on the top (in columns) is higher.*

Locality	Hågøy	Jøsok	Uttian	Frøya2	Tungodden	Frøya1	Nerlandsøy	Lurekalven	Tangane	Rottingen	Intian
Hågøy											
Jøsok											
Uttian											
Frøya2											
Tungodden											
Frøya1											
Nerlandsøy											
Lurekalven											
Tangane											
Rottingen											
Intian											

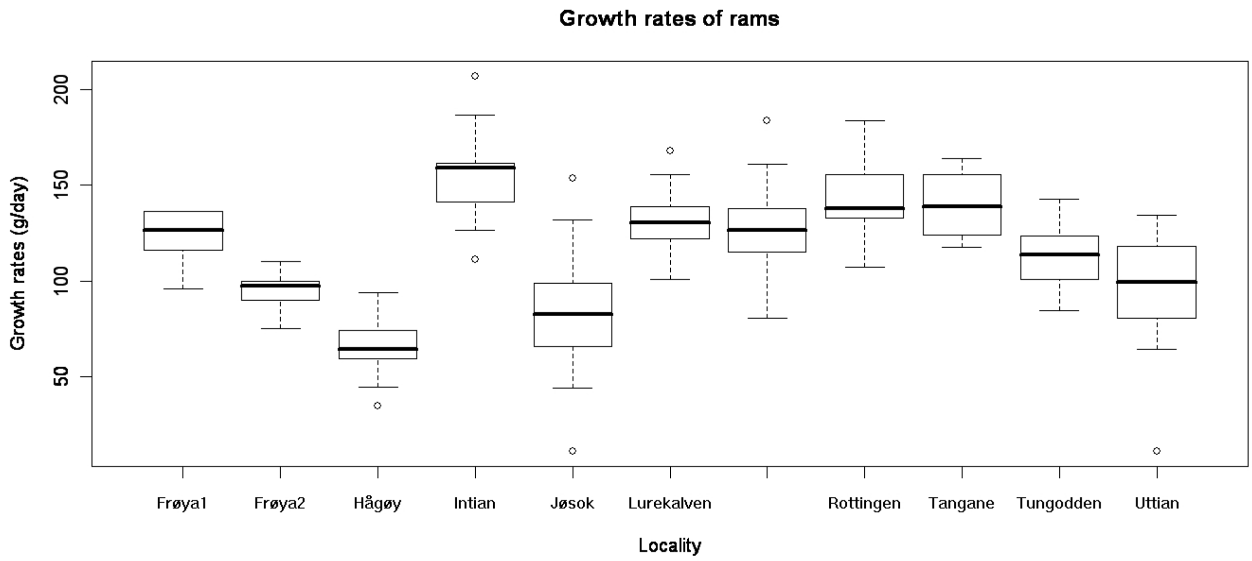


Figure 9. *Growth rates of ram lambs for each locality.*

__Table 6.__ Comparison of log-transformed mean slaughter weights between localities (Tukey HSD test). Green indicates significant differences (α level = 0.05), while red indicates no significant difference between pairs. Localities are ordered from low to high values. This means that when two localities differ, the one listed on the top (in columns) has lambs with a higher slaughter weight.

Locality	Hågøy	Jøsok	Horgo	Tungodden	Frøya1	Nerlandsøy	Hille	Lurekalven	Tangane	Uttian	Rottingen	Intian
Hågøy												
Jøsok												
Horgo												
Tungodden												
Frøya1												
Nerlandsøy												
Hille												
Lurekalven												
Tangane												
Uttian												
Rottingen												
Intian												

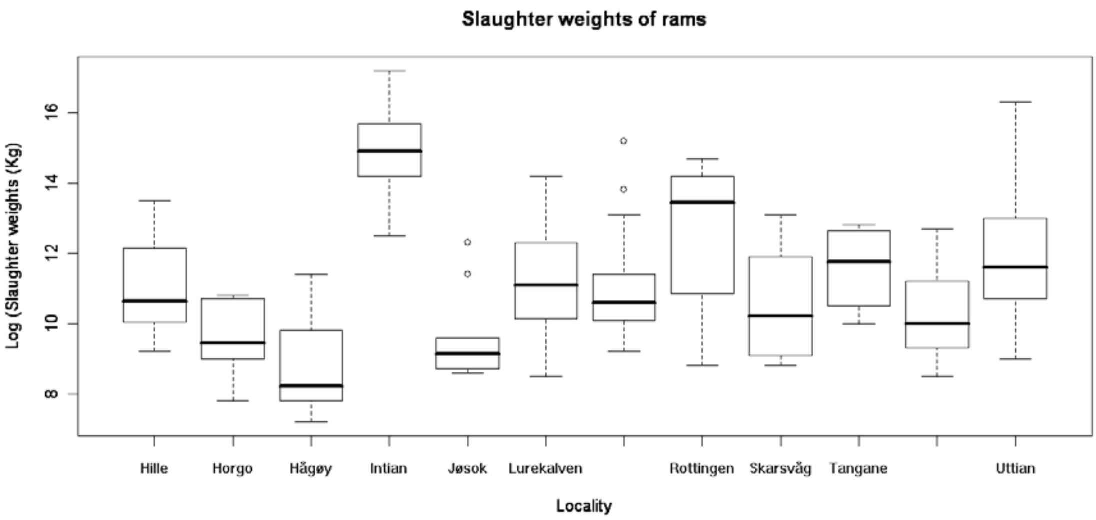


***Figure 10.** Slaughter weights of ram lambs for each locality.*

3.2.1.3 Weight differences between localities and sexes

Ewes and rams` growth rates did not depart from a normal distribution when pooled (*Shapiro-Wilk test, p=0.354*). Variance was heterogenous among sexes (*Levene test, p<0.001*) and among localities (*Levene test, p<0.001*). Growth rates of rams and ewes were significantly different (*Wilcoxon-test, p=0.0062*). In 8 localities, rams tended to have higher growth rates than ewes, but the pattern was not consistent and differences in growth rates between sexes varied among localities (*Kruskal Wallis test, p<0.001*), see figure II in Appendix B.

3.2.2 Slaughter weights

3.2.2.1 Rams

The slaughter weights were not normally distributed (*Shapiro-Wilk test, p<0.001*); the lower values had a "sharp edge". Log-transformed slaughter weights did not depart significantly from normal distribution (fig. 11) (*Shapiro-Wilk test, p=0.093*), and were used in the further analyses, except for comparison with other, non-transformed data. Table VI in Appendix B shows the number of observations from each locality for all weight datasets.

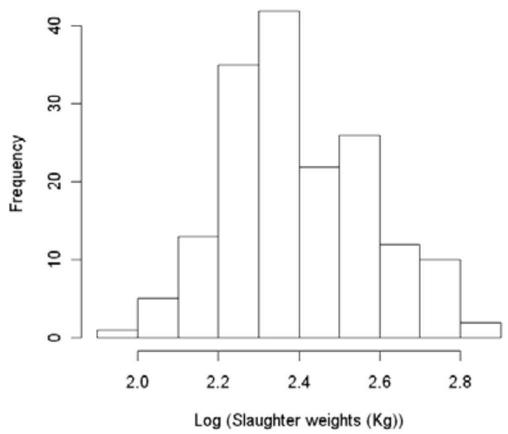


***Figure 11.** Histogram of log-transformed ram slaughter weights, normally distributed.*

Variance in log-transformed slaughter weights within each locality was homogenous among localities (*Levene test, p=0.47*).

There were significant differences among localities in log-transformed mean slaughter weights of ram lambs (*ANOVA, p-value<0.001*) (fig. 10).

Table 6 shows a comparison of ram slaughter weights for pairs of localities, based on a Tukey Honest Significant Difference test. Intian has exceptionally high slaughter weights and stands out among the other herds, while Hågøy stands out with the lowest mean slaughter weights. The remaining herds have intermediate slaughter weights that are more equal to each other, but two threshold values of mean growth rates is suggested; through the sharp transitions; one close to that of Frøya 1 and one close to that of Uttian.

3.2.2.2 Ewes

Fewer ewe lambs are usually slaughtered than are ram lambs, and there were too few ewes in the dataset to perform reliable analyses. Slaughter weights of ewes were therefore excluded from all analyses.

3.2.3 Comparison of growth rates and slaughter weights

For the ten localities where both data on growth rates and on slaughter weights were available, all herds` mean values except Uttian had similar ranks relative to one another. Uttian had the third highest mean slaughter weight and the third lowest mean growth rate. There is a smoother transition between each mean value of growth rates than of slaughter weights (log-transformed). However, slightly significant values are not shown in Table 5 and 6. These exist in the transitions, smoothing the rather stepwise impression of the differences in slaughter weights between herds.

Individual growth rates correlate significantly with slaughter weights (Pearson's product-moment correlation test, $p<0.001$, correlation coefficient=0.48, n=116). Mean values correlate even more strongly (*Pearson's product-moment correlation test, $p=0.0070$, correlation coefficient=0.79, n=10*). See Figure 12. Uttian is the outlier among the mean values.

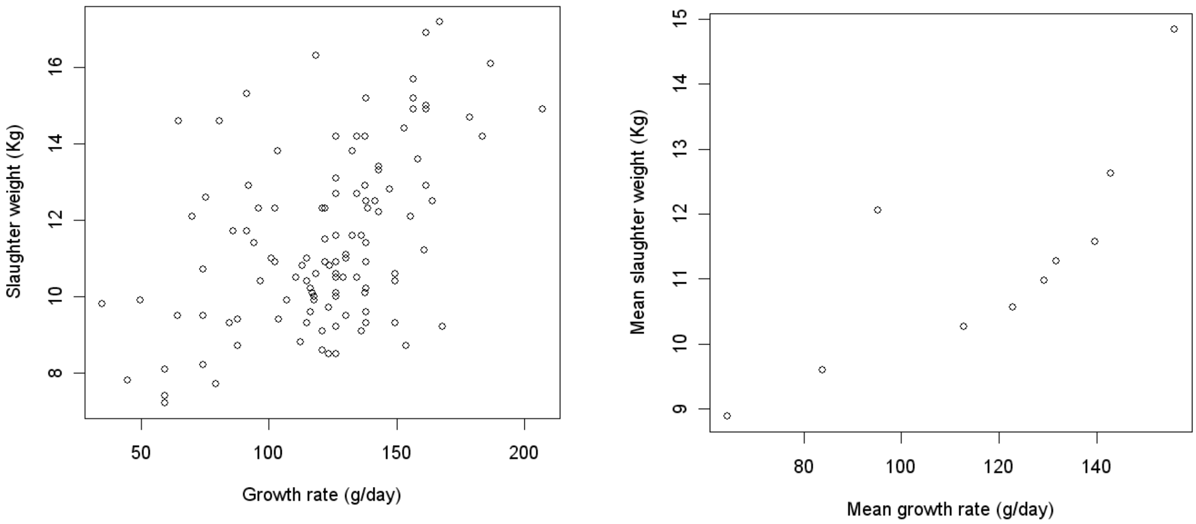


Figure 12. *Plots showing correlation between growth rates and slaughter weights.* ***Left:*** *Values based on individual sheep.* ***Right:*** *Mean values (study sites).*

3.3 EXPLORATION OF WEIGHT DATA AND GEOGRAPHIC VARIABLES

A few patterns emerged from the exploratory analyses of geographical and land-use variables as explanatory factors for lamb growth rates or slaughter weights between the study sites: The percentage cover of the class Grass and pioneer vegetation, as well as precipitation, were factors that a showed significant effects on lamb weights.

It should be noted that these are exploratory data analyses, not formal hypotheses testing. On one hand,small datasets on the between-herd level results in low power and few significant patterns. On the other hand, high number of tests and many explanatory variables compared to observations could lead to spurious significances. As the growth rate and slaughter weight data are not perfectly correlated, similarities in patterns between the growth rate and slaughter weight data are interpreted as support for the pattern observed. The results are useful in that they can indicate areas for further investigations. This is discussed further in the Discussion section. In all plots, red lines in the regression analysis plots indicate significance at α level 0.05, while blue lines indicate significance at α level 0.20. Boxplots are not colour coded.

3.3 Physical-geographical data

3.3.1.1 Latitude

Latitude does not explain the variation in mean growth rates (*Y = -61- 0.00x, r2=0.018, p=0.69*), but slaughter weights increase slightly towards the north (log(*Y) = 1.060 + 5.028*10^{7}x, r2=0.32, p=0.055*) (fig.13).

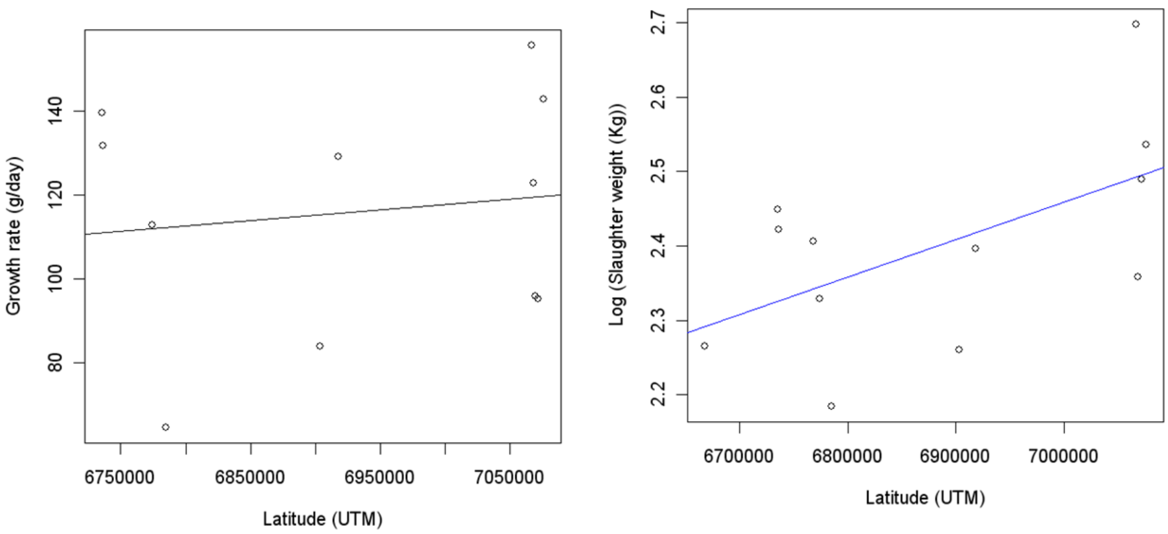


Figure 13. Left: *Mean growth rate modelled as a function of latitude in UTM coordinates on each study site.* ***Right:*** *Mean slaughter weight modelled as a function of latitude in UTM coordinates on each study site.*

3.3.1.2 Discharge

Slaughter weights decrease slightly with increasing annual total discharge (fig. 14), or water runoff from the terrain ($\log(Y) = 2.64 - 2.097*10^7 x$, $r^2=0.30$, $p=0.064$), but although there is a trend in the same direction annual discharge has no significant effect on growth rates ($Y = 135.09 - 0.018x$. $r^2=0.56$, $p=0.47$).

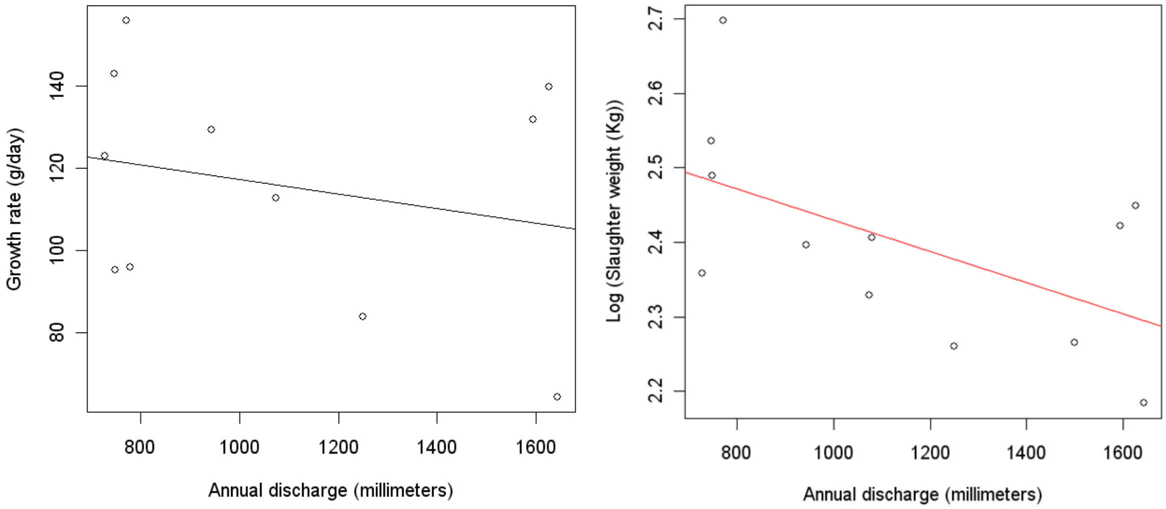


Figure 14. *Annual discharge has a slight negative effect on slaughter weights, but none on growth rate.* ***Left:*** *Mean growth rate modelled as a function total annual discharge on each study site.* ***Right:*** *Mean slaughter weight modelled as a function of total annual discharge on each study site.*

3.3.1.3 Precipitation

Slaughter weights decrease with increasing annual precipitation (fig. 15) ($\log(Y) = 2.77 - 0.00024 x$, $r^2=0.12$, $p=0.041$) measured from climatic normal values (1961-1990), but annual rainfall has no effect on growth rates ($Y=151.036 - 0.024x$, $r^2=0.088$, $p=0.38$).

The total amount of rain through the summer season from measurements in the study period (May to August) has no effect on lambs (growth rates: $Y = 108.10+0.00x$, $r^2=0.012$, $p=0.74$; slaughter weights: $\log(Y) = 2.49 - 0.00021x$, $r^2=0.09$, $p=0.33$), although the plots (fig. 14) could indicate a negative effect on slaughter weights following a similar trend as with annual rainfall.

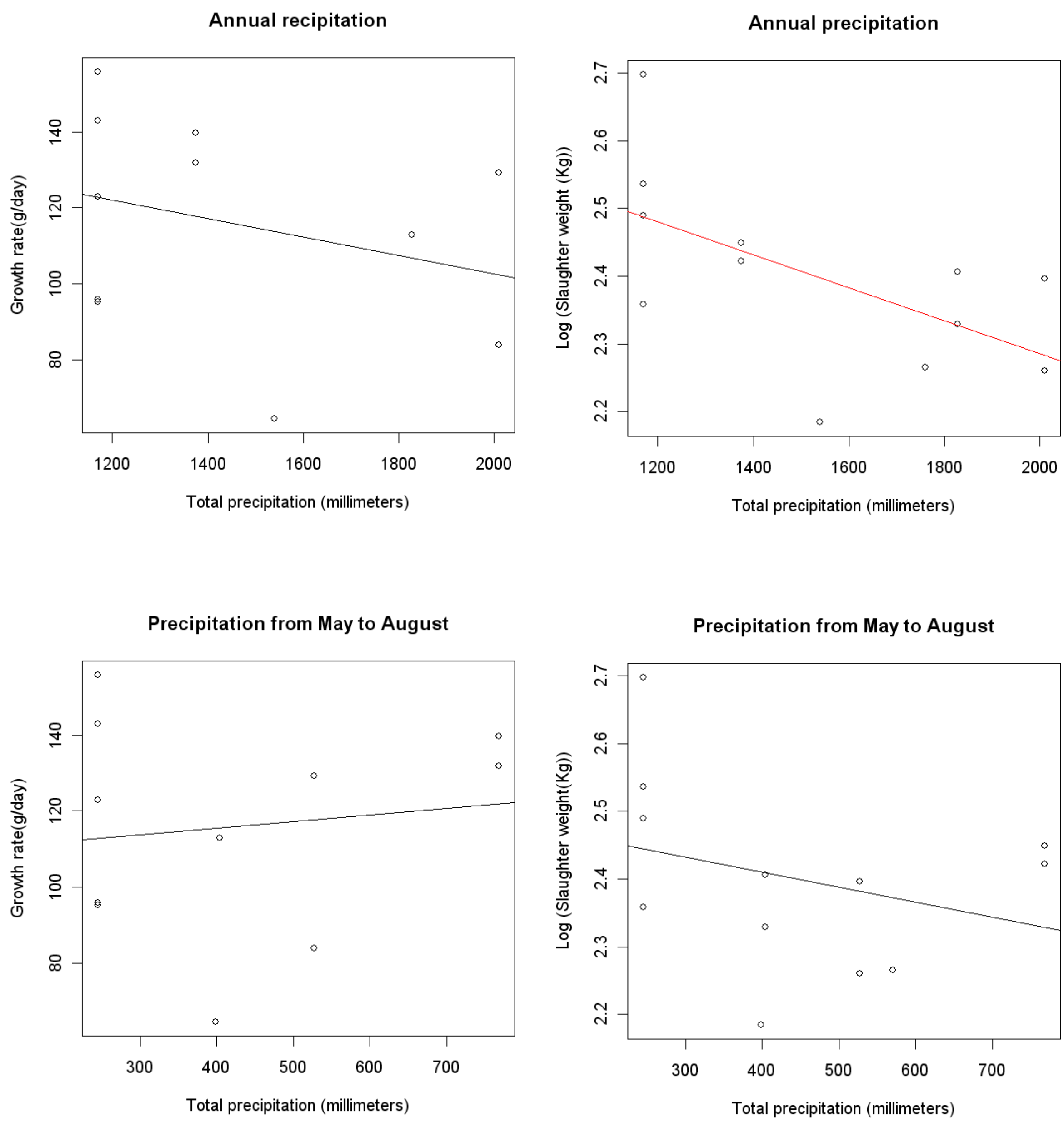


Figure 15. *Annual precipitation has a significant negative influence on slaughter weights, but no effect on growth rates. Precipitation during the seasons or at selected time intervals, have no influence on either growth rates or slaughter weights.* ***Upper left:*** *Mean growth rate modelled as a function of annual total normal precipitation on each study site.* ***Upper right:*** *Mean slaughter weight modelled as a function of annual total normal precipitation on each study site.* ***Lower left:*** *Mean growth rate modelled as a function of precipitation from May through August 2007 on each site.* ***Lower right:*** *Slaughter weight modelled as a function of precipitation from May through August 2007 on each site.*

3.3.1.4 Temperature

The range of summer temperatures among the localities in the study is one degree (14.3 (Frøya) – 15.3 (Møre))°C. Mean summer (July) temperature has a slight but not significant negative effect on lamb growth rates ($Y = 545.80 - 29.36x$, $r^2=0.12$, $p=0.25$), but no pattern is seen when summer temperature is plotted against slaughter weights $\log(Y) = 1.03 + 0.031x$, $r^2=0.0094$, $p=0.76$) (fig. 16). Herds have both low and high mean values at both ends of the temperature range.

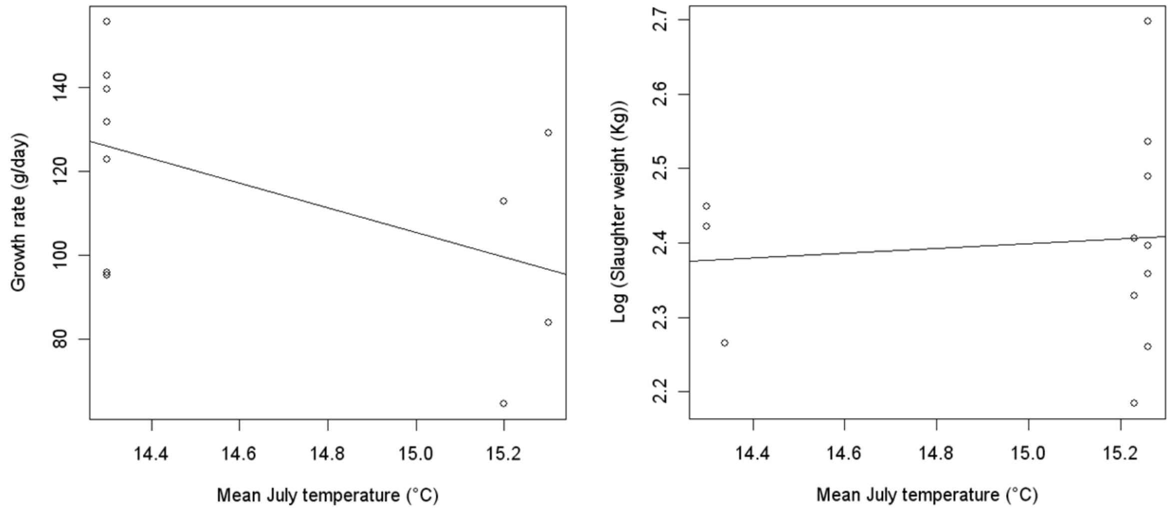


Figure 16. Summer temperatures show no effect on growth rates or slaughter weights. ***Left:*** *Mean growth rate modelled as a function of mean July temperature on each study site.* ***Right:*** *Mean slaughter weight modelled as a function of mean July temperature on each study site.*

Mean winter (January) temperature (fig. 17) ranges from 2.6° C at Jøsok and Nerlandsøy to 5.0° C at the Tangane and Lurekalven). No obvious pattern is distinguishable (growth rates: $Y = 77.14 + 11.77x$, $r^2=0.13$, $p=0.28$; slaughter weights $\log(Y) = 2.43 - 0.0094x$, $r^2=0.0047$, $p=0.83$).

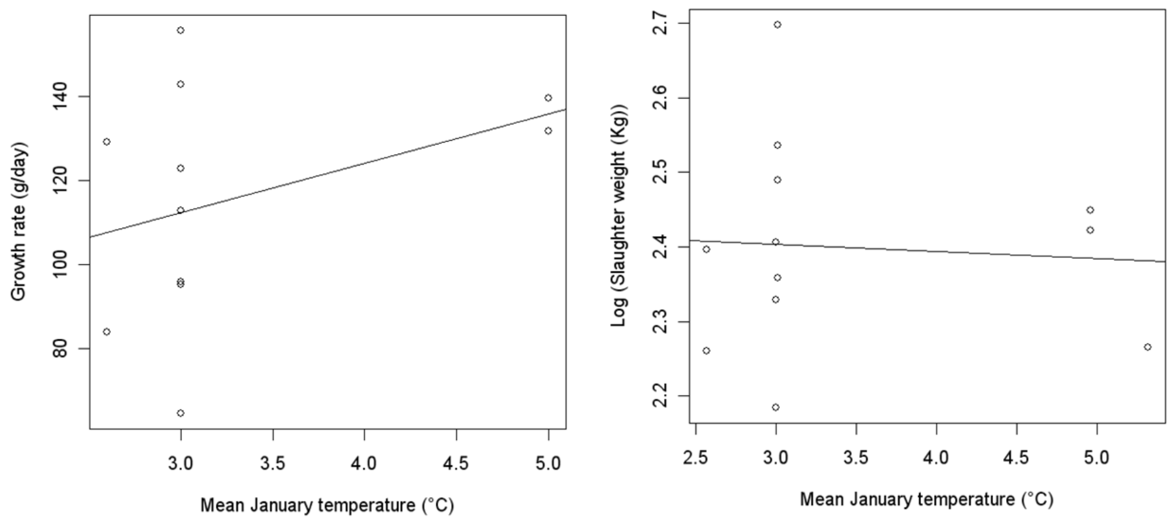


Figure 17. Winter temperatures show no effect on growth rates or slaughter weights. ***Left:*** *Mean growth rate modelled as a function of mean January temperature on each study site.* ***Right:*** *Mean slaughter weight modelled as a function of mean January temperature on each study site.*

3.3.2 Land cover

Rock

The percentage of rock does not affect growth rates (Y = 125.73 - 0.54x. r^2=0.13, p=0.31) or slaughter weights (fig. 18) (log(Y) = 2.48 - 0.0038x. r^2=0.21, p=0.22) of ANBOS in the study. The pattern indicated by the regression line looks similar for the two datasets, but the spread is high.

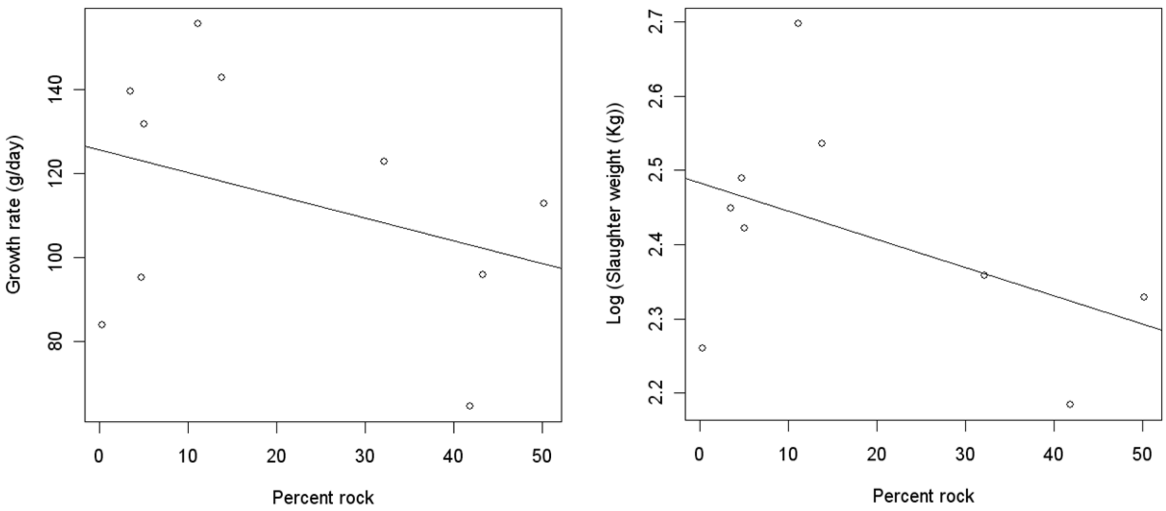
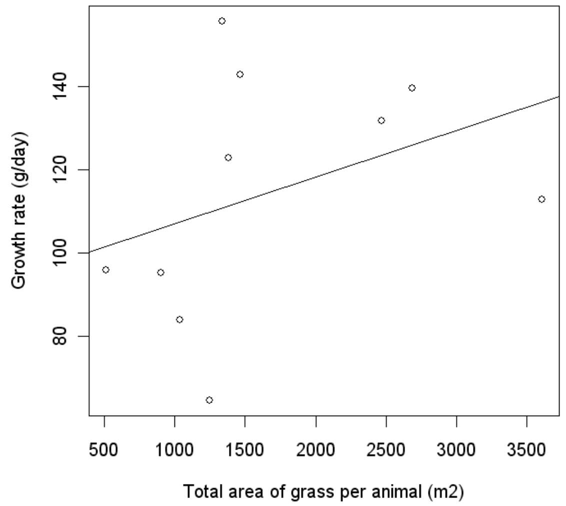


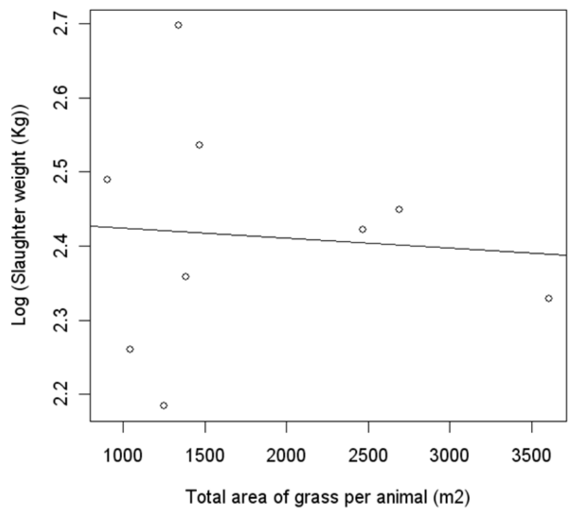
Figure 18. *The percentage of rock is not affecting the growth rate or slaughter weight of lambs.* ***Left:*** *Mean growth rate modelled as a function of the percentage of rock on each study site.* ***Right:*** *Mean slaughter weight modelled as a function of the percentage of rock on each study site.*

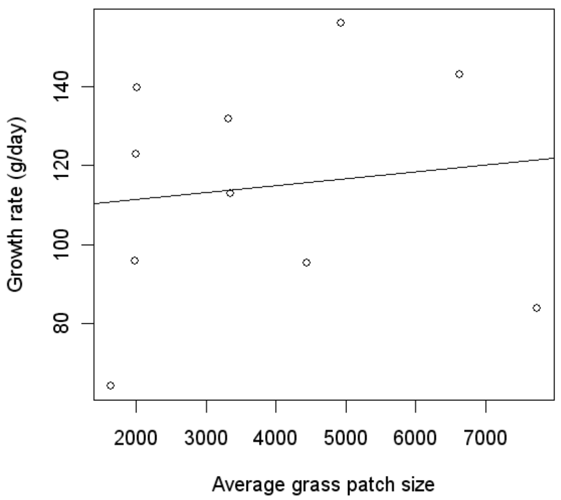
Grass

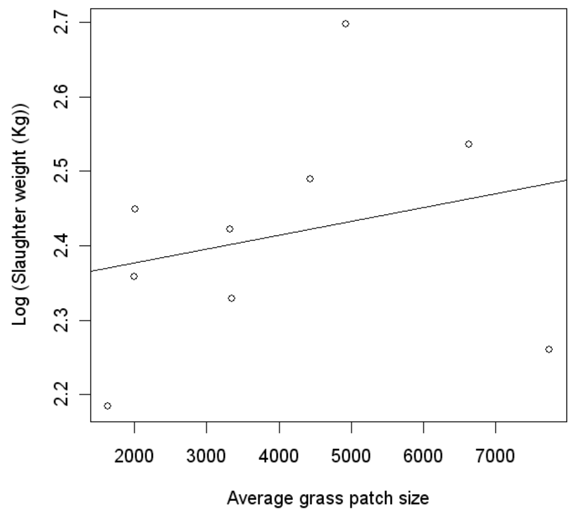
Figure 19 shows plots related to grass areas. The growth rate did not show any relationship with grass area available per sheep[4] (Y = 95.82 + 0.011x, r^2=0.13, p=0.30), although herds with growth rates lower than 100 g/day also have the lowest grass areas available per animal. Growth rates are generally higher but very variable when more than 1500 m^2 of grass area is available per animal. The values range from 500 to 3500 m^2 (or five to 35 da) per sheep. No pattern is seen when the same variable is plotted against slaughter weights (log(Y) = 2.44 - $1.35*10^7$ x, r^2= 0.0064, p=0.84).

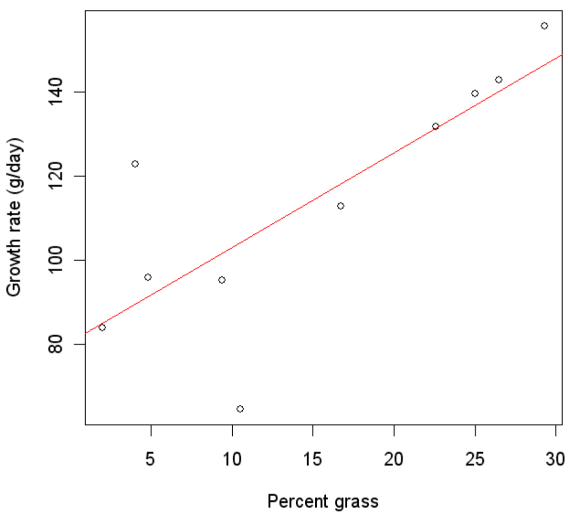
[4] Per sheep in terms of fodder units grazed per sheep, see Equation 2, in Ch.3 Materials & Methods, page 29.


Growth rate (g/day)
80
100
120
140
500
1000
1500
2000
2500
3000
3500
Total area of grass per animal (m2)


Log (Slaughter weight (Kg))
2.2
2.3
2.4
2.5
2.6
2.7
1000
1500
2000
2500
3000
3500
Total area of grass per animal (m2)


Growth rate (g/day)
80
100
120
140
2000
3000
4000
5000
6000
7000
Average grass patch size


Log (Slaughter weight (Kg))
2.2
2.3
2.4
2.5
2.6
2.7
2000
3000
4000
5000
6000
7000
Average grass patch size


Growth rate (g/day)
80
100
120
140
5
10
15
20
25
30
Percent grass

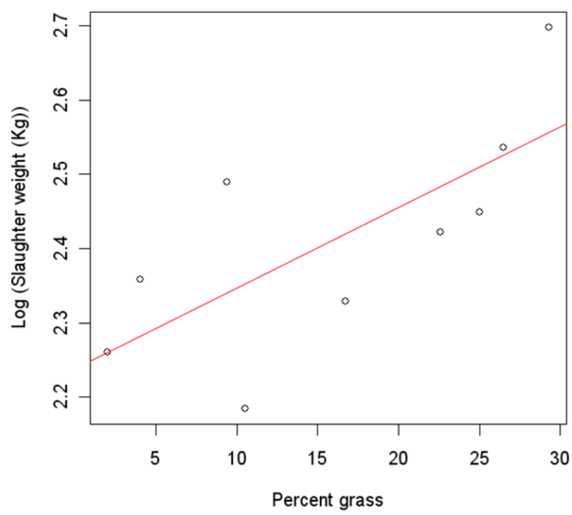

Log (Slaughter weight (Kg))
2.2
2.3
2.4
2.5
2.6
2.7
5
10
15
20
25
30
Percent grass

Figure 19 (previous page): *The differences in growth rate and slaughter weight cannot be explained by the grazing pressure on grass areas calculated as areas of heather per animal, and neither by grass patch size, but grass areas have a significant positive effect on both lamb growth rates and on slaughter weights.* ***Upper left:*** *Mean growth rate modelled as a function of the area of grass available per animal on each study site.* ***Upper right:*** *Mean slaughter weight modelled as a function of the area of grass available per animal on each study site.* ***Middle left:*** *Growth rate modelled as a function of average grass patch size on each site.* ***Middle right:*** *Slaughter weight modelled as a function of average grass patch size on each site.* ***Lower left:*** *Mean growth rate modelled as a function of percentage grass areas on each site.* ***Lower right:*** *Slaughter weight (g/day) modelled as a function of percentage grass areas on each site.*

Average grass patch size ranges from about 1600 to 7800 m^2 (or 16 to 78 da), and both low and high growth rates occur within nearly the whole range. Hence, grass patch sizes do not explain variation in lamb growth rates ($Y=108.0 + 0.0018x$. $r^2=0.015$, $p=0.73$) or slaughter weights ($\log(Y)=2.34 + 1.87*10^5 x$. $r^2=0.067$, $p=0.50$).

However, lambs have significantly higher growth rates and slaughter weights when the proportional occurrence of the class Grass and pioneer vegetation to the remaining area on the pasture is high (growth rates: $Y=80.52+2.26x$, $r^2=0.62$, $p=0.0066$; slaughter weights: $\log(Y)=2.23+0.010x$, $r^2=0.51$, $p=0.030$).

Heather

The percentage of the study site covered by the class Dry heather does not affect growth rates ($Y=114.77 +-0.12x$. $r^2<0.001$, $p=0.99$) or slaughter weights ($\log(Y)= 2.34 + 0.036x$, $r^2=0.052$, $p=0.55$). (fig. 20). Neither the size of heather area available per sheep nor the average heather patch size has any effect on the lambs.

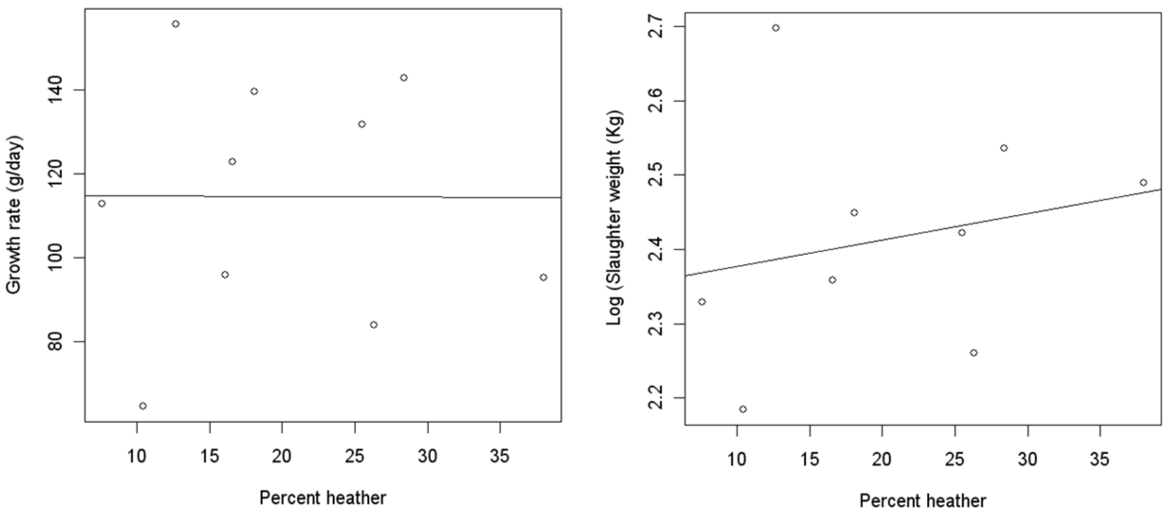


Figure 20: *The percentage of heather areas on the pasture does not affect growth rates or slaughter weights.* ***Left:*** *Mean growth rate modelled as a function of percentage heather areas on each site.* ***Right:*** *Mean slaughter weight modelled as a function of percentage heather areas on each site.*

3.3.3 Interviews

3.3.3.1 Additional fodder

Herds that were given emergency rations of hay did not have growth rates or slaughter weights different from the other herds (*mean T*[5]*=117.34, mean F=111.97, t=0.21, p=0.85, df.=2.58*).

Only two of the herds were given grain feed. The two groups were not significantly different from each other (growth rates: t-test, *mean T=139.40, mean F=110.64, t=1.53, p=0.23, df.=1.69*; slaughter weights: *Wilcoxon-test, W = 25, p = 0.31*). Herds that do not receive grain feed can have high growth rates, but as seen in figure 21, the highest mean growth rates and slaughter weights occur in the group of herds that do receive grain feed.

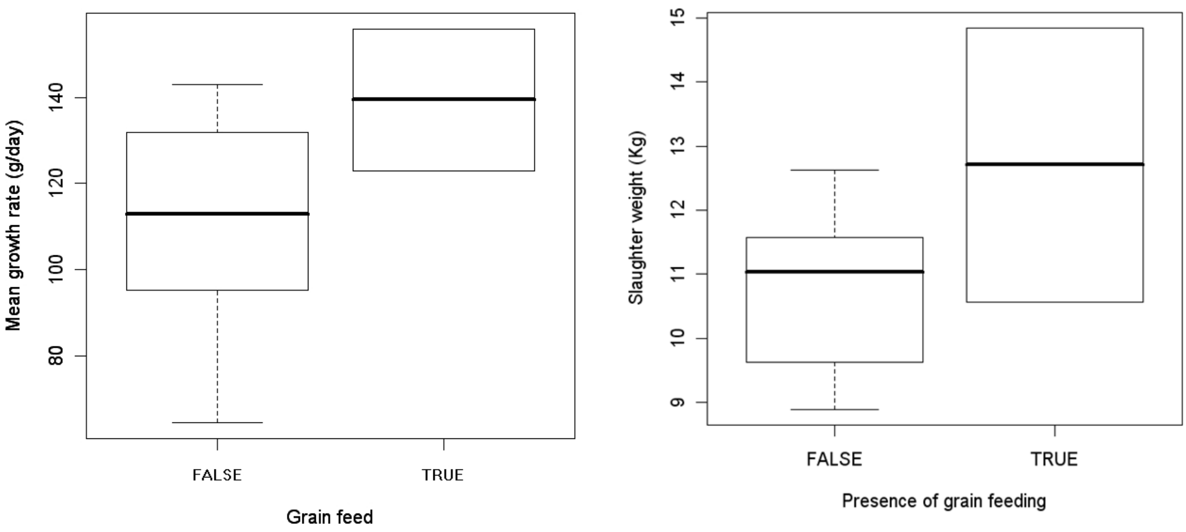


Figure21: *Grain feeding has no significant influence on growth rates or slaughter weights, but a very weak positive trend can be assumed.*

3.3.3.2 Grazing grounds

Only two study sites did not have infields or areas previously managed as infields. A few study sites had large proportions of infield areas. Most localities had occurrences of old infields, but most of these were small areas. The presence of infields did not significantly influence either growth rates (*mean T=118.9444, mean F=102.0500, t=0.439, p=0.73, df=1.092*), or slaughter weights (*Wilcoxon-test, W=7, p=0.60*).

[5] Mean values are referred to as T for the group s *True* and F for the group s *False*.

The mean growth rate of lambs in the group of herds that graze limed pastures is not significantly different from the mean growth rates of the herds that graze non-limed pastures *(mean T=100.8667, mean F=121.5000, t=1.32, df=5.58, p=0.24)* (fig. 22), and the lowest values are found in the group with the highest mean (non-limed). There is no difference in slaughter weights between the two groups (*Wilcoxon-test, W=19, p=0.37*).

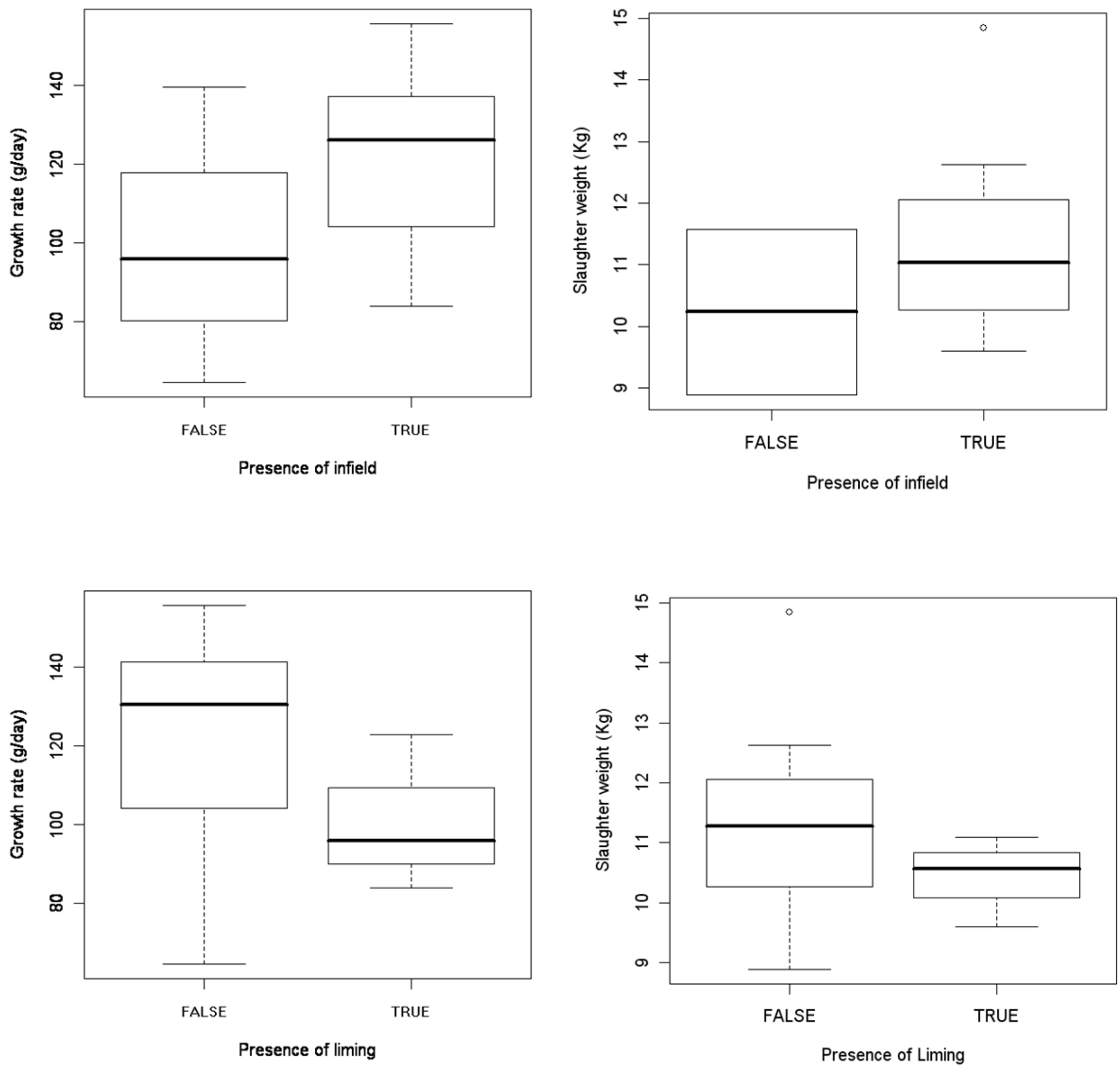


Figure22: *No effect was seen in growth rate or slaughter weights of the presence of infields, but a weak positive trend is visible. Only two localities did not have infields. A very slight negative trend is visible, but no significant effect of liming on growth rates or slaughter weights is evident.*

Traditional heathland burning was regularly being performed on six of the study sites. There was no difference between the mean growth rates (*mean T=112.18, mean F=117.99, t=0.29, p=0.78, df=5.24*) or slaughter weights (*Wilcoxon-test, W=25, p=0.31*) of the herds that graze pastures where heather burning is performed (fig. 23). The data is based interviews and not on the maps created; the variable is a two-level factor and does not take the area of the burnt heather into account. The study sites that were being burned had occurrences of bracken, and the pattern is identical to that of heather burning when measured on a two-level scale of occurring or not occurring (in areas that meet the mapping criteria) on the site.

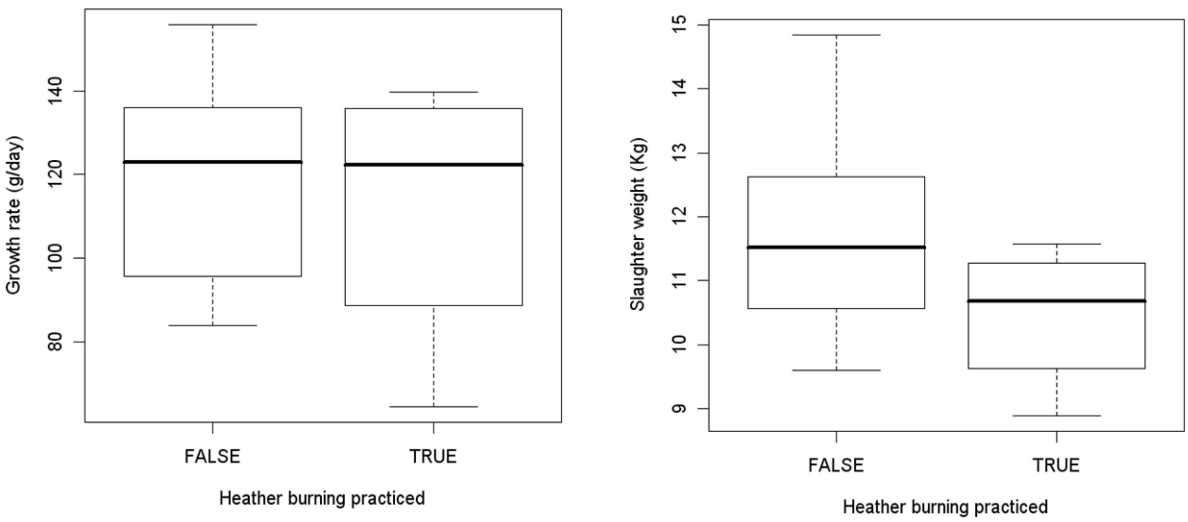


Figure 23: *There is no difference in mean growth rates or slaughter weights between herds on sites where heather burning is practiced.*

3.3.3.3 Proportion of lambs not slaughtered

Due to the bonus class limits of the slaughter houses, herds with generally small growth rates and slaughter weights are likely to have a high proportion of lambs that are not slaughtered, which may remove low slaughter weight values and thereby lead to more equal slaughter weights data than is really the case. The proportion of lambs that were not slaughtered was plotted against growth rates and slaughter weights (fig. 24) to get an idea of how large this effect may be. There was no clear trend, especially not when it comes to growth rates ($Y = 122.86 - 0.46x$, $r^2=0.08$, $p=0.41$), but slaughter weights decrease with the percentage of lambs that are not slaughtered ($\log(Y) = 2.46 - 0.0038x$, $r^2=0.21$, $p=0.13$).

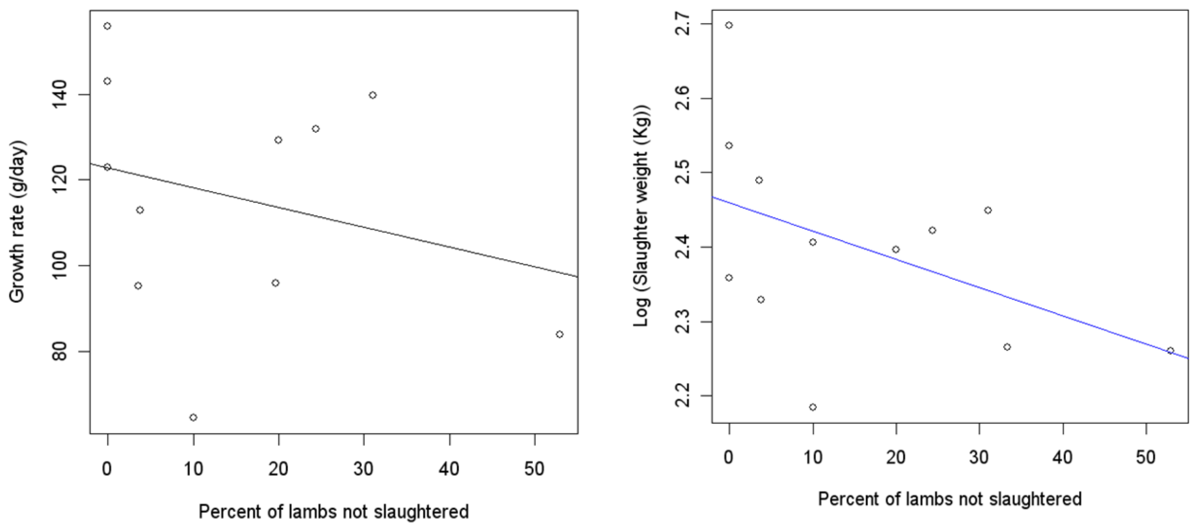


Figure 24: *Percent of lambs not slaughtered.* ***Left:*** *The percentage of lambs not slaughtered modelled as a function of mean growth rate at the different study sites.* ***Right:*** *The percentage of lambs not slaughtered modelled as a function of mean growth rate at the different study sites.*

3.3.3.4 Birth date

Growth rates are slightly higher when lambs are born late ($Y = 75.62 + 7.26x$, $r^2=0.022$, $p=0.15$), but most of the herds have lambing in April, and the variation in growth rates among these herds is high. There is no relationship between slaughter weights and the date of birth ($\log(Y)= 2.35 + 0.013x$, $r^2=0.052$, $p=0.67$). (fig. 25). At Uttian, lambs were born as early as in late February.

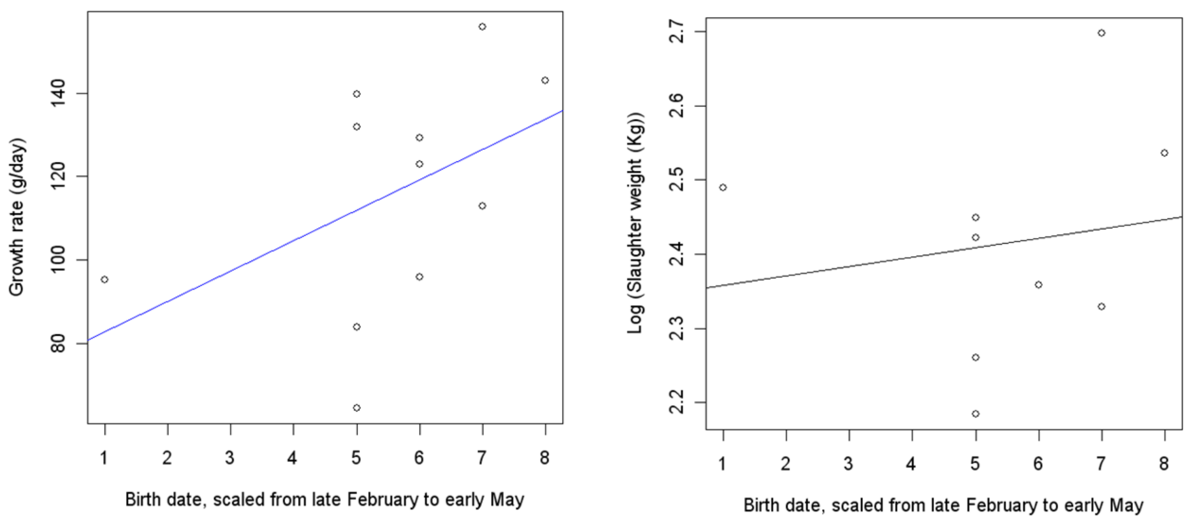


Figure 25: *Herds that have late lambing have slightly larger growth rates than herds where lambing is early. The same pattern does not exist for slaughter weights.* ***Left:*** *Birth date modelled as a function of mean growth rate at the different study sites.* ***Right:*** *Birth date modelled as a function of mean slaughter weight at the different study sites. Each interval represents 1/3 of a month, starting on 1=last third of February.*

4 Discussion

4.1 LAND COVER MAPS

The heterogeneity of the land cover maps show that the ANBOS have variable grazing grounds, which may lead to different behaviour and resource use.

Evaluations of the suitability of land cover classes

The eleven classes found appropriate on which to base the mapping are well separated in terms of nutritional values, though the methods are limited by spatial resolution. Of course, within each class, both edible and non-edible plants may occur. In addition, fodder value is determined not only by the actual production of the system and nutritional values of the plants in the system, but also by the degree of utilization of the plant material, which is related to the animals` preferences (Rekdal 2003), among other things. Unfortunately, little is known about grazing preferences of ANBOS. Sheep are generally selective compared to other breeds, and the short-tailed breeds are the most selective, grazing leaves for example (Nedkvitne et al. 1995). Therefore, drawing categories that reflect fodder value has an element of uncertainty.

The percentage area of rock on each study site was tested as a variable that represent non-edible areas, but may also be important as a landscape element to the animals, being a bare and open feature where sight is good.

The classes that did not appear on all study sites were unsuitable for comparisons between localities, but were important to include in order not to introduce error to the other classes, as well as for usefulness for future uses other than for the exploratory analyses performed.

Map accuracy

The map accuracy of 86.1% is in accordance with other studies using aerial photography interpretation. For comparison, the Norwegian Forest and Landscape Institute created maps with an overall accuracy of 74.8% but used as much as 103 classes, and they did not sample away from patch borders (Cf.Fjellstad *et al.* 2004).

The differences between aerial photograph interpretations and field surveys can have several explanations, and a discussion of these is presented in Appendix E.

4.2 EXPLORATORY ANALYSES

4.2.1 Summer fodder

The increasing lamb growth rate and slaughter weight with higher percentage of grass areas on the pasture is consistent with common knowledge about ruminants` feeding habits. Grasses are an important constituent of the summer fodder of sheep, and as the study period is during the growth season, it is not surprising that grass areas have a direct effect on the growth of lambs. But how can the significance of percentage grass on the pastures compared to the non-significant variable areas of grass available per sheep be explained? Percentage grass cover is probably a better indicator of grass availability than animal density. Most areas are In a study performed in drier environment, food abundance was found to be the strongest factor among a range of factors, including food quality, affecting sheep habitat use during spring (Rueda et al. 2008). However, results similar to ours regarding the importance of grass relative abundances have been found for sheep in Norway on summer pastures (Garmo and Skurdal 1998), with the suggestions that under poor conditions for plant growth, sheep cannot be as selective as they are when conditions are good.

Since heather is a winter resource, and the measured variables of growth and slaughter weights are of lambs during summer, the percentage of heather is not as likely to be important to the lambs as grass, which is a summer resource. The possibility is still there that conditions experienced by ewes in the winter influences the foetus and continues to affect lambs after they are born. However, no relationship was seen.

A possible source of error is the variability of vegetation types occurring within the land cover class Grass and pioneer vegetation. Grass occurrences may be of varying composition and fodder value at the different study sites. Especially, the occurrences of

Molinia heaths, which are of lower fodder value than other grassland types, however interestingly, when dead, the plants have higher fodder value than other grass types (Manley *et al.* 1994). Molinia heaths have been reported by farmers to expand in south-west Norway, and has been shown to expand in Europe due to nitrogen deposition (Prøsch-Danielsen and Øvstedal 1994) and is seen as threat to biodiversity and pasture quality .

4.2.2 Discharge and precipitation

Precipitation may have a direct affect on the quality of pasture grass by drowning it. Occurrences of large single amounts of rainfall should be important in this relation, as it is sudden flooding, and not continuous, lower levels of precipitation that would have such an effect. The May to August rainfall variable which was tested may not have had sufficient temporal resolution to cover such incidences, since growth rates and slaughter weights did not decrease with this variable as they did with the annual values. The May to August variable may also have had an insufficient temporal extent, as precipitation is highest later in the autumn. Measurements after August would not be applicable for exploration of growth rate data in this study, as the last weighing was done during September. Annual precipitation values may conceal variations in precipitation during the year, but may also to a higher extent take account of the geographical variability of climate and precipitation.

Another role high precipitation values may play in the negative relationship with slaughter weights is through leaching of essential or trace elements. Continuous high rainfall may be more likely to cause leaching of essential and trace nutrients than short periods of high rainfall.

Rainfall may also have a direct effect on animal behaviour and activity.

The possibility of discharge as a factor affecting health of lambs should not be excluded, although the data presented here is too scarce and unreliable to base such an assumption on. Runoff is not independent of annual precipitation, as it is estimated from precipitation normals (1961-1990), and slope, so an explanation for the negative effect it has on slaughter weights may be the same; essential nutrients or trace elements are taken away from the soil, influencing the uptake in vegetation and again affecting the lambs` intake. However, how quickly this would affect the health of lambs in this relation is uncertain. A lag effect could possibly explain why slaughter weights are more affected by precipitation during the season than growth rates are. Low soil or plant cobalt content has been hypothesised as one of the reasons for low slaughter weights and growth rates of lambs in western Norway (Velle and Waldeland 2006), as it is a constituent of B12 (cobalamin) (Smith 1987) and can directly affect B12 blood levels or ruminants which are able to and dependent on synthesizing this vitamin in their rumen (Ulvund 1995a).

4.2.3 Management

No additional fodder seems necessary to retain sufficient growth rates or slaughter weights. Grain feed was only given in small amounts in order to tame the animals, and hay usually only as emergency rations. This emphasises the ability of ANBOS to live off of scarce resources, and supports the view that traditional management methods sufficiently secure animal welfare. On the other hand, since higher mean slaughter weights and growth rates occur in herds that are fed even small amounts of grain feed (although not significantly higher), grain feeding can possibly influence the weight and hence the other results in this study.

Liming is known to influence the uptake of cobalt in pasture plants (Ulvund 1995b), but the data gathered do not have sufficient power to indicate whether this affects lamb growth variability.

4.2.4 Evaluation of weight data and exploratory methods

A possible explanation for the difference in ranks in Uttian between the growth rate and slaughter weight data is that the lambs here were born as early as in February, and had already finished a large part of their growth when they were weighed the first time, as growth rates of ruminants are fastest during the first weeks and months (Rèale and Boussès 1999).

The correlation between growth rates and slaughter weights shows that growth rates are an important parameter concerning the ANBOS farming industry. The outcome of the exploratory analyses should subsequently reflect similar results. The most likely reason for why this was not always found is that it was not entirely the same data that were used, which alongside with a small sample size, made each observation contribute much to the mean.

Slaughter weights can be collected more easily than live weights, rendering possible a decreased workload. However, slaughter weights are error prone due to differences in decisions on which lambs to slaughter and keep. Some owners select for heavy animals, and these will consequently not be sampled, while others select for typical characters of the breed, which includes lower weights than the average domestic sheep breed. Some owners keep the sheep as a hobby, while others try to make a living out of it and have an economic incentive to maximize their yield. The sharp edge of the slaughter weights histogram before log-transformation can be explained by the lower limits for bonus classes of the slaughter houses.

Most lambs that are going to fall below these classes are kept on the pastures over the winter. Different slaughterhouses have different bonus classes, and not all owners use the same slaughter house. Caution should be taken when considering slaughter weights as random samples.

Lambs that are not slaughtered are a source of error, especially related to slaughter weight (see fig. 24). Errors related to the weight data include wet fur when raining, sheep wriggeling on the scale, as well as human errors when reading off the weight.

This study has not taken a temporal dimension into consideration. Variability of lamb growth rates, especially if they are related to climatic conditions, is likely to occur over time as well as space.

4.2.5 Research design, statistical analyses and the use of GIS in the study

It proved difficult to find a sufficient number of localities, as ANBOS farming is not common. The project was left with the choice of whether to include herds that did not meet the selection criteria (see M&M), and therefore were not considered comparable, or to exclude them and be left with a low number of observations, losing statistical power. For example, herds that were given grain feed

Had there been more observations (study sites), I would have been able to tell a lot more. Different tests than those performed could have been done, such as multiple regressions, opening for testing interaction between the different variables. It would also give more opportunities for nuances in the results. For example, grain feeding could with many more observations be divided in further detail (eg. how often, or whether given sporadic or as a constant supply).

Hence, due to a low number of observations, and a high number of explanatory variables, making firm conclusions based on the results of the analyses performed is not scientifically sound. However, the strength of this study is in its broad base, covering a large geographic area and investigating many fields that were possibly of interest. Although few were very telling, the study has assembled much knowledge. The exploration of potentially important factors has led to hypotheses that should be considered for further study.

Through the extraction of mean values from the datasets for exploratory analysis, I have averaged away much interesting information. There is a large quantity of information in the database created that has not been utilized, and a well of possibilities for further investigations using spatial analysis, concerning distribution of vegetation patches and performing analyses on issues briefly presented in this study through qualitative visualization. The land cover geodatabase has been designed to render possibilities for further investigation, and a brief discussion of this is provided in Appendix E.

The mapping procedures were quite time demanding, but highly valuable, and the use of Color RGB photographs have proved satisfactory, although difficult decisions had to be made. Using infrared photographs could probably enhance map quality by opening for the separation of more classes. For example, in IR photos it would be easier to distinguish mires from other, drier graminoid- or grass dominated areas. It could also possibly improve accuracy even more.

GIS is a highly applicable tool for creating and analysing spatial information, and it has been essential in the production of the data presented.

4.3 Suggestions for further investigations in the project

4.3.1 Summary of study

Through the exploration of growth rates and slaughter weights in relation to different explanatory variables, I have produced background data and identified areas of possible interest to further research in the Feral Sheep project. These areas include summer fodder, seasonality and precipitation.

The data used in the study has a wide breadth. This approach is useful in the initial phase of a research project, particularly in a project that is built on new ideas. In a research area where little is known, basic knowledge needs to be collected. This baseline study is important in order for the project to find areas for narrowing down the approach and themes, and for allocation of resources and effort. The research questions proposed are then being founded on solid ground, so the investigations to be carried out can produce results that meet the aims of the research project.

4.3.2 Research questions generated from the baseline study

1) **Do ANBOS behave differently in pastures during summer and winter?**

The main output of the baseline study was related to summer fodder, which seemed to be important to the lambs, while additional fodder did not seem necessary. Other studies have suggested that summer fodder is more important for juvenile ruminants than winter resources

(Weladji *et al.* 2003). ANBOS are thought to be exceptionally good at allocating resources temporally, saving up energy for the winter, and possibly reducing activity.

Since my response variables are directly related to the summer season, it is first of all necessary to find out more about the effect of winter on sheep health. Additional broad investigations which comprises the winter season should be performed.

The maps provided from this baseline study can be used in combination with GPS collars to find out in which vegetation type sheep spend time in and to which time of the year in order to compare activities. One can calculate to what time they move and at what speed they move, how long do they stay at different places, as well as compare their locations to digital elevation models, slope and aspect data, and test for distance trends to water sources. Climatic data for known dates can be used for comparisons with the GPS locations. With such an approach, it is possible to find out how the sheep move in relation to the weather. GPS collars may be very useful for obtaining knowledge about ANBOS grazing preferences, as well as preferences related to slope, elevation and weather.

2) **Which properties of grass areas are important to ANBOS lambs?**

My results indicate that the relative abundance of grass vegetation can be more important than patch sizes and the area available per sheep. Other studies have proposed that abundance of grass is more important than the quality or nutrient value of grass (Rueda *et al.* 2008, Weladji *et al.* 2003). However, the weak gradients in the coastal regions is also reflected in the grass protein content during the summer season, which varies less here than further inland, have been suggested to impact behaviour in ruminants (Albon and Langvatn 1992). More investigations on the quality and distribution of grass areas on different ANBOS pastures may be relevant in finding out about the role of summer fodder in the health of ANBOS lambs.

Specific tasks may include measuring sward height, biomass, production and nitrogen content of grass at different sites or in different grassland types grazed by ANBOS, and compare with measurements of growth rates.

In order to find out if the sheep preferences of grass are related to any of the parameters measured, similar approaches as in the previous section may be chosen.

The maps may be used for finding grass areas to perform sampling in, but having observed variation in grassland types between the study sites, I suspect that the maps have high variation of grassland types within the class Grass and pioneer vegetation, including grassland types of both low and high fodder values.

3) Which properties of precipitation affect ANBOS lambs?

My results show that high annual precipitation may have a negative effect on ANBOS lamb slaughter weights. Within annual values, many causal factors may be hypothesised. The numbers of rainy days, presence of short, or intense periods of precipitation are possible variables to look at.

It may be possible to measure precipitation directly at the ANBOS pastures throughout the year, and compare it to weight data and blood samples in order to find out what temporal scale and resolution the precipitation impacts consists of. Otherwise, using data from the Norwegian Meteorologial Institute may be an option.

4.3.3 General considerations

My results show that latitudinal variations exist, and in the investigations that are being done, it is therefore important to sample along a wide latitudinal range.

The MLURI hill grazing management model (Manley *et al.* 1994) is a computer program that, based on climate, fodder value and sheep densities calculate management models for sheep farmers. Could a similar approach be valuable, and could it be developed for conditions in western Norway?

An interesting finding that can not be concluded over due to the scarce data, but may be interesting to look into in further detail was the total overlap of the classes Burnt heather and Bracken. This could indicate that heather burning promotes expansion of *Pteridium aquilinum*, which is a relevant assumption as fire promotes the growth of bracken (Watt 1955), and it generally responds to human disturbance and clearance of vegetation (Marrs and Watt 2006), as well as to increased nutrient availability (Schwabe 1953). However, the sites it appeared on are precisely the southernmost of the localities included, which reflects the distribution patterns of *P. aquilinium* (Watt 1955), although the northernmost locality is well within the northern distribution limit of *P. aquilinium*. Where they appeared, bracken areas constituted from 0.9 to 7.1% of the total site area. In Scotland, bracken covered from 8 to 13 % percent of the mapped heathland area using remote sensing methods at four different sites (Stove 1983), which is higher, but comparable to my results.

It is important to take local knowledge into account, and base projects on cooperation with local farmers. In addition to detailed investigations mentioned earlier, it is can be a good strategy to keep a quantitative broad-scale approach. It could be interesting to start a cooperation project with farmers and with Telespor AS where one grants access to sheep

GPS databases they provide, in order to analyse properties about their behaviour that would provide new knowledge.

4.3.4 Map restrictions

Certain analyses should not be performed with the current land cover datasets. Mapping criteria included assumptions on distribution of land cover classes when there was not sufficient information in the aerial photograph colour signature or texture to base the decisions on. Therefore, such distribution patterns should not be tested using the maps, as the variables will not be independent of each other. These assumptions are that:

- Dry heather appears on hilltops (convex structures)
- Damp heath appears in flat, low-lying areas and depressions
- Mire appears in flat, low-lying areas and depressions
- Mire appears close to water

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Appendix A

– Land cover maps

The extent of the study sites is based on available information of where the ANBOS herds graze, and nothing outside the pasture is mapped. The map boundary information is based on fences, water or approximate borders of where the sheep stay based on the interviews or in one case, GPS trackers. Hence, the outside of the mapped area is in some cases land, in other cases water and in some cases a mixture.

Map colours were chosen based on the tool ColorBrewer (Brewer 2008), but with three additional classes, and slightly modified colours. When choosing the colour scheme, the visual clarity and separability of the colours, as well as their "logic" (for example green for forest) were taken into account. Also, an attempt to use equal colour saturation was made in order to reflect qualitative classes of equal importance. A traditional land cover or vegetation classes` colour scheme has not been followed, as the classes do not reflect traditional classes.

All maps are in the projection Universal Transverse Mercator 32N and with the datum World Geodetic System 1984. The maps are vector polygon shapefiles. Metadata and a layer file containing the colour scheme used in the maps provided here is available. The numeric *Veg* is the layer join field. The string field *Vegetation* contains the land cover name, and does not necessarily correspond with the Veg field, allowing for more details in certain maps if used, but reducing consistency among the maps provided. The two double fields *Area* and *Perimeter* are used in the calculation of the double field *Complexity* by the equation

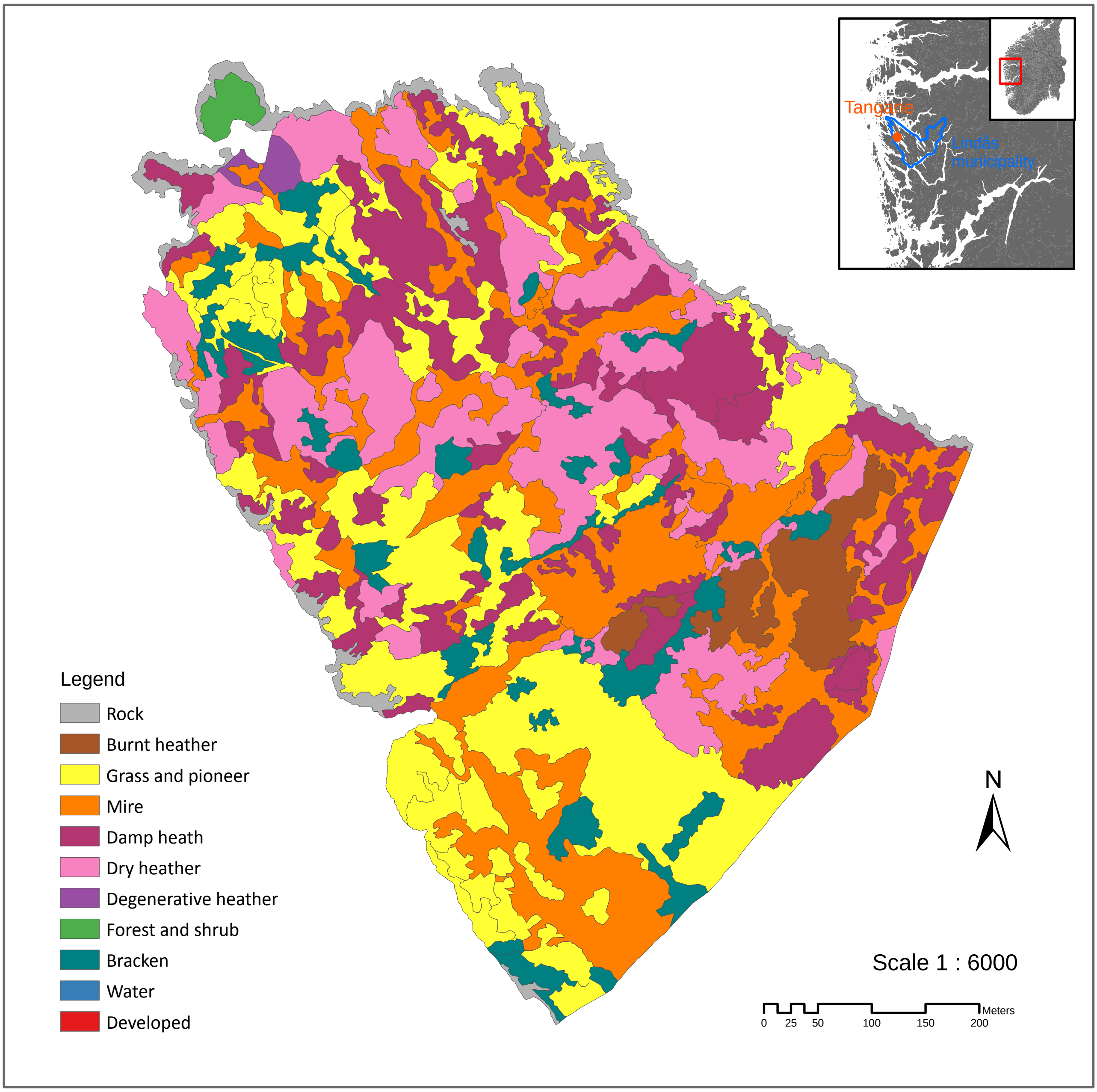
$$S = \frac{P}{\sqrt{4\pi A}} \qquad \textit{Equation I}$$

where S is the shape complexity, P the perimeter and A is the area of each map feature.

Vegetation maps

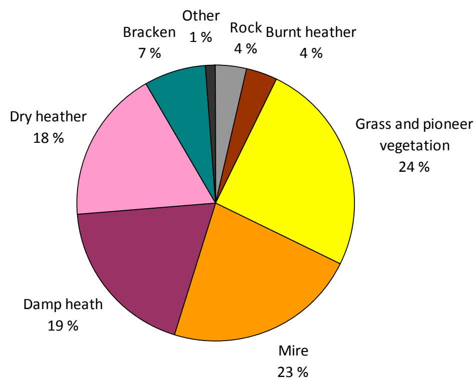
Tangane

Tangane is located at the North-Western tip of Lygra, Hordaland.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep

The map shows vegetation types that reflect fodder value particularly for this breed.

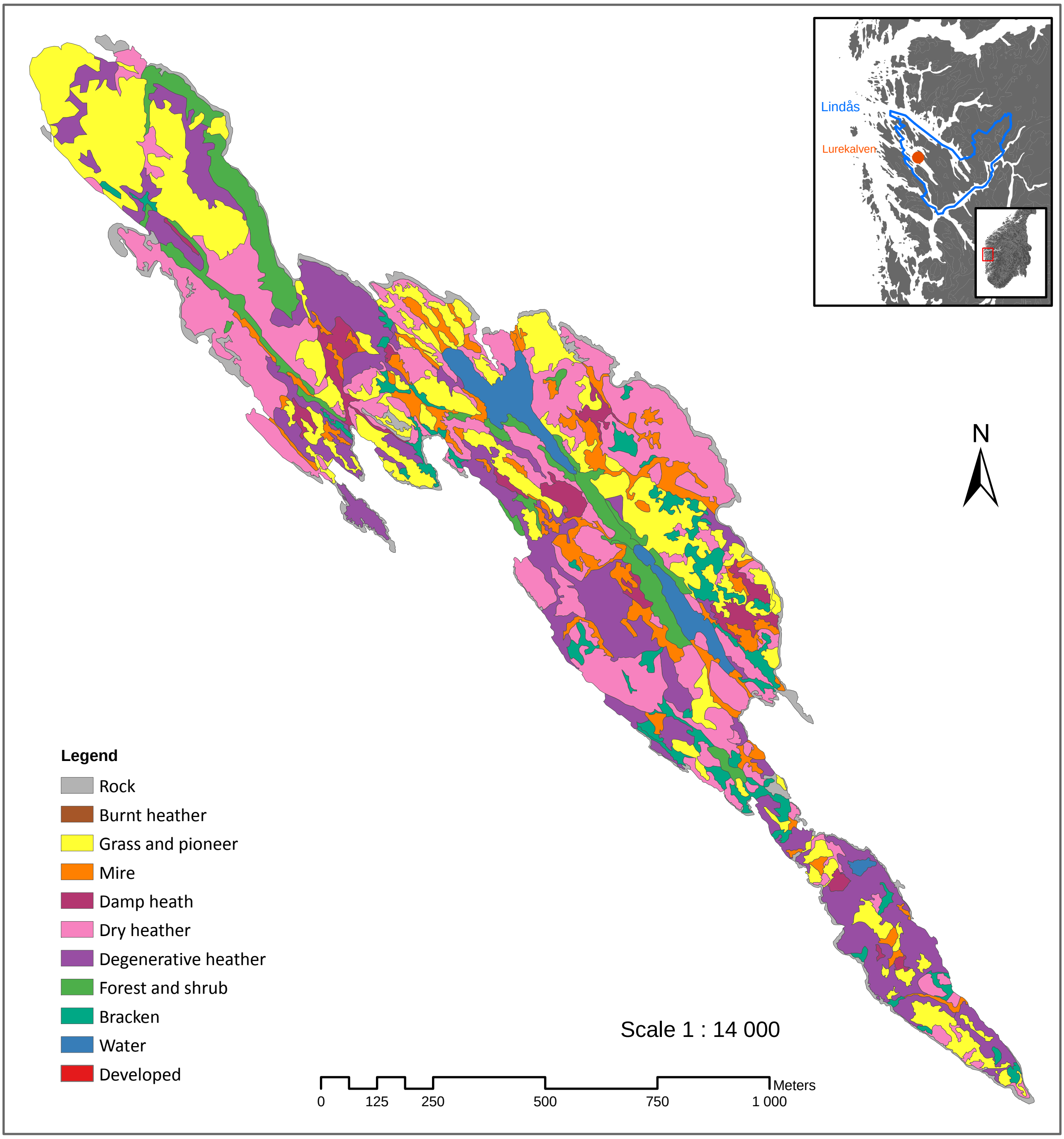


Made by Eva Kittelsen
Projection: Universal Transverse Mercator 32N, WGS84.
Inset map data source: AR2000, Norwegian Map Authorities.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

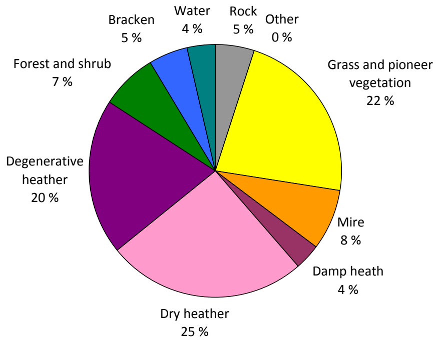
Lurekalven

Lurekalven is an island north-west of Lygra in Hordaland County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.



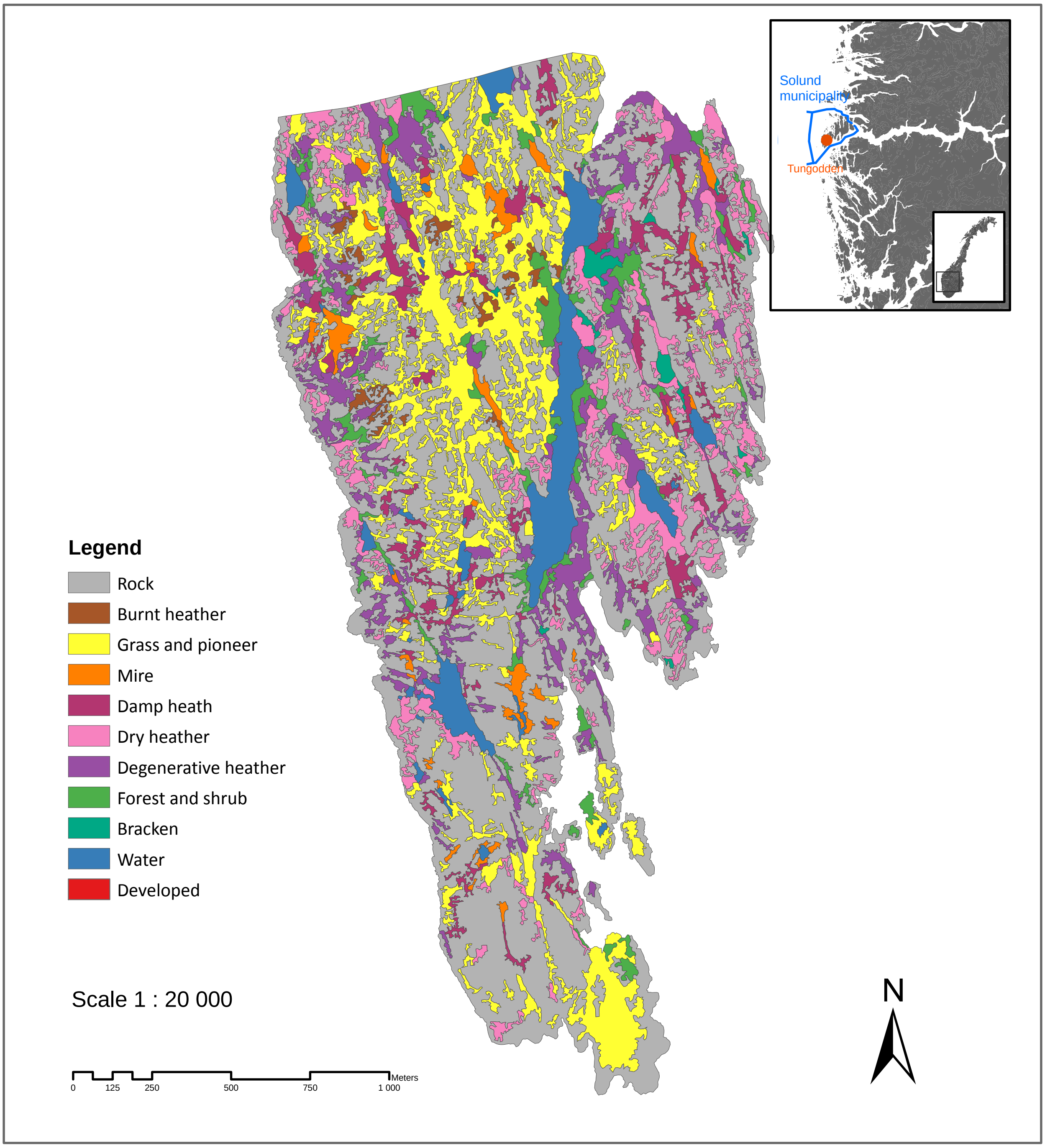
Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Eva Kittelsen, MSc thesis, University of Bergen, Institute of Biology, 2008

Vegetation maps

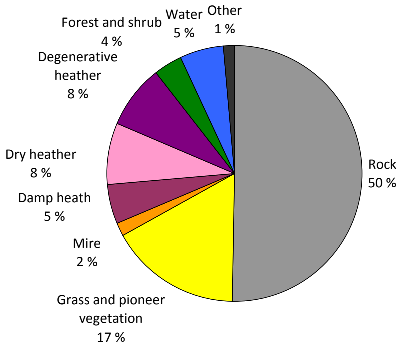
Tungodden

Tungodden is a peninsula in Solund, Sogn og Fjordane County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

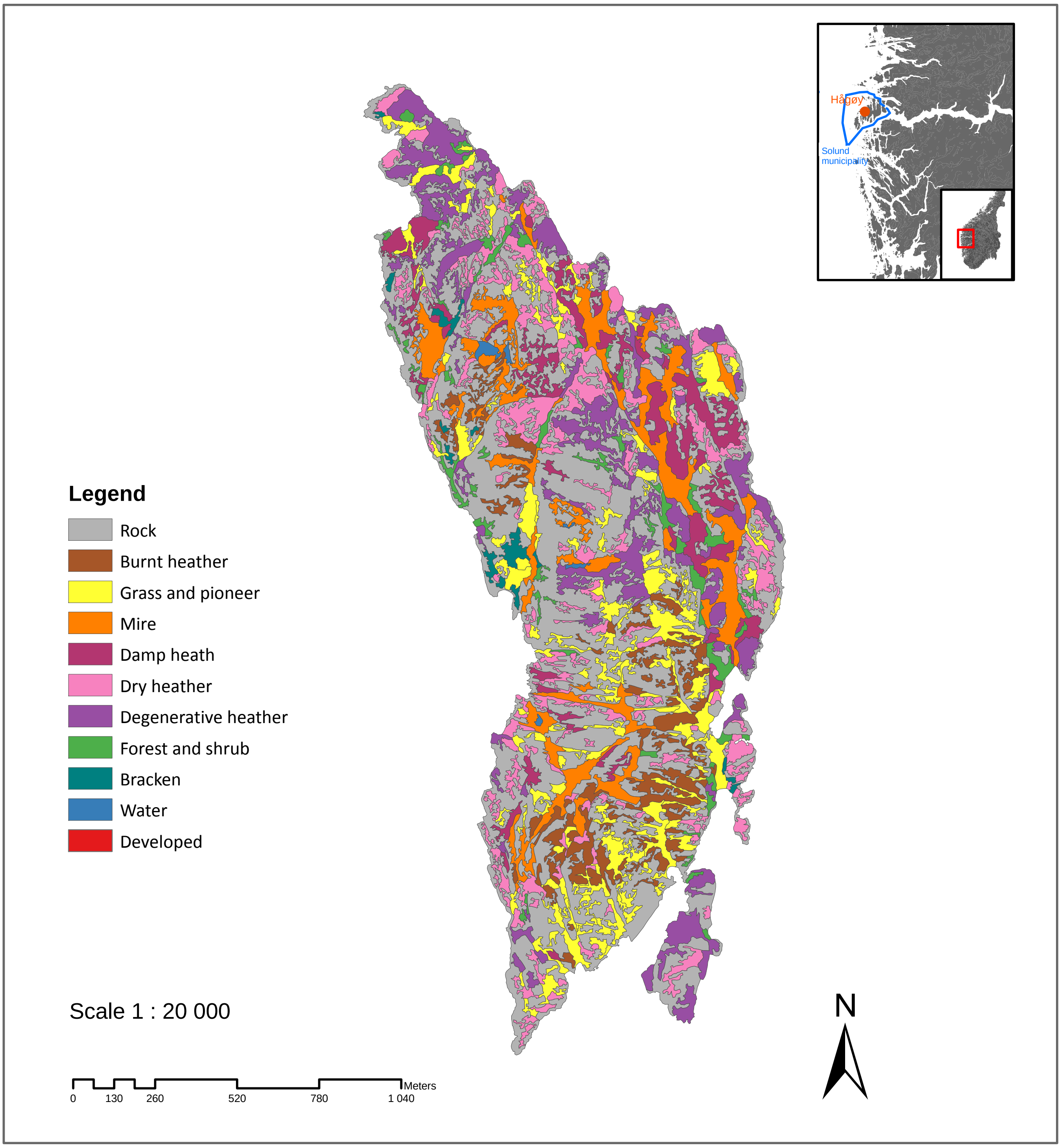
The map shows vegetation types that reflect fodder value particularly for this breed.



Made by Eva Kittelsen
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorities.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

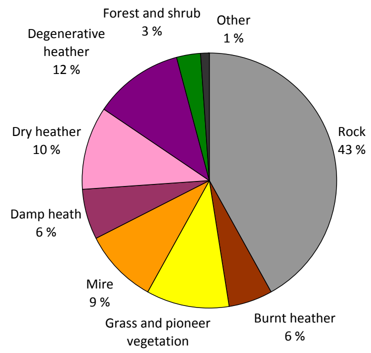
Vegetation maps
Hågøy

Hågøy is an island located in Solund, Sogn og Fjordane County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.

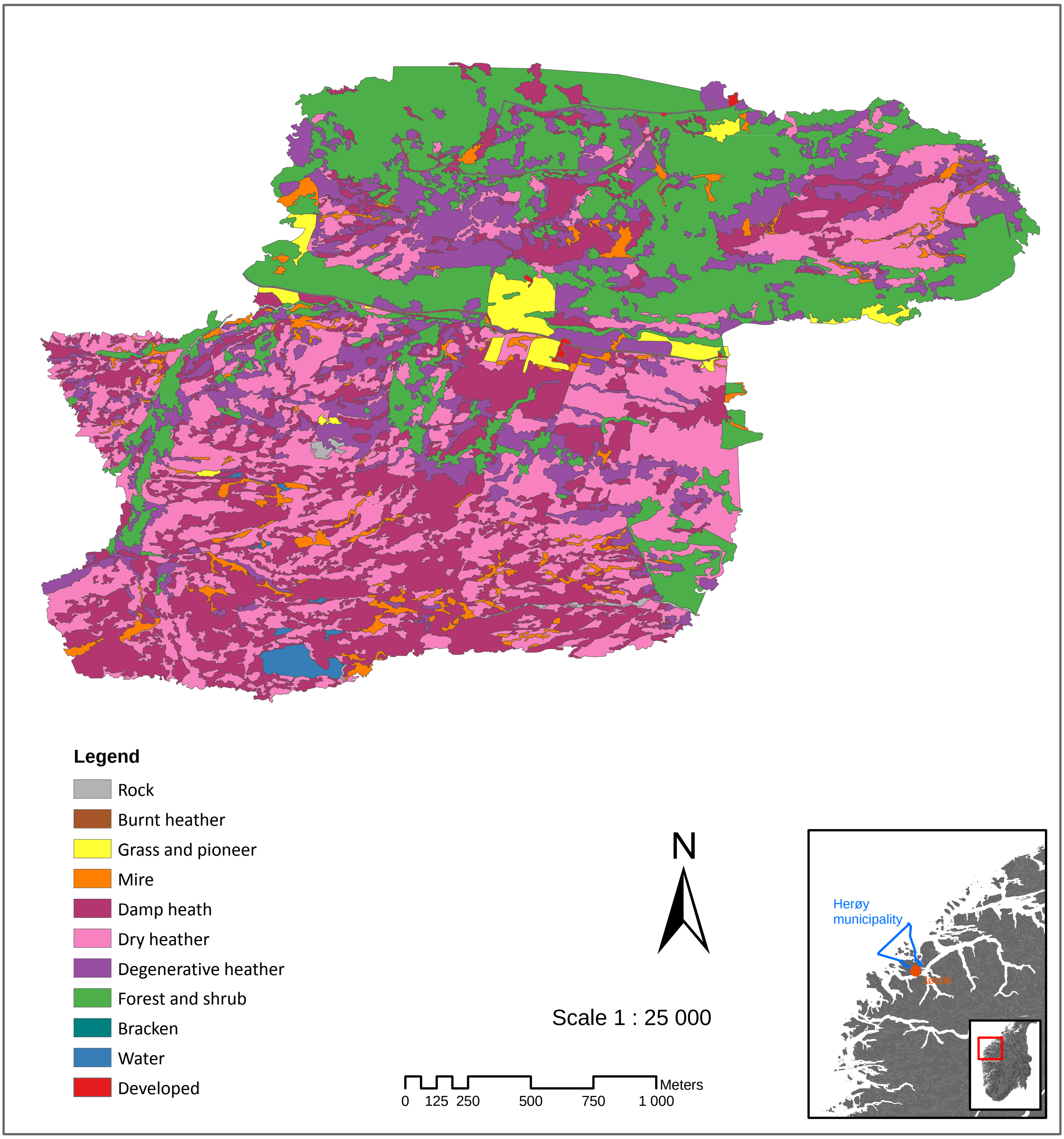


Made by Eva Kittelsen
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

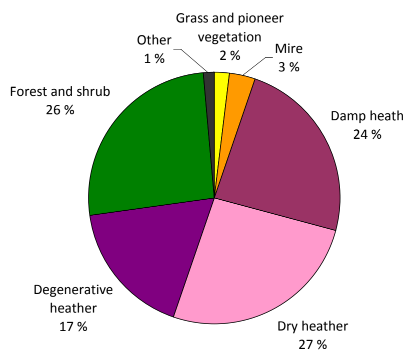
Jøsok

Jøsok is an area in the southern part of Gurskøy, Møre and Romsdal County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.

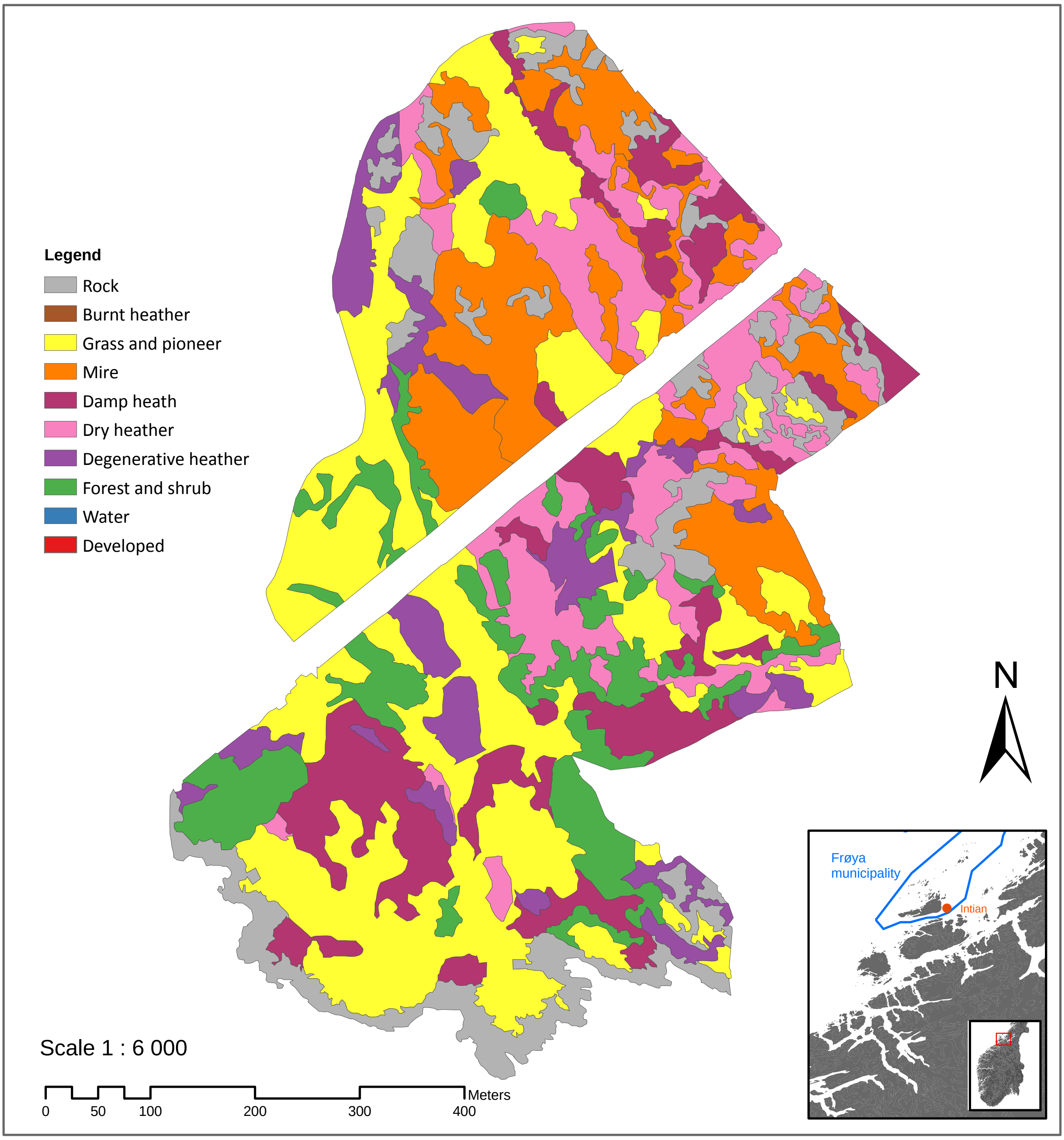


Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

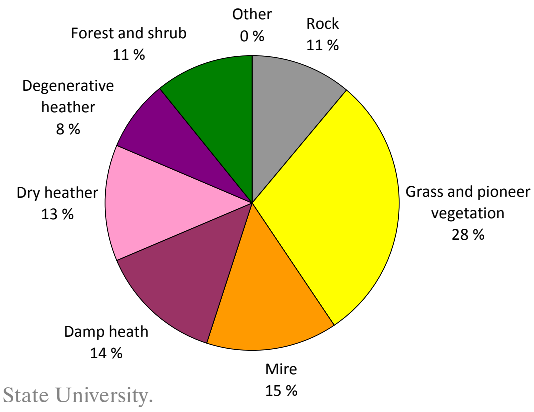
Intian

Intian is an island east of mainland Frøya in Sør-Trøndelag County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.

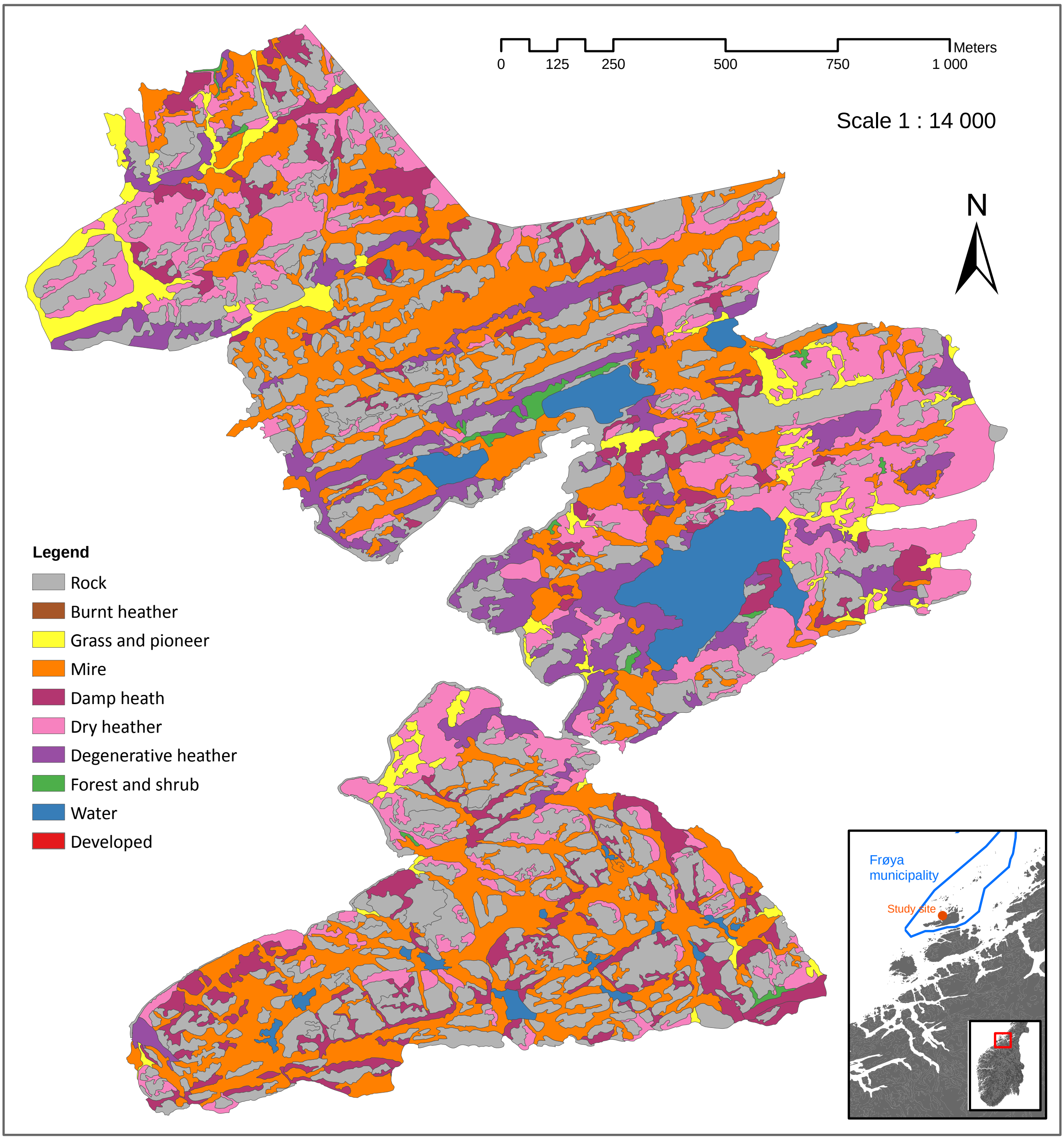


Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

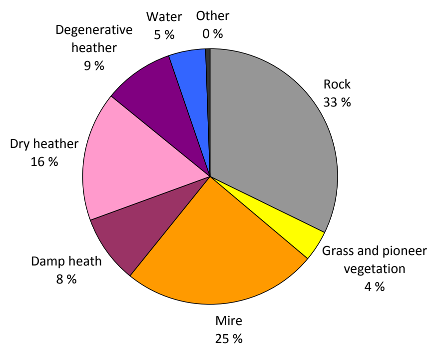
Frøya 1

The study site is located at the mainland of Frøya in Sør-Trøndelag County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.

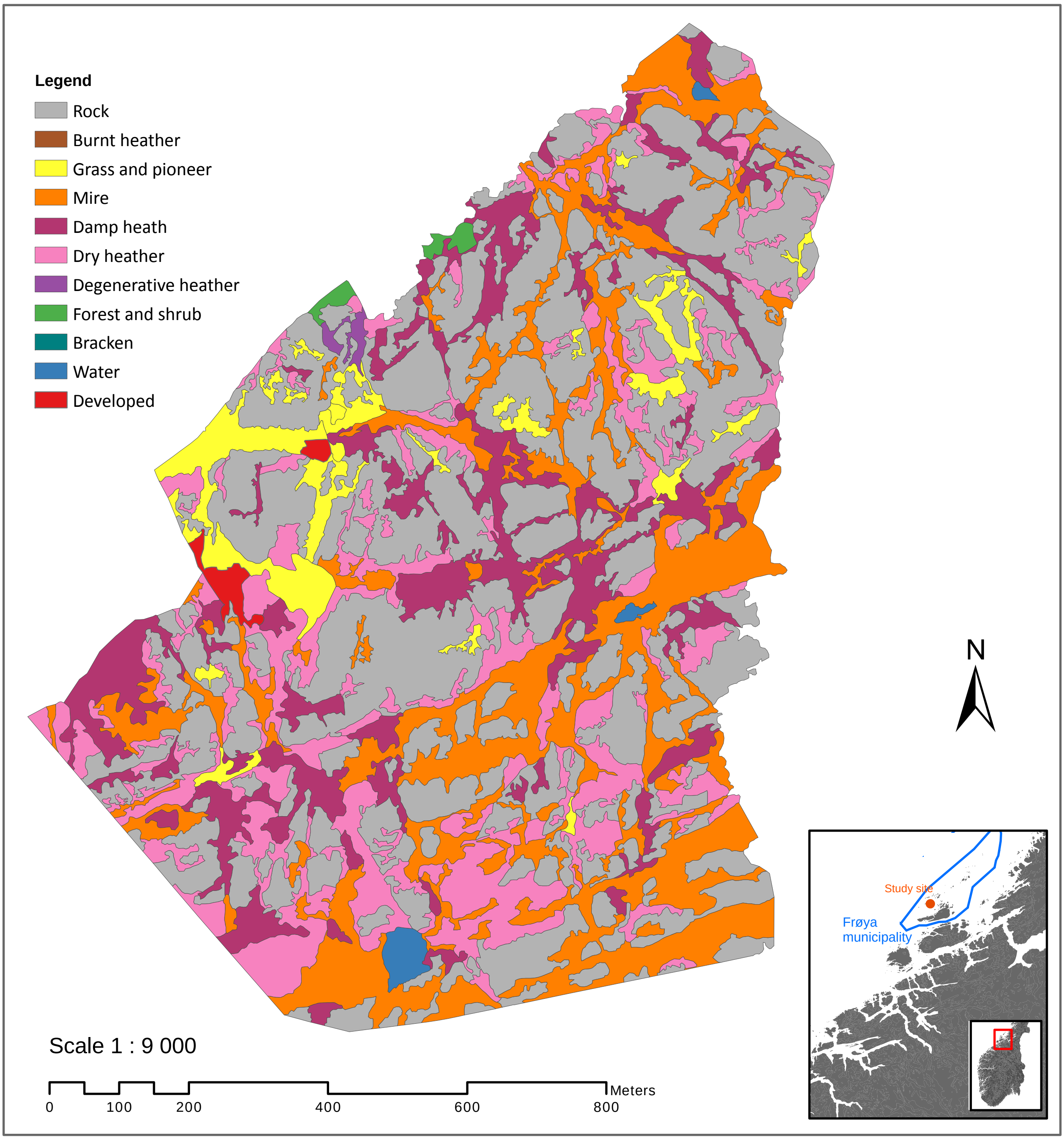


Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

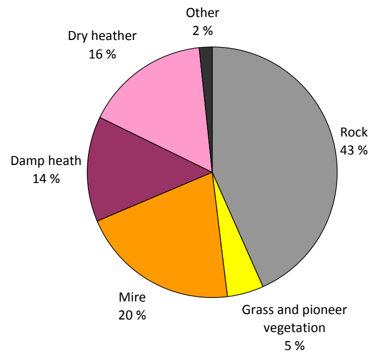
Frøya 2

The study site is located at the mainland of Frøya in Sør-Trøndelag County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.

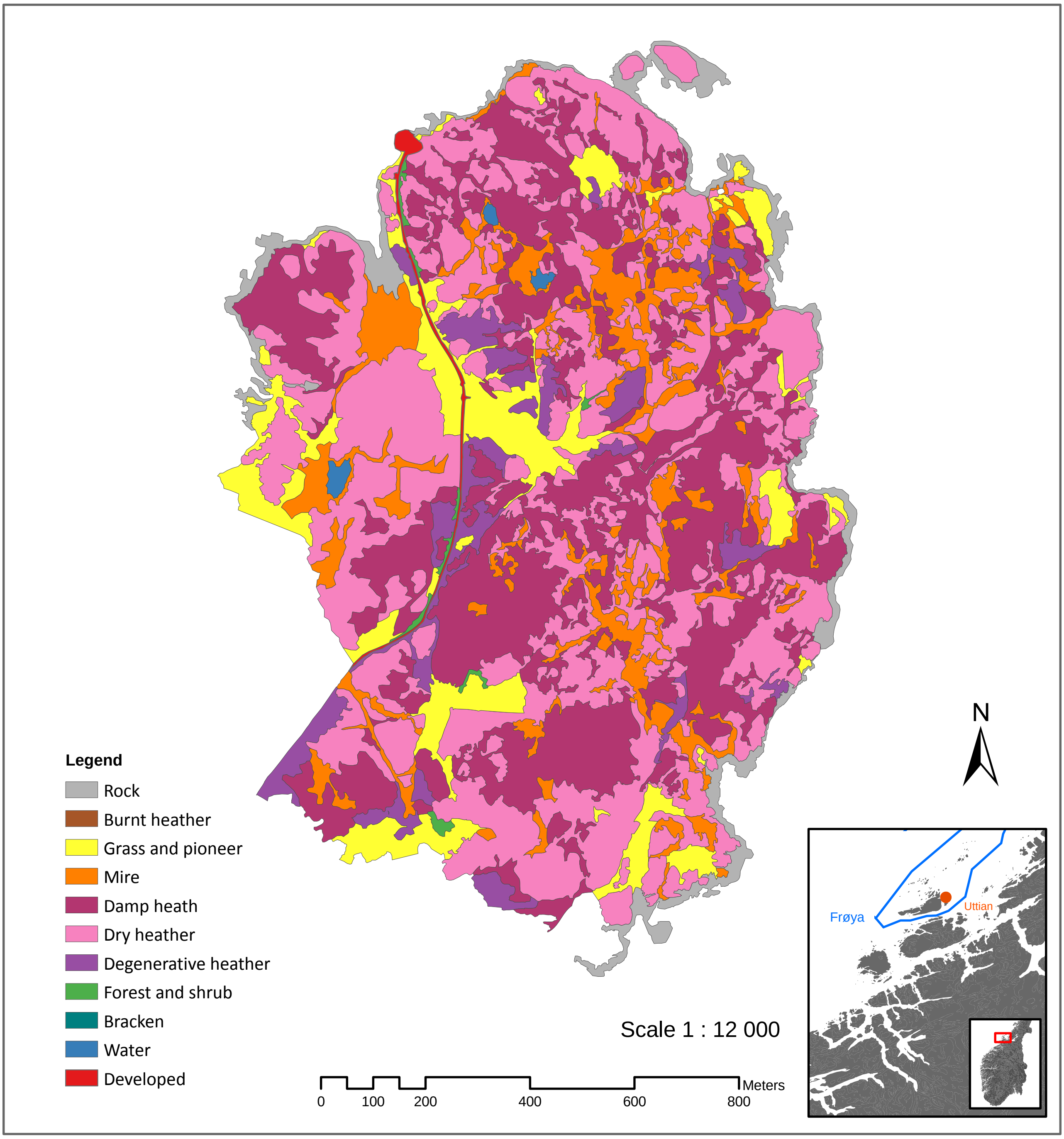


Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorities.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

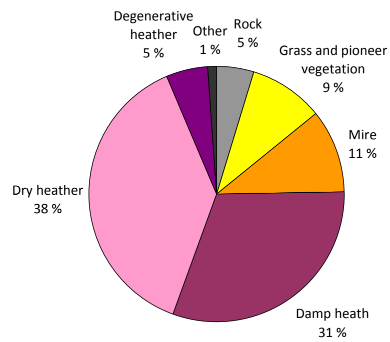
Uttian

Uttian is an island east of mainland
Frøya in Sør-Trøndelag County.



The mapped area is grazed by a herd of
the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect
fodder value particularly for this breed.

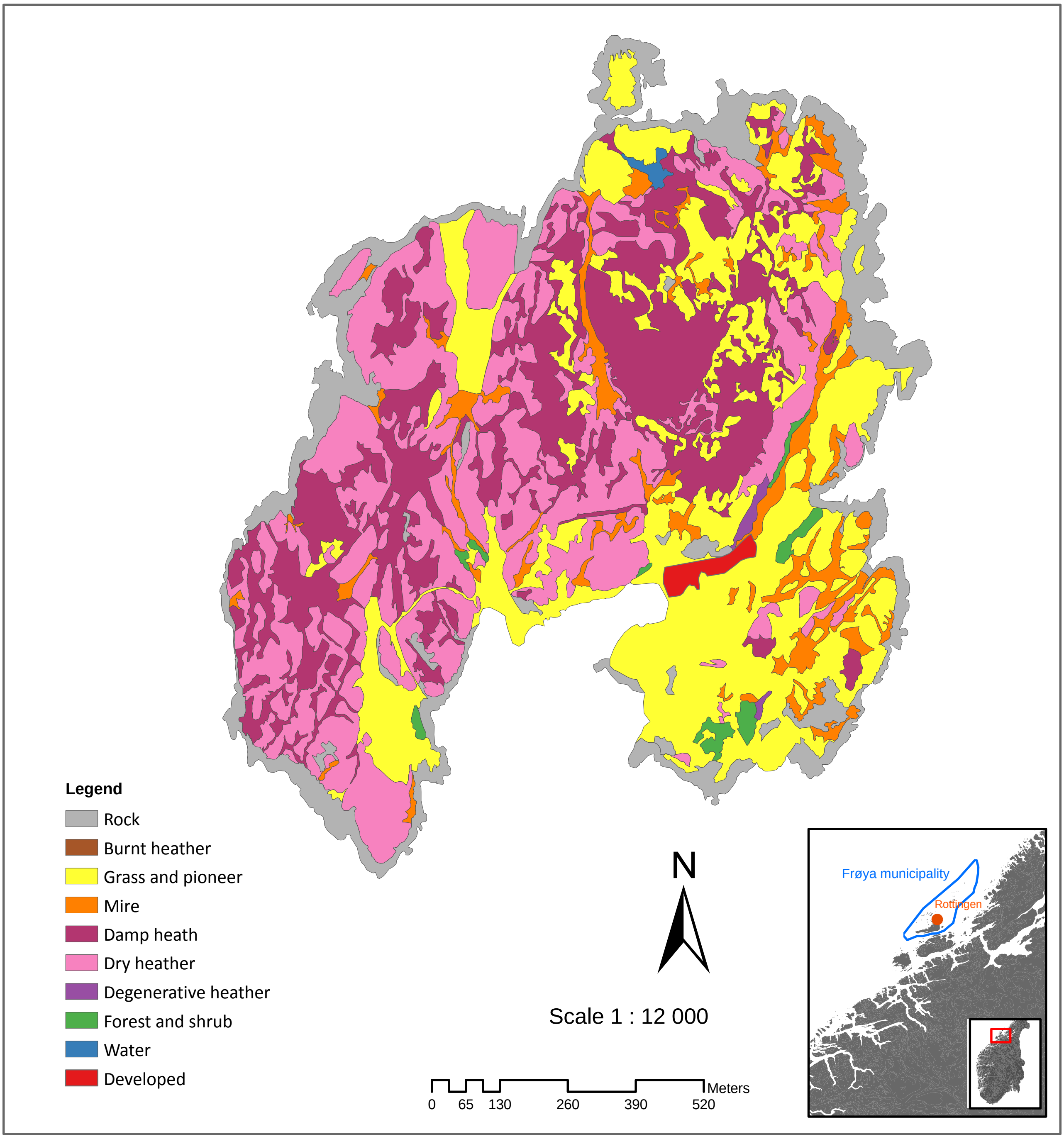


Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Vegetation maps

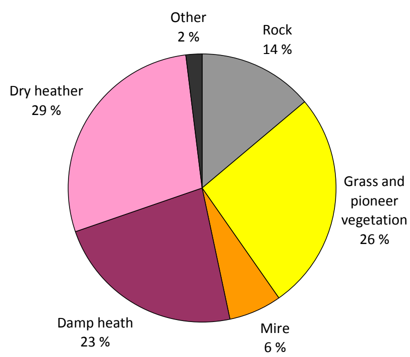
Rottingen

Rottingen is an island north of mainland Frøya in Sør-Trøndelag County.



The mapped area is grazed by a herd of the ancient Norse breed of outwintered sheep.

The map shows vegetation types that reflect fodder value particularly for this breed.



Made by Brooke Wilkerson and Eva Kittelsen.
Projection: Universal Transverse Mercator 32N, WGS84
Inset map data source: AR2000, Norwegian Map Authorieties.
Color choices based on www.ColorBrewer.org by Cynthia A. Brewer, Geography, Pennsylvania State University.

Appendix B

– Additional tables and figures

Table I. Information on the weather station used for downloading temperature and precipitation data from the meteorological institutes` database.

	Temperature data from 2007		Precipitaton data from last climatic normal period (1961-1990)		Precipitation data from 2007	
Locality	Station	Altitude	Station	Altitude	Weather station	Altitude
Horgo	Slåtterøy fyr	25	Fitjar	20	Fitjar	24
Lurekalven	Fedje fyr	19	Fedje	19	Eikanger	72
Tangane	Fedje fyr	19	Fedje	19	Eikanger	72
Hille	Takle	38	Ytre Solund	3	YtreSolund	3
Tungodden	Takle	38	Ytre Solund	3	YtreSolund	3
Hågøy	Takle	38	Værlandet	15	Værlandet	15
Jøsok	Fiskøy bygd	41	Fiskøy bygd	41	Fiskøy bygd	41
Nerlandsøy	Fiskøy bygd	41	Fiskøy bygd	41	Fiskøy bygd	41
Intian	Sula fyr	5	Hitra	23	Hitra	23
Uttian	Sula fyr	5	Hitra	23	Hitra	23
Rottingen	Sula fyr	5	Hitra	23	Hitra	23
Frøya1	Sula fyr	5	Hitra	23	Hitra	23
Frøya2	Sula fyr	5	Hitra	23	Hitra	23

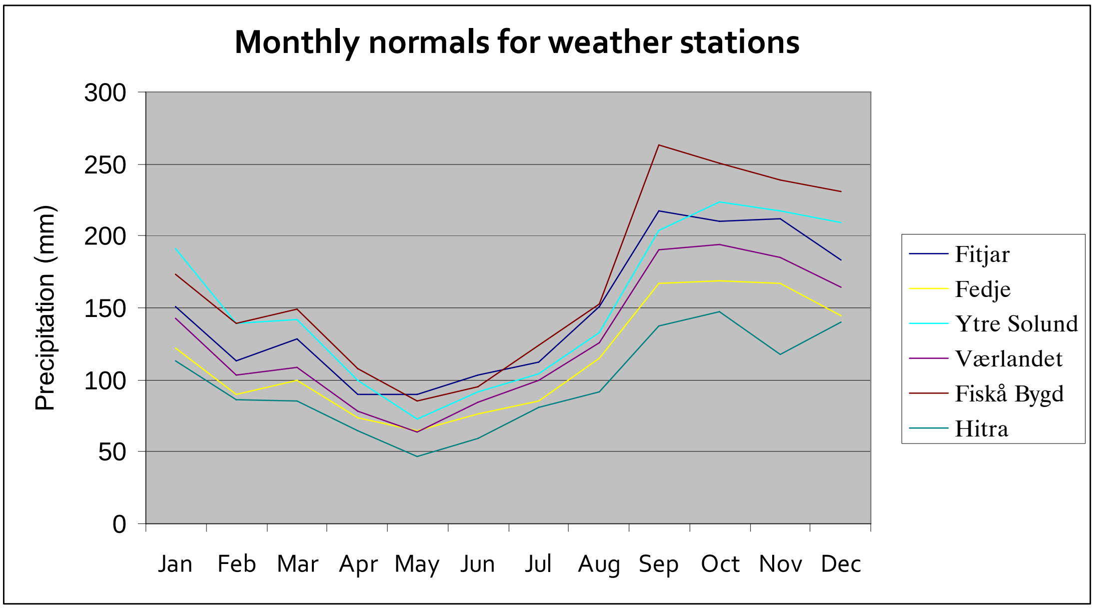


Figure I. Monthly normal precipitation values from the metereological stations used for downloading precipitation data on annual values. The data is from the last climatic normal period. Refer to Table I for a list of localities that these stations are used to compile data for.

Table II Metadata of the aerial photographs

Locality	Number of photos	Photography dates	Photography year	Cell size (cm)
Hågøy	1	09. June	2005	25
Intian	1	20. July	2006	31
Lurekalven	3	18. July	1997	31
Rottingen	1	20. July	1997	31
Frøya1	3	20. July	2006	21/41
Tangane	1	18. July	1997	31
Tungodden	2	09. June	2005	25
Uttian	2	20. July	2006	31
Frøya2	1	20. July	2006	41
Jøsok	3	01. June	2006	20

Table III. Vegetation classes used, along with the associated types in a common classifation system expected to be included in each class. The most probable types are listed first.

Vegetation class	Vegetation type as defined by Fremstad (1997)	
	Code	Name
Bare rock		Areas of bare rock (not vegetation)
	H1e	Dry heath; Calluna – *Racomitrium lanoginosum* – lichen subtype
Burnt heather		Areas of bare soil due to recent heather burning (not a vegetation type)
Grass and pioneer vegetation	G1	Damp poor grassland
	G4	*Agrostis capillaris - Festuca rubra - Anthoxantum odoratum* grassland
	G2	*Molinia caerulea* grassland
	H3g	Damp heath; *Molinia cearulea* subtype
	H2	Dry grass and herb-rich heath
	H1	Dry heath (young stages)
		Areas totally dominated by *Pteridium aquilinum* (not regarded a vegetation type)
Mire	K3	Poor lawn fen
	K4	Poor mud bottom fen
	K2	Poor hummock fen
	G1a	Damp poor grassland, *Juncus squarrosus* subtype
	J3	Ombrotrophic lawn bog
	J4	Ombrotrophic carpet/mud-bottom bog
	L3	Intermediate lawn fen
	L4	Intermediate mud bottom fen
	L2	Tall-sedge fen
Wet heather	H3	Damp heath
	K2	Poor hummock fen
Dry heather	H1	Dry heath
	H4	*Calluna vulgaris – Blechnum spicant* heath
Degenerative heather	H1	Dry heath (late stages)
	H3	Damp heath (late stages)
		Also the same classes as for Forest, but where the tree and / or scrub layer cover is low.

Forest and shrub	A6	Rock ledge woodland
	A7	Poor, grass-dominated woodland
	E1	Poor swamp woodland
	E2	Lowland *Salix* swamp
	K1	Wooded poor fen
	L1	Intermediate wooded and scrub-covered fen
	H1	Dry heath (late stages)

***Table V:** Dates of live animal weighing and slaughter on the different localities in 2007*

Locality	Spring weighing	Autumn weighing	Slaughter
Frøya1	26. June	3. October	14. October
Frøya2	25. June	3. October	NA
Hille	NA	11. October	16. October
Horgo	23. June	NA	1. October
Hågøy	7. June	16. October	17. October
Intian	28. June	5. October	7. October
Jøsok	1. June	30. September	25. / 30. October
Lurekalven	12. June	9. October	11. October
Nerlandsøy	20. June	15. September	8. / 30. October
Rottingen	30. June	6. October	9. October
Tangane	11. June	8. October	11. October
Tungodden	14. June	29. September	5. October
Uttian	29. June	30. September	1. October

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Intian	28. June	5. October	7. October
Jøsok	1. June	30. September	25. / 30. October
Lurekalven	12. June	9. October	11. October
Nerlandsøy	20. June	15. September	8. / 30. October
Rottingen	30. June	6. October	9. October
Tangane	11. June	8. October	11. October
Tungodden	14. June	29. September	5. October
Uttian	29. June	30. September	1. October

Table . *Data available for the different localities. Green indicates available data, while red indicates that the data is not available.*

Locality	Growth rate	Slaughter weights	Vegetation data	All other
Frøya	[green]	[green]	[green]	[green]
Frøya2	[green]	[red]	[green]	[green]
Hille	[red]	[green]	[red]	[green]
Horgo	[red]	[green]	[green]	[green]
Hågøy	[green]	[green]	[green]	[green]
Intian	[green]	[green]	[green]	[green]
Jøsok	[green]	[green]	[green]	[green]
Lurekalven	[green]	[green]	[green]	[green]
Nerlandsøy	[green]	[green]	[red]	[green]
Rottingen	[green]	[green]	[green]	[green]
Tangane	[green]	[green]	[green]	[green]
Tungodden	[green]	[green]	[green]	[green]
Uttian	[green]	[green]	[green]	[green]

Table VI. Growth rate and slaughter weight values

	Ewes		Rams	
	Growth rate (g/day)	Slaughter weight (Kg)	Growth rate (g/day)	Slaughter weight (Kg)
Locality	n	n	n	n
Frøya1	10	13	6	13
Frøya2	11	0	12	0
Hille	0	7	0	16
Horgo	0	2	0	10
Hågøy	13	0	17	13
Intian	14	1	14	13
Jøsok	33	0	52	10
Lurekalven	25	18	14	15
Nerlandsøy	31	16	33	25
Rottingen	13	7	12	12
Tangane	10	6	4	4
Tungodden	13	1	8	17
Uttian	20	10	18	20

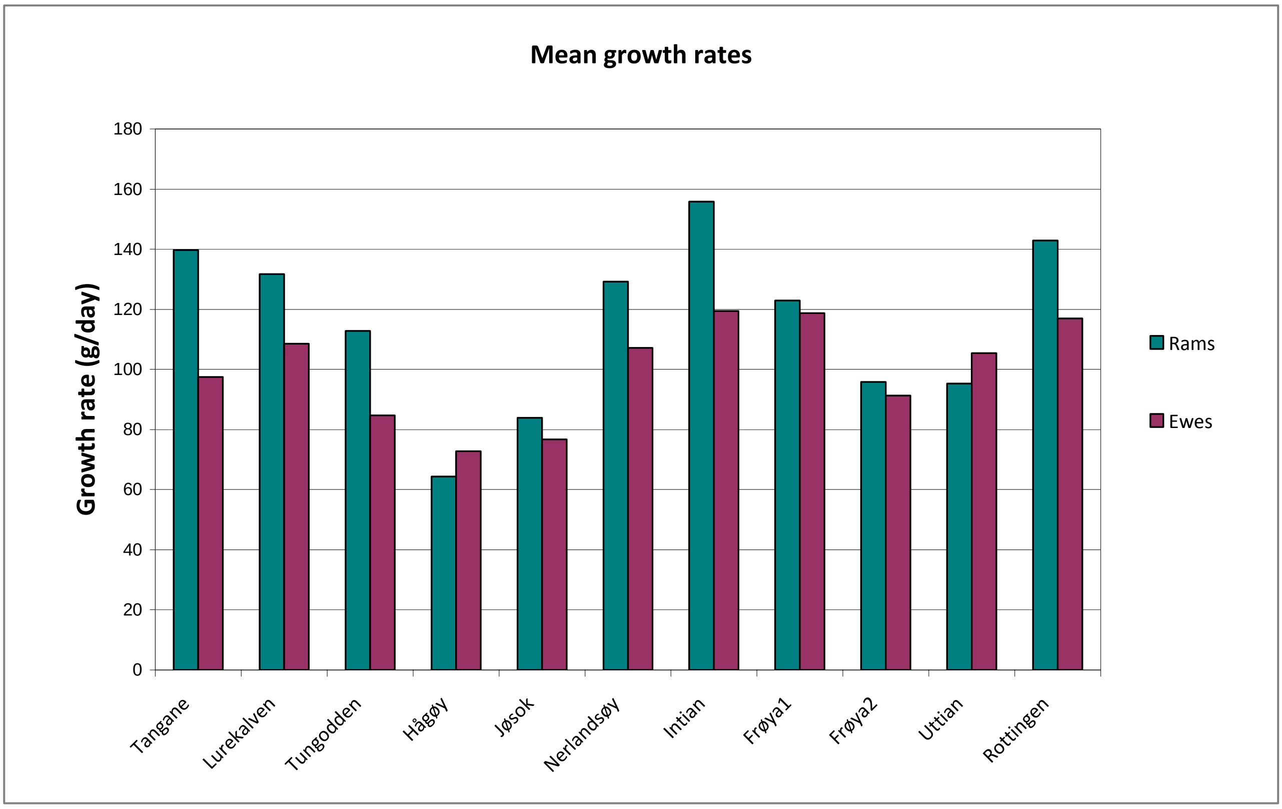

Figure II. *Mean growth rates of rams and ewes at the different localities.*

Table VII. Percent cover of the land cover classes on the study sites.

Vegetation	Tangane	Lurekalven	Tungodden	Hågøy	Jøsok	Intian	Frøya1	Frøya2	Uttian	Rottingen
Rock	3.5	5.0	50.2	41.9	0.3	11.1	32.2	43.3	4.7	13.8
Burnt heather	3.8	0.0	0.9	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Grass and pioneer vegetation	25.0	22.6	16.7	10.5	2.0	29.3	3.9	4.8	9.4	26.5
Mire	22.5	7.6	1.9	9.4	3.2	14.6	24.8	20.4	10.5	6.4
Wet heather	18.9	3.5	5.0	6.5	24.0	13.5	8.5	13.7	30.9	23.1
Dry heather	18.1	25.5	7.6	10.4	26.3	12.7	16.4	16.1	38.0	28.4
Degenerative heather	0.5	20.0	8.1	11.6	17.3	7.8	9.0	0.2	5.3	0.2
Forest and shrub	0.6	7.2	3.6	2.9	26.1	10.9	0.5	0.3	0.3	0.9
Water	0.0	3.5	5.5	0.3	0.6	0.0	4.8	0.6	0.3	0.0
Developed areas	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.5	0.5	0.6
Bracken	7.1	5.1	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0

Appendix C
– Breed terminology

The breed referred to in the current study has many names which are heavily debated, and a discussion of these is necessary. The common Norwegian name *Villsau* also refers to the product (meat) it gives, Norsk Villsau, which is a registered trademark (Norsk Villsaulag BA 2008). *Feral Sheep* is suggested as a translation of Villsau, but is not desirable, as the term *feral* may be misleading when used for a domestic animal. *Utegangar* is also commonly used in Norway, and is a describing term in that it covers the fact that the animal is outwintered as opposed to the more common breeds. It is also used in the Domestic Animal Diversity Information System hosted by the Food and Agriculture Organisation (FAO) of the United Nations (DAD-IS 2008). Norsk Sau og Geit, which are the authorities approving sheep breeds, uses the term *Gammelnorsk sau* (NSG 2008), a term also used in the Oklahoma State University database Breeds of Livestock (1999). Norsk Villsaulag BA, an organisation which seek to promote the use of the animal, as well as its product, uses the common name Villsau and the term *Gammel Norsk Sau* (Christiansen 2005), or Gammelnorsk sau (Norsk Villsaulag BA 2008). Gammelnorsk, Utegangarsau, Steinaldersau and Ursau are other names that are beeing used. Gammelnorsk can be translated to Old Norwegian in English (Mason and Porter 2002, Fjærli 2005) although the term also refers to an era and the translation does not cover this element. *Norsk* may not either be describing in this sense, since the breed probably existed before Norway became a nation in the Viking era. Utegangersau av gammel norrøn rase is also a commonly used term (Cf. Velle 2005). *Norrøn* is used about language, culture and religion in the Nordic region before the Nordic nations were established, and although the term *gammel* (old) is superfluous when *norrøn* is also used, this is the most describing name of those that are already in use. The term also covers the fact that the sheep is outwintered (utegangar, meaning *one that walks outside*).

I have therefore chosen to translate this expression using *Ancient Norse breed of outwintered sheep*.

Appendix D

- Land cover mapping

Land cover classes

The maps created were based on manual interpretation of aerial photographs. An explanation of the signature of each land cover class and the importance of separating the particular class is given in the following section. Also, each vegetation class (Water and Developed areas omitted) is compared to the standard classification system in Norway, based on Fremstad (1997) *Vegetasjonstyper i Norge*, and the classes from this system that are likely to be included in the land cover map created is mentioned.

Bare rock

Areas of *Bare rock* appeared very bright compared to all other land cover types. They appeared in belts along the shore, and in small patches elsewhere. This class was not difficult to delimit from the other classes. In the sites in Frøya municipality, there were some rocky areas covered with the moss *Racomitrium lanuginosum* and the lichen *Cladonia sp.* that were included in the rock class, as these types gave off similar signature and were not easily distinguishable in the aerial photographs (at the mapping scale used).

Bare rock is obviously not commonly classified as a vegetation type, but the *R. lanuginosum* and reindeer lichen dominated areas, which were difficult to separate from Rock areas because they often appeared intermingled, is classified as H13 Dry heath; *Calluna – Racomitrium lanoginosum* – lichen subtype.

This class represents areas that are without fodder. *R. lanuginosum* is not eaten and the merging of these types is therefore not problematic, but *Cladonia sp.* is highy edible and may represent an important winter fodder source. One of the farmers pointed *Cladonia sp.* out in a question about what the animals rely on during winter. The inclusion of *Cladonia sp.* in the class may be a source of error.

Burnt heather

Some areas in the aerial photographs had a grey to brown signature that looked non-vegetated. This is believed to be burnt heather or bare soil, based on information about heather burning from interviews.

Figure III: *Burnt heather. Photo from Tungodden, Eva Kittelsen.*

Burnt heather areas are also not commonly classified as a vegetation type. These areas have no fodder value, but are an important component to know about. They represent a spatial-temporal change of fodder value in the heather system. These areas were previously covered by degenerating stages; vegetation that represents low fodder value. They exist only in a short period of time after burning, and will be colonized by a pioneer community. They have been mapped in order to retain this important information.

The class was not found in all study sites. This is probably because not all farmers practice heather burning (consistent with results from the interviews), or did not burn the year the aerial photography from the site was taken.

Grass and pioneer vegetation

Grass dominated areas appeared green. In many sites, old houses were surrounded by grasslands. Typical places where sheep seem to spend much time are heavily grazed and fertilized by faeces and dominated by grasses (fig. IV). Smaller patches were often intermingled with bare rock, bracken and patches of heather, especially young heather, and in edges of mire. This type was merged with areas of young heather, which occurred as light brown, also intermingled with bare rock or grass. Young heather was also included in this class. Areas dominated by *Molinia caerulea* were very common in the sites at Solund municipality, and they represent a somewhat different grass system with lower fodder value than in most other study sites. However, grazed *M. cearulea* was observed as well as sheep actually grazing it (fig. IV, and it is therefore included in the Grass and pioneer vegetation class.

Figure IV: *Different types of Grass and pioneer vegetation.* ***Upper left:*** *Hågøy, heavily grazed.* ***Upper right:*** *Grassy hills of fine scale topographic variation at Rottingen.* ***Lower left:*** *ANBOS grazing* Molinia caerulea *at Tungodden.* ***Lower right:*** *Grazing ANBOS at Tangane. Photos: Eva Kittelsen.*

When placing this class among common vegetation types, several types are included. G4 *Agrostis capillaris - Festuca rubra - Anthoxantum odoratum* grassland appeared in most sites I visited, however in varying abundance. G2 *Molinia caerulea* grassland or H3g Damp heath, *Molinia cearulea* subtype, H2 Dry grass and herb-rich heath is assumed to appear in most areas, and open, green or light patches were assumed to belong to this type. Some places this type appeared in very small patches or intermingled with other vegetation types, and it has thus been subject to being excluded due to the least mapping unit (300 m^2) criteria. Young stages of heather belong to the type H1 Dry heath or to H2. To some degree, this solved the problem of excluding H2 areas, as young heather was often intermingled with this vegetation type. Areas of G1 damp poor grassland may also have been included in the Grass and pioneer vegetation class. *Molinia caerulea* dominated heaths is considered by some to be classified in the wet heath (Prøsch-Danielsen and Øvstedal 1994), which is called Damp heather type, subtype *Molinia caerulea* by Fremstad (1997), but also may be classified as a type of grassland, G2 *Molinia caerulea* grassland (Fremstad 1997).

An important feature for delimiting the class Grass and pioneer vegetation was the different dates of the aerial photos. The green-up of grasses was necessary for distinguishing the class. Low cover of grasses in the photos taken early in the season is thus a source of error in this class. Other problematic issues with the class are those related to low fodder value of G2/H3g areas.

The class Grass and pioneer vegetation is important in the ANBOS management as a source of summer fodder (i.e. Introduction part).

Mire

The texture of mires was smooth and often with drainage patterns. They were assumed to be in flat, low-lying areas and close to water bodies (inland). Mires were separated from wet heather in that they were not dominated by heather species, which are easily detectable in the aerial photographs, but by graminoids (fig. V). Mires therefore appeared yellowish to brownish (fig. VII) or green (fig. V). The colour could be confused with that of Grass and pioneer vegetation, so texture and topography was an important feature in the delineating mires from this class.

Figure V: *Graminoid mire at Tungodden. Photo: Eva Kittelsen.*

Mires in the coastal heathland section are generally poor. Both hummock, lawn and mud-bottom types were mapped as mire. Hummocks were not included in the type if they were continuous through an area and at a percent cover that qualify for a patch, but were then mapped as Wet heather.

Vegetation types that are likely to be covered in the Mire class are K3 Poor lawn fen, K4 Poor mud bottom/carpet fen (see under Grass and pioneer areas) K2 Poor hummock fen. J3 Ombrotrophic lawn bog, J4 Ombrotrophic carpet/mud-bottom bog is probably abundant, and fens from group L Intermediate fen may also be included. Wet types of G1 damp poor grassland were seen at the study sites visited in Frøya municipality, and were also included in the Mire class, as the type is usually highly dominated by *Juncus sp.* and has more similar edibility to that of mire than to that of the Grassland and pioneer vegetation type. The G1 class is closely related to Wet heather, and the character used when distinguishing these is the domination by *Calluna vulgaris*, which is easily separable in the aerial photographs.

In edges of mires, grasses are often abundant, but seldom in patches large enough to meet the mapping criteria. Therefore, narrow mires were mapped as Grass and pioneer vegetation rather than as mire if the mire structure (drainage patterns) was not very evident.

Mire is not regarded a valuable food source for sheep (Rekdal 2003), but there are edible plants growing in mires, such as *Trichophorum sp.*, and mires might thus be of importance. Also, highly edible grass species such as *Festuca rubra*, *Agrostis capillaris* and *Anthoxantum odoratum* may appear in the G1 class (Fremstad 1997), and it is likely that young individuals of the *Juncus sp.* may be eaten early in the growing season. There is, however, a great difference in the moisture of mires within the class, ranging from soft bottom mires through mats and with some hummock mire.

Dry heather

Dry heather in its mature and some in its building phase is included in this class. Dry heather had a dark brown colour and appeared rather homogenous across the area it occupied. The texture was rougher than that of young heather. Where there was variation in topography, dry heather was assumed to grow on hilltops.

The domination of *Calluna vulgaris*, growing in dense shrub layers, provided Dry heather to appear rather homogenous across the area it occupied, and the class was not difficult to distinguish. The signature was quite constant through these areas. Hilltops were often covered with this type, as is consistent with common understanding of heather dynamics and physiognomy. In some areas a more greenish colour was seen. My interpretation of this signature is that it could be co-dominants in the dry heather system, which appear in areas where *C. vulgaris* grow in lower forms and do not cover them. A co-dominant which is common in the dry heather type is *Arctostaphylos uva-ursi* (Fremstad 1997).

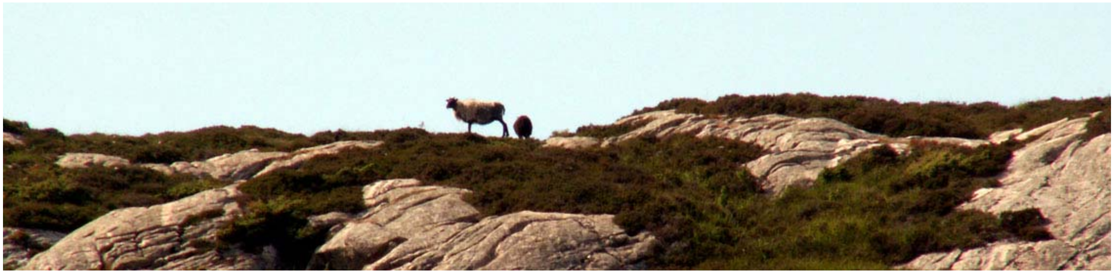

Figure VI: *ANBOS in a Dry heather patch at Horgo. Photo: Eva Kittelsen.*

This green signature can also be species that indicate slightly more humid conditions, such as *Vaccinium myrtillus*, perhaps as a transition from H1 to H4 type, where *Blechnum spicant* and other ferns are also common, and *Juniperus communis* might also be evident. *J. communis* representing a degenerative phase, but growing in low forms in these areas might lead to misinterpretation of this type as Dry heather when it should have been mapped as Degenerative heather. However, *J. communis* is assumed to be largely evident in the aerial photos, as the structure of a degenerative type was usually rougher.

The class Dry heather usually belongs to H1 Dry heath, H1a *C. vulgaris* subtype.

The class is important in the ANBOS management because dry heather is a source of winter fodder (i.e. Introduction part).

Damp heath

Damp heath or wet heather in its mature and some in its building phase is included in this class. Damp heath was less homogenous than dry heather, but gave off the same signature, a dark brown colour. It was assumed to appear in flatter areas than dry heather, and close to or building up from mires (fig._). Hummocks in mires were also assigned to this class if they appeared in a pattern that met the mapping unit criteria (>50% cover in a continuous patch ≥ 300 m^2).

The type was generally not difficult to distinguish, although in some study sites it was similar to Dry heather. Damp heath may be an intermediate stage between Dry heather and Mire, and had to be divided between these when it did not meet the mapping criteria as a single patch.

Figure VII: *Mire with a patch of Damp heath. Photo: Eva Kittelsen*

The class Damp heath was believed to consist mainly of class H3 Damp heath. Mire hummocks may also be included in this class when these were dominating the mire in an area that qualified for a patch in the mapping process.

Damp heath is not believed to be as important as Dry heather to ANBOS. Thus it is important to separate the two classes. *Molinia caerulae*, belonging to the subtype H3g (see also discussion under Grass and pioneer vegetation) was probably also included in the Damp heath class. Grazed *M. caerulae* was observed, and might thus be of importance.

Degenerative heather

Degenerative heather was delimited based on areas of heather with single trees or shrubs such as *Juniperus communis*. These were seen as bumpy dots in the images, often with a shadow. The colour was always green, but could range from light to dark. In a late succession stage, dry heather may first be invaded by *P. aquilinum* or *J. communis*, while wet heather rather will be invaded by *Myrica gale* or *Salix aurita* (Fremstad 1997). Both may be invaded by tree species in later stages. When

Figure VIII: *Degenerative heather with* Juniperus communis*. Photo: Eva Kittelsen.*

these areas appeared in patches large enough to meet the mapping criteria, they were mapped as Forest and shrub.

The commonly recognized vegetation classes that this class includes are late stages of and H1 Dry heath and H3 Damp heath. Also, the same classes as for Forest was mapped in this class, but where the tree and / or scrub layer cover is low and only single trees or shrubs occur.

Degenerative heather is an important category to distinguish as it has low or no fodder value.

Forest and shrub

Where single trees appeared in assemblages or dominating an area that qualified for a patch, the patch was assigned to the Forest and shrub class. Forest and shrub appeared bright to dark green, often with different shades of green intermingled, which were probably different tree species. Different tree and shrub species was mapped in one class, as the reliability when it comes to distinguishing them was low, and each species did probably (normally) not occur in patches large enough to meet the mapping criteria.

Figure IX: *The edge of a lee forest at Rottingen. Photo: Eva Kittelsen.*

Forests function as shelter for the animals. Some species are also eaten. Forests are a source of seeds, and spread easily in the coastal heathlands, especially when grazing pressure is low.

Broad-leaved and coniferous trees and shrubs often appeared intermingled, and did seldom on their own qualify for being a patch (i.e. least mapping area 300m^2). There were also difficulties in distinguishing different species and growth forms of shrubs and trees. Different tree types were mapped in the same unit, and the class *Forest* thus consists of both broad-leaved forest including small and/or young trees and bushes as well as coniferous trees. Since broad-leaved trees, especially young trees such as *Sorbus aucuparia* and small trees or shrubs such as *Salix* *aurita* are being browsed by ANBOS while coniferous trees and shrubs, being mostly *Picea abies*, *Pinus* sylvestris and *Juniperus communis*, have low or no fodder value, it would have been preferable to have these as a single mapping unit. In this sense, the final analysis is not reliable when it comes to forest and fodder value, but as shelter, age indicator and source of seeds, it is valuable.

Leaves are an important feature in distinguishing deciduous trees, and early photo date may have lead to a lower proportion of this class.

Forest is important as shelter, and some species are browsed.

Bracken

Pteridium aquilinum is bracken species that can dominate pastures in quite large areas, and are considered a pest. *P. aquilinum* was not present in all study sites. This information was confirmed by the interviews. *P. aquilinum* appeared bright green in the aerial photographs, but was difficult to separate from grassland, shrubs (especially *Salix sp.*) and low deciduous forest, especially without fieldwork. Bracken is commonly not regarded as a vegetation class, but represents an intruding element in other vegetation types, mainly in dry areas, and in the coastal heathland systems they often appear in cleared areas or invading grass vegetation.

Bracken is desirable to separate as a class because it is potentially important in the ANBOS feeding grounds, as it takes over areas of nutritious grasslands and makes them unavailable, being inedible to ANBOS.

Appendix E

- Map accuracy

Table VIII. Differences in interpretations of aerial photographs and field surveys

Aerial photograph	Field survey	Quantile
Dry heather	Burnt heather	3^{rd}
Grass and pioneer vegetation	Damp heath	1^{st}
Grass and pioneer vegetation	Dry heather	3^{rd}
Forest and shrub	Degenerative heather	3^{rd}
Forest and shrub	Bracken	4^{th}

Total map accuracy was 86.

Errors may be related to temporal land cover changes since the photograph was taken. Because coastal heathlands are temporally variable systems, this error type may be relevant, especially for the classes Burnt heather, Grass and pioneer vegetation and, to some extent, Degenerative heather and Dry heather.

Interpretation errors are also probable errors encountered in the current study. Inter-operator errors are errors introduced by different interpretations of photographs or sites by the same mapper. Different seasons and years, as well as different weather and light conditions may affect comparability of aerial photographs. The misinterpretation of burnt heather as dry heather is probably due to burning after the aerial photograph was taken. Intra-operator errors are errors introduced by different interpretation of features by different mappers, and may be relevant in this study, where mapping has been performed by two people.

Errors related to the diffuseness of borders between vegetation patches is a type of error which is likely to be different between classes. Rock and Water border edges are crisp, while, for example, Degenerative heather tends to be very diffuse. Such errors are difficult to avoid as the diffuseness exists in real life, though I have tried to avoid such errors by selecting field validation points as far from borders as possible (minimum six meters). An alternative classification method to the crisp classes used in this study is fuzzy classification, where classes are allowed to overlap or may be hierarchic. This type of classification scheme is useful in several settings, but not for the current study, where classification was done to extract values that were to be compared to each other. Differences in the interpretation of these borders (an inter-operator error) may be more interesting, but has not been investigated.

The last type of error that may be encountered is related to location mismatches. The highly accurate results of the crisp, temporally constant and unambiguous classes Water and Rock indicates that such error, for example through non-accurate GPS or aerial photograph geographical locations, do probably not explain the misinterpreted results of the classes that were not in accordance with the field survey results.

Vegetation interpreted as the class grass and pioneer vegetation in the photographs, but defined as dry to wet heather in the field surveys can be explained by a large proportion of *Molinia caerulea* as a co-dominant in the heather system, since much *M. caerulea* litter was seen. This gives a signature in the aerial photograph which can easily be confused with *M. caerulea* grassland. The site could probably be included in the class H3g Damp heath, *Molinia caerulea* subtype in Fremstad (1997). *M. cearulea* heaths are controversial and difficult to classify. They are ecologically variable, especially along gradients of moisture and cultural influence (Fremstad 1997), but are classified as wet heath by Prøsch-Danielsen and Øvstedal (1994).

A similar case is found in the site where grass and pioneer vegetation was expected from the aerial photography classification, but where dry heather found to be dominating after the field survey, with some occurrences of *J. communis* and some patches of *M. caerulea*. This system was drier than the previously discussed patch, but still with much *M. caerulea*. This, together with *J. communis,* can have overruled the signature of the dry heather and led to the interpretation as an H2 *M. caerulea* grassland class, hence belonging to the Grass and pioneer vegetation class in the mapping. Difficulties distinguishing grassland from other open areas were also encountered by Fjellstad (2004).

The site initially classified as Forest and shrub, but after the field survey described as Degenerative heather, was located on a slope, and demonstrates the difficulty of interpreting 3D features in a 2D environment. The misinterpretation could be caused by the contracting of the topographic structures, resulting in the highest structures being displayed in the photograph. The polygon had a greenish colour which correctly was interpreted as *J. communis*, but although it was dominating in the polygon on the aerial photograph, the species did not actually dominate the slope. I also realize that the interpretation of this polygon as Forest and shrub could be incorrect, as the texture was not very coarse.

Before the validation field work was performed, I did not separate Bracken as a class, assuming that *P. aquilinum* was not visible in photographs taken as early as 9th June. However, map validation showed that this was wrong, as a large area of *P. aquilinum* was found at one validation point classified as shrub. Maps have therefore been reclassified after the field validation, before the weight analyses. Hence, the class Bracken was included in the maps only after the map accuracy field work, and is not validated.

Even though the accuracy of the class Damp heath was 100%, I was in several of the points unsure whether I should call the vegetation seen in the field wet or dry heather, but I decided to assign wet heather in all cases considering the concave topography, soil thickness and moisture. Mainly, it was the large quantiles that were misinterpreted, which may be related to high internal patch variability of large patches, but due to few sampling points this cannot be generalized over.

Map accuracy was only estimated at one study site. Since the aerial photographs and the study sites are so different, it cannot be assumed that the result is applicable to all study sites. However, interviews correctly confirmed the presence and absence of burnt areas and bracken dominated areas as interpreted from aerial photographs in all study sites, indicating that at least these signatures may be comparable among several study sites.

I have been more certain about the decisions made in the mapping process for the sites where I have had field investigations, and conclude that more fieldwork would probably have increased mapping accuracy. A contrasting interpretation was done in a study of aerial photography interpretation, where Strand et al. (2002) found that neither field experience or field training sites before mapping affected vegetation mapping accuracy. However, the mappers in this study felt that field work was clarifying their interpretations.

Appendix F

- Detailed data sources

Table IX. Data sources

Owner	Provider	Date	Recieved via	Content	Format	Location	File or folder name (as recieved)
Norges Geologiske Undersøkelse	Norges Geologiske Undersøkelse	14-aug-07	Free download (WMS, http://www.ngu.no/)	Bedrock	Shapefile	Austevoll, Bømlo, Rennesøy	berggrunn_n250_1_arcims14527482.zip
Norges Geologiske Undersøkelse	Norges Geologiske Undersøkelse	14-aug-07	Free download (WMS, http://www.ngu.no/)	Bedrock	Shapefile	Frøya, Hitra	berggrunn_n250_1_arcims14527484.zip
Norges Geologiske Undersøkelse	Norges Geologiske Undersøkelse	14-aug-07	Free download (WMS, http://www.ngu.no/)	Bedrock	Shapefile	Sande, Herøy	berggrunn_n250_1_arcims223524881.zip

Norges Geologiske Undersøkelse	Norges Geologiske Undersøkelse	14-aug-07	Free download (WMS, http://www.ngu.no/)	Bedrock	Shapefile	Solund, Gulen, Lindås	berggrunn_n250_1_arcims14527483.zip
Statens Kartverk	Norsk Institutt for Skog og Landskap	03-aug-07	Free download (WMS/database, http://kart4.skogoglandskap.no/uttak /Arealis_Markslag_Bonitet/e95984.zip)	Landmass	Shapefile	Norway	e95984.zip
Norges Vassdrags- og Energidirektorat	Norges Vassdrags- og Energidirektorat	20-jun-07	E-mailed from provider after agreement	Discharge	Shapefile	Western Norway	arsavrpunkt6190.shp
Norges Vassdrags- og Energidirektorat	Norges Vassdrags- og Energidirektorat	20-jun-07	E-mailed from provider after agreement	Discharge	Shapefile	Western Norway	arsavrpkt6190.shp
Norges Vassdrags- og Energidirektorat	Norges Vassdrags- og Energidirektorat	20-jun-07	E-mailed from provider after agreement	Discharge	Shapefile	Western Norway	arsavrlinj30-60.shp
Norges Vassdrags- og Energidirektorat	Norges Vassdrags- og Energidirektorat	20-jun-07	E-mailed from provider after agreement	Discharge	Shapefile	Western Norway	arsavrpkt30-60.shp
University of Bergen	University of Bergen	01-jun-07	Institute of biology	Aerial photographs	Analog photographs	Lindås municipality	-
Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Austevoll municipality	N50
Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Lindås municipality	N50

Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Gulen municipality	N50
Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Solund municipality	N50
Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Herøy municipality	N50
Statens Kartverk	Norge Digitalt	21-aug-07	Students`contact person at UiB	N50 Kartdata	Shapefile	Frøya municipality	N50
Statens Kartverk	Norge Digitalt	28-apr-08	Iinstitute of Geography, University of Bergen	Digital ElevationModel	DEM	Western Norway	6602_25m_32.dem
Statens Kartverk	Norge Digitalt	28-apr-08	Iinstitute of Geography, University of Bergen	Digital Elevation Model	DEM	Western Norway	6702_25m_32.dem
Statens Kartverk	Norge Digitalt	28-apr-08	Iinstitute of Geography, University of Bergen	Digital Elevation Models	DEM	Western Norway	6803_25m_32.dem
Statens Kartverk	Norge Digitalt	28-apr-08	Iinstitute of Geography, University of Bergen	Digital Elevation Models	DEM	Møre	6903_25m_32.dem
Statens Kartverk	Norge Digitalt	28-apr-08	Iinstitute of Geography, University of Bergen	Digital Elevation Models	DEM	Trøndelag	7004_25m_32.dem
Norge i Bilder	Norge Digitalt	13-feb-08	Institute of Geography, University of Bergen	Orthophotos	TIFF	Solund	Eksport 9194 "Bestilling110208", dekning nr. 05020

Norge i Bilder	Norge Digitalt	24-feb-08	Institute of Geography, University of Bergen	Orthophotos	TIFF	Sunnmøre	Eksport 9274 "Sunnmøre", dekning 13306
Terratec	Terratec		CD in mail	Aerial photographs	TIFF	Frøya municipality	Dekning 13304

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