Range Characteristics and Productivity Determinants for Reindeer Husbandry in Sweden

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Över vinterns skarbundna snövidder komma vårvindar och dagsmeja. Då gäller det för renskötaren att hålla djuren samlade i lagom stora skockar och att hitta backar med gott bete och lös snö

(Excerpt from Same Sita - Lappbyn)

Cover illustration: Drawing by Nils Nilsson Skum, in "Same Sita - Lappbyn" by Ernst Manker, Bokförlags Aktiebolaget Thule, Stockholm 1938

Photo: Nordiska museet.

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Abstract

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Factors expected to affect reindeer productivity, and their spatial and temporal variation within the reindeer husbandry area in Sweden, were examined through multivariate statistical analyses. Data for the studies were extracted from different mapped databases and statistics from the herding districts. Initially 37 variables presumed to affect reindeer productivity were derived, quantifying variation in topography, climate, snow conditions, insect harassment, vegetation, forage abundance and qualities, and fragmentation of the ranges. A method was proposed, termed 'reachability', to quantify in cost-benefit terms the available grazing resources in relation to infrastructural fragmentation. The range-related variables were mapped for the entire reindeer husbandry area on a raster scale of 100 km^2. The 37 variables were reduced to 15 using stepwise principal component analyses. These were thereafter used for characterisation of the reindeer herding ranges and for zonation of the Swedish reindeer herding area into seven zones. Furthermore, the 51 reindeer herding districts were divided into 10 groups with the help of cluster analyses. The remaining 15 variables were also related to productivity on the herding-district level with the help of canonical correlation analyses and structural equation modelling, in order to identify the important productivity determining factors, both in spatial and temporal scales.

Larger variation in productivity was found between herding districts than between years. Different variables were found important for the between-district and within-district productivity variations, where season lengths and animal densities were significant at both scales. Other important factors were terrain ruggedness, insect harassment, calf slaughter and animal condition previous year. Snow conditions, disturbances and forage quality were not found to have large impact on productivity on this scale. These factors, however, may have been counteracted by husbandry measures and were therefore not easily detectable in relation to slaughter statistics. The most important environmental factors affecting reindeer productivity were used to suggest an ultimate grouping of herding districts into seven administrative groups for administrative planning and management purposes.

Keywords: Rangifer t. tarandus, multivariate analyses, PCA, CCA, SEM, fragmentation, reachability, density dependence, climate, forage, ruggedness, insect harassment, animal condition, ice-crust formation

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Från naturen...

...till naturen

Contents

Supplements

Publications I–IV

My thesis is based upon the following papers, which I refer to by their Roman numerals.

I.
Lundqvist, H. 2007. Ecological cost-benefit modelling of herbivore habitat quality degradation due to range fragmentation – *Transaction in GIS 11(5)*: 743-761.

II.
Lundqvist, H., Norell, L. & Danell, Ö. 2007. Multivariate characterisation of environmental conditions for reindeer husbandry in Sweden – *Rangifer 27 (1)*: 3-21.

III.
Lundqvist, H. & Danell, Ö. 2007. Multivariate clustering of reindeer herding districts in Sweden according to range prerequisites for reindeer husbandry – *Rangifer 27 (2)*: xx-xx. (in press)

IV.
Lundqvist, H., Norell, L. & Danell, Ö. 2007. Relationships between biotic and abiotic range characteristics and productivity of reindeer husbandry in Sweden (manuscript)

Introduction

There are few investigations that identify and examine potential factors that affect productivity of a grazing herbivore on a large scale and with a multivariate approach. To understand the determining factors for reindeer ecology and productivity, *i.e.* the possibilities as well as the constraints and vulnerabilities, investigations with such an approach are essential. A clearer, more lucid understanding of the Swedish reindeer herding area needs to be characterized based on these determining factors. A zonation of the area would be valuable, especially to be able to make relevant comparisons between reindeer herding districts and suggest proper means for improvement of resource utilization and productivity.

The spatial and temporal variation of factors expected to affect reindeer productivity were initially examined on a fine scale through multivariate statistical analyses. The multivariate approach of investigating the variation in many small observation areas was the basis for variable reduction and a zonation of the entire reindeer herding area in Sweden. Subsequently, the analyses assessed the variation of these factors on the reindeer herding-district scale, and were the basis for a suggested grouping of similar herding districts. The factors were ultimately related with productivity figures on a herding-district level, in order to identify the determining factors for reindeer productivity both in spatial and temporal scales. A division of the Swedish reindeer herding districts based on the most relevant environmental variables affecting reindeer productivity was finally suggested, similar to productivity zones in agriculture, horticulture and forestry. Such division of reindeer herding districts is suggested to be useful in administrative planning and management of the reindeer herding industry.

Objectives of the thesis

The main objective of the thesis was to characterize the reindeer husbandry area, focusing on factors suggested to affect reindeer ecology, and evaluate these factors on their importance for reindeer productivity. These factors were quantified in pseudo-permanent variables, such as topography and range extensions, long-term changing variables such as climate, vegetation, infrastructure and fragmentation levels, and short-term changing variables such as weather events, snow conditions, insect harassment and slaughter strategies.

The main objective can be further subdivided as follows:

(1) To develop a methodology for evaluating range quality that simultaneously takes forage quality classes, landscape fragmentation and landscape edge effects into account.

(2) To characterize and zonate the Swedish reindeer herding area based on environmental factors suggested to affect reindeer ecology.

(3) To estimate the effect of environmental factors on reindeer productivity, both on a spatial and on a temporal scale.

(4) To classify the reindeer herding districts and suggest a division of herding districts based on their similarities and differences in the most relevant determining factors for reindeer productivity.

Background

Reindeer ecology

Reindeer (*Rangifer tarandus*) is a highly migratory species that inhabits the Arctic and sub-Arctic of the northern hemisphere. To survive the harsh conditions that characterize this area, reindeer have adapted to low temperatures, short growing seasons and deep snow. *Rangifer* has evolved into several sub-species that inhabit different parts of the area (Flagstad & Roed, 2003). Some subspecies migrate between summer and winter ranges, such as the Eurasian tundra reindeer (*R. t. tarandus*), Canadian barrenground caribou (*R. t. groenlandicus*) and Alaskan caribou (*R. t. grantii*), while the reindeer on Svalbard (*R. t. platyrhynchus*), for example, are more stationary and live on tundra all year round. The Peary caribou (*R. t. pearyi*) is adapted to and lives in high arctic areas on the islands of northern Canada where it can migrate between islands on the sea ice. Other subspecies, such as the Eurasian forest reindeer (*R. t. fennicus*) and the North American woodland caribou (*R. t. caribou*) (Flagstad & Roed, 2003), have adapted to be able to inhabit forest areas.

The reindeer's nutritional requirements are adapted to the arctic climate and environment, where the variation of forage, both availability and digestibility, follows the changing seasons. In summer, with plenty of green forage, the reindeer accumulate body storages of protein and fat (*e.g.* Eilertsen *et al.*, 2001). This weight gain is later lost during winter and spring when forage is scarce, but not necessarily due to starvation (*e.g.* Leader-Williams, 1988; Reimers, 1983).

A generalized overview of the reindeer system is shown in Figure 1. The reindeer can be regarded as a refiner of pastures into fat and protein, hides, antlers and milk, or actually ultimately to human livelihood when herded or hunted. The pasture and forage are the primary resources on which the reindeer are dependent, and therefore all factors that affect the reindeer directly or forage indirectly affect the productivity of reindeer. Such factors are climate and weather (*e.g.* Lenart *et al.*, 2002; Pettorelli *et al.*, 2005; Raven, Evert & Eichhorn, 1998; Solberg *et al.*, 2001; Weladji & Holand, 2003; Weladji & Holand, 2006), topography and soil characteristics (*e.g.* Mysterud *et al.*, 2001; Mårell & Edenius, 2006; Raven, Evert & Eichhorn, 1998), forage quality and availability (*e.g.* Lenart*, et al.*, 2002; van Soest, 1994), reindeer and large carnivore density and distribution (*e.g.* Nieminen & Leppäluoto, 1988; Nybakk, Kjelvik & Kvam, 1999; Pedersen *et al.*, 1999; Skogland, 1989; Sunde *et al.*, 2000), seasonal distribution of grazing lands and reindeer densities (*e.g.* Kojola & Helle, 1993a; Skogland, 1985; Solberg*, et al.*, 2001), and geographical allocation of competing industries, human urbanisation and infrastructure (*e.g.* Dyer *et al.*, 2001; Reimers, 2001; Vistnes *et al.*, 2001; Wolfe, Griffith & Gray Wolfe, 2000).

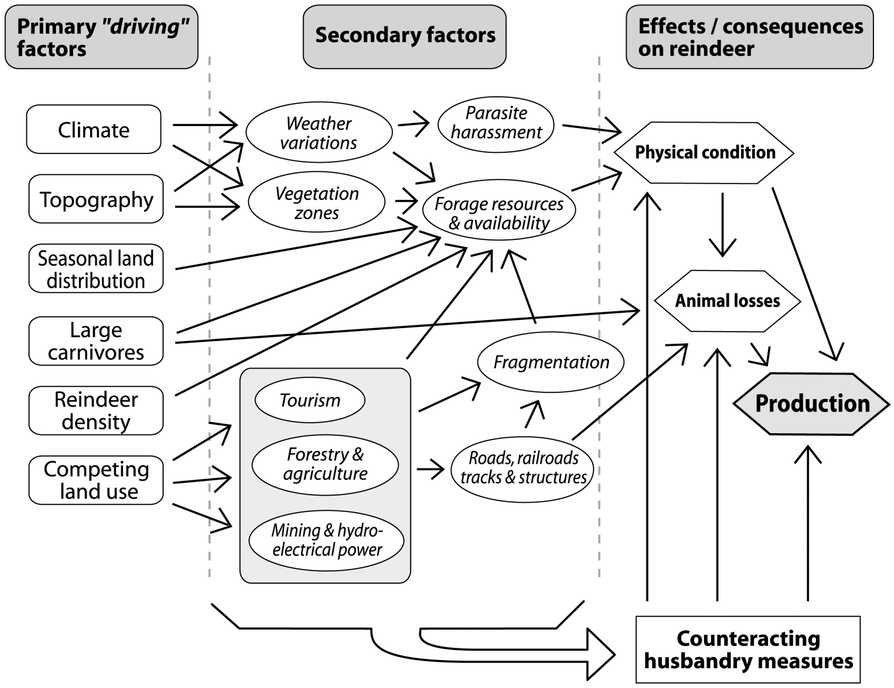

Figure 1. A generalized flow chart of factors affecting reindeer condition, animal losses and subsequently productivity. The factors and interactions are divided into primary driving factors, and secondary factors and their consequences on reindeer. The reindeer husbandry tries to mitigate limiting factors and optimise the use of existing resources.

Some factors, such as parasites, large carnivores and disturbances, affect the reindeer's moving patterns and consequently their ability to achieve the valuable forage by reducing the time spent feeding or locking reindeer out of grazing areas (*e.g.* Colman *et al.*, 2000; Nellemann *et al.*, 2001; Vistnes *et al.*, 2002). Hence, one can conclude that the amount and quality of available forage and grazing time are the major factors for production, and all circumstances affecting these major factors are relevant.

Reindeer husbandry, density and economy

Reindeer industry produces a marginal amount of the total meat production in Sweden (Statistics Sweden, 1999). Regionally, and especially for the Sami, this production is however an important economic resource. Reindeer husbandry is also important for the Sami culture and society by means of non-marketable values and preserved traditions, as well as, for conserving the Sami language.

Main strategies in harvesting are the traditional strategy of building a considerable part of the production on slaughter of adult males in September before they come into rut, and the strategy of maximising calf slaughter in late autumn. In both strategies, culling of old females makes up a noteworthy part of the production.

As long as there have been records, the total reindeer population size in Sweden has regularly fluctuated around 225,000 ± 50,000 animals in winter stock (SJV, 2005b; Statistics Sweden, 1999). The annual harvest has varied between 30,000 and 90,000 animals and calf slaughter has increased steadily during the last 30 years (SJV, 2005a; SJV, 2005b; Statistics Sweden, 1999). The county administrative boards decide the maximum number of reindeer allowed in each herding district. The decisions are today based upon historical data and routine.

Theoretically, there is an upper limit in animal number, which the grazing land can bear without being deteriorated. This level, *i.e.* the ecological carrying capacity, is far from desirable in reindeer husbandry, since the net production would be marginal. The husbandry therefore aims to keep the herd significantly below this level, in a state of rapid growth where the surplus is harvested and the grazing resources are kept highly productive (Danell & Gaare, 1999). Through the harvest the number of reindeer is down-regulated and fluctuates less than a wild reindeer population might do under similar ecological conditions (Mallory & Hillis, 1998; Statistics Sweden, 1999). Through slaughter the herd demography can also be regulated to achieve a higher herd growth rate, *i.e.* a more productive herd (*e.g.* Lenvik, 1990).

With an increased animal density, the animal condition and the meat produced per animal decreases, due to *e.g.* lower fat reserves, decreased fecundity and endurance against parasites, as well as higher mortality (*e.g.* Helle & Kojola, 1993; Kojola & Helle, 1993b; Skogland, 1986). Therefore, the optimum density in meat production terms (Figure 2a) is well below the ecological carrying capacity. The running cost of high animal densities increases due to more herding and handling, parasite treatments and smaller buffers before emergency feeding must be commenced at extreme weather events. Thus, the net profit has its maximum at lower animal densities than the gross income (Figure 2b) (Danell & Gaare, 1999).

According to Statistics Sweden (1999), the normal productivity level has been 7–8 kg per animal in winter stock under conditions where adult females weigh around 70 kg in the autumn. The harvest comprises around 40% calves and 25–35% adults of each sex. Productivity has been both higher and lower during periods when animal numbers have been reduced, both intentionally and due to adverse conditions. Danell and Gaare (1999) reported that available empirical results indicate that the "normal" abundance in Fennoscandia of 1.4–1.8 reindeer per square km (including all season's ranges) corresponds to autumn weights around 70 kg on average for female reindeer.

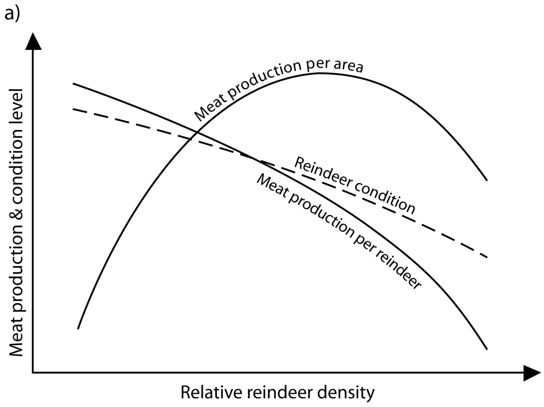

*Figure 2*a) Reindeer condition and meat production per animal and area in relation to reindeer density (Danell & Gaare, 1999).

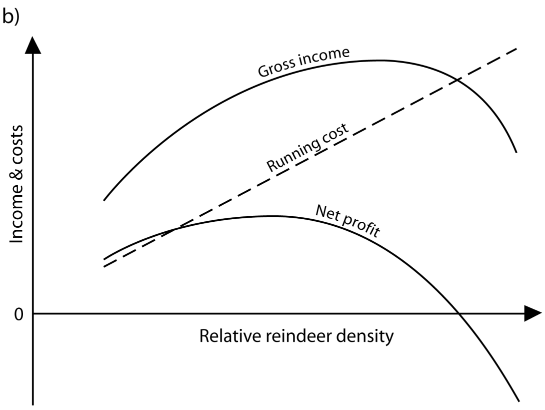

Figure 2b) Running costs, and gross and net income in relation to reindeer density (Danell & Gaare, 1999).

Reindeer husbandry in Sweden

The total Swedish reindeer herding area (Figure 3) covers approximately half of Sweden's land area, *e.g.* 200,000 km^2. The total area is divided into winter and all-year grazing areas. Summer ranges of the mountain herding districts are usually in the western alpine areas on land categorized as year-round ranges by the state, and winter ranges are generally in the eastern part of the herding area towards the Gulf of Bothnia (County Administration Boards, 2000). The reindeer are allowed to be on the winter ranges between the 1st of October until the 30th of April, as stated in the Reindeer Herding Act (Swedish Code of Statutes (SFS), 1971).

There are 51 reindeer herding districts in Sweden, which utilize the grazing resources on a common property basis. The herding districts are divided into mountain, forest and concession herding districts. Generally the mountain herding districts are found all along the mountain range of the Scandes Mountain Range, the forest herding districts in the central north and the concession herding districts in the northeast. Furthermore, the access to grazing lands has decreased significantly during the 20th century, due to a gradual increase of competition with other land use and closure of the Swedish-Norwegian border for reindeer migration (Svensk-Norska Renbeteskommissionen, 2001). In addition to this, increasing conflicts with landowners due to the lack of legally defined extents of the grazing rights have occurred (Danell, 2000).

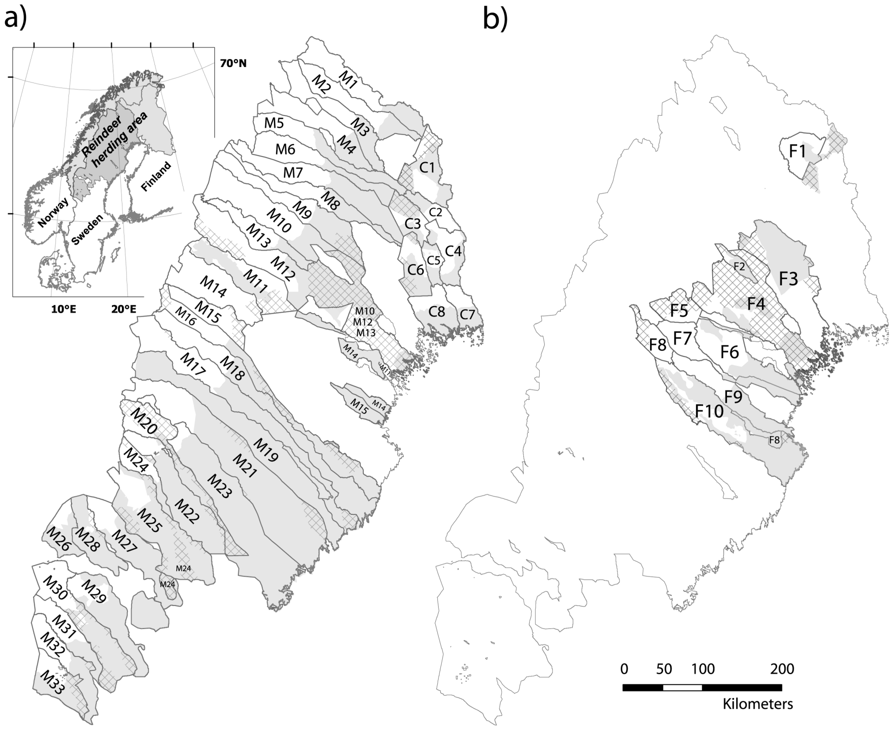

Figure 3. The Fennoscandian reindeer herding area (shaded area in the small map) and the 51 reindeer herding districts in Sweden. The concession reindeer herding districts (C) and mountain reindeer herding districts (M) are shown in map a) and the forest reindeer herding districts (F) are shown in map b). The winter ranges are shaded in the large maps. Some seasonal ranges are overlapping (grey cross-striped) and are usually shared by two neighbouring herding districts. Reindeer herding district F4 shares its whole-year ranges with the winter ranges used by districts M10, M12 and M13. See appendix for names of the herding districts.

In Sweden, reindeer husbandry is mainly connected to the Sami rights to use land for their traditional livelihoods. About 1,900 people out of 17,000–20,000 Sami are active herding members/reindeer owners, and about 1,800 are involved as so-called "additional members", in the herding communities. These numbers exclude about 1,000 non-Sami reindeer owners in the concession herding communities, in the eastern part of the county of Norrbotten.

A herding community consists of reindeer herding enterprises, which usually include families and relatives as members. The reindeer husbandry normally contributes between 10–50% to the family income, but the variation is large with many having all their livelihood from reindeer husbandry, reflecting a large variation in enterprise size. In 2003, there were 937 reindeer herding enterprises in Sweden (SJV, 2005b).

Table 1. *Number of reindeer, enterprises and reindeer owners in 2003 (SJV, 2005b; Statistics Sweden, 1999)*

	Reindeer herding districts	Enter-prises	Reindeer owners	Reindeer	Reindeer / owner
Counties					
Norrbotten	32	726	3 951	139 070	35
- Mountain herding districts.	15	584	2 089	96 144	46
- Forest herding districts	9	125	875	30 248	35
- Concession herding districts	8	17	987	12 678	13
Västerbotten	7	102	344	54 980	160
Jämtland	12	109	301	44 769	149
Total per year 1994–2003					
mean	51	937	4 635	238 819	51
standard deviation		18	127	19 700	3.4

There is a large variation between reindeer herding districts in both structure (Table 1) and production such as slaughter weights (Figure 4). More herders and reindeer, but lower reindeer densities, characterise the northern herding districts. These herding districts consist of many small enterprises with fewer reindeer per herder. The southern herding districts are perhaps more productivity-focused, and have fewer enterprises and more reindeer per herder. The north-eastern districts are concession districts, in which non-Sami land owners are allowed to graze a maximum of 30 reindeer on common land (Swedish Code of Statutes (SFS), 1971). Therefore, the number of herders in concessions districts is high in relation to animal numbers.

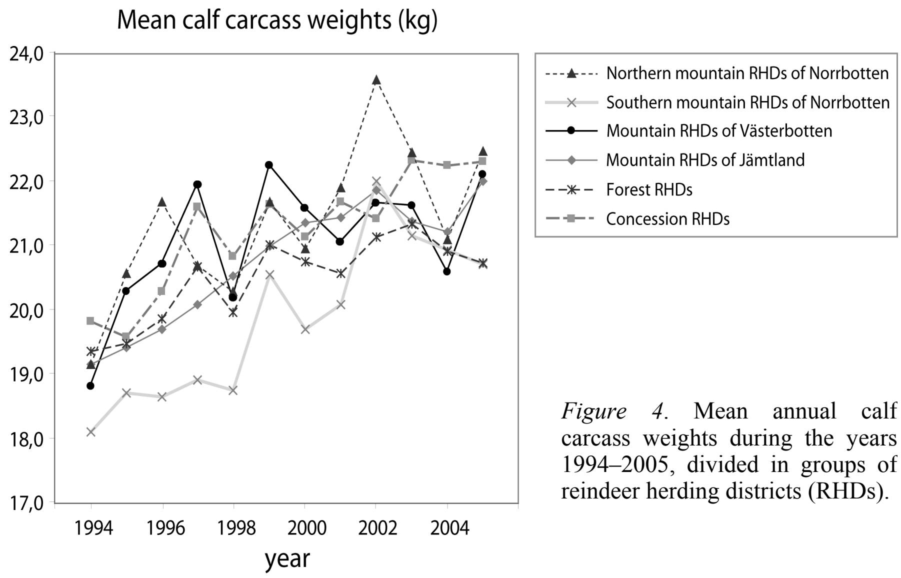

Figure 4. Mean annual calf carcass weights during the years 1994–2005, divided in groups of reindeer herding districts (RHDs).

Materials and methods

Data included in the analyses were collected from a variety of sources. The cartographic data used in the thesis were achieved from the National Land Survey of Sweden distributed by Metria. This included the Terrain elevation databank, Land cover data, and roads from the Blue Map (NLSS, 1998; NLSS, 2002a; NLSS, 2004), as well as the National Atlas of Sweden (NLSS, 2002b). The Sami herding districts' boundaries and seasonal ranges, as well as the reindeer forage classifications of vegetation maps, were extracted from the reindeer husbandry database REN2000 (County Administration Boards, 2000). Climatic data were collected from the National Atlas of Sweden, produced and distributed by the National Land Survey of Sweden (NLSS, 2002b). The meteorological data were collected by the Swedish Meteorological and Hydrological Institute (SMHI, 2005). Classified satellite imagery on forest age used in **II** was derived by Jacobson *et al.* (2002) for the Swedish Environmental Protection Agency (SEPA). The reindeer numbers and slaughter data used in **IV** were achieved from the Swedish Board of Agriculture (SJV, 2005a). The inventories of large carnivores were achieved from the Sami Parliament (SP, 2005).

From these sources, 37 variables, all presumed to affect reindeer ecology and productivity, were derived and mapped in 1,958 evenly sized squares (each 100 km^2), covering in total 86% of the total grazing land including land in Norway. The means of each variable of each square were extracted and analysed further with multivariate analysis statistical methods.

These variables included topography, climate and snow conditions, forest conditions and forage quality, insect harassment and infrastructure. In order to evaluate forage quality and availability in a fragmented landscape, a spatial cost-benefit method comprising forage value and fragmenting structures, termed 'reachability', was developed (**I**).

To quantify factors on a landscape scale, all variables had to be spatially applicable in an appropriate resolution and cover the total reindeer herding area in Sweden. Vegetation and infrastructure variables were used as is, or weighted according to class or type, derived from the GSD source maps. Topographical variables were derived from GSD digital elevation model (DEM) using common GIS functions. Meteorological measurements collected from weather stations, and variables derived thereof, were interpolated using kriging techniques commonly used in GIS analyses. Data from the National Atlas of Sweden, present as isolines, were linearly interpolated to cover the entire herding area. Reachability was modelled for the entire area using vegetation and road maps, and a sample point density of 0.25 sample points per km^2.

The relations between the environmental variables were analysed and a set of 15 variables were retained (**II**). Similar variables were excluded with the intention of capturing as much of the compound variation between the observations by the different variables as possible. Results from these analyses were used to identify independent patterns of variations (principal components, see below) and for a zonation of the reindeer herding area. The 15 retained variables were also applied on a herding district scale and each variable was applied only on its relevant seasonal herding range, and hence used for grouping herding districts on the basis of the presumed productivity determining factors (**III**). As a last step, the 15 retained variables were correlated to productivity measures derived from the district statistics and slaughter data (**IV**). In these analyses, factors that were important for between-herding-district and between-year variation, respectively, were identified. The five most prominent factors were thereafter used for grouping herding districts and an ultimate grouping was suggested by combining these results with results in **II**.

The statistical methods used in these analyses were:

LM (**IV**) – Linear regression models were used to examine the relationships between the independent environmental variables and each dependent productivity variable. LM was used both for analyses between districts and between years. The residual covariance matrices from these analyses were used in CCA to examine the between-herding-district and between-year variations.

PCA (**II, III**) – Principal component analysis was used to examine the multidimensional space of the included environmental variables and identify the principal components (PCs) describing the major part of the compound variation. PCA was also used for variable reduction and to characterise the resulting groups of herding districts.

CCA (**IV**) – Canonical correlation analysis was used to identify the multivariate sets of independent environmental and dependent productivity variables, by identifying the components (canonical variates, CV) of each variable set with maximised correlation between the sets. CCA was used for analyses both between herding districts and between years.

SEM (**IV**) – Structural equation modelling was used to examine the multicausal structure of the system. Due to its ability to analyse chains and webs of causalities, multicausal models including latent variables could be constructed as path diagrams and tested statistically.

CA (**II**, **III**, **IV**) – Cluster analysis was used to group similar observations. In **II**, CA was used to cluster the 1,958 squares in order to produce a zonation of the reindeer herding area. In **III** and **IV**, CA was used to group herding districts based on their characteristics.

Summary of research presented

The outline of the thesis can be divided into three main parts. In the first part (**I**), a reachability method was developed. In this, habitat fragmentation by patchiness and linear structures were integrated with forage quality on a large scale. In the second part (**II, III**), variables presumed to affect reindeer productivity and ecology were described, analysed and reduced, and a zonation of the herding area was suggested. The reduced variable set was applied upon the reindeer herding districts of Sweden to characterise and group herding districts with similar prerequisites for reindeer ecology and productivity. In the third part (**IV**), statistics from reindeer herding districts and slaughter statistics were used to analyse the relationships between environmental factors and reindeer productivity, and a division of reindeer herding districts in Sweden was suggested.

Publication I

Ecological cost-benefit modelling of herbivore habitat quality degradation due to range fragmentation.

A method termed 'reachability' was developed to evaluate large-scale forage ranges, consisting of patches with classified forage values and fragmenting linear structures traversing the ranges. The reachability model evaluates ranges by including effective distances from sample points to forage patches over a heterogeneous landscape with fragmenting structures, water bodies and edges (Figure 5). The model was developed from the concept of cost-distance calculations to achieve a functional or effective distance (*e.g.* Adriaensen *et al.*, 2003), which includes cost of traversing different vegetation types or topographical features (*e.g.* Nikolakaki, 2004). These costs are defined as friction values in a digital grid, which correspond to the investigated species' cost to move over a surface, according to a particular factor. In the reachability model, least-cost distances are calculated from evenly distributed sample points to all surrounding cells, each with a forage value according to the forage quality for the investigated species. Further information could be included in the model, such as topography, hydrology, the studied species' preference for biotopes and predator distribution, all of which may affect the animals' distribution and act as a fragmenting factor.

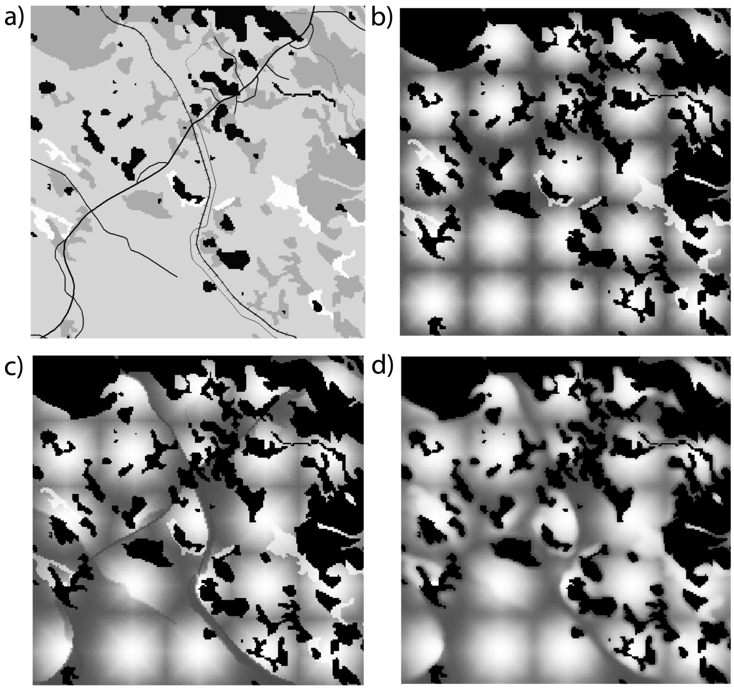

Figure 5. a) Map of a calibration square showing lakes (black), very good forage (white), good forage (light grey), less good forage (grey) and the road net including trails (dotted), roads and highways (lines), and railroad (crossed line). b) Cost-distance calculations from evenly distributed sample points to classified forage patches, linear structures excluded.

c) Cost-distance calculations including linear structures. d) Cost-distance calculations including linear structures and edge effects.

The main objective of this particular study was to calibrate the model for all its parameters regarding weights of fragmenting structures, edge effects, sample point distribution and vegetation classifications for use on reindeer. A model test was done by applying it on reindeer movements in the reindeer herding district of Handölsdalen, derived from GPS data. The results of the reachability model were compared with other observational studies on reindeer.

In the study of Handölsdalen, the reindeer population density appeared to decrease up to 1 km away from roads, but no effect from hiking trails was detected (Figure 6). The reachability model suggested a loss of 2.2–2.7% in range quality in this example due to range fragmentation. Related to the 8,000 reindeer grazing in the area, the decrease in reachable resources is approximately equivalent to 175–215 fewer animals if the area is optimally stocked.

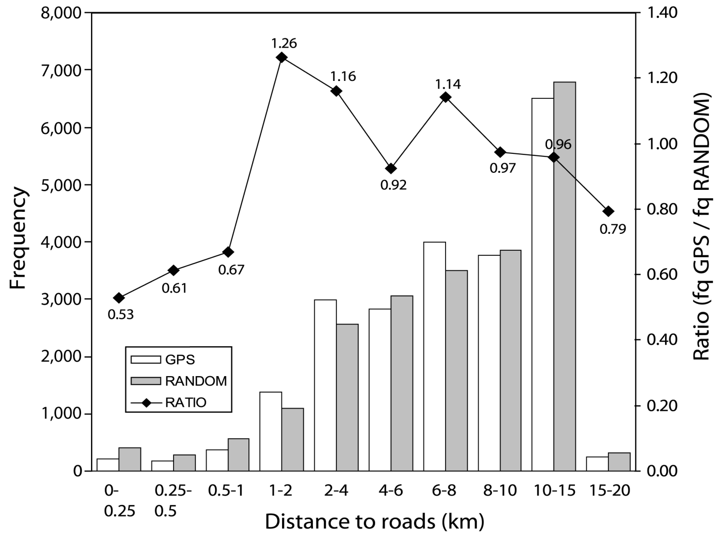

Figure 6. Distances between GPS positions of 10 reindeer females and roads in the Handölsdalen study area during the free-ranging periods of summer compared to an equal number of random positions within each reindeer's minimum convex polygon (MCP) home range. The comparison suggests avoidance behaviour at up to 1 km from roads and an aggregation of reindeer between 1 and 4 km from roads.

Publication II

Multivariate characterisation of environmental conditions for reindeer husbandry in Sweden.

Thirty-seven variables quantifying geographical location, topography, vegetation, forage classification, forest age, infrastructure, climate, harassing insect activity, ice-crust probability and weather observations were extracted from digital maps and databases. The topographical variables included elevation, slope, aspect of slopes, and five different measurements of ruggedness. The vegetation variables included amounts of forest and clear-cuts, old forest, forest with lichen, classified winter and green forage ranges. The climate variables consisted of snow and growing season lengths, snow precipitation, and from meteorological data variables of insect activity developed by Mörschel (1999) and developed variables of ice-crust probability were introduced. Fragmenting roads and railroads were included in six different reachability variables using the method developed in **I**.

The variables were mapped in 1,958 squares, enclosing 100 km^2 each and analysed with PCA in order to reduce the number of variables. Highly spatially correlated variables were identified and one variable of each considered factor was retained to save degrees of freedom, while minimizing information loss.

Fifteen variables describing the reindeer herding area were ultimately retained and were used to categorise zones and ranges based on reindeer requirements. The retained variables were also clustered to investigate their relationships, which resulted in two major groups of variables. The first group consisted of variables with high values towards the north and west, and the second cluster included variables with increasing values towards the south and east. The first five PCs in a PCA of the reduced variable set explained 84% of the total variation of the 15 retained variables. The PCs from the original set of 37 variables and the reduced set of 15 variables were well correlated; r = 0.96, 0.87, 0.88, 0.54 and 0.37, respectively. Further reduction of variables showed increased loss of variation and decreased correlations between the PCs. The main northwest-southeast gradient was identified and isolated in the first PC, and the balance between winter and spring-summer-autumn (SSA) forage was the dominating pattern of the second PC. The third PC captured patterns of variables related to winter and high elevation terrain versus forest- and forage-related variables, with special emphasis on snow conditions. The fourth and fifth PC emphasised slope direction and forests, with longitudinal and latitudinal pattern gradients, respectively.

These results were the basis of a zone division of the Swedish reindeer herding area into seven tentative zones (Figure 7), using CA on the information mapped in the 1,958 squares. Zone A was characterised by having a short growing season and high snow precipitation but low ice-crust probability. It was also highly elevated with low amounts of roads, forests and lichen. Zone B was similar but not as extreme. Zone C was less rugged and with high amounts of lichen and green forage. Zone D was characterised by very good winter forage but not as good green forage. Zone E and F had long growing seasons and low snow precipitations but high probabilities of ice-crust formation and insect harassment. They also had high abundance of roads and forestry. Zone F was more extreme in most variables compared to zone E. Zone G had very good winter forage with high lichen abundance, but was scarce in summer forage.

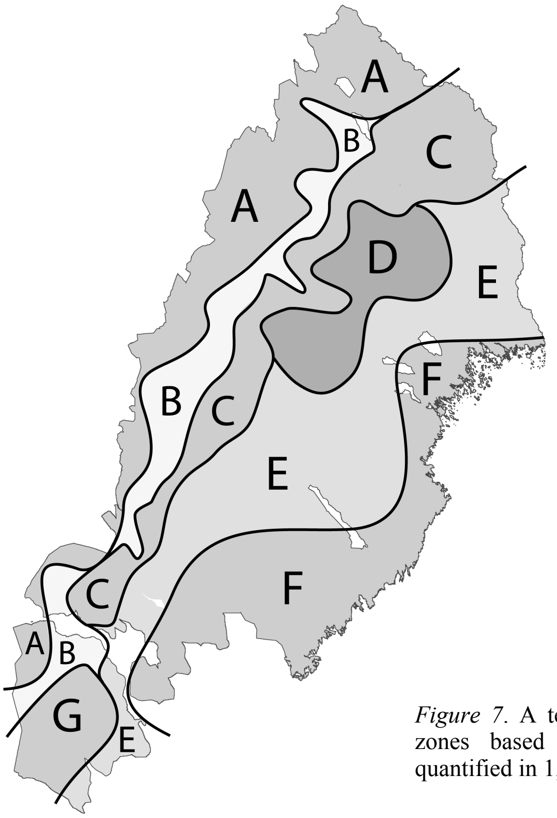

Figure 7. A tentative zone division into seven zones based on the 15 retained variables quantified in 1,958 squares, each 100 km^2.

Publication III

Multivariate clustering of reindeer herding districts in Sweden according to range prerequisites for reindeer husbandry.

The retained 15 variables in **II** were analysed for the 51 reindeer herding districts, and the variables were applied on the corresponding seasonal ranges of each herding district. The herding districts were examined using PCA, and grouped according to the similarities in the retained variable set using CA.

Ten groups of herding districts were distinguished, of which three were single outliers (Figure 8). One group consisted of 14 herding districts and was therefore further divided into four subgroups, which were not unique enough to be separate groups. All groups' characteristics were identified using the mean PC score of each group compared with the total mean score of all herding districts. The scores of smaller herding districts tended to be more extreme, likely due to their limited inclusion of heterogeneous landscapes and climate characteristics. Herding districts with extensive outstretched shapes thereby including more diverse biotopes, achieved correspondingly more average scores. This grouping was combined with the groups derived in **IV** in order to suggest an ultimate partition of the reindeer herding districts.

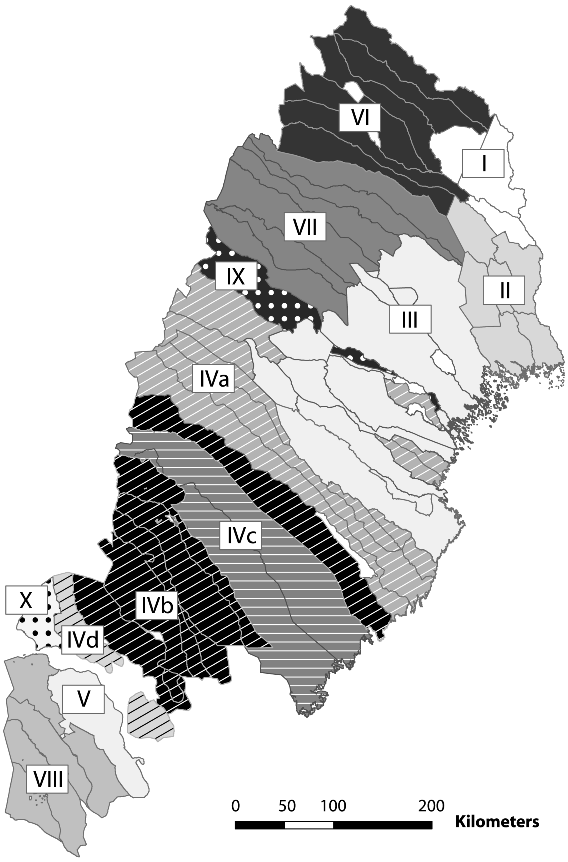

Figure 8. The distribution of the clusters of the Swedish reindeer herding districts based on 15 variables quantifying topography, vegetation and forage, fragmentation, ice-crust probability, insect harassment, season lengths, and snow precipitation. Some herding districts are overlapping (see Figure 3) and are therefore partly hidden in the map.

Publication IV

Relationships between biotic and abiotic range characteristics and productivity in reindeer husbandry in Sweden.

The variables retained in **II** were correlated to registered district statistics (number of reindeer, enterprises and reindeer owners) and slaughter data from the 51 herding districts during 1994–2004. The slaughter data included approximately 600,000 carcass records with gender, weight, and fatness and conformation classifications. The approach was to examine which environmental variables were relevant in describing the productivity variations between herding districts, as well as the variation in productivity between years. LM was used to explore the effects of the independent variables on each productivity variable separately, and to extract residual covariance matrices on a between-herding-district and between-year basis, respectively. CCA was used to identify the canonical variates with maximum correlations between environmental and productivity variable sets, both between herding districts and between years. SEM was used to construct and evaluate path diagrams (Figure 9) with latent variables describing the system of productivity determinants and productivity variables. Thereafter, a grouping of herding districts was made using CA, similar to the CA done in **III**.

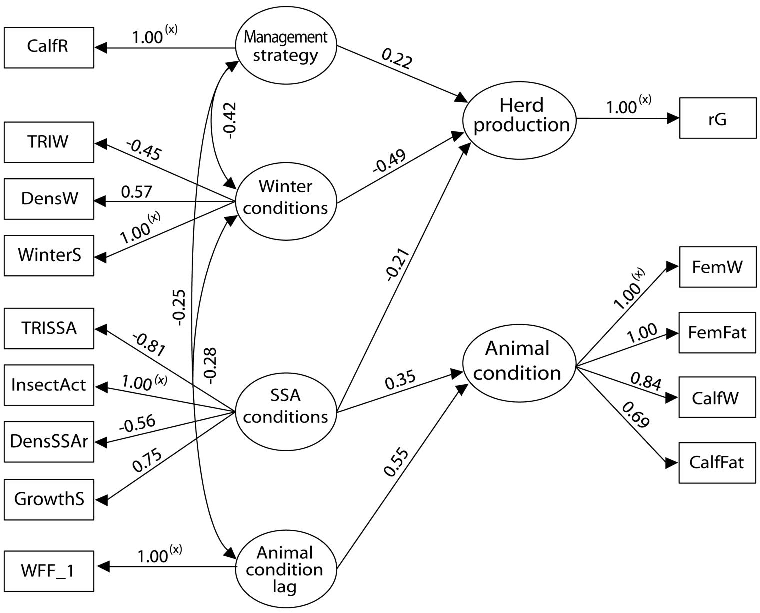

Figure 9. Final structural equation model for the analysis between herding districts. Measured manifest variables are in squares and latent constructed variables are in ovals. Single arrows show causal correlations and double-sided arrows show correlations between exogenous latent variables. The numbers are path coefficients (standardised regression coefficients) and correlations.

In the between-district analyses, two latent productivity variables were constructed; *Herd production* and *Animal condition*. *Herd production* was positively correlated with growing season length, spring, summer and autumn (SSA) animal density, ruggedness and calf slaughter-dominated slaughter strategy, and negatively correlated with winter season length, insect activity and winter animal density. *Animal condition* was negatively correlated with SSA animal density and topography, while positively correlated with growth season length, insect activity and animal condition previous year. Differences could however be found between adult females and calves, *e.g.* longer growing seasons were positive for condition in calves, but negative for adult females. The opposite effect was found for increased harassing insect activity. Reindeer herding districts with better herd production had females in poorer shape, but calves in better shape. The most relevant factors for distinguishing herding districts were season lengths (SSA and W), animal density in summer, animal condition lag, ruggedness (SSA and W) and insect activity, followed by calf slaughter.

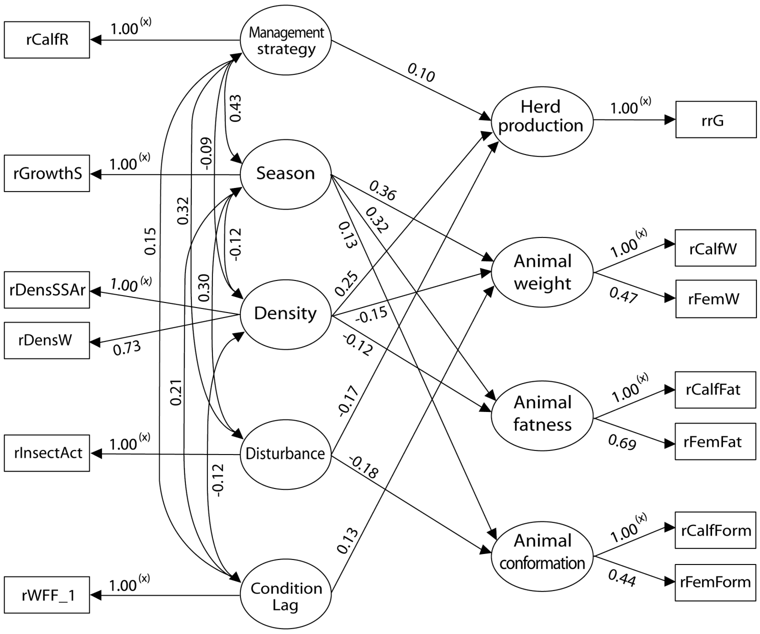

Figure 10. Final structural equation model for the analysis between years. Measured manifest variables are in squares and latent constructed variables are in ovals. Single arrows show causal correlations and double-sided arrows show correlations between exogenous latent variables. The numbers are path coefficients (standardised regression coefficients) and correlations.

In the analyses on interannual variation (Figure 10), four latent productivity variables were constructed: *Herd production*, *Animal weight*, *Animal fatness* and *Animal conformation*. There was a positive correlation between calf slaughter and *Herd production* but not as apparent as in the model between herding districts. Growing season length was positively correlated with animal conditions. Animal density was negatively correlated with *Animal weight* and *Animal fatness*, but did not seem to affect *Animal conformation*. Insect activity did, however, affect *Animal conformation* as well as *Herd production* negatively. The animal condition previous year only affected *Animal weight*. The most relevant factors for describing annual variation in productivity were growing season lengths, animal densities (SSA and W) and insect harassments, followed by animal condition lag and calf slaughter.

A clustering of the herding districts using the five environmental variables; season lengths (SSA and W), ruggedness (SSA and W) and insect activity, recommended six groups of districts (Figure 11), which formed a basis for a division of the herding districts in Sweden (Table 2). This grouping of herding district was similar to the more general clustering analysis of **III**.

Generally, the results support the idea that, above all, animal densities and growing season lengths determine the reindeer productivity. The remaining variables should however not be discarded as irrelevant for reindeer productivity, but may be partly mitigated by husbandry measures, or being veiled in the intricate pattern of causalities.

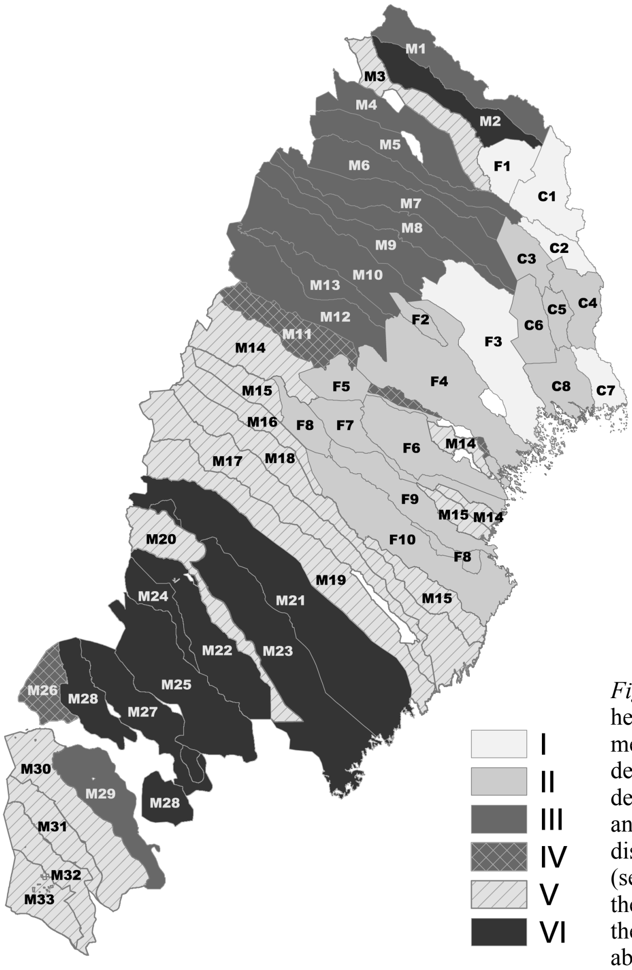

Figure 11. Clusters of herding districts based on means of productivity determining variables derived from the SEM analyses. Some herding districts are overlapping (see Figure 3) and are therefore partly hidden in the map. Se Appendix for abbreviations.

Table 2. *Suggested grouping of the reindeer herding districts based on the combined results in **III** and **IV**. See Figure 11 for the locations of the herding district and Appendix for district abbreviations*

Group	Herding districts
A	C1, C2, F1
B	C3–C8
C	F2–F10
D	M1–M10, M12, M13
E	M11, M14–M19
F	M20–M25, M27, M28
G	M26, M29–M33

General discussion

Methodological aspects

The principal purpose of the research behind this thesis was to generalise the complexity of the physical conditions for reindeer husbandry in Sweden. The foremost difficulty in this work has been to find a way to elucidate the very complex web of interacting factors in sufficiently simple terms to be useful for users of the results. To do this, it was necessary to adopt a multitude of not very commonly known methodologies. The results from these are not easily understood in the regular "cause-effect" assessment, as they are multidimensional and the object of interpretations based on variable constructs (*e.g.* principal components and latent variables). A way to generalise the results was to partly depart from the quantitative representation of results. In this work, this was done by zonation of the reindeer husbandry area (**II**) and by grouping herding districts (**III**, **IV**).

Zonation and grouping can be seen as ways to round off results to an integer scale. The ambiguousness of this solution shows up in that several zonations and groupings are presented. As a complement to these, the variables eventually used in the last publication were mapped in the Appendix. Furthermore, for the interpretation of the results, it is essential to point out that many of the variables included are constructs in themselves, derived with the purpose of capturing spatial variation within the background factor. The 15 retained variables in **II** out of the 37 alternative variables illustrate this. It is clear that more than 37 environmental variables could have been derived. From an analysis point of view, a limit on the number of variables is imposed by the number of observations, which on the herding district level was 51.

Of the methods used, derivations of some of the variables are novel. This particularly includes the reachability concept, developed in **I**, evaluating forage quality and availability of ranges in relation to fragmenting structures, with an effective distance approach (*e.g.* Adriaensen*, et al.*, 2003; Röder *et al.*, 2007; Storfer *et al.*, 2006).

Evaluations of fragmenting structures on habitats is complex and the effects of fragmentation are often difficult to isolate in biological systems, as the effects can be masked by confounding factors when investigated (see Ewers & Didham, 2006). The actual loss of forage due to fragmentation will probably not be completely quantified in models, but assessing the problem with a cost-benefit approach could hopefully get us closer to the actual effects. Delicate tentative decisions in the method are sample point density, friction values and forage quality according to the investigated species. The key difficulty is how to calibrate these parameters, as there are limited empirical studies done on the effects of different fragmenting factors in different types of landscapes and vegetation. A thorough calibration and model test should be considered when applying the method on new types of ranges or different species.

The advantages of the proposed reachability model are that it is not species-specific and can include various friction weights in accordance with various ground types, topographical barriers, and linear structures such as infrastructures and rivers. The model was aimed to be suitable for large-scale evaluations, thus reachability quantifications in small areas were avoided.

Foreseeable model applications are, for example, the use of the method in complex evaluations of areas before and after a planned infrastructural construction, where *e.g.* ecological non-marketable values often come up short in arguments against economical gains. The fields of applications are likely quite many, but are not further discussed here since the method has not yet been evaluated in other situations.

One difficulty in the analysis of variables was to achieve data in appropriate resolutions. For a number of variables, such as climate and weather-dependent variables, data are in a coarser resolution than 10 km × 10 km. Therefore, interpolations between the existing measurements of different scale were necessary. Obviously, there is a large amount of possible sources of bias doing this, due to *e.g.* microclimate and topography, as well as issues in the interpolation techniques. However, as long as the approach is to compare and investigate gradients over large areas, such methods were assumed appropriate. Using such assessment in a downscaling approach for investigations of absolute values on small areas or patches is difficult and was avoided.

Another variable construct, which has not been tested elsewhere, is ice-crust probability. This variable was constructed indirectly using weather data to identify certain weather events known to cause ice-crust formation (*e.g.* Colbeck, 1989; Ryd, 2001). A variable to reflect the harassing insect activity using Mörschel's index (Mörschel, 1999), was done with the same kind of approach. Neither of these two variable constructs was empirically verified here, but they were both assumed to likely reflect the large-scale variation of ice-crust formations and insect harassments.

The data quality in the digital sources used in this analysis is varying. This is especially noticeable in the vegetation maps, which are derived both from satellite imagery and from inventories on ground. This is of course highly relevant in studies such as this one, and some variables may therefore be biased.

Concerning the statistical methods used for the analyses, they are well documented and known in other applications, although rather new in this area of research. In spatial studies, variables often suffer from strong autocorrelations. Thereby relevant factors could be masked in correlation with other variables and the 'true' causalities could be difficult to detect. Multivariate analyses are also intricate to interpret, and require concern and sometimes complementary statistical methods to be fully reliable. In a few situations, as in SEM (**IV**), standard requirements for model fits could not be met. In spite of that, it seems that the results were relevant. Due to the complexity of the system with several uncontrollable factors as is often the case in ecology, and the relatively small amount of observations in this study, the poor measures-of-fit could perhaps be expected. Each significant path coefficient in the SEM model was, however, of interest, as they were concurring with the results of the other statistical analyses. The SEM method seems to be helpful when studying multilevel ecological systems, as *e.g.* it can be used in both exploratory and confirmatory analyses.

There are dilemmas with including many independent variables together with several dependent variables. As there are collinearities in the dimensions of the included independent variables, the same should be expected among the dependent variables. Hence, latent factors (*e.g.* principal components) in each set of variables need to be assessed and thereafter compared with the opposite set, or latent factors thereof. There are natural parallels between PCA and CCA, as well as between LM and CCA, which implied the usage of CCA in the study. LM seemed to be a valuable complement to CCA and SEM, as LM can include class variables. We could thereby analyse the relation between herding districts as well as between years. By using the residual matrices of these LM analyses, we were able to achieve a similar multi-level approach in the CCA and SEM. Several methods, such as random forest (Breiman, 2001), classification and regression trees (CART, *e.g.* Breiman *et al.*, 1984; De'ath, 2002), or artificial neural networks (*e.g.* Stern, 1996), can be used to cluster or group observations based on similarities. CA is however, a well-tested and popular method, which for our purpose seemed sufficient.

Productivity determinants

The variables found to explain the most variation in reindeer productivity in this study were different in spatial and temporal scales. When comparing the Swedish reindeer herding districts, the most relevant environmental variables were season lengths, animal densities, topography, insect harassment, calf slaughter and animal conditions previous year. Season length and topography are determining factors for the primary production and were expected to have a large impact on reindeer. Permanent factors, such as topography and vegetation, were for natural reasons not found to have any impact on the interannual variations in production. Calf slaughter and animal conditions previous year were not as significant in the interannual analyses compared with the analyses between herding districts. Another interesting result was that certain factors affect the productivity variables differently, although they could be expected to have similar effects on all productivity variables. For example, animal densities were negatively correlated with animal condition, which was expected, but positively correlated with herd growth. It is difficult to have a definite explanation for this. Attempts to define an optimum reindeer density for each individual herding district in **IV** were not successful. Therefore, the actual densities in relation to optimal densities (Figure 1) cannot be determined. One suggestion is, however, that the opposite signs of the correlations between density and animal condition and herd growth, respectively, indicate that the districts in general had animal densities lower than what corresponds to maximum population growth.

Animal densities showed stronger correlations with productivity than *e.g.* forage quality. This may give an impression that the vegetation resources might not be a critical factor, as opposed to density dependence or grazing pressure. Therefore, the minor importance of reachability and fragmentation compared to animal density is not surprising. The suggestion is, however, that fragmenting factors should not be marginalized, as they indirectly affect animal densities due to exclusion of grazing ranges.

As discussed in **IV**, the weak correlations between snow variables and productivity were suggested to be explained by the counteracting measures, such as complementary feeding and forced migrations, taken by the reindeer herders at severe snow conditions. Thereby, such events may go undetected when analysing productivity. These events are, however, very costly for the reindeer industry and in severe years may erase the complete net outcome of the affected enterprises. These factors and incidents therefore need to be included in further investigations, in spite of the limited impact found here.

Herd growth showed negative correlations with female weight and condition but positive correlations with calf weight and condition (LM, in **IV**). This contradictory result might be an effect of higher calf survival, indicated by the higher herd growth. This negatively affects female condition since the females invest energy and resources in their calves at a cost of their own body reserves (*e.g.* Reimers, 1997; Rönnegård, Forslund & Danell, 2002). High insect harassment showed the opposite effect and therefore seemed positive for females. Possibly the negative effect of insect harassment increased the calf mortality and hence releasing resources for the females to invest in their own body mass. This confirms that calves especially seem to be affected by severe insect harassments, in agreement with previous studies (Helle & Kojola, 1994; Helle & Tarvainen, 1984).

Zonation of the area and grouping of herding districts

Several attempts to develop a zonation of the reindeer herding area were made in the thesis. They differ depending on the scale and the data used. In **II**, the cluster analyses were based on 1,958 equally sized (100 km^2) observations, using the 15 variables extracted from the larger set of 37 variables presumed to be important. The resulting zonation should thus be regarded as a description of the area concerning similarities and dissimilarities of the underlying variables without any ranking, weighting or valuation of these variables. Due to the small scale, a smoothed zonation could be performed, which was shown to follow the major topographical and latitudinal gradients.

To group the herding districts based on their characteristics, each variable was applied on the relevant seasonal ranges of each herding district (**III**). The number of observations was lower, as there are only 51 herding districts in Sweden. The number of variables was 15, *i.e.* the same as in **II**. Strong groups, *i.e.* highly similar herding districts, were easily distinguished, as well as unique herding districts falling out as outliers. This clustering was also based on variation in environmental conditions without verification against productivity.

The division of herding districts done in **IV** was based on the five environmental variables found to be most relevant as determinants of variation in productivity between herding districts. Due to the low number of included variables, the clustering results became spatially rather heterogeneous. To achieve a manageable division, the final zonation (Figure 12a) was therefore adjusted, where some adjacent districts were joined and similar, but geographically distant, districts were divided. This was done in accordance with the suggested groups in **II**. The administrative division of herding districts, which is based on county borders and herding district type (shown in Figure 12b), differ from this division. In the groupings suggested here, the mountain districts are shifted southwards. The concession districts are divided into two groups, in which the northern group includes one forest herding district (F1). One result to point out is the distinctiveness of the southern mountain herding districts (M29–M33), which are more like the northern herding districts than their neighbours in Jämtland county. The suggested division of reindeer herding districts in Figure 12a could hopefully improve administrative planning and management of the reindeer herding industry.

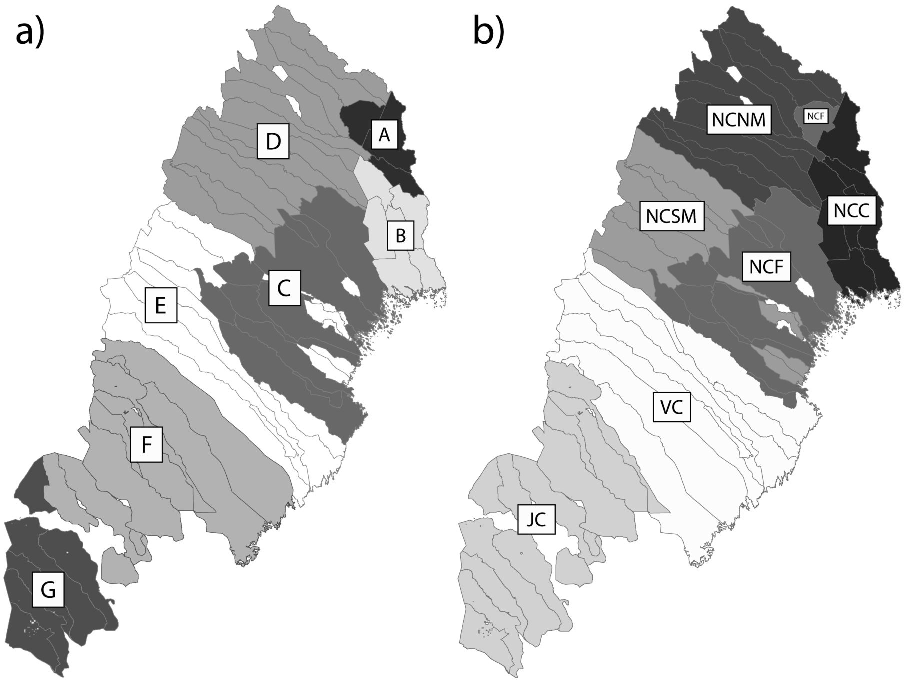

Figure 12. a) The suggested division of reindeer herding districts based on spatial distribution of factors shown to be relevant for reindeer productivity. b) The administrative division of reindeer herding districts based on county borders and herding district type, *e.g.* mountain, forest or concession. For abbreviations in b) see Table 3.

Table 3. *Abbreviations of current administrative division of herding districts, used in Figure 12b*

Abbreviation	Reindeer herding district group
NCNM	Norrbotten county northern mountain herding districts
NCSM	Norrbotten county southern mountain herding districts
NCC	Norrbotten county concession herding districts
NCF	Norrbotten county forest herding districts
VC	Västerbotten county herding districts
JC	Jämtland county herding districts

Reindeer husbandry and climate change

This thesis does not include models or projections of the reindeer husbandry in a future climate change. Several results of the studies are, however, connected to weather and climate variables, and therefore a discussion of possible impacts of a proceeding climate change on reindeer ecology and husbandry could be of interest. Another reason to discuss this issue is that the mapping done in this thesis was intended to be a platform for later projections of climate change impacts on reindeer husbandry.

In climate scenarios for the next hundred years, mean temperatures are suggested to increase significantly, especially in polar areas (ACIA, 2004; IPCC, 2007; SMHI, 2007). The impact of climate change is, however, ambiguous, and likely quite different in different parts of the reindeer herding area, as summarized by *e.g.* Weladji & Holand (2006) and Danell (2007), and is conceivable from detailed examinations of the variables used in this study (see maps in Appendix). The predictions suggest that winter temperatures in particular will increase, which could lead to an increment of temperature passages through 0 ºC in winter. This will accordingly increase the risks for ice-crust formations together with increased risk for rainfall during snow season, probably even in areas not suffering as much from such weather events today (Appendix, Figure r). Both ice crust and rain on snow have been shown to be negative for reindeer (*e.g.* Chan et al., 2005; Kohler & Aanes, 2004; Putkonen & Roe, 2003; Solberg, et al., 2001). The snow season is predicted to become shorter, however, which may counteract the increasing ice-crust formations. In regions where the snow season already is short (Appendix, Figure j), the season length will shorten markedly in relative terms. As a consequence the ice-crust incidences will likely decrease in importance. In parallel to this, the growing season for protein-rich green forage would be longer and the reindeer would have more time to build up their body storages. Longer growing season has, *e.g.* in this study, been shown to be positive for animal condition.

Increasing summer temperatures may increase insect harassments, which in this and other studies has been shown to strongly affect reindeer productivity (*e.g.* Hagemoen & Reimers, 2002). This will also negatively affect the occurrence of snow patches that reindeer use for insect relief and thermoregulation during summer (Anderson & Nilssen, 1998; Hagemoen & Reimers, 2002). Retreating snow edges and lingering snow patches also offer fresh nutrient-rich sprouts in their immediate vicinity (Mårell, Hofgaard & Danell, 2006). This disadvantage may, however, be counteracted both by the longer growing season and by a higher expected primary production. The climate models also predict increased precipitation, which might keep the vegetation from withering and from achieving high cellulose/protein ratio early in season.

In a longer perspective, the vegetation composition could be altered as species migrate northwards and towards more elevated areas. In Sweden, the tree line has already moved towards higher elevations in recent years (Kullman, 2007). Lichen, the important winter forage, may be out-competed by faster-growing vascular plants at higher temperatures (Cornelissen et al., 2001), and thereby negatively affect the winter forage abundance. This may on the other hand be counterbalanced by shorter winters, especially in regions which already have short winter seasons (Appendix, Figure j). The effects on reindeer due to anticipated alterations in the distributions of competing herbivores, predators and parasites are harder to estimate from the data included in this study.

Conclusions

- A zonation of the Swedish reindeer herding area into seven zones based on factors assumed to be relevant for reindeer ecology and productivity seemed to be a reasonable compromise between practicality and level of detail. The zones followed the topographical northwest–southeast gradient, which is perpendicular to the extensions of the mountain herding districts and historical migration routes for reindeer. This suggests that the adaptation of the species and industry has been to incorporate landscapes as heterogeneous as possible to utilize throughout the different seasons. Exceptions are the non-migratory forest and concession reindeer herding districts, which operate in landscapes with suitable year-round ranges.

- Growing season length, harassing insect activity, topographical ruggedness and calf slaughter strategy were found to be important factors explaining variation in herd growth between herding districts.

- Important factors explaining variation in animal condition between herding districts were animal density, harassing insect activity, and to a lesser extent, growing season length, extent of clear-cuts and topographic ruggedness on winter ranges. The strong correlation with animal condition the previous year indicates high repeatability in animal conditions.

- Animal density on summer ranges, winter season length and harassing insect activity were found to be important factors explaining variation in herd growth between years.

- Factors explaining variation between years in animal condition were primarily growing season length and animal density on summer ranges, and to a lesser extent, harassing insect activity and animal condition the previous year.

- A division of the reindeer herding districts in Sweden into six groups, using the most important variables affecting reindeer productivity, seems to be a viable alternative to the current administrative division.

Future research

During this thesis research, some research problems have appeared to be important for improving the analyses and models to increase the quality of the outcome.

The model regarding reachability in I demands additional research to achieve better species-specific reachability calculations. Animal movement over ecological and infrastructural barriers needs to be examined in a larger extent, as well as the behavioural aspects of the animals regarding fragmenting structures and forage ranges. Avoidance behaviour and preferences of investigated species should be carefully mapped and considered when calibrating the cost of movements, and also how deep and large the impacts of edge effects are on animal habitats. In addition, energy expenditure investigations due to topography and vegetation are of great interest, together with inter-species interactions such as competition for forage and interactions with predators, which can have a severe fragmenting effect on a species' habitat. The reachability model itself needs to be calibrated in several applications to estimate its stability and accuracy.

The effect on reindeer productivity by factors investigated in publications II - IV need to be better understood, together with the herding and slaughter strategies and counteracting measures done to mitigate the negative impacts of environmental factors. This is a difficult task since management measures are common and not well documented in relation to slaughter data. Animal handling, slaughter strategies and husbandry measures to mitigate severe events should be mapped to decrease the unexplained variation in multivariate analyses such as this. An economic approach for further investigations would also be highly valuable. Such an approach could include costs of husbandry measures and analyse the specific impacts of severe weather conditions, both for the reindeer productivity as well as the economy of the industry.

Further investigations on the strengths and weaknesses among the reindeer herding districts would be valuable for development of strategies to improve reindeer productivity.

One of the most burning research questions is to investigate the possible impacts of global climate change. Primarily, studies on alterations of a considerable number of environmental variables determining reindeer productivity need to be assessed. Thereafter, projections of these changes in a multivariate perspective on both a short and long temporal scale should be valuable. Projections of weather-dependent variables, such as ice-crust formations, could be included in climate models directly to improve the predictions and subsequently the effects on reindeer productivity.

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Appendix A

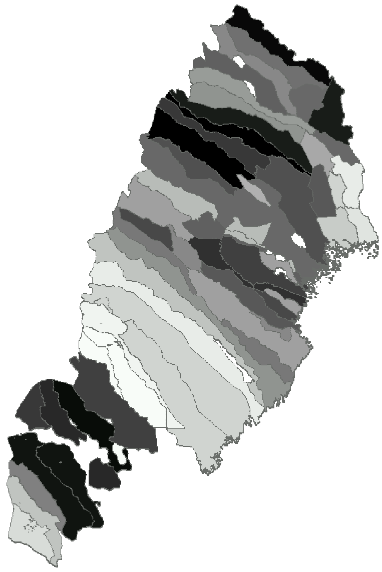
List of abbreviations

C1 – C8	Concession reindeer herding districts
CA	Cluster Analysis
CCA	Canonical Correlation Analysis
CCC	Cubic Clustering Criterion
CV	Canonical Variate
DEM	Digital Elevation Model
F1 – F10	Forest reindeer herding districts
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Geographical Sweden Data
IPCC	Intergovernmental Panel on Climate Change
LM	Linear Model (of regression)
M1 – M33	Mountain reindeer herding districts
MCP	Minimum Convex Polygon
MI	Mörschel's Index (harassing insect activity index)
PCA	Principal Component Analysis
PC	Principal Component
REN2000	Reindeer Husbandry Database
SEM	Structural Equation Modelling
SEPA	Swedish Environmental Protection Agency – Statens naturvårdverk
SJV	Swedish Board of Agriculture – Statens jordbruksverket
SFS	Swedish Code of Statutes – Svensk Författningssamling
SMHI	Swedish Meteorological and Hydrological Institute
SRG	Simulated Reachability Grid
SSA	Spring, Summer & Autumn (seasonal range)
TRI	Topographical Ruggedness Index
W	Winter (seasonal range)

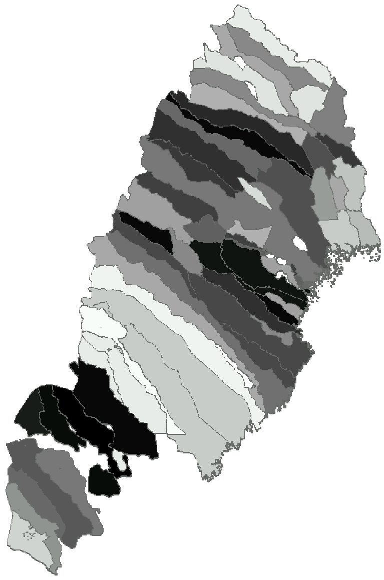
Appendix B

Maps of variables

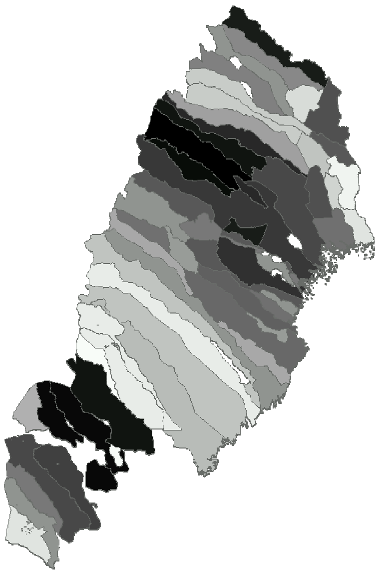
The maps are showing the relative means of each variable per reindeer herding district. Black is the lowest and white is the highest values. Some herding districts are overlapping (see Figure 3) and are therefore partly hidden in the map.



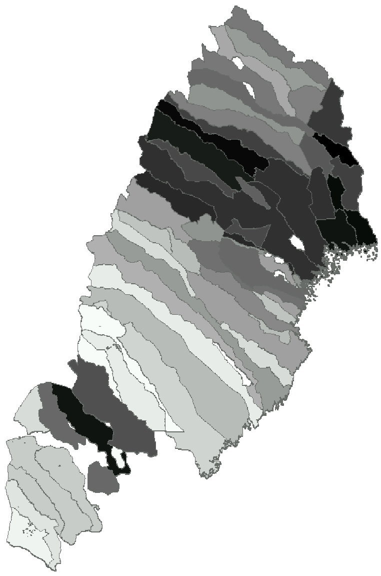
a) Female weight (*FemW*)



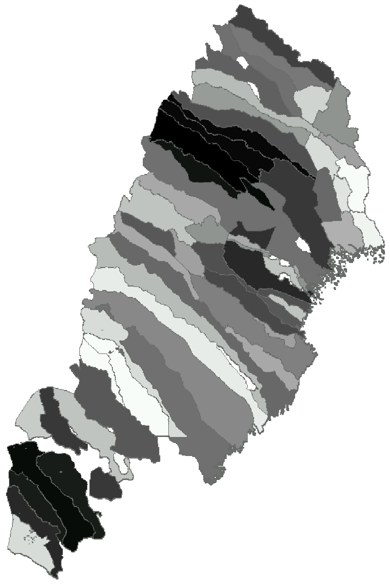
b) Calf weight (*CalfW*)



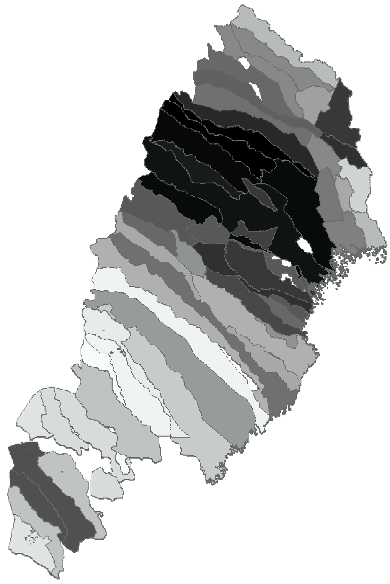
c) Female fatness class (*FemFat*)



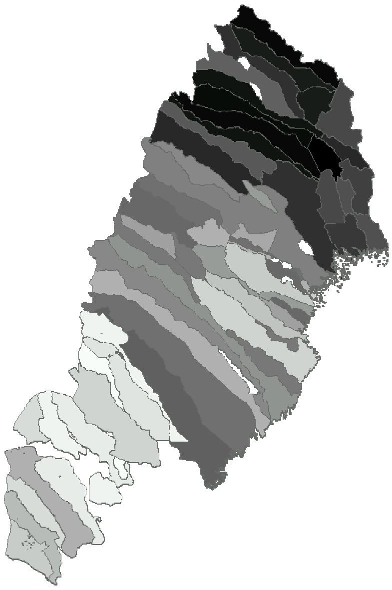
d) Calf fatness class (*CalfFat*)



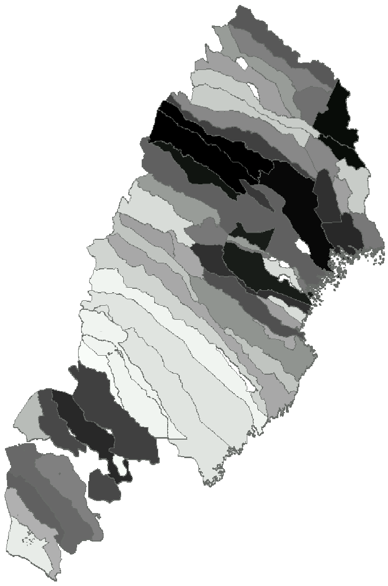
e) Female conformation class (*FemForm*)



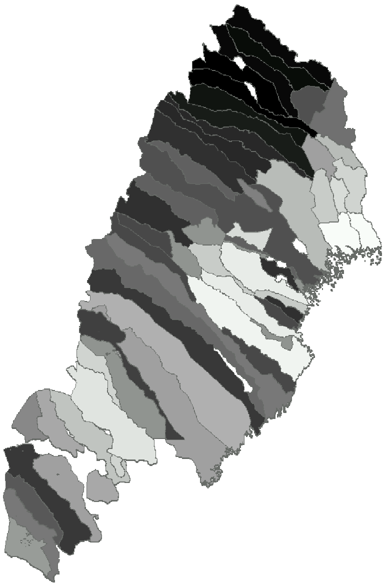
f) Calf conformation class (*CalfForm*)



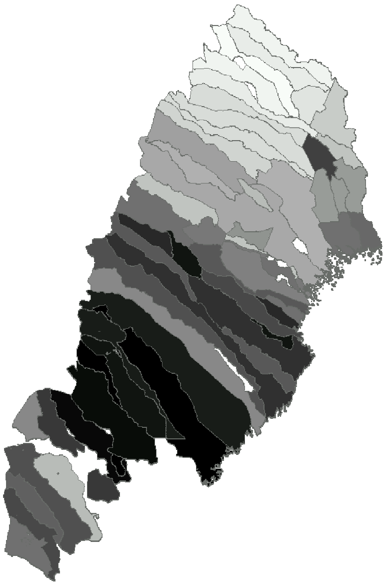
g) Herd growth (*rG*)



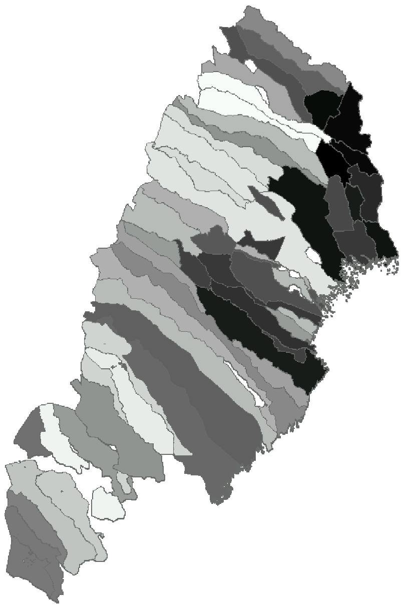
h) Animal condition lag (*WFF_1*)



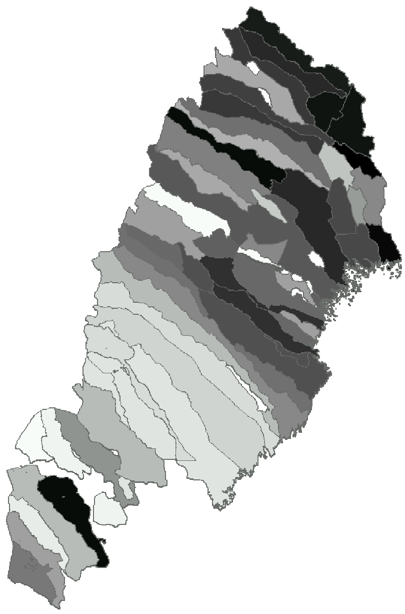
i) Growing season length (*GrowthS*)



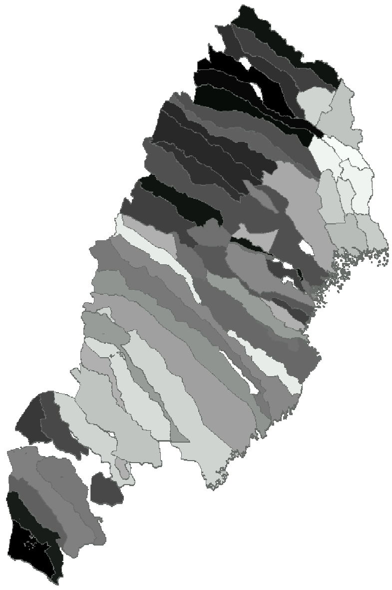
j) Winter season length (*WinterS*)



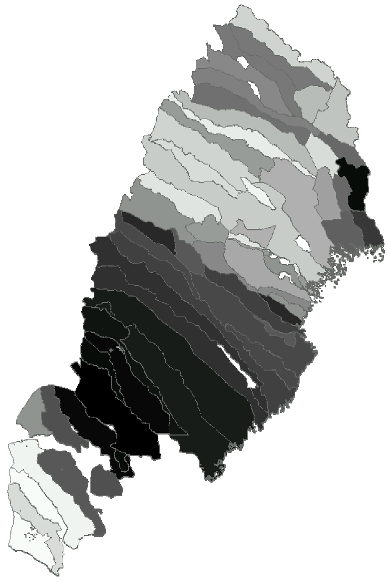
k) Ruggedness SSA (*TRISSA*)



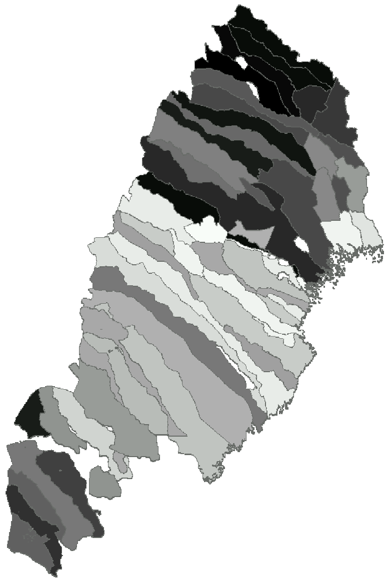
l) Ruggedness winter (*TRIW*)



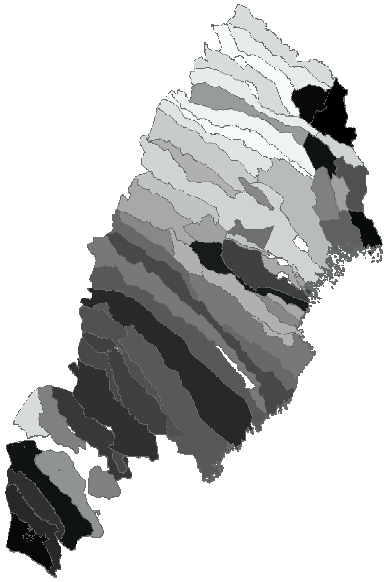
m) Reachability SSA (*Reach*)



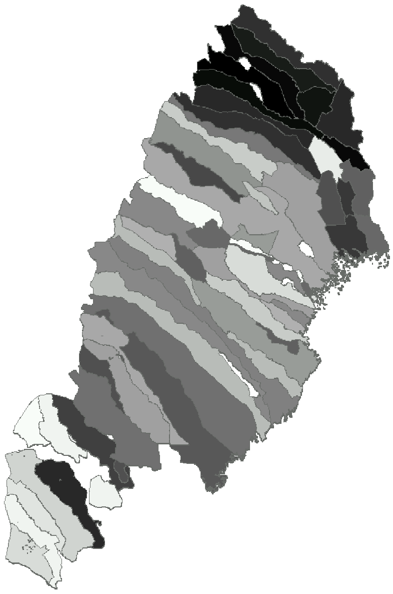
n) Winter forage (*ForageW*)



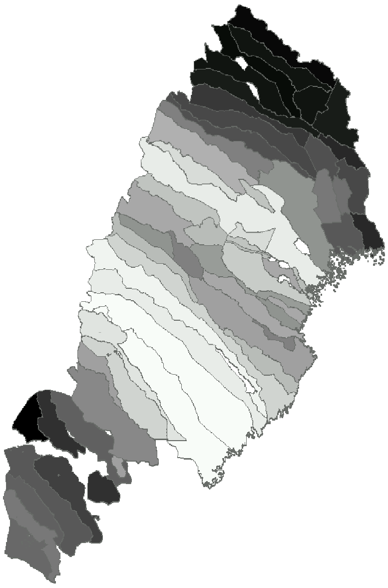
o) Road density (*RoadDens*)



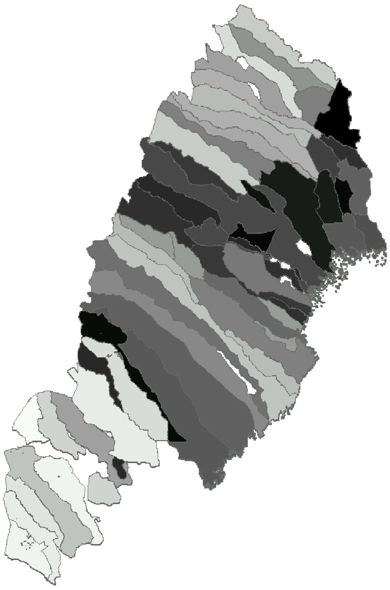
p) Clear-cuts (*ClearCut*)



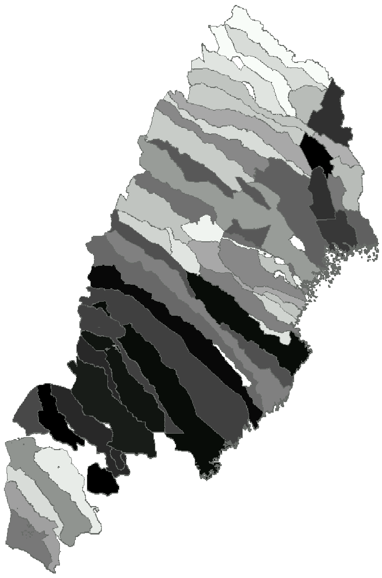
q) Snow precipitation (*SnowPrec*)



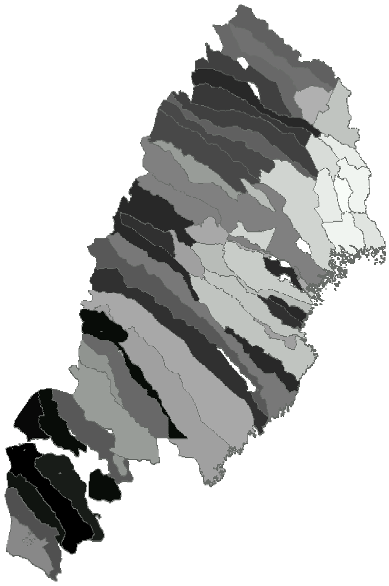
r) Ice-crust formation (*IceCrust*)



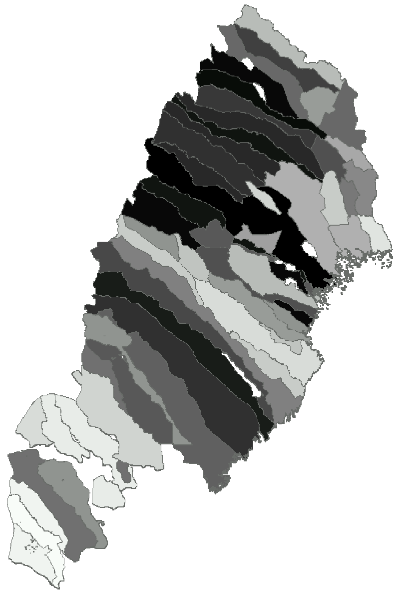
s) Animal density SSA (*DensSSA*)



t) Animal density winter (*DensW*)



u) Harassing insect activity (*InsectAct*)



v) Calf slaugter ratio (*CalfR*)

Svensk sammanfattning

Bakgrund

Det fennoskandiska renskötselområdet omfattar över 400 000 km^2 land från Atlant- och Ishavskusterna i väster och norr till de boreala skogarna i det inre delarna av Sverige och Finland. Utsträckningen i nord-sydlig riktning är ca 1200 km mellan 61 och 71°N. Den svenska delen av området omfattar ca 200000 km^2 (ca hälften av Sveriges landyta) med en väst-östlig bredd mellan fjäll och kust i norr på ca 300 km och med en nord-sydlig utsträckning på ca 900 km.

Området är generellt sett mycket heterogent och spänner över arktisk öken/tundra i norr, nederbördsrik Atlantkust i väster, alpina områden och boreal barrskog med varierande nederbördsförhållanden i mellanområdet och områden med kontinentala klimatdrag i söder och öster. Berggrund och näringsförhållanden för växtligheten varierar över området. Renantal och produktivitet fluktuerar regelbundet med intervaller på 20–30 år. Därtill finns också en stor variation i produktionsresultat (kg kött per livren) mellan samebyar och mellan enskilda år.

Renskötsel, som är ett pastoralt djurhållningssystem, bygger på att man med renhjorden som ”skördemaskin” tillvaratar en allmän resurs i form av naturligt växande bete. Om förhållandena är sådana att renhjorden tillväxer kan man slakta en viss mängd djur utan att tära på renhjordens kapital. Genom slakten finns vissa möjligheter att reglera renhjordens storlek och dess köns- och ålderssammansättning för att optimera förutsättningarna för hjordtillväxt, eller hellre de ekonomiska nettointäkterna. I övrigt är möjligheterna att modifiera eller förstärka de naturliga förutsättningarna mycket små, frånsett att medvetet utnyttja variationen inom det egna renskötselområdet genom olika markanvändningsstrategier.

Arbetes syfte och mål

Arbete har syftat till att på övergripande nivå analysera och beskriva de resursmässiga förutsättningarna för renskötsel i olika delar av renskötselområdet och med hjälp av dessa förklara orsakerna till skillnader i produktivitet mellan samebyar och år. De faktorer som påverkar renskötseln är mycket svåra att studera experimentellt beroende på det komplexa förhållandet mellan faktorer och det stora antalet okontrollerbara faktorer i systemet. Huvudsakligen analyserades renskötselområdet för att få ändamålsenliga zonindelningar av renskötselområdet och gruppindelningar av samebyarna.

Material och metoder

De viktigaste datakällorna har varit digitala underlag såsom topografiska kartmaterial och vegetationskartor från Lantmäteriet, renlängdsstatistik samt slaktstatistik med vikter och klassning av slaktkroppar från jordbruksverket (Tabell 1).

Tabell 1. *Översikt över undersökta miljö- och produktivitetsvariabler*

Variabler	**Källor**
Betesmarksdata samebyvis	
Topografiska förhållanden - höjd - brutenhet (sommar- och vinterland) - andel nordsluttningar	Material från Svensk-norska renbeteskommissionen
Vegetationstyper - sommarbete - vinterbete	Rennäringens kartskåp – REN2000
Skog - lavskogar - skogsbruksintensitet	METRIA:s kartmaterial (Lantmäteriet)
Klimatvariabler - sommarsäsongslängd - snösäsongslängd - nederbörd som snö	Väderstatistik från SMHI
Frekvens av försvårande väderleksförhållanden - skare (vår- och vinterland) - insektsstörningar	
Infrastruktur, fragmentering - vägar, järnvägar och leder - sommarbete inklusive fragmenterande objekt (reachability)	
Djurdata samebyvis	
Antal kalvar, vajor och tjurar Antal slaktade kalvar, vajor och tjurar Beräknade egna uttag av renägarna	Renlängd- och slaktstatistik från jordbruksverket
Rovdjursförekomst, predation Slaktvikter och klassificering (fett, form) Andel kalvslakt	Rovdjursinventeringar från Sametinget.
Djurtätheter olika säsonger	Ägarstrukturer från SCB

Fragmentering av betesområden, d.v.s. sönderstyckning av områden p.g.a. fysiska hinder i vägen för renen att nå olika områden, är ett problem och det är ont om metoder att beräkna denna betesförlust förutom direkta arealberäkningar. Som ett led i framtagningen av variabler utvecklades en metod (**I**) för att beräkna ett områdes beteskvalitet som inkluderade linjära fragmenterande objekt såsom vägar och järnvägar. Denna metod, på engelska benämnd ’reachability’, bygger på begreppet ’effektiv distans’ vilket är avståndet man får om man multiplicerar det faktiska avståndet med ett visst friktionsvärde för marken. Fragmenterande strukturer kan tilldelas högre friktionsvärden än det omgivande landskapet och blir då hindrande i modellen.

Inledningsvis härleddes 37 variabler som kvantifierades i 1958 rutor om 100 km^2 (**II**). Med stöd av multivariata statistiska analyser, såsom principalkomponentsanalys (PCA), reducerades dessa 37 variabler till 15 utan att förlora en allt för stor del av variationen mellan de 1958 observationsrutorna. Sju zoner identifierades i renskötselområdet med avseende på de 15 kvarvarande variablerna. Därefter grupperades samebyarna baserat på deras likheter och skillnader med avseende på de 15 variabler som användes i zoneringen (**III**). Zoneringen av renskötselområdet och grupperingen av samebyarna genomfördes med hjälp av clusteranalyser (CA) Det slutliga steget var att koppla samman de 15 variabler med produktivitetsdata från varje sameby för att identifiera de omgivningsvariabler som har störst betydelse för produktiviteten (**IV**). Detta gjordes med linjära regressionsmodeller (LM), kanoniska korrelationsanalyser (CCA) och strukturella ekvationsmodeller (SEM). De mest relevanta omgivningsvariablerna användes för att gruppera samebyarna ytterligare en gång med hjälp av clusteranalyser. I kombination med den tidigare grupperingen föreslås en indelning av samebyarna i sex grupper. De resulterande grupperna skiljde sig från de befintliga grupperingarna som baseras på länstillhörighet och samebytyp.

Faktorers påverkan på produktiviteten i renskötseln

De variabler som visade sig förklara mest av variationen i produktivitet mellan samebyar var säsongslängder, djurtätheter, insektsstörningar, samt andel kalvslakt. Renarnas kondition föregående år visade också starkt samband med produktivitet, vilket kan tolkas som hög upprepbarhet i produktionsresultaten. De variabler som inte visade sig ha stor betydelse var bland annat snöfall, skareförekomst, betesvärde, skogsbruksintensitet och fragmenterande strukturer. Renskötarna arbetar dock med att minska effekten av sådana faktorer och sätter in motåtgärder när det behövs. Detta gäller speciellt vid allvarliga väderhändelser såsom låst bete vid skarebildning, då stödutfodring ofta sätts in som åtgärd för att hålla djuren vid god kondition. Därmed kan dessa incidenter döljas i produktionsvariablerna men fortfarande ha en mycket stor negativ effekt på renskötseln p.g.a. stora extrakostnader för dessa åtgärder. Betesvärden på sommar och vintermarker, konkurrens med andra näringar såsom skogsbruk samt negativa effekter av fragmentering döljs sannolikt i djurtäthetsvariablerna. Med andra ord minskar dessa variabler bärigheten för betesmarker och bör inte underskattas i ett produktionsperspektiv. Minskas åtkomsten av betesmarker, beroende på t.ex. fragmentering, ökar djurtätheten på kvarvarande betesmarker.

Renskötsel och klimatförändring

Dessa undersökningar har även betydelse för att utröna effekterna på renskötseln av en klimatförändring. Troligen kommer vi att se ökade temperaturer (speciellt under vintern), längre växtsäsong, ökad nederbörd, samt fler antal nollgenomgångar av temperaturen under snösäsongen som ökar risken för skarebildning. Detta kan kanske uppvägas av att växtsäsongen blir längre då renarna fyller på sina förråd, vilket gör att renarna kan vara i bättre form då snösäsongen kommer. Det är än så länge väldigt svårt att uttala sig om de totala effekterna på renskötseln av en klimatförändring, men att vi skall vara beredda på förändringar står klart. I och med det blir det allt viktigare för renskötseln att ha goda marginaler, såsom reservbetesmarker, för att kunna hantera ökat antal störningar och förändringar.

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