Towards Adaptive Management of Reindeer Grazing Resources

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Abstract

This thesis aims to create a scientifically founded proposal for improvement of optimal and sustainable use of reindeer pasture resources by an adaptive management approach. Hence, the adaptive management concept is reviewed and discussed with specific reference to reindeer husbandry.

Two potential indicators of changes in the grazing resources of reindeer husbandry were investigated and proposals for how these indicators could be monitored are given. Reindeer body condition, estimated from commercial slaughter data, was suggested as proxy for monitoring pasture condition during the snow-free season. Altogether, 430 000 carcass records from 1994-2007 were analysed, together with additional information on body sizes of 699 reindeer. The results showed that between-year variations in body condition (reflecting pasture conditions) were similar in all animal categories. Accuracy of monitoring could be improved by ensuring that ages of calves are correctly classified, differentiating calves by sex, separating yearlings from older animals, and adjusting data for slaughter date.

Lichen height measurements were suggested for monitoring changes in winter grazing resources. Results from analysing data collected at totally 31 study sites showed that distances between measurement points should exceed 4 m and that 200-2000 points are needed for detecting changes in lichen height with sufficient statistical power. Large-scale spatial gradients, forest stand structure and moisture levels of lichen also need to be considered.

A dynamic model of the reindeer-pasture system was developed. The model consists of three modules describing lichen dynamics in winter pastures, energy dynamics of reindeer and reindeer population dynamics at herd level. The model appears to capture important empirically known mechanisms of the system and have potential utility, after adaptation to the conditions of individual herding districts, as a tool for interpreting monitoring results and evaluating management actions.

Keywords: carcass measures, change indicators, dynamic model, lichen height, monitoring, pastoral system, range management, *Rangifer*, stocking rates, uncertainty.

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You could not step twice into the same river; for other waters are ever flowing on to you.

Heraclitus of Ephesus (Plato – Cratylus)

Contents

List of Publications

This thesis is based on the work contained in the following papers, which are referred to by the corresponding Roman numerals in the text:

I Olofsson, A., Danell, Ö., Forslund, P., Åhman, B. (2008). Approaches to estimate body condition from slaughter records in reindeer. *Rangifer* 28, 103-120.

II Olofsson, A., Danell, Ö., Åhman, B., Forslund, P. Carcass records of autumn-slaughtered reindeer as indicators of changing grazing conditions. (Manuscript, submitted to *Rangifer*).

III Olofsson, A., Danell, Ö., Forslund, P., Åhman, B. (*In press*). Monitoring changes in lichen resources for range management purposes in reindeer husbandry. *Ecological Indicators* (2011), doi:10.1016/j.ecolind.2010.12.015.

IV Olofsson, A., Danell, Ö., Forslund, P., Åhman, B. A model of herbivore-pasture dynamics and indicator responses with reference to reindeer husbandry (manuscript).

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1 Introduction

In pastoral systems the availability and abundance of good pasture are critical factors for production of the animals. In Sweden, reindeer (*Rangifer tarandus tarandus*) husbandry is an example of a common-pool pastoral system, in which several users share the resources within the 51 herding districts. The reindeer population size in Sweden has fluctuated between 150 000 and 300 000 during the last century (Sami Parliament in Sweden *et al.*, 2010; Statistics Sweden *et al.*, 1999; SOU 1983:67, 1983). The main driver of these fluctuations are believed to be variation in the productivity of the reindeer caused by fluctuations in pasture conditions (Couturier *et al.*, 2009; Helle & Kojola, 2008; Helle & Kojola, 2006; Klein, 1968; Tyler). However, delays in adaptation of herd size to changes in pasture conditions, caused by slow detection and social-economical factors, may exacerbate the fluctuations. The varying productivity creates an unstable economic situation for reindeer herders and an unstable cash flow in reindeer-dependent business areas.

Early warnings of changes in the grazing resources, together with sufficient understanding of the dynamics of the resource system, are essential to adapt management to the fluctuations. In a common-pool management system it is also important to generate accurate information that all resource users can rely on. Adaptive management is a decision support framework that involves monitoring of changes and systematic improvement of knowledge and understanding of the resource system dynamics (Walters, 1986).

This thesis is aimed to develop scientifically rational recommendations for improving and optimising the sustainable use of reindeer pasture resources by an adaptive management approach. Issues related to monitoring changes of grazing resources and the theoretical understanding of the (human)-pasture-reindeer system are addressed in this thesis.

2 Background

Reindeer and caribou (*Rangifer tarandus ssp.*) inhabit the circumpolar north and are important elements of people's livelihood in these regions. The Eurasian tundra reindeer (*R. t. tarandus*) is the only subspecies that has been domesticated. Northern Eurasia is inhabited by populations of both tame and feral tundra reindeer. In North America there are some domesticated tundra reindeer populations of Asian and European origin, while Iceland and Greenland host feral tundra reindeer populations. Most tame reindeer are herded in pastoral systems of various intensities.

2.1 Reindeer Husbandry in Sweden

In northern Sweden, reindeer husbandry is an economically and culturally important activity for the indigenous Sami people. Some of the land used for reindeer husbandry is governmentally owned and some privately owned. The access to land and water for Sami reindeer husbandry is based on rights prescribed from time immemorial and tied to membership of a herding community (Cramér & Prawitz, 1970). The ranges of each herding community are commonly governed. The Swedish term "sameby" encompasses both the herding community (as an institution) and the land used, here denoted as a herding district. In total, there are 51 herding districts with varying sizes and layout of ranges.

2.1.1 Governmental Regulations

Governmental regulation of reindeer husbandry is partly intended to ensure that the population density of reindeer in each district remains below a set maximum number (SFS 1992:1433, 2010; SFS 1993:384, 2010). The County Boards have the authority to control the reindeer numbers in the herding districts.

The maximum number of reindeer allowed for each district is based on judgements of how many reindeer the area can support in a long-term perspective through inventories of grazing ranges, historical information about reindeer numbers and how many reindeer other interests are expected to tolerate (SOU 2001:101, 2001; SOU 1966:12, 1966). In practice, this means that the maximum numbers of reindeer allowed has been rarely changed. In addition, the maximum number of reindeer is a very imprecise way to manage pastures.

The government also promotes high productivity of the reindeer herd, as opposed to high animal numbers, by providing subsidies for the meat produced, currently 14 SEK per kg meat from calves and 8.50 SEK per kg meat from older animals (Sami Parliament in Sweden *et al.*, 2010). Calf meat receives high support to promote the slaughter of a higher proportion of calves, in relative to the high proportion of adult males that are traditionally slaughtered. The intention is to increase the proportion of reproductive females and thus the productivity of the herd (SOU 1983:67, 1983).

2.1.2 Herding Communities and Districts

Within each herding community the reindeer owners are organized in reindeer herding firms. The number of firms in the herding districts ranged in 2009 from one to 89 (Sami Parliament in Sweden, 2010), while the number of reindeer owners per district ranged from 12 to over 400. For decision-making, each herding community has a board, elected at a general meeting of all community members (SFS 1971:437, 2010), that is assigned to lead the work, including management of the community's grazing resources, according to regulations and policies decided at the general meeting. The board can, if necessary, decide the maximum number of reindeer that an individual member is allowed to own (SFS 1971:437, 2010). In addition, the reindeer herders make daily decisions about their own herds.

Of the 51 herding districts, 33 are so-called mountain herding districts, in which the reindeer spend the snow-free period in the mountain areas of western Sweden and the winter season in the boreal forests further east in Sweden (Danell & Nieminen, 1999). In the mountain herding districts there are often long migrations between the seasonal lands. There are also 10 forest herding districts, in which (as the name implies), the reindeer stay in the forest area all year round (Danell & Nieminen, 1999). In these herding districts, the migrations between the seasonal lands are usually quite short. In addition, there are eight so-called concession herding districts in the area between the "Lappmarksgränsen" and the Finnish border. These herding districts are similar to the forest districts with respect to herding practises, but differ in legal rights to land (SFS 1971:437, 2010).

2.1.3 Seasonal Use of Grazing Resources

Reindeer usually migrate between seasonal ranges, selecting ranges that provide good forage and peaceful grazing. Important factors affecting habitat selection by reindeer include the weather, vegetation, disturbance by insects and human activities, predator presence, and natural or human-made obstacles (Briand *et al.*, 2009; Hins *et al.*, 2009; Vistnes, 2008; Kitti *et al.*, 2006; Mårell & Edenius, 2006; Skarin *et al.*, 2003; Johnson *et al.*, 2002; Rettie & Messier, 2001). In reindeer husbandry the herders' preferences of habitat are also important. Natural borders greatly ease herding, and possibilities to hunt and fish, accessibility by motorbike or snowmobile and closeness to home or herding hut are other important factors (Kitti *et al.*, 2006).

In spring (~April-May), females seek out areas where snow melts and vegetation growth starts early, for example southern slopes (Danell & Nieminen, 1997; Skjenneberg & Slagsvold, 1968). Females normally calve at the same time and same place year after year (Rettie & Messier, 2001; Skjenneberg & Slagsvold, 1968). During the calving period the females are very sensitive to disturbances, and may abandon their newborn calves if disturbed (Skjenneberg & Slagsvold, 1968). In mountain herding districts males may stay in the lowlands, where green forage appear earlier (Danell *et al.*, 1999a; Skogland, 1989; Skjenneberg & Slagsvold, 1968). During this time, the forage consists of a mixture of lichens, grasses, roots and leaves (Warenberg *et al.*, 1997; Skjenneberg & Slagsvold, 1968).

Early summer (~June) is a quiet period for both reindeer and herders. Reindeer now use open forests (birch forest in the mountains) and wetlands with early growth of palatable vegetation (Danell & Nieminen, 1997; Skjenneberg & Slagsvold, 1968). This is a period of recovery and consolidation for the reindeer, when they can rapidly regain weight lost during winter (Danell *et al.*, 1999b; White, 1983). Grazing conditions are generally good, with relatively cool weather and few mosquitoes and other insects. Through selective feeding reindeer are able to increase the digestibility of their ingested forage and their total dry matter intake, thereby considerably increasing their daily intake of metabolisable energy (White, 1983).

In summer (~June-July) reindeer graze in the higher mountains or on plains and heaths, where the wind makes heat and insects less troublesome

(Skarin *et al.*, 2010; Skjenneberg & Slagsvold, 1968). At the end of June or beginning of July herders gather the reindeer for calf marking. Reindeer are then often spread over waste areas and gathering them may take weeks depending on weather conditions (Skjenneberg & Slagsvold, 1968).

Early autumn (~August) is slightly cooler (especially at night) and disturbance from insects and mosquitoes declines. Reindeer now build up body resources prior to the coming winter (Skogland, 1989). Good grazing lands are birch forests and marshlands, where there is still good access to grass and herbs. Mushrooms, which are rich in protein and phosphorus, are also important foods (Kitti *et al.*, 2006).

In autumn (~September-October) the reindeer of mountain herding districts mainly graze in the lower mountains, while the vegetation withers and its nutrient content declines (Skjenneberg & Slagsvold, 1968). In forest herding districts, sparse forest and marshlands are still used. In the herding districts that have a separate bull slaughter, this takes place before the rutting period, which starts at the end of September. The males can attain weights up to 200 kg just before the rut, but much of their body resources are lost during the 2-3 weeks of rutting, when males are pre-occupied with gathering and fighting for their harems.

During early winter (~November-December) there is usually snow on the ground and the reindeer graze in forest and marshlands where they can still find green vegetation (Warenberg *et al.*, 1997; Skjenneberg & Slagsvold, 1968). When the snow cover deepens the reindeer gradually increase the lichen portion of the diet. The reindeer are gathered for main slaughter and separation into winter groups. After that, the winter groups migrate to their respective winter grazing areas. Sometimes, e.g. in places where traditional migration routes have been destroyed by infrastructure or other human activities, reindeer are transported by truck.

During winter (December-March) reindeer mainly graze in lichen-rich forest areas. Now the reindeer are herded more intensively, since winter lands are often close to sites of human activities and infrastructure. Reindeer mainly feed on various lichens and shrubs. Different types of forest stands are suitable for grazing, depending on snow conditions. Snow cover is usually deeper in open areas, and its depth generally increases with increasing distance from nearest tree (Lofvenius *et al.*, 2003). The snow easily becomes too hard to dig through in clear-cuts and open areas (Roturier & Roue, 2009; Inga, 2007; Kumpula & Colpaert, 2007). Thus, these pastures are preferably used in early winter, when snow cover is thin. A mere decimetre of hard snow is sufficient to prevent reindeer accessing pasture (Ryd, 2001). Older sparse forests are preferred as grazing grounds in mid-winter (Roturier

& Roue, 2009; Inga, 2007; Kumpula & Colpaert, 2007), depending to some degree on snow conditions (Roturier & Roue, 2009). In late winter ice crust is more common. Then old forests rich in aboreal lichens are essential. If there is insufficient access to aboreal lichen, the herders have to provide supplementary feed for their reindeer.

In the early spring (~March-April) reindeer still feed on lichens. The aboreal lichens are even more important at this time, since access to ground vegetation may be limited by early spring snow crust. The migration from winter to spring and calving ranges takes place during this period. The timing of spring migration varies, depending on the weather and snow conditions. Female reindeer migrate to their calving lands in lower alpine areas, while males tread more slowly if allowed (Loe *et al.*, 2006; Danell *et al.*, 1999a; Skogland, 1989; Skjenneberg & Slagsvold, 1968). In forest districts reindeer are also moved to their calving ranges in the forest area.

2.1.4 Competition with Other Interests

The total area used by reindeer husbandry is a sparsely populated region, inhabited by less than 10% of the human population in Sweden (Statistics Sweden, 2010), occupying about half of Sweden´s total land area (Lundqvist, 2007b). However, this area includes more than 40% of Sweden's productive forest area (Swedish Forest Agency, 2010). It is also an important area for tourism, mining and wind- and hydro-electric power generation (Lundqvist, 2007a). Thus, reindeer herders clearly compete with several other interests for use of their traditional land.

The reindeer herding area hosts large forests, in which and reindeer husbandry and forestry interests often conflict. The forest ranges are particularly important for reindeer during winter. The middle-aged and old forest stands are the most productive lichen areas (Čabrajić, 2009; Roturier & Roue, 2009). The introduction of forest cultivation, which started in the middle of the 20th century, has changed the conditions for reindeer husbandry. Berg *et al.* (2008) estimate that 30-50% of the good grazing grounds in the area they studied, in southern Norrbotten, was lost during the 20th century. Official statistics show that from the period 1993-1997 until 2005-2009 the coverage of forest stands older than 60 years has decreased by 15-19% in the three northernmost counties Norrbotten, Västerbotten and Jämtland (Swedish Forest Agency, 2010).

Other human activities like wind- and hydro-electric power generation, tourism, mining and nature preservation interest cause more or less permanent fragmentation and loss of land (Lundqvist, 2007a). In addition, several studies have shown that reindeer avoid grazing lands where humans are present if other choices are available (Nellemann *et al.*, 2010; Apps & McLellan, 2006; Skarin *et al.*, 2004; Vistnes *et al.*, 2004)

The reindeer herding area hosts most of the carnivore populations in Sweden, including brown bear (*Ursus arctos*), lynx (*Lynx lynx*), wolverine (*Gulo gulo*) and golden eagle (*Aquila chrysaetos*) (SOU 2007:89, 2006). Reindeer are a main prey for these carnivores and through extensive conservation efforts their population sizes have generally increased. It has been estimated that predation currently reduces meat production from reindeer husbandry by more than 50% (Danell *et al.*, 2009).

2.2 Management of Renewable Natural Resources

The ancient Greeks believed in natural harmony; that the nature was designed to support and provide the requirements of all animal and plant species. In such a belief system, natural catastrophes were regarded as punishments from the gods (Hixon *et al.*, 2002; Worster, 1996; Krebs, 1994). Even though the scientific understanding of ecosystems and evolution improved during the 18th and 19th centuries, the assumption that most populations are in equilibrium lingered into in the 20th century (Wu & Loucks, 1995). In the second half of the 20th century, however, it was fully recognized that no populations are stable, but rather parts of hierarchical and dynamic ecological systems. Thus, natural resources cannot be managed at the population level, instead a dynamic ecosystem perspective is required (Wu & Loucks, 1995; Grumbine, 1994).

2.2.1 Maximum Sustainable Yield

One of the most extensively used concepts in the management of renewable resource systems is the maximum sustainable yield (MSY), which is theoretically defined as the maximum possible catch that allows the population biomass to continue to regenerate (Folke, 2007; Milner-Gulland & Mace, 1998). The concept is based on the rationale that at intermediate population densities there are sufficient food resources and the stock is sufficiently large to maximize productivity. At this point, the harvest is maximal when only the annual production is harvested. However, Larkin (1977) heavily criticized the MSY concept, stating that it placed harvested populations at risk because of the simplifying assumptions underlying it (notably that it accounts for neither spatial variability of productivity nor for populations of other species in the ecosystem). Partly to address such criticism, in recent studies on harvests in marine environments, MSY models that incorporate varying forms of stochastic noise have been proposed (Bousquet *et al.*, 2008; Jensen, 2005).

2.2.2 Institutional Aspects of Resource Management

Sustainable harvesting of renewable natural resources in fluctuating environments requires flexible management institutions. The most appropriate institutional designs for common-pool systems have been heavily debated for at least 50 years. A key concept, introduced by Hardin (1968), is the "Tragedy of the commons", essentially the idea that users of a commons resource will not use the resource sustainably since they are in competition. He concluded that coercion is required to sustain commons in a long-term perspective, and proposed that two state-enforced arrangements could be used for this purpose: centralized governance or private ownership of the resources. This rationale was widely accepted, although there was very little empirical support for it (Feeny *et al.*, 1996; Feeny *et al.*, 1990). Indeed, self-governing institutions that provide sustainable management have often developed when humans use common-pool resources (Ostrom, 2005; Vollan & Ostrom). In addition, Clark (1973) showed theoretically that for both private property and commonly used properties (when there is high competition for resources), maximizing profits risks overexploitation of renewable resources. Designing management policies thus requires understanding of the stability, and factors that may affect the stability, of ecological systems as well as the institutional and social systems they are connected to (Clark, 1973).

All resources used by humans are embedded in complex, socio-ecological systems, composed of multi-layered subsystems that interact at various levels (Ostrom, 2009; Tyler *et al.*, 2007; Walker *et al.*, 2004; Walker *et al.*, 2002; Ostrom & Cox). Hence, the concept of social-ecological systems has been increasingly used to address the interdisciplinary problems of resource management. Furthermore, in the management of social-economical systems there has been increasing recognition of the importance of resilience, i.e. (in this context) the degree of stress the system can sustain and still remain in a given state, its self-organization capacity, and the capacity for learning and adaptation within the system (Folke *et al.*, 2002).

2.3 Adaptive Management

Adaptive management is a structured and iterative management process (Figure 1), key aspects of which are monitoring indicators, developing models of the system, incorporating observations from resource users and policy-makers, repeated evaluation and updating the understanding of system dynamics, and optimizing the decision-making in the face of uncertainty (Folke *et al.*, 2004; Walters, 1986; Walters & Hilborn, 1978). Monitoring system state variables is important for obtaining feedback regarding management actions, as well as detecting changes in system behaviour. The choice of indicators should be based on management policy goals and resource users' requirements (Carruthers & Tinning, 2003; Holling, 1978). The set of indicators used for monitoring the system should also be repeatedly evaluated (Holling, 1978).

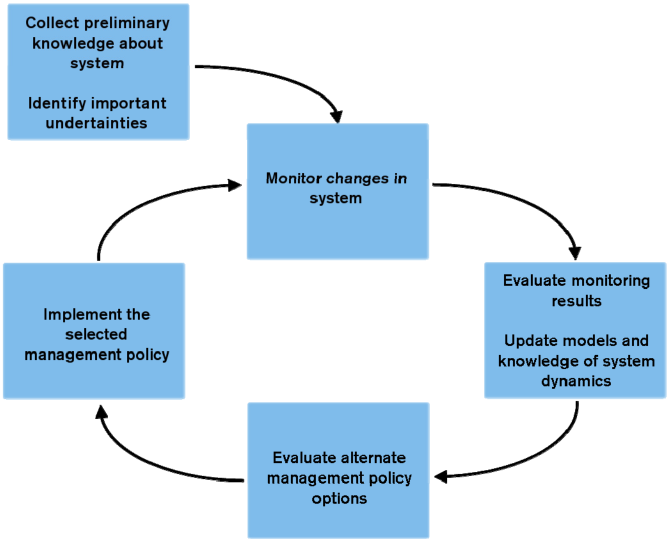

Figure 1. Schematic figure of the different phases in the iterative Adaptive Management process.

In an initial phase of adaptive management, models are useful for pinpointing uncertainties in the system (Walters, 1986). At this point, the purpose of model building should be to construct predictive models in order to focus on the most fundamental mechanisms of the system (Walters & Holling, 1990). Indicators should be included in models as variables, if their behaviour is important for the choice of management policy options (Holling, 1978). Advocates of this approach often recommend the use of so-called adaptive environmental assessment workshops to gather stakeholders and experts to help construct and test models of the system (Walters, 1986; Holling, 1978), which can be improved and simplified in later sessions. Ideally, several alternative models should be created, all of which can describe key aspects of the system. Workshops of this type should involve resource managers (with experience and understanding of the actual system), decision-makers (with responsibility for defining management objectives and options), research scientists from various disciplines and a modelling team (with knowledge of mathematical models and computational simulations) (Walters, 1986).

Predictions from the alternative models and monitoring results can be used to formulate and evaluate possible management policy options (Walters, 1986). Different users and managers are likely to have diverging management objectives, favouring varying goals and assigning different weights to long-term goals versus short-term advantages. The evaluation process can help to highlight whether or not different policy objectives can be harmonized in policy options or if they conflict too fundamentaly. Moreover, the process is important for finding policy options that can improve the understanding of system behaviour (Walters & Holling, 1990; Walters, 1986). The process can also bring clarity to different trade-offs and their consequences for different users and policy objectives. The policy optimisation process should preferably be supported by statistical estimations of outcomes, using Bayesian methods (Walters, 1986; Walters & Hilborn, 1978). An essential aspect of adaptive management is that the process of policy evaluation and optimization should be continuously repeated; using new understanding obtained from monitoring and experience.

2.3.1 Passive and Active Adaptive Management

There are essentially two approaches to adaptive management: the management actions may be chosen either solely according to the expected results in the current situation (passive), or according to both the expected results and the improvement in information the action is expected to deliver (active)(Lawler *et al.*; Walters, 1986; Walters & Hilborn, 1978).

2.3.2 Adaptive Management Across Scales

Adaptive co-management is a further development and an increasingly widely used approach for governance of social-ecological systems. Adaptive co-management combines the active, iterative learning processes from adaptive management with collaboration across social-ecological scales (Folke *et al.*, 2002). Thus, rights and responsibilities become jointly shared between institutions. Through the combination of adaptive management and cross-scale collaboration, different knowledge systems can be synthesized and used to support an approach to governance that embrace complexity and cross-scale linkages (Folke *et al.*, 2005).

2.3.3 Adaptive Management in Reindeer Husbandry

> We have some knowledge about how to live in a changing environment. The term "stability" is a foreign word in our language. Our search for adaptation strategies is therefore not connected to "stability" in any form, but is instead focused on constant adaptation to changing conditions. *Johan Mathis Turi, Reindeer Herder (Eira et al., 2009)*

The citation above indicates that reindeer husbandry is already practised in a manner that incorporates elements of adaptive management. Being heavily dependent on natural resources herders have always have had to adapt to changes in the resource they depend upon.

There are also various other examples around the world of indigenous groups whose traditional ecosystem management systems show similarities to adaptive management (Berkes *et al.*, 2000). The view of the environment, uncertainties and adaptation in reindeer husbandry are also similar to the adaptive management perspective, and thus may ease an eventual implementation of adaptive management.

3 Aims of the Thesis

The overall objective of the work this thesis is based upon was to develop scientifically founded recommendations for optimizing the sustainable use of reindeer pasture resources to be used in an adaptive management approach.

The specific aims were to:

- investigate the suitability of selected indicators of change in the reindeer-pasture system,
- determine how the selected indicators should be monitored to ensure that they are reliable and accurate
- create a dynamic model of the reindeer-pasture system with potential utility for evaluating effects of alternative management policies.

4 Summary of the Studies

This thesis is based on studies described in four papers, three of which focus on indicators for detecting changes in the grazing resources of reindeer husbandry. The possibility of using slaughter records to indicate changes in pasture quality of ranges used during the snow-free period is considered in Papers I and II. In Paper III monitoring of lichen height was proposed as an indicator of changes in the lichen resources, important components of the winter pasture.

In the study presented in Paper IV, my colleagues and I (hereafter we) developed a model for studying the dynamics of the (human)-reindeer-pasture system of reindeer husbandry. The model was designed to be adaptable for individual herding districts and used as a support tool in decision-making for management purposes.

4.1 Paper I

Paper I is the first of two papers that address possible uses of slaughter records to detect changes in body condition of the reindeer herd, and thus changes in pasture quality. It focuses on the relationships between reindeer body condition and carcass weight, conformation, fatness and size. The aim was to elucidate whether (and if so how) measurements of the carcasses of slaughtered reindeer can be to obtain accurate indications of changes in body condition. The official slaughter records provided information on the slaughtered reindeers' owners, herding district, slaughter plant, category (calf, female, bull or steer), EUROP classification of conformation and fatness, and carcass weight. Following three questions were specially addressed. Is body condition adequately reflected in all three carcass measures, weight, conformation and fatness? How should potentially confounding effects of skeletal size on the amount of body resources in carcass weight be accounted for? How can effects of variations in sex ratios of calves and age ratios of adults be differentiated from changes in actual body condition?

4.1.1 Materials and Methods

In this study we used records of 696 reindeer slaughtered on eight occasions in three slaughter plants from November 2002 to February 2003. The records included information on carcass weights and conformation and fatness classifications according to the EUROP scale. In addition, three body size measures (back length, jaw length, and radius length) were recorded for each reindeer. Moreover, carcasses of male and female calves were differentiated and yearlings were differentiated from older adults. Prior to statistical analyses of the results, the conformation and fatness classifications were transformed to quasi-normally distributed variables using a threshold model for calculating the expected value of the underlying variable in each class.

Initially, the relationships between carcass weight, carcass classifications and body size measures were assessed by Pearson correlation analysis. Then to further explore these relationships and their connection to body condition and body size the common underlying dimensions of the variables were identified by Principal Component Analyses (PCA). Using structural equation models (SEMs) we analyzed how the latent variables (body condition and body size) interact, and how they affect our measurement variables (carcass conformation, fatness and weight, and the three body size measures). We constructed two SEMs, one based on all data (SEM-I, Figure 1 in Paper I) and one simplified (SEM-2; Figure 2 in Paper I). To investigate the potential for improving the precision of carcass weight records by adjusting for body size, reproductive status (only adult females), sex (only calves) and age group (yearling or adult) we used linear regression models with carcass weight as the dependent variable and herding district, slaughter period (November-December or January-February), one slaughter measure, reproductive status and sex or age as independent variables.

4.1.2 Main Findings

The SEM-I analyses showed that body condition positively affected the body size of calves, but no covariances were found between body condition and body size in female yearlings or adults, and a negative covariance was found in male yearlings. Thus, body size was confounded with body condition in calves, but not in female yearlings and adults. Furthermore, both conformation and fatness were strongly affected by body condition, although the effects of fatness varied considerably. The models explained 65-99% of the variance in conformation score and 13-72% of the variance in fatness score. Body condition had the least effect on fatness scores of male yearlings, which we suggested may be due to their low energy intake during the preceding rutting period. Since conformation and fatness were well explained by body condition, and also had strong associations with weight and body size-adjusted weight, these classifications should preferably be included when estimating body condition from carcasses.

Carcass weight was the measurement variable least affected by body condition in all animal categories except male calves. Carcass weight was more affected by body size than by body condition in calves and male yearlings. However, body condition and body size jointly explained 78-94% of the variation in carcass weight. In all categories, the three body size measurements were affected by body size, and in male calves the best model also connected body condition to radius length. Neither the SEM-I nor SEM-II models indicated any general grading of the three body size measurements, although radius length had the highest degree of explained variance in all models.

Regression analyses of carcass weight showed significant effects of discrimination both between female and male calves and between female yearlings and adults. The residual standard deviation (SD) of weight was reduced by 36% when discriminating between female and male calves. Discrimination between female yearlings and adults reduced the SD with 15%. All body size measures were significantly associated with weight and explained similar amounts of the variation of the data, except for female yearlings, for which jaw length was not significant. Adjusting weight for body size, by including the body size measures in the model, reduced the residual SD of weight by up to 33%. The study showed no significant effects of either the slaughter period or the reproductive status of females.

4.2 Paper II

The study presented in Paper II focused on dynamics of long-term variations in body condition of reindeer. The aim was to further elucidate the prospect of using data from slaughter records as indicators of long-term changes in the body condition of reindeer in the autumn. Towards this end this we addressed the following questions. Are long-term trends in carcass quality detectable in commercial slaughter data? Can carcass records serve as reliable indicators of general changes of animal condition in a reindeer herd? How do reindeer population density and the time of slaughter affect the results and should these factors be taken into account when analyzing the data in an adaptive management context?

4.2.1 Materials and Methods

In this study we analyzed data from the commercial slaughter of reindeer in Sweden from 1994 to 2007. In addition to carcass weight and classifications, the records include information on the date of slaughter, reindeer ownership, herding district, and animal category for each slaughtered reindeer. There were four animal categories (calves, adult females, adult bulls, and steers), but in the statistical analyses bulls and steers were merged and classified as ‘males’. The discrimination between calves and adults was based on maturation stage of the skeleton, according to herders sometimes results in immature yearlings being classified as calves.

In order to capture the main slaughter season data from September were selected for males and data from October to December were selected for females and calves. Prior to the statistical analyses the fatness and conformation classifications were transformed into quasi-normal distributions to enable them to be analysed as normally distributed variables. To assess population densities and herd structure each herding district, we used information on the number of reindeer in the winter stock of each reindeer owner.

To analyze how herd and time factors affect the carcass measures we used generalized equation estimation (GEE) models that assumed data to be correlated within herding district and year. One model for each of the three carcass measures and each of the three animal categories was developed. Independent variables were year, slaughter time (week during the slaughter period), herding district, relative population density, calf ratio at slaughter, and proportion of females in the herd.

4.2.2 Main Findings

All three carcass measures were significantly affected by year, and these effects were strongly correlated between the three animal categories within carcass measure (Table 1). The strong correlation between year effects among the three animal categories shows that factors varying between years affect the whole herd. Additionally, we found significant positive trends in carcass weight and fatness of all animal categories, and a positive trend in male conformation. These findings indicate that trends over time are detectable in the slaughter data, which is encouraging from a monitoring perspective.

Several of the investigated independent variables significantly affected the carcass measures and should thus be accounted for when using carcass data as indicators of long-term changes in pasture conditions. Slaughter date had significant, but opposite, effects in females and calves; generally females gained body resources from October to December, while calves lost resources. Reindeer population density negatively affected female and calf, but not male, body resources. The effects of herding districts were similar for calves and females, but differed between females and males. This may be explained by variations in slaughter selection between districts, timing of slaughter or feeding ranges between animal categories. Uncertainties in the discrimination between calf and yearling carcasses may also contribute to variation between years and districts.

Altogether, the similarities in year effects between animal categories support the notion that carcass data could be suitable indicators of animal condition in the living herd.

Table 1. *Pearson correlations of the estimated effects of year on carcass weight (CW), conformation (Conf) and fatness (Fat) for calves, females and males.*

	Calves			Females			Males		
	CW	Conf	Fat	CW	Conf	Fat	CW	Conf	Fat
Calf CW	1.0								
Calf Conf	0.4	1.0							
Calf Fat	0.7^{**}	0.4	1.0						
Female CW	0.7^{**}	0.6^{*}	0.5	1.0					
Femal Conf	0	0.6^{*}	0.1	0.7^{*}	1.0				
Female Fat	0.7^{**}	0.4	0.9^{****}	0.7^{**}	0.3	1.0			
Male CW	0.9^{****}	0.1	0.5	0.6^{*}	0	0.6^{*}	1.0		
Male Conf	0.6^{*}	0.6^{*}	0.3	0.7^{**}	0.6^{*}	0.5	0.5	1.0	
Male Fat	0.7^{**}	0.5	0.8^{**}	0.5	0.2	0.7^{**}	0.7^{**}	0.4	1.0

Significances: **** $P<0.0001$, $^{***}P<0.001$, ** $P<0.01$ and. $^{*}P<0.05$.

4.3 Paper III

This paper presents a method developed for obtaining indications of changes in lichen resources based on monitoring of changes in lichen height. The method was based on results in a previous study (Moen *et al.*, 2007), where lichen abundance was estimated by measurements of lichen height alone. This method provided a useful approach but required further development to be suitable for repeated monitoring of changes in lichen abundance over larger areas.

The aim of the study presented in Paper III was to identify ways to monitor lichen height repetitively in order to obtain robust indications of the directions and rates of change in lichen resources in the reindeer herding districts.

4.3.1 Materials and Methods

Information was gathered from 31 sites in northern Sweden, at altitudes ranging from 170 to 250 m a.s.l., selected to represent a wide variety of grazing sites for reindeer in lichen-dominated boreal forest. The sites were all located in winter ranges within the reindeer herding area, except for two (ungrazed) sites further south. All the sites within the reindeer herding area were regularly grazed by reindeer during winter. The sites were selected to ensure that forest stands of varying ages were represented and the composition of the ground and field vegetation layer varied between forest stands within sites.

The height of mat-forming lichens (mainly *Cladina* and *Cetraria spp.*) was measured with a specially designed tool, a ruled rod, and a circular plate that is lowered down to rest on the highest lichen thalli. In order to estimate the lichen biomass-height relationship, its height was measured at randomly selected points, and its coverage was estimated in circular areas around each point, then lichen biomass within the circles was collected and dried and weighed.

For analyses of small- and large-scale spatial variations, lichen height was measured along of 20 m and 100 m transects, respectively. In the large-scale sampling, 2-4 transects were used in each forest stand. At all sites but one, forest stands of more than one forest age class were represented. The choice of additional data to be recorded within each site focused on factors that might change over time and thus cause changes in the lichen abundance, independently of grazing pressure. More specifically: the age of each forest stand was categorized in the four non-contiguous age classes; the density of the forest along each transect was estimated by measuring the stem basal area (m^2/ha); and to elucidate the effect of moisture on lichen height, lichen density and moisture level (water content) were recorded subjectively at one site.

Small-scale spatial autocorrelations (over distances of 0.1 to 20 m) were analyzed to determine the least distance between measurement points that can be used without risk of losing information due to dependence between neighbouring measurement points. Large-scale autocorrelations (up to 1000 m) were also analyzed to elucidate how spatial patterns should be considered when choosing measurement sites and deciding of the distribution of measurement points. The statistical power for detecting mean differences, assuming three different lichen height standard deviations was also calculated to obtain indications of how many measurement points are needed within an area.

A mixed linear model was used to analyze how forest stand characteristics, lichen density and study site affect lichen height. The measurement points were assumed to be spatially autocorrelated within each sampling transect and a binomial regression model was used to determine which factors affect the lichen coverage.

Three types of regression models (ordinary linear regressions, linear regressions through the origin, and geometric mean regressions) were used to estimate the relationship between lichen height and lichen biomass. A linear mixed model was used to analyze the effect of moisture on lichen height.

4.3.2 Main Findings

The small-scale autocorrelation analyses showed that autocorrelation in lichen height disappeared within a distance of 4 m at all the investigated sites. Thus, a minimum distance of 4 m between points is sufficient to avoid autocorrelated measurement points. Power analyses showed that the number of measurement points needed for detecting a change of 5 mm with power 0.95 ranged from 200 to 2000, depending on the variation in lichen height within the area. These findings imply that if data are collected along transects with 4 m between points, the total length of the transects would need to be 800 to 8000 m, depending on lichen height variation within the area. The variation in lichen height was, however, correlated with lichen height, and thus generally larger in thicker lichen mats. Therefore, in a thicker mat with large variation it might be possible use fewer measurement points with lower statistical power to the relatively large changes.

A significant positive relationship between lichen height and lichen biomass was found, irrespective of the regression model applied. Geometric mean regression of these data indicated that lichen biomass increases by 11-17 g m^{-2} per millimetre increment in lichen height. Since the results are based on a functional relationship between height and biomass, it can be assumed that the relationship is consistent even when mean heights (i.e. including coverage) are used.

Lichen moisture (water content) was shown to affect the measured lichen height positively; moist lichen was 9 – 11% taller than dry lichen.

Our results also showed that forest stand structure has significant effects on lichen height. Generally, there was a negative relationship between lichen height and basal area, but at some sites the relationship was positive. Middle-aged forest stands (40-60 y) were found to have the shortest lichen, but the greatest lichen coverage.

The choice of area to manage (management unit) is naturally highly significant, and homogeneity in both geographical features and use of the area is preferred. The results showed there were significant variations in large-scale spatial variation between study sites. In an area with large spatial variation precision could be gained by splitting the area. Since gradual changes occur in the forest and vegetation within managed areas, variation in lichen height within an area might also change over time. Therefore, it is important to regularly re-consider the size of the managed areas as well as the distribution and number of measurement points. It is also relevant to evaluate how forest stand characteristics change when interpreting monitoring results, since they may affect interpretations of, and responses to, changes.

4.4 Paper IV

The fourth paper focuses on reindeer-pasture dynamics. The aim of the study it presents was to develop a general model of the system with potential capability to improve theoretical understanding of the dynamics of the local reindeer-pasture system following adaptation to the circumstances in a particular reindeer herding district. In addition, we applied the model to certain type situations to validate it.

4.4.1 Model Description

The model is composed of three interacting modules (Figure 2) formally depicting winter pasture, the reindeer energy budget and reindeer herd dynamics (designated the Lichen, Energy and Herd modules, respectively).

The Lichen module models the status, growth and grazing of lichens and pasture availability on winter ranges. The module is time-discrete with two time steps per year: the snow-free period when lichen is growing, and the winter period when lichen ranges are grazed by reindeer (Paper IV, Figure 2). The lichen ranges within the considered herding district are treated as a single lichen area with no spatial variation, i.e. with even growth and grazing pressure. Lichen growth is assumed to approach logistic growth, and growth rate includes a stochastic component in stochastic simulations.

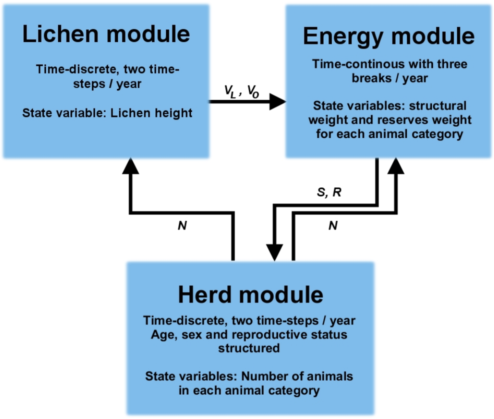

Figure 2. A schematic figure showing how the three modules of the developed model interact. *N* is a matrix of herd structured herd sixe, V is the amount of winter forage available per reindeer in each category, (subscripts differ between lichen (*L*) and other (*O*) forage) and *S* and *R* are structural and reserve mass, respectively, of reindeer in each category.

The Lichen module provides the Energy module with the available feed in winter pastures in terms of average available lichen and other winter feed per day during the winter. The availability of winter pasture is affected by a variable representing varying snow-conditions. In the deterministic simulations this variable is static while it is a random variable in the stochastic simulations. Other feed (for example shrubs, and withered grasses and herbs) is assumed to always be present, and unaffected by reindeer grazing. Reindeer are provided a lichen intake equivalent to 90% of their metabolisable energy requirements and lichen resources are reduced accordingly. Lichen is assumed to be utilizable when its height exceeds the minimum threshold (i.e. a mean lichen height of 0.3 mm). When the availability of utilisable lichen is declining, the proportion of other feed is increased.

The Energy module is a time-continuous energy budget model simulating energy intake and expenditure of reindeer within each of three seasons: spring/early summer, summer/autumn and winter. The model is structured by age, sex, and reproductive status in 26 categories of reindeer and returns structural and reserve body masses for average individuals of each reindeer category to the Herd module.

The availability of winter pasture is retrieved from the Lichen module, while available pasture during the snow-free period is simulated as an amount per individual using a sinusoid function directly in the Energy module. The intake of pasture during the snow-free period is assumed to decrease with increasing stocking rate according to the feeding level concept. In stochastic simulations the feeding level has a stochastic component. Food intake is also dependent on forage availability and the individual's structural body mass. Furthermore, the reindeers' appetite is reduced with increases in the reserves' proportion of body mass. Energetic costs for the reindeer include maintenance and growth, for all categories, plus pregnancy and lactation costs for reproductive females.

The Herd module projects the reindeer herd size and structure in two time-steps per year. Reindeer are structured into the same classes as in the Energy module. Time-steps of the Herd module have been chosen to match the routine events in reindeer husbandry during which reindeer can be counted. At these two points in time the Herd module provides the Lichen and Energy modules with information about herd size and structure.

Winter, spring and early summer survival rates, together with numbers of calves born and early calf survival, are calculated at a calf marking event set to July. Both survival and calf production rates are dependent on reindeer body condition, calculated from the relationship between the reindeers' structural and reserve masses, which are retrieved from the Energy module. Survival from calf marking until autumn slaughter, which is also dependent on body condition, is calculated at a slaughter event, set to occur in November. At this point slaughter outtake is calculated.

The selection of animals for slaughter is based on a combination of proportional and threshold harvesting, in which it is assumed that the manager has full knowledge of the actual herd size and structure. Set proportions of male calves and older males are slaughtered each year and the numbers slaughtered are adjusted to preserve a predetermined proportion of males in the herd. All 10-year-old females are slaughtered as well. If the herd size is still too large after this, scaled proportions of female calves and 1-9 year old females are slaughtered, so that the desired herd size is reached.

Output variables are the indicators suggested in Papers I-III (carcass weights and lichen height), complemented with calving results, herd size and total meat production.

In order to validate the model against empirical knowledge about the reindeer husbandry system, three type-cases of reindeer herding districts were simulated (limited snow-free and good winter resources, good snow-free and limited winter resources, and limited snow-free and winter resources). For each type-case nine scenarios with different target population densities were used and both deterministic (one simulation over 155 years) and stochastic simulations (100 replicates over 55 years) were carried out. All simulations started from the same herd size.

4.4.2 Main Findings

The general weight development generated by the model was consistent with empirical knowledge and the predicted carcass weights were in accordance with the range of carcass weights found in slaughter records.

At high stocking rates in the two scenarios with limited snow-free pastures, fecundity became too low for the herd to produce sufficient female calves to maintain population growth and the target herd sizes could not be reached. Comparison of the scenarios with good snow-free/limited winter pastures and limited snow-free/good winter pastures showed that higher carcass weights and lower calf production were generally projected for the former than for the latter, during the last year of simulations. Thus, reindeer were actually projected to become smaller, but still could have sufficient body resources to produce calves, a conclusion supported by empirical knowledge. In the scenario with limited snow-free and winter pastures the model projected more severe effects of depleted lichen at higher stocking rates, which is not an unlikely outcome in reality.

Stochastic simulations for all type-case herding districts showed that risks of lower production increased with increases in target herd sizes, even if most cases gave high production. In reality, such an effect may result from disturbances, for instance warm weather and insects, that cause reindeer to gather in undisturbed areas and thus further increase stocking rates in these areas.

Overall, it was concluded that the model captured important mechanisms of reindeer-pasture system dynamics and seemed to provide an appropriate first step towards the development of locally adapted models. Since further empirical knowledge is lacking, further adjustments without empirical feedback would probably increase the complexity of the model without providing compensatory improvements.

5 General Discussion

Since pasture is a key requirement for any pastoral system, access to pasture and its abundance are two of several potentially limiting factors for reindeer husbandry in Sweden. In order to manage natural renewable resources such as reindeer pastures sustainably, it is essential to detect changes in them at an early stage and adapt their management accordingly. Thus, the aim of this thesis, and the underlying studies, was to identify ways in which adaptive management could be applied to pasture resource management to facilitate reindeer husbandry in Sweden. Two possible indicators of changes in the grazing resources, and possible ways to monitor them, have been identified. In addition, a dynamic model has been developed that could provide a useful tool for interpreting monitoring results, after adaptation to the conditions of specific herding districts.

5.1 Managing Change

Due to the complexity of most social-ecological systems, understanding and prediction of their behaviour is inevitably subject to large degrees of uncertainty. Accordingly, reindeer husbandry is a sub-system that is strongly influenced by other social-ecological systems of varying scales (Moen & Keskitalo, 2010). Notably, diverse human activities affect reindeer husbandry across a wide variety of temporal, spatial and social scales, for example the construction and use of recreational facilities, forestry and conservation of carnivores (Moen & Keskitalo, 2010; Danell, 2005). Climate change is a large-scale factor that may also profoundly affect it (Heggberget *et al.* 2002; Lawler *et al.*, 2010; Tømmervik *et al.*, 2005). Thus, when reindeer management policies and decisions are formulated, factors spanning several social-ecological scales should be considered.

Historically, the Sami-reindeer relationship has proven to be resilient and adaptable to changes (Moen & Keskitalo, 2010; Danell, 2005). However, this might not continue in the future, since for example ongoing land fragmentation and losses may deprive reindeer herders of the buffering capacity that is a key element of the resilience and flexibility of their resource use (Moen & Keskitalo, 2010; Danell, 2005).

The possibilities of reindeer herders to influence management within other social-ecological scales (i.e. possibilities to influence actions of competing interest groups) are limited (Moen & Keskitalo, 2010; Widmark & Sandstrom, 2008). Moreover, their influence on the maximum allowed reindeer levels is very limited. The numbers have been static during the last half century, even though they are supposed to be partly based on biological factors. The non-existing re-evaluation of numbers indicates that the interpretation of the maximal guidelines is consistent with the simple, and now heavily criticized, concepts of maximum sustainable yield and carrying capacity. At present there are no indications of general over-grazing of reindeer pastures (Moen & Danell, 2003), but that is no insurance for the future. If the fragmentation and loss of grazing land continue, eventually the grazing resources will be overused, at least in some areas. On the other hand, there might be other areas with capacity to hold higher reindeer densities than today. Implementation of an adaptive management approach to reindeer husbandry may prevent such mismatches.

The biological resource system of reindeer husbandry is not fully understood, and neither are the mechanisms involved in its linkages with the rest of the social-ecological system. Thus, there is a large amount of uncertainty to handle when formulating management policies. Uncertainty and differing management objectives may delay necessary management actions, and hence probably magnify the effects of changes. Thus, it is important to develop a management framework with set rules for handling uncertainties and changes, embedded in flexible institutional arrangements adapted to govern changes.

The focus of this thesis and the underlying studies has been on the reindeer husbandry per se, and the application of adaptive management at a herding district level. Thus, the primary concerns have been limited to the biological resource system. However, it should be remembered that the holistic social-ecological perspective cannot be omitted from management policies.

5.2 Indicators

In the studies underlying this thesis the potential utility of two types of indicators has been investigated: slaughter data and lichen height measurements. These indicators may not be ideal choices for all herding districts and circumstances, and there might be a need for complementation with additional indicators. I suggest and discuss some examples of possible indicators below. Burkhard and Müller (2008) have also proposed several indicators for reindeer husbandry at national or larger levels that may provide additional inspiration regarding relevant indicators at herding district levels (the levels at which indicators should ideally be selected, since circumstances differ from district to district). Indicators that are intended for use by reindeer herders should reflect processes that are relevant for the herders, and they should also be utilisable by herders if they are to be used in practice (Carruthers & Tinning, 2003).

5.2.1 Carcass Measures

An advantage of using commercial carcass measures as indicators is that the procedure for recording data already exists. Slaughter records also show good prospects for indicating the general body condition of the reindeer herd (Papers I & II). The body condition of reindeer is affected by grazing conditions, especially during the snow-free season when body resources are gained (White, 1983). Thus, the indicators of body condition should reflect changes in pasture quality and grazing conditions during the snow-free period. However, although this connection seems intuitively sound, it has not been confirmed in the studies this thesis is based upon.

The results presented in Paper I showed that all three of the routinely recorded carcass measures — weight, fatness and conformation — are linked to body condition (and hence nutritional status) of the reindeer. They also showed that male yearlings slaughtered after the rut differed considerably in body condition from females and calves. However, results presented in Paper II indicated that there are strong similarities in patterns of between-year variations in carcass measures of calves, females in late autumn and males in September (before the rut). Similarities in long-term trends for the three animal categories were also found, supporting the assumption that some factors affect all reindeer categories in a very similar manner, even though they are slaughtered during different time periods. It is possible that large year-to-year variations mask long-term changes in individual districts, but overall it can be concluded that carcass measures have high potential as indicators of the body condition status of the reindeer herd.

5.2.2 Lichen Measurements

Paper III sketched a plan for monitoring changes in lichen resources, involving measurements of lichen height at appropriately spatially distributed points, from which the frequency of measurement points where lichen is present (points with lichen height > 0), also provide a coverage measure.

The method showed high potential for obtaining indications of changes in lichen resources, since it could detect differences in both lichen height and cover. It also proved advantageous for monitoring changes in the lichen resource over large areas, since it captured spatial variation with relatively little effort. Thus, it could be a useful tool for management of the lichen resources in reindeer husbandry.

5.2.3 Other Possible Indicators of Changes

Complementary indicators considered in Paper IV are calving data (Bonenfant *et al.*, 2005; Gerhart *et al.*, 1997a; Gerhart *et al.*, 1997b; Skogland, 1985). Pregnancy and early calf survival rates are strongly influenced by female body condition at both mating and parturition times (Skogland, 1985; White, 1983).Hence, they can provide good indications of general pasture conditions during the year. Calving data could be acquired through pregnancy tests, records at birth (if the reindeer calve in pens), aerial photography in the weeks subsequent to parturition (Danell, 2011), and/or records collected at calf marking. Some of these methods are invasive, since they would require extra handling of reindeer, but they may still be feasible. Indeed, calving data are already used in Norway as indicators when deciding levels of population sizes in reindeer husbandry (Norwegian Ministry of Agriculture and Food, 2008).

Since reindeer-pasture dynamics are interactive elements of a sub-system of larger social-ecological systems, several non-biological factors might also be worth monitoring. Depending on the factor and situation, the results from monitoring non-biological indicators could be used either to adjust results related to the biological indicators or for understanding and interpreting biological monitoring results. The particular types of information that would be most relevant to consider need to be decided within the individual reindeer herding districts.

The reindeer herders are components of the managed system and the efficiency of different management procedures in reindeer husbandry also affects reindeer body condition. However, these effects may be confounded with the effects of variations in pasture conditions, especially if practices change slowly over time and the changes are not recognised by the herders. Therefore, measures of the efficiency of various aspects of reindeer husbandry could also be usefully recorded (e.g. the length, time and number of migrations and gathering processes, or the time consumed by procedures during gathering occasions). Disturbance from other human activities also affect reindeer pasture and reindeers' use of ranges, hence it may be relevant to monitor indicators of such disturbance too.

In addition, climate and weather affect reindeers' use of ranges in several ways. Snow conditions, for example, strongly influence their use of winter ranges (Roturier & Roue, 2009), while summer temperatures affect insect disturbances and (hence) reindeer use of summer pastures (Skarin *et al.*, 2004; Skarin *et al.*, 2003). Moreover, lengths of seasons and pasture growth are dependent on climate and weather. These factors cannot be influenced by herders, but understanding them may improve understanding of the fundamental dynamics of the reindeer-pasture system. Thus, measurements of indicators of climatic variability may be beneficial.

Finally, knowledge of local predator populations might be important in order to adapt management actions in districts where they significantly affect population growth and use of grazing ranges. Official numbers of predators might not be sufficient, and if so other indicators would have to be found. It may be possible for herders themselves to monitor predator presence at local scale.

5.3 Design of Monitoring Programs

Any monitoring program must be appropriately designed in order to obtain accurate indications of changes in any resource, or any variable of interest. In this context, the monitoring should preferably be designed at herding district level, since the general management policy decisions are settled at this level. However, some herding districts overlap, and in these cases monitoring efforts should preferably be shared between herding communities and thus designed to cater for such sharing.

5.3.1 Defining Management Units

When designing a monitoring program, an obvious preliminary task is to define the management units (i.e. the subareas of the herding district within which the same management treatments should be applied). In this context, the changes in grazing resources in response to use of the lands are the key aspects of interest, since the use of grazing lands can be actively adjusted to detected changes, and better knowledge can be gathered about reindeer pasture dynamics. Thus, the management units have to be relevant from the perspective of resource use. In reindeer husbandry the reindeer usually use more extensive ranges during the snow-free period than during winter (especially in mountain herding districts), thus the management units for the snow-free pasture have to cover greater areas than the resources used during winter.

Carcass characteristics have been proposed here as indicators of the pasture conditions in the extensive ranges used during the whole snow-free period. These are relatively large spatial and temporal scales to be covered by a single management unit, but they are relevant for the purpose. However, if reindeer are separated into groups even during the snow-free period, or parts of it, it may be relevant to divide the area into smaller units. A way to gain understanding of the interactions among the dynamics of the different units within the snow-free pastures is to set up well-defined experiments (manipulating the use of ranges) and evaluate the effects of the treatments on the indicator variables (Lawler *et al.*; Walters, 1986; Walters & Hilborn, 1978).

Lichen height has properties as an indicator that, theoretically, do not impose either minimum or maximum constraints on the size of management units (Paper III). Since homogeneity improves accuracy there might be an optimum range of sizes that represents a realistic trade-off between accuracy and the number of measuring points. However, this range will be dependent on the spatial variation in lichen height in the area. From the range-use perspective, the use of winter resources is spatially more fragmented, and thus requires more differentiation of management units. The area defined as a unit has to be used evenly, i.e. the number of reindeer grazing days and time period when it is used has to be fairly constant. Thus, it might be rational to initially evaluate core areas as management units. If lichen abundance in a core area is known or suspected to have large spatial variation, accuracy might be gained by splitting the area.

5.3.2 Improving Accuracy of Slaughter Records

There are already routines for collecting carcass measures, but there is room to improve their reliability as indicators of body condition in the herd. Notably, to improve their accuracy, more correct and narrower differentiations of animal categories than those currently applied are required (Papers I and II). Moreover, animal categories that are rarely slaughtered should preferably be excluded, since they cannot be assumed to be representative samples of the population.

Another problem is that small, undeveloped yearlings may be classified as calves at slaughter (Paper II). To ensure that correct indications are obtained from calf slaughter records it is essential to differentiate between calves and yearlings correctly. In addition, differentiation between female and male calves is highly desirable (Paper I), since (for example) in the absence of such differentiation an apparent change in body condition detected in statistical analyses may really be due to a change in the ratio of male to female calves that are slaughtered (Paper I). The same consideration applies to animal categories that span several age classes with differing mean weights, thus it is desirable to at least separate yearlings from older animals or to adjust weight for body size (Paper I). Conformation and fatness classifications, however, were only weakly related to body size of adults (Paper I), and may thus be more reliable when some adults have not been correctly classified.

Another important step towards obtaining correct indications is to adjust data to account for confounding factors. For example, when using carcass measures as indicators of long-term changes, the within-season variation in carcass measures must be considered. Otherwise, effects of differences in slaughter dates may be confounded with the effects of other between-year variations. Results presented in Paper II illustrated general trends within the slaughter season for calves and females, notably that calves lost resources while females gained body resources. However, the effect of time within season may differ between districts. In addition, the effect of reproductive status, i.e. whether or not a female had a calf in the last season, may also be confounded with pasture effects on all three carcass measures. If there is accurate information on the reproductive status of slaughtered females it might be useful for improving the accuracy of body condition indicators, although the study presented in Paper I did not confirm this hypothesis.

5.3.3 Ensuring Accuracy in Lichen Monitoring

A fundamental requirement for obtaining accurate results from statistical analyses is that the data must be representative, i.e. randomly but sufficiently frequently sampled. To ensure that representative data are obtained when measuring lichen height, it is important not to choose the measurement points subjectively. One way to ensure this is to locate measurement points along previously decided geometrical lines or patterns, like transects or sampling grids. To obtain representative samples for a whole management unit, the points should be well-distributed over the management unit area, covering all main plant communities containing lichen. To cover possible directional spatial variations within the area, the measurement points should ideally be distributed in a two-dimensional pattern (Paper III), like triangles (Linden *et al.*, 1996). If measuring points are too close together, there are risks of autocorrelation and loss of efficiency of the statistical analyses. Thus, as concluded in Paper III, a minimum distance of 4 m between neighbouring points is recommendable. It is also essential to have a sufficient number of measurement points to ensure there is adequate statistical power to detect the intended magnitude of change (Paper III).

Results presented in Paper III also show that lichen height is affected by the moisture level of the lichen. Hence, to avoid weather effects confounding effects of more permanent changes in the lichen resource there are two alternatives. The easiest is to always take the measurements during times with similar weather conditions. If this is not possible, the moisture level of the lichen should be recorded during measurements, and included as a factor in the statistical analyses. Thus, it is important to evaluate, and clearly state, how lichen moisture should be treated in any lichen monitoring plan.

Pertinent factors within sites that vary over time should also be considered in the monitoring plan; not necessarily to adjust data to account for variations in them, but to analyse their effects in order to improve understanding of the dynamics. In forested areas, the forest stand structure is an essential factor to consider. In the study described in Paper III we used forest age classification and basal area as variables representing forest stand structure, and these proved to significantly affect lichen height. An alternative to basal area, considered for instance by Čabrajić *et al.* (2010), is site openness.

5.3.4 Analyzing Monitoring Results

The statistical analyses are important in order to get reliable results from monitoring. In addition to use of robust, accurate data, it is also essential to apply appropriate statistical analyses in order to get reliable results from monitoring. Thus, the choices of statistical models should be thoroughly considered.

An essential aspect to remember when using simple descriptive statistics like means and standard deviations is that in order to test their significance they must be obtained from continuous, normally distributed variables. Thus, these kinds of statistics cannot be used to detect significant changes in class variables like carcass conformation and fatness, without first transforming the variables into quasi-continuous scales (Papers I and II). However, more advanced statistical analyses, do provide methods that are adapted to such types of data, for example generalized linear models.

In addition, data from consecutive years should not be assumed to be independent from each other when analysing results from long-term monitoring in cases where data have been repeatedly obtained from the same material over several years. Thus, statistical models used for analysing trends and year-effects have to include a covariance structure for the error variables that accounts for autocorrelation between measurements. Otherwise, the results significance tests may imply incorrect. The same consideration applies to spatially repeated measurements (e.g. from lichen monitoring).

Regression models, which were frequently used in the studies underlying this thesis, have great potential for analysing monitoring results. Furthermore, regression methods are available for handling most kind of data distributions, and several co-variance distributions of error terms to choose from.

In Paper I, structural equation models (SEMs), which are kinds of factor analysis models that are suitable for confirmatory testing of theories about explanatory relationships between indicator variables and unobservable (latent) variables (Raykov & Marcoulides, 2000), were used to analyse the latent variable body condition and relationships between body size and body condition. Advantages with this method are that it includes measurement errors and can evaluate complex relationships between variables. A disadvantage is that at least 100 observations are recommended for accurate results.

Various Bayesian statistical approaches have also been suggested for analyses of monitoring results (Nikolov *et al.*, 2007; Clark, 2005; Wintle *et al.*, 2003). Bayesian approaches have great potential to deal with uncertainties and complex relationships, and afford the possibility to include prior information in constructed models.

5.3.5 Beyond Indicators

Monitoring changes should not rely solely on indicators. Essential complements are workaday observations of the system, common sense and understanding of the resource system. One reason for this is that no indicator of change in a resource system is absolute. There will always be changes that are not detected by indicators, even indicators designed to be as general as possible. Thus, observations from resource users are important complements. People that have good understanding of the system, and spend time dealing with the resource system, have good opportunities to discern changes and features of the system that are hidden from others and undetectable by the indicators. Such observations should be exploited by using them to improve understanding of the dynamics of the resource system.

There are, nevertheless, drawbacks with including such observations. First, they cannot usually be assumed to be random or representative.

Second, in order to use these types of observations, there has to be a framework for including them, evaluating their accuracy and weighing them against objective results.

5.4 Improving Understanding of the Reindeer-Pasture System

Paper IV provides a model that can be used as a tool to evaluate and improve understanding of the dynamics of the system. The model is focused on important mechanisms of the reindeer-pasture system and based on current knowledge and understanding of reindeer-pasture dynamics. But it is of general design, rather than being adapted to the circumstances of any particular herding district. Therefore, an initial step towards the implementation of an adaptive management regime would be to adapt the model for specific herding districts.

The proposed model is composed of three modules, which is advantageous since the modules can be implemented either jointly or individually. This eases the adaptation of the model and allows component aspects of the dynamics to be studied in detail. In addition, the model parameters were all set to values in accordance with empirical knowledge, and results presented in Paper IV indicate that the model can capture essential features of reindeer-lichen dynamics. Hence, it seems to be a promising first attempt to construct a model that could be used in local adaptive management.

When projections of models such as this are considered, attention should focus on the general direction of indications rather than the exact quantity of the output. It is essential to realise, when using them, that they generate projections based on the parameters and input data. Such projections should not be confused with predictions or forecasts. In addition, the model will not provide credible long-term projections, since input data will be based on the current situation and will not include future variations. This will hold true even after the model has been adapted to local circumstances and evaluated and re-modified for a longer time. Therefore, what the model can provide is a set of possible future scenarios, and hopefully indications of probabilities of the different scenarios.

The model presented here is simply a proposal for a suitable model. As long as knowledge and understanding of the local dynamics are subject to some degree of uncertainty (i.e. always) there will be more than one way to adapt the model to local circumstances, and more than one type of model to choose from. Thus, several alternate ways of adapting the model could be tested and evaluated against monitoring data, and increasing knowledge and understanding, as the adaptive management steps are iterated.

5.4.1 Pinpointing Uncertainties and Designing Experiments to Improve Learning

During the process of building or adapting a model to the circumstances of an actual herding district, knowledge gaps and uncertainties about local dynamics can be pinpointed. Even in a longer perspective modelling can be useful for this purpose, since relevant uncertainties to investigate or acknowledge will depend on the particular situation.

Through recognition of specific uncertainties, insights regarding which mechanisms require careful monitoring can be gained. Thus, models are important when selecting a set of indicator variables to be monitored.

In an active adaptive management approach, modelling is essential for designing "experiments" to gain as much information about a particular mechanism as possible, without taking hazardous risks in a long-term perspective (Walters, 1986, p. 224). Since the active approach is focused on continuously maximizing learning opportunities (in addition to managing the resources to achieve decided goals), it yields the most improvements of understanding of the system in the initial phases.

5.4.2 Improving Understanding of Social-Ecological Dynamics

As well a providing a tool to assist management decisions at herding district level, the improved understanding of reindeer-pasture dynamics can be used in wider perspectives. For example, it can help reindeer herders to better understand consequences of the impact of other human activities and climate change. In addition, it can be useful in negotiations between reindeer communities and other land users about competing land uses. Information from monitoring together with model predictions can also improve estimates of effects of different disturbances and loss of grazing land.

5.5 Practical Considerations

Implementation of adaptive management in reindeer husbandry requires some practical considerations. Notably, for adaptive management to work successfully, the management framework needs legitimacy within the herding community. Thus, a well-defined action plan for implementing the phases of adaptive management, which is accepted by all members, should be produced. This plan should include measures to take when consensus among the members cannot be reached on policy options and decisions.

If the adaptive management concept is to replace, or complement, the simple restriction on the maximum numbers of reindeer applied today, it will be important for the division of responsibilities between the herding community and the governmental administrative authority to be clear and to have recognized legitimacy from both parties. This kind of project should preferably be initiated by the reindeer herding communities themselves, since it would lend true legitimacy to the management approach within the communities. However, the initiative for such a management approach could also come from an organisation representing reindeer husbandry interests (e.g. Renägarförbundet or the National Union of the Swedish Sami People), the Sami Parliament or scientists participating in a research project.

Regarding resources needed for an implementation of adaptive management in reindeer husbandry, different solutions can be used depending on the resource situation. First, to handle monitoring data, any spreadsheet or database software is sufficient. However, database resources with regular backup-features should be preferred for long-term security.

Since slaughter records are already collected in a database under the aegis of the Sami Parliament, an obvious solution would be to expand this database with additional records. If this approach is adopted, additional recording could be done when reindeer are sent to slaughter, and be registered in the slaughter database via the slaughter plants. If additional recording cannot be performed by the slaughter plants, and thus cannot be included in the database it would be possible to keep parallel records at herding district level. Most of the additional information needed, apart from body size measures, is already known by reindeer herders, simply routines for recording and storing this information are required.

Concerning lichen monitoring results, an additional alternative could be to include monitoring data in RenGIS, a geographical information system tool that is used for mapping reindeer grazing resources at herding district level (Swedish Forest Agency, 2003). RenGIS already includes information on the current status of lichen resources, and could easily be adapted to include more detailed information.

Second, both the statistical analyses of data (excluding descriptive statistics) and the modelling work demand inputs from people with appropriate statistical and mathematical education and understanding of ecological dynamics. These kinds of human resources cannot be provided at herding district level, and thus have to be provided at national level, again the Sami Parliament is an alternative. It is however important to ensure that the herding community feels involved and in control of the building and steering of an adaptive management plan, and in control of discussions about policy decisions.

5.5.1 Labour vs. Information Demand

Implementing a framework for managing resources of the magnitude of a complete adaptive management program will inevitably require a significant amount of labour from the herding community. Thus, high ambitions for monitoring, analyses and evaluations of data should be weighed against realistic workloads in a long-term perspective.

Required routine changes for improving accuracy in slaughter records, are not very laborious, except for recording body size measures and accurately recording female reproductive status.

Regarding lichen monitoring, the method proposed here implies construction of a new monitoring program from scratch. The accuracy of monitoring results is dependent on the definition of the monitoring areas, the number and placement of measurement points and lichen height variation within the area. The potential to detect changes at an early stage depends on how often the areas are monitored. If the labour has to be decreased, it is recommended to reduce the number of measurement points (decreasing the statistical power) or lengthen the time period between monitoring sessions.

Calving data are already recorded at calf marking in many districts, and this procedure should suffice. High depredation may however decrease the reliable of the results considerably and lower the value of this information. In such cases, other methods for estimating calving data, would be more sufficient.

Regarding statistical analyses, advanced methods will give more thorough understanding of the magnitude of the changes and interactions involved, and such methods are required to adjust data to account for confounding factors. However, simply calculating averages can still reveal general trends to some extent as long as year-to-year variations are low.

5.6 Future Research

The next step towards adaptive management should ideally involve implementation of its principles in reindeer husbandry. At a local perspective there are several aspects that would warrant investigation during and after implementation.

Firstly, methods to improve the accuracy of calving results as indicators of grazing resources could be scientifically investigated. Other aspects that could be usefully explored are the long-term variations in lichen monitoring data. In order to find an appropriate trade-off between labour and frequency of lichen monitoring, empirical knowledge of variations in the magnitude of lichen height changes would be helpful. Deeper understanding of long-term spatial variations in lichen abundance could also be valuable.

Additionally, there is little information on variation in reindeer-pasture dynamics at local scale. Greater details in slaughter records would provide better data for understanding long-term dynamics of reindeer body resources.

Finally, in a social-ecological perspective there is need for better understanding of interactions between reindeer husbandry systems and other social-ecological systems and how resilience in these systems could be enhanced. Since there are indications that resilience in reindeer husbandry is diminishing (Moen & Keskitalo, 2010; Danell, 2005), there is an urgent need to pay further attention to this issue.

6 Adaptiv förvaltning av renbetesresurser

6.1 Bakgrund

Tillgång till bra bete är en kritisk faktor i pastorala system för att uppnå bra produktion i hjorden. I Sverige är renskötseln ett exempel på ett pastoralt system med gemensamma betesresurser som brukas av flera användare. Antalet renar i Sverige har varierat mellan 150 000 och 300 000 under det senaste århundradet. En viktig orsak till dessa fluktuationer tros vara att förändringar i betesresurserna orsakar variation i renarnas produktion. Om förändringarna inte upptäcks i tid, eller om sociala och ekonomiska faktorer orsakar fördröjningar i anpassning av renskötseln, kan konsekvenserna av förändringarna i betesresurserna dessutom förvärras. Därför är metoder och kunskap som kan hjälpa till att tidigt upptäcka och tolka förändringar mycket viktiga. När flera användare ska samsas om gemensamma betesresurser, är det också viktigt med metoder och kunskap som alla användare har förtroende för. Eftersom sociala, ekonomiska och biologiska systemen påverkar varandra, och dessutom på olika rumsliga och tidsmässiga skalor, så brukar man idag ofta tala om social-ekologiska hierarkiska system.

Renskötseln i Sverige är en viktig näring i norra Sverige, speciellt för Samisk kultur och ekonomi. Rätten för samer att bruka land och vatten på sina traditionella marker bygger på urminnes hävd och är numera knuten till medlemskap i en sameby. Det finns 51 samebyar, och varje sameby har ett landområde som de har rätt att nyttja. Inom samebyn förvaltas betesresurserna gemensamt, från myndigheternas sida sker endast en kontroll av att antalet renar i byn inte överskrider ett bestämt antal. Högsta tillåtna antal renar förutsätts vara baserat på vad markerna långsiktigt kan tåla, och på vad andra intressen i området kan acceptera, men kopplingen till betesresursen är relativt otydlig. De högsta tillåtna antalen renar har i stort sett inte ändrats sedan de infördes för över 50 år sedan.

Storleken på samebyarna, både i fråga om medlemsantal och antalet renar, varierar mycket och så gör även de geografiska förutsättningarna inom samebyarna. Samebyarna brukar delas in i tre grupper, fjällsamebyar, skogssamebyar och koncessionssamebyar. Fjällsamebyarna (33 st) har betesmarker både i fjällen och fjällnära områden, där den snöfria perioden tillbringas, och i skogslandet där renarna är om vintern. I många fjällsamebyar innebär detta långa flyttningar på vår och höst. Skogssamebyarna (10 st) tillbringar hela året i skogslandet och här är det endast kortare sträckor som renen rör sig mellan de olika beteslanden. Koncessionbyarna (8 st) i Torne och Kalix älvdalar liknar skogssamebyarna i det mesta, men rätten till att nyttja marken skiljer sig, eftersom dessa byar ligger nedanför Lappmarksgränsen och renskötarna då behöver tillstånd från Länsstyrelsen att bedriva renskötsel här.

Adaptiv förvaltning är en förvaltningsprocess som syftar till att underlätta förvaltnings beslut genom att följa pågående förändringar i resursen och i det social-ekologiska systemet och på förbättrande av kunskap och förståelse av dynamiken i systemet. Adaptiv förvaltning innehåller ett antal steg som kontinuerligt upprepas, nämligen övervakning av systemet med hjälp av indikatorer, utvärdering av kunskap, val av förvaltningspolicy och genomförandet av denna (kapitel 2.3, figur 1). I den initiala fasen samlar man in så mycket kunskap man kan om resurssystemet, och identifierar viktiga mekanismer och osäkerheter som man behöver utforska ytterligare. Sedan under pågående förvaltning så är en delprocess att kontinuerligt övervaka indikatorer som kan visa på viktiga förändringar i systemet. Resultaten från mätningar av indikatorerna används tolkas med hjälp av kunskap om systemet. De används också för att utvärdera och förbättra den kunskap och de modeller man har av systemet. De förbättrade kunskaperna och modellerna används i sin tur till att välja mellan olika förvaltningsåtgärder. Genom att formalisera kunskapen i modeller kan man också studera hur systemet kan tänkas reagera på förändringar som ännu inte är gjorda. Bortsett från att ett hållbart nyttjande är i fokus när man väljer strategi så är möjligheterna att införskaffa ny kunskap också viktiga, dvs. ”experiment” är prioriterade. Efter att man beslutat om en förvaltnings policy så genomför man denna och följer noga upp och utvärderar effekterna av den med hjälp av indikatorer och modeller.

I renskötseln är det betesresurserna, renhjorden och de mänskliga resurserna som är viktiga att förvalta optimalt. Betet är den grundläggande resursen, och därmed är det prioriterat att följa hur detta förändras och hela tiden anpassa sig så bra som möjligt. Därmed så är den grundläggande synen på naturen lik den i adaptiv förvaltning. Detta är inget ovanligt, i flera traditionella förvaltningssystem världen över så har förvaltningsprocesser liknande adaptiv förvaltning upptäckts.

Syftet med denna avhandling är att lägga en vetenskaplig grund för ett optimalt och uthålligt användande av betesresurserna inom rennäringen genom adaptiv förvaltning. Det görs genom att identifiera mått som kan användas som indikatorer på förändringar i ren-bete-systemet och att utveckla metoder för att mäta dessa. Dessutom föreslås här en matematisk modell där befintlig kunskap formaliseras och som kan användas för simulering av olika åtgärder och att få bättre förståelse för systemets dynamik.

6.2 Sammanfattning av studierna

I två av studierna undersöks möjligheten att använda den information om slaktade renar som registreras slakterier som en indikator på förändringar i renarnas generella kroppskondition och därmed av beten de använder före slakt, barmarksbetena. I den första studien (Artikel I) undersöks relationen mellan vikten, formklassningen och fettklassningen på slaktkropparna och deras relation till djurets storlek. Resultaten visade att vikt, fett och form var starkt korrelerade och därmed alla tre indikatorer av renarnas kondition. Fett och formklassning var endast i mindre grad relaterat till djurets storlek (bara hos kalvar) medan vikten till stor grad var beroende av både kondition och storlek. Det framkom också att man få betydligt förbättrad precision på vikt som indikator om man, till skillnad från idag, skiljer på hon- och hankalvar, samt om man skiljer mellan åringar och äldre djur. Även att justera vikten för djurets storlek (i det här fallet i form av käklängd, rygglängd eller längden på *radius/ulna* benen) visade sig vara effektivt för att förbättra precisionen av slaktkroppsvikten som indikator på kondition.

I den andra studien (Artikel II) studerades variation i slaktkroppsmåtten på olika tidsskalor och mellan samebyar genom analyser av de kommersiella slaktregistren från höstslakter (oktober – december) åren 1994-2007 (totalt drygt 430 000 slaktade djur). Resultaten visade att effekten av år är starkt korrelerad mellan kalvar, vajor och handjur (oxar och tjurar ihop), trots att handjursdata var från sarvslakter i september medan vaj- och kalvdata var från oktober till december. Detta är lovande för möjligheterna att använda slaktkroppsdata för att detektera förändringar i betesresurserna. Det fanns även en positiv trend i slaktkroppsmåtten över tidsperioden, denna var tydligast i vikten och fettklassningen.

Det visade sig viktigt att ta hänsyn tidpunkten för slakt när man analyserar slaktkroppsdata. Vajorna ökade generellt i mängden kroppsresurser från oktober till december medan kalvarna minskade, men denna effekt kan variera mellan samebyar beroende på hur de lokala betesförutsättningarna ser ut. Resultaten visade också en signifikant effekt av hjordstruktur/slaktstrategi på flera av måtten, denna kan ha orsakats av dels av en koppling mellan hjordstruktur och hjordstorlek, och alltså vara en effekt av djurtäthet, och dels ha orsakats av slakturval då de tre djurklasserna innehåller djur av olika storlek på grund av kön och ålder. Detta stärker alltså resultaten från Artikel I, att en snävare klassificering av djuren är att föredra. Variationer i populationstäthet i sig påverkade också slaktkroppsmåtten på kalvar och vajor. Detta är dock inte en faktor man vill räkna bort när man analyserar data, men det kan vara nyttigt att få information om. Slutligen, så påverkades slaktkroppsmåtten även av vilken sameby djuret var ifrån. Men effekten av sameby var inte konsistent mellan djurtyperna, vilket delvis kan bero på olika slakturval i byarna.

Den tredje studien (Artikel III) fokuserade på en indikator på förändringar i lavbetet, vilket är viktigt vintertid. Metoden som undersöktes var mätningar av lavhöjden inom viktiga betesområden. Metoden visade sig bra för att fånga upp rumsliga variationer i lavhöjden, och flera rekommendationer för mätdesign i praktisk tillämpning föreslogs. Först och främst så bör området man mäter vara någorlunda homogent och i stort sätt användas på samma sätt. Det visade sig att den rumsliga variationen i lavhöjd skiljde mycket mellan områden. Därför rekommenderas det att sprida punkterna inom varje område så att rumslig variation kan detekteras. Det är även en fördel att dela upp ett område som har tydliga rumsliga gradienter i lavhöjd, för att få bättre precision. För att ha statistisk styrka nog att kunna upptäcka förändringar, så bör man ha 200-2000 mätpunkter beroende på variationen i lavhöjden inom området. De enskilda punkterna bör också vara placerade med minst fyra meters mellanrum för att undvika nära relation mellan punkterna. Skogsbeståndets ålder och täthet påverkade lavhöjden. Laven var lägst i medelålders skog (40-60 år), men hade också bäst täckningsgrad i dessa bestånd, vilket sannolikt är en indikation på bra och välanvänt bete. Skogens struktur är kanske inte något man vill justera lavhöjden för, men dess effekter på lavhöjden i det aktuella området är viktigt att vara medveten om för att planera användningen på ett bra sätt. Lavens fuktighetsgrad påverkade också lavhöjden, därför är det bra att antingen alltid mäta lavhöjden vid samma typ av väderlek, eller registrera fuktighetsgraden så att effekten kan tas med i analys av data.

I den sista artikeln (Artikel IV) utvecklades en dynamisk modell av ren-bete-systemet. Modellen beskriver hur laven, renarnas kondition och hjordens struktur samspelar. Den består av tre moduler (kapitel 4.4, figur 2). Lavmodulen beskriver lavens höjd och tillväxt, hur den betas, samt tillgången på annan föda för renen under vintern. Energimodulen beskriver tillgången på bete under barmarksperioden, samt energiintag och viktsutveckling tillväxt för medelrenar av olika åldrar och kön och reproduktiv status för vajor. Hjordmodulen projicerar födslar, mortalitet och slakt i två tidssteg per år (förlagda till kalvmärkning och höstslakt att kunna jämföras med verkliga siffror). Modellen beräknar och ger information om hjordstorlek, slaktvikter, lavhöjds förändringar, kalvnings resultat, köttproduktion under de simulerade åren. Dock måste man komma ihåg att modeller endast bearbetar de data man förser dem med och kommer aldrig kunna förutsäga framtiden, bara tala om sannolikheten för en viss utveckling utifrån den inmatade informationen.

Simuleringar med modellen med olika konstellationer av vinter- och barmarksbete visar att den kan fånga upp viktiga mekanismer i ren-bete-systemet som är kända från empiriska studier. Därför är nästa steg att i ett tillämpningsskede anpassa den till förhållandena i enskilda samebyar, innan den används som stöd i en adaptiv förvaltning i praktiken.

6.3 Användning av adaptiv förvaltning i renskötseln

Den här avhandlingen bidrar med grundläggande kunskap av vad som behövs om adaptiv förvaltning av betesresurser ska implementeras i renskötseln i Sverige.

När man nyttjar en biologisk resurs, är det viktigt att man inte bara följer de biologiska delarna av det social-ekologiska systemet, utan även ser hur andra faktorer t.ex. klimat, och konkurrerande markanvändning, och hur olika förvaltningsåtgärder påverkar systemet. Dagens förvaltning av systemet från myndigheternas sida, med fasta högsta tillåtna renantal i kombination med ständigt ökad fragmentering och förlust av betesmarker pga. andra mänskliga aktiviteter och även betydande rovdjursnärvaro har inte stöd ur biologiskt perspektiv och bådar inte gått för renskötseln i det långsiktiga perspektivet. Fragmenteringen av betesmarkerna stör förvaltningen av betesresurserna inom samebyarna, genom att anpassningsåtgärder till betet blir mycket svåra i praktiken. Bland annat beror det på frånvaro på lämplig information att styra efter. Analyser av resiliensen (uthålligheten och förnyelseförmågan) i renskötseln visar en alltmer trängd näring. Ett förvaltningssynsätt som tar ett mer helhetsperspektiv på det social-ekologiska systemet och som är mer flexibelt är att föredra och då är adaptiv förvaltning eller till och med adaptiv samförvaltning möjliga alternativ.

På samebynivå kan ett införande av adaptiv förvaltning ge en effektivare förvaltning av betesresurserna genom snabbare upptäckt av förändringar, sitt systematiska förbättrande av kunskaper och genom en handlingsplan för identifiering av förändringar samt för beslut som har legitimitet i hela samebyn. Ytterligare en eventuell fördel är att konkreta argument (inklusive siffror) underbyggda med vetenskapligt testade metoder kanske kan ge extra tyngd i förhandlingar om markanvändning än endast erfarenhetsbaserade argument. Det finns dock en del överväganden att göra inför en introduktion av adaptiv förvaltning i renskötseln.

Det viktiga i valen av vilka indikatorer som ska övervakas och av vilka landområden som ska inkluderas i övervakningen, är att man fokuserar få nyckelfaktorer för det lokala systemet. Det är inte säkert att det är renarnas kondition (Artikel I-II), lavhöjden (Artikel III), samt kalvningsresultat (som var ytterligare en indikator i Artikel IV), som ska övervakas i alla byar. Till exempel kan rovdjursnärvaro vara en nyckelfaktor i dynamiken och därmed behöva övervakas. En central del i den inledande fasen av adaptiv förvaltning (och som sedan följs upp i utvärderingsstegen), är identifiering av viktiga mekanismer i systemets dynamik och osäkerhetsfaktorer i förståelsen av systemet. Detta är en process som måste göras på lokal nivå, och valet av indikatorer ska sedan baseras på denna kunskap. I processen för att identifiera mekanismer och osäkerheter, så är modeller av systemet en essentiell del. Genom att resursanvändare och beslutfattare sätter sig ned tillsammans med modelleringskunniga och bygger och anpassar alternativa modeller av systemet till den kunskap man har, så visualiseras både viktiga resurser och luckor i kunskapen. Modellen som presenteras i Artikel VI kan användas som utgångspunkt i denna process. Men för att kunna fungera i praktiken kräver den noggrann anpassning till data från det verkliga systemet och eftersom projektionerna som den ger är en effekt av de data man matar in kommer dessa projektioner ändå inte vara tillförlitliga i ett långtidsperspektiv.

För införande av adaptiv förvaltning så kommer det att behövas resurser av olika slag, dels är det arbetsinsatser för att övervaka indikatorerna och lagra data, dels är det resurser för statistiska analyser av mätresultaten och anpassning och förbättringar av modeller av systemets dynamik.

När det gäller arbetsinsatser för att övervaka förändringar så är slaktkroppsmåtten enklast att övervaka. Bortsett från storleksmåtten på slaktkropparna så finns all information som behövs för att förbättra säkerheten i förutsägelserna redan i systemet (t.ex. kön på kalvar, skillnad på åringar och äldre och slaktdatum). Det som saknas är systematisk dokumentation och användning av informationen. När det gäller lavmätningar, så handlar det om utveckling av ett nytt mätsystem och det kommer att kräva en del arbete. Metoden är dock enkel att använda och det som kommer ta mest tid är att röra sig över hela området så att man får ett representativt urval av betesområdet. Fördelen är att om laven inte är kritiskt låg så kan man eventuellt väga noggrannhet (i form av antal punkter eller hur ofta mätningar ska genomföras) mot arbetsinsats.

Lagring av data från indikatorerna kan ske i kalkylprogram eller databasprogram inom samebyn. Men för slaktkroppsdata finns det ju redan en databas med rutiner för insamling av data i användning. Att utveckla detta system vore att föredra i alla fall ur arbetsbelastningssynpunkt. När det gäller lavhöjdsdata så finns även alternativet att inkludera dessa data RenGIS, ett program för geografisk information anpassat för planering av renskötselns markanvändning, i.e. en del av Renbruksplansprojektet.

När det gäller analys av data, så går det att använda sig av medelvärden. Det är dock inte att föredra, utan mer avancerade metoder kan ge betydligt säkrare resultat och det kan vara svårt att tillgodose på samebynivå. Därför är en central statistikresurs att föredra, kanske kan sametinget tillhandahålla detta. När det gäller modelleringsbiten så kräver en detaljerad anpassning av modellen, till lokala förhållanden, en gedigen modelleringskunskap. Detta kan inte tillhandahållas på samebynivå. För bästa utbyte av modelleringsdelen behövs därför en central resurs även för detta.

En grundläggande faktor införande av adaptiv förvaltning av betesresurserna i en sameby, är att processen har legitimitet hos samebyns medlemmar. Därför är det bästa alternativet att initiativet till ett adaptivt förvaltningsprogram kommer från samebyn. Men andra alternativ är naturligtvis att en intresseorganisation som Svenska Samers Riskförbund eller Renägarförbundet tar initiativet, eller att Sametinget gör det, bara processen förankras väl i samebyarna.

Nästa steg i processen mot adaptiv förvaltning är främst på det praktiska planet. Nu finns den grundläggande generella kunskapen och det som behövs är kunskap om lokala förhållanden och det fås bäst genom ett fullskaligt experiment, i genomförandeprocessen.

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