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Monitoring changes in lichen resources for range management purposes in reindeer husbandry

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ABSTRACT

Mat-forming lichens are important as food source for reindeer during the winter, and thus a vital resource to manage in reindeer husbandry. In this paper we suggest a method for monitoring of changes in lichen height with the purpose to early detect changes in lichen abundance in reindeer grazing areas. The method is intended for measuring geographically uniform lichen areas, evenly used for reindeer grazing. We analysed spatial variations in lichen height at the meter and 100 m scales, and calculated sample size requirements, and estimated effects of forest density and age, lichen moisture and lichen density on lichen height, and assessed the correspondence between lichen height and biomass. The variation in lichen height differed considerably between sites and, hence, the required sample size to detect a 5 mm change in lichen height with a power of 0.95 ranged from 200 to 2000, depending on the standard deviation of measured heights. Based on the autocorrelation in lichen height found between adjacent measurement points, a minimum distance of 4 m between measurement points is also recommended. Lichen height was significantly affected by lichen moisture, and the results suggest that this effect of moisture might vary with lichen density. Lichen height varied spatially within the study sites, and the spatial variations were partly caused by forest age and density. Thus, gradual changes in the forest characteristics are likely to alter the spatial variation in lichen height and it is therefore important to regularly re-evaluate the locations of measurement points within the monitored area. This study provides suggestions for a variable that could be used as an indicator of changes in the lichen resource, and aspects that should be considered when designing a monitoring program. The accuracy of detecting changes depends on the monitoring efforts, i.e. the number and distribution of measurement points and how often an area is monitored. In conclusion, our results indicate that measurements of lichen height have considerable potential for monitoring of changes in lichen resources within reindeer husbandry.

1. Introduction

Reindeer and caribou, *Rangifer tarandus* (L), inhabit strongly seasonal habitats in the circumpolar north. Pasture quality is a major factor limiting both their population density and herd productivity (Brown et al., 2007; Couturier et al., 2009; Klein, 1968; Skogland, 1985; Wittmer et al., 2005). Knowledge of variations in the pasture with time is therefore crucial in reindeer husbandry.

In the winter ranges, lichen is an important food resource for reindeer, usually constituting between 30% and 80% of the total diet (Gaare and Skogland, 1975; Heggberget et al., 2002; Kojola et al., 1995; Mathiesen et al., 1999; Mathiesen et al., 2000). *Cladonia* spp. and *Cetraria* spp. are abundant mat-forming lichens in boreal forests and are hence a vital food source for reindeer. These lichens are perennial and susceptible to grazing and trampling. After intense grazing it can take decades for a lichen mat to recover to high producing lichen mats (Gaare and Skogland, 1980; Klein, 1987; Gaare, 1997; Väre et al., 1996). Their growth rates are dependent on the individual species, and temperature, and availability of light and water (Čabrajić, 2009). Thus, their performances are dependent on vegetation type including the structure of the ground layer, field layer and the forest stand, in combination with geographical features and soil properties. In addition, reindeer grazing is affected by forest stand structure and geographical features that affect snow hardness and ice crust. The lifecycle of lichen is longer than the timescale of most of the decision-making processes in reindeer husbandry. Effects of management on the lichen

Abbreviations: MP, Measurement point; SD, Standard deviation; LR, Linear regression with intercept; LRO, Linear regression through the origin; GMR, Geometrical mean regression.

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resource therefore become delayed, and the behaviour of the highly dynamic lichen–reindeer system needs particular consideration in a resource management context.

Adaptive management provides a supporting framework for management decisions in dynamic resource systems where uncertainty has to be taken into account (Folke et al., 2004; Walters and Holling, 1990). The management decisions are based on an understanding of ongoing trends and of the effects of management actions, achieved through continuous monitoring and interpretation of changes in the resource system, together with knowledge and experience of resource users and decision-makers and a continuously improved theoretical understanding (Walters, 1986). If adaptive management is to be applied in reindeer husbandry, various indicators of change in the resource system has to be developed. Monitoring change in the lichen ranges while actively testing different range use options and evaluating the effects of the alternative management decisions improves knowledge of how the use affects the different ranges within the herding district. In addition, monitoring can provide early warnings of unexpected changes as well as also improve the understanding of how forest development and other external factors influence the tolerance of lichen resources to reindeer grazing.

There have been several approaches to assess the abundance of lichens; these include collecting lichen and measuring its dry weight (biomass) per unit area (Eriksson, 1975; Ferguson et al., 2001), estimating lichen cover and then calculating lichen volume per unit area, either by multiplying cover by lichen height or by assuming a linear relationship between lichen coverage and biomass (Dunford et al., 2006; Kumpula et al., 2000). These methods are, however, not primarily intended for frequent monitoring changes in lichen abundance within a management program. Such methods need to be labour effective, as well as uncomplicated enough to be used without considerable training (Carruthers and Tinning, 2003). Moen et al. (2007) estimated lichen biomass in 0.25 m^2 plots, from lichen height alone which automatically included lichen coverage by the frequency of points with lichen within the plot (lichen height > 0). 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 purpose of this study was to investigate how to design repetitive lichen height monitoring in important grazing areas for reindeer in order to indicate direction and rate of changes in the lichen resource. More specifically, we addressed the following four questions. Firstly, how many measurement points are needed to detect relevant changes in lichen height? Secondly, how should measurement points be distributed spatially in order to acquire accurate indications of changes in height? Thirdly, does lichen height vary with varying degree of moisture? Finally, should external factors that change over time, in this case, forest age and forest density, be considered during the planning and implementation of measuring, and when analysing results? In addition, for validation purposes, we investigated the relation between lichen height and biomass.

2. Materials and methods

2.1. Study sites and data collection

Four sets of data on lichen height – a *Small-scale dataset*, a *Large-scale dataset*, a *Moisture dataset* and a *Biomass dataset* – were collected with differing purposes. The purpose of the *Small-scale dataset* was to determine the smallest appropriate distance between adjacent lichen height measurement points (MP) and the dataset was also used for designing the data collection for the *Large-scale dataset*. The aims of the *Large-scale dataset* were to determine the approximate sample size required to detect relevant changes in lichen height, to elucidate the consequences of the choice of MPs within the monitored area, and to investigate the effects of some potentially influential factors that change over time. The intention of the *Moisture dataset* was to investigate the possible effect of moisture (water content) on lichen height and the *Biomass dataset* was collected to verify the relationship between lichen height and biomass.

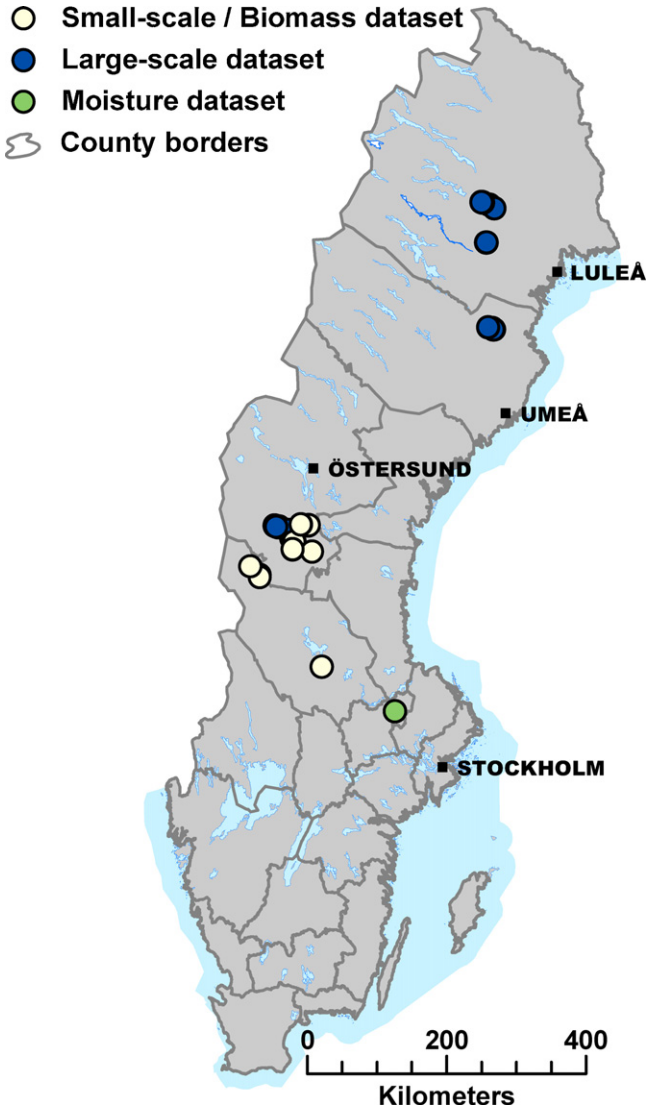

Fig. 1. Map of Sweden showing the location of the study sites for each of the collected datasets (the *Biomass dataset* was obtained using samples from 11 of the sites used for the *Small-scale dataset*).

The four datasets were collected from a total of 31 study sites in northern Sweden (Fig. 1). Since the aim of the study was to develop a monitoring method usable in most lichen ranges in Sweden, the sites were selected (i.e. non-randomly sampled) to represent a variety of frequently used grazing sites for reindeer. The sites were distributed between 66°34′N and 61°45′N in winter ranges within the reindeer herding area, with two additional (ungrazed) sites further south (at latitudes of 60°2′N and 60°37′N). The sites were located at altitudes ranging from 170 to 250 m a.s.l. and all sites within the reindeer herding area were regularly grazed by reindeer during winter. All sites were located in lichen-dominated boreal forests, selected so that forest stands of varying ages were rep-