Snow conditions and usability value of pastureland for semi-domesticated reindeer (*Rangifer tarandus tarandus*) in northern boreal forest area

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Abstract: We studied variation in snow conditions and selection of pasture area according to altitude by semi-domesticated reindeer (*Rangifer tarandus tarandus*) during 1999 - 2002 in a pine forest area utilised by forest industry in the Ivalo reindeer herding district, northern Finland. Snow conditions were measured over the course of three winters along equilateral triangles (side 3.5 km) for three times per winter. The altitudinal selection of pasture area by reindeer was studied using GPS tracking data (10 977 locations) from 29 female reindeer. We observed that interannual weather variation mostly affected the depth, density and hardness of snow in the study area. At the forest landscape level, snow depth and density increased with altitude. Thinnest and deepest snow cover occurred on western and northern slopes, respectively. In contrast, forest harvesting did not seem to affect snow conditions. From spring to autumn, reindeer mainly used higher altitudes in pastures. In early and mid-winter, when snow conditions were easy or moderate reindeer still preferred higher altitudes, but in late winter when snow conditions and food accession were at their most difficult, they preferred lower altitudes. We conclude that especially the use of high elevation forestland pastures may become more difficult for reindeer if the global climatic change causes higher winter precipitation to the northern boreal forest area. In general, the low-elevation forestland areas have primary winter grazing value for reindeer but these areas are also intensively used by forest industry.

Key words: altitude, elevation, forestry, grazing, pasture selection, slope aspect.

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Introduction

Although reindeer and caribou tolerate deep and long-lasting snow cover, snow forms an essential ecological factor for behaviour (Helle, 1981; 1984; Vandal & Barrette, 1985; Kumpula *et al.*, 2004a), life history traits (Reimers, 1982; Adams & Dale, 1998; Kumpula & Colpaert, 2003) and population dynamics (Aanes *et al.*, 2000; Helle *et al.*, 2001; Solberg *et al.*, 2001) for these animals. Depending on the duration of the snow cover period, snow depth and hardness, snow cover can regulate access to terrestrial food during winter (Pruitt, 1959; Skogland, 1978; Rominger & Oldemeyer, 1990). Snow also affects energy expenditures and the locomotion rate of reindeer and caribou (Boertje, 1985; Fancy & White, 1985). Snow conditions also maintain and intensify feeding competition in winter, (Helle, 1984), which may have favoured evolutionary selection for antlers in female reindeer and caribou (Henshaw, 1968; Bubenik, 1975; Kumpula *et al.*, 1993).

To minimize energy expenditure when migrating, or digging for food, caribou and reindeer usually prefer habitat with thin snow cover or snow-free patches if available (Duquette, 1988; Nellemann, 1996, Johnson *et al.*, 2001; Larter & Nagy, 2001). On the other hand, reindeer and caribou will dig even in difficult snow conditions when plenty of food is accessible on the spot (Helle, 1984; Brown & Theberge, 1990; Larter & Nagy, 2001). In woodland areas, reindeer and caribou can also replace terrestrial food with arboreal lichens (Helle & Tarvainen, 1984; Rominger & Oldemeyer, 1990; Terry *et al.*, 2000). The digging expenditures compared to profit of food intake has, indeed, an important role in feeding site choice for reindeer and caribou (Helle & Tarvainen, 1984; Kumpula, 2001).

Difficult snow and digging conditions usually reduce reproduction rate of reindeer and caribou in the following spring (Solberg *et al.*, 2001; Kumpula & Colpaert, 2003). In woodland pasture areas, reindeer populations may occasionally suffer high mortality in winters with high snow accumulation or formation of thick ice crust, especially if availability of arboreal lichens or other compensatory food is limited (Helle, 1980; Kumpula & Colpaert, 2003; Kohler & Aanes, 2004). Consequently, both large-scale and local changes in weather and snow conditions may have negative effects on the herding and hunting of reindeer/caribou through the northern hemisphere where they constitute essential sources of food and income (Putkonen & Roe, 2003; Kumpula & Colpaert 2003; Weladji & Holand, 2003).

Large-scale climatic oscillation measured as the North Atlantic Oscillation index (NAO)[1] affects much the interannual variation in temperature and precipitation patterns in northern latitudes and seems to correlate with body size, fecundity and population change of northern ungulates (see e.g. Post *et al.*, 1997; Post & Stenseth, 1998; Mysterud *et al.*, 2000; 2001; Weladji & Holand, 2003). However, connections of large herbivore dynamics (e.g. red deer, caribou and reindeer) to NAO-index are complex and differ between geographical regions and spatial scales (see Post & Stenseth, 1999; Aanes *et al.*, 2000; Mysterud *et al.*, 2000; Forchhammer *et al.*, 2002; Reimers *et al.*, 2005). Also, in high-arctic areas another index, the Arctic Oscillation (AO), may be a better predictor of ecological consequences resulting from climate change than the NAO index (Aanes *et al.*, 2000; 2002).

Apparently, besides the global climatic fluctuation there are several geographical and local factors, such as altitudinal, expositional or vegetation patterns, which can affect snow conditions within a certain area (Tappeiner *et al.*, 2001; Hiemstra *et al.*, 2002; Vajda *et al.*, 2006). Large scale human operation, such as forest harvesting, may also affect snow conditions especially in large felling areas where forest canopy is considerably reduced (Eriksson 1976; Kirschhoff & Schoen, 1987; Koivusalo & Kokkonen, 2002; D'Eon, 2004). In Finland, about two-thirds of the whole reindeer herding area is partly or completely utilized by forest industry and for a long time there have been debate and conflicts between reindeer herding and forest industry about effects of forest harvesting on reindeer pastures and reindeer herding (Kyllönen & Raitio, 2004). Therefore both effects of local factors on snow conditions as well as behaviour responses by reindeer to these local factors should be studied more comprehensively.

This work is linked to a detailed habitat study of semi-domesticated reindeer (*Rangifer tarandus tarandus*) made in the Ivalo reindeer herding district located in the boreal forest area, northern Finland (Kumpula *et al.* 2007). Forest industry has operated intensively in the study area for over 80 years, producing a varied landscape with forests stands of varying ages. The aims of this paper are to show; 1) how snow conditions vary within a rugged pine forest landscape utilised by forest industry. 2) what are the relative effects of local factors on snow conditions compared to interannual weather variation; effects of elevation, slope aspect, and forest age structure on snow conditions were studied to assess importance of these factors on the usability value of pine forestland pastures in winter. 3) that snow conditions can, affect pasture selection by reindeer during winter in a pine forest landscape. On the basis of our results, we evaluate effects of forest harvesting on the usability value of pine forestland pastures in winter and present a hypothesis how the global climatic change may affect the usability value of winter pastures in the boreal forest area.

Methods

Study area

The Ivalo reindeer herding district is located in the northern part of the Finnish reindeer management area (Fig. 1). The average reindeer winter stock following the autumn slaughtering season in the Ivalo district during the last ten years has been about 5500 heads (maximum number permitted is 6000 reindeer). This makes an average of 2.1 reindeer per km^2 on the total land area during winter. About 70% of the winter herd consisted of female reindeer. The reindeer were herded during winter in two main herds with slightly different management systems. In the southern and central parts 4000 reindeer were provided with supplementary feed (mainly pre-dried

[1] NAO = North Atlantic Oscillation – index which refers to a meridional oscillation in atmospheric mass with centres of action near Iceland and over the subtropical Atlantic from the Azores across the Iberian Peninsula. A substantial portion of the climate variability over the Atlantic basin is associated with the NAO, which is a dominant pattern of atmospheric circulation variability (see http://www.ldeo.columbia.edu/NAO/).

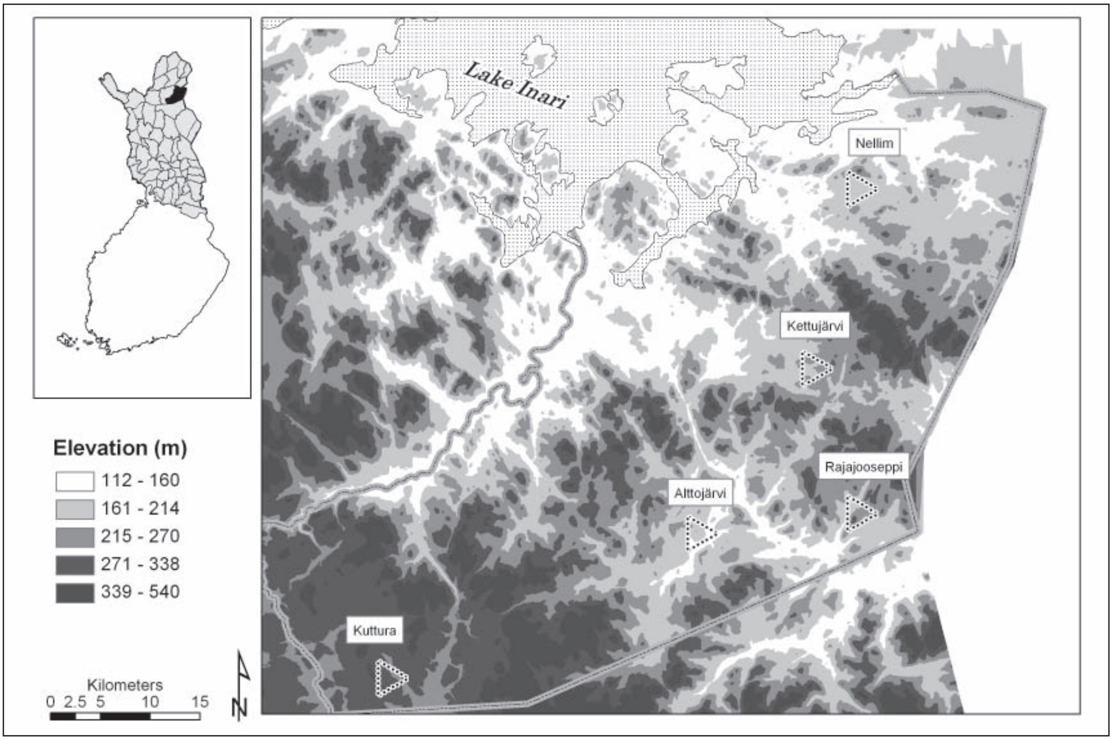

Fig. 1. Location and elevation classes of the Ivalo reindeer herding district and sites with snow measurement triangles.

hay silage) from January to April. Feeding sites were always situated near cratering areas and reallocated in accordance with reindeer movements. In spite of systematic supplementary feeding, reindeer still acquired 2/3 of their nutrition from natural pastures (calculated from the daily amount of given feed). In the northern part of the district, a herd of 1500 reindeer was kept with a management system where supplementary winter feeding was used less systematically. During summer season reindeer were allowed to graze relatively freely with the exception of calf marking in mid summer and rutting season in late autumn when reindeer were gathered for round-ups.

The size of the Ivalo district is 2861 km^2; nine per cent of the area consists of lakes and rivers (Kumpula *et al.*, 2004b). The relief of the study area is rugged with several hills and treeless tops of low mountains (fell highland type). The highest mountaintops are about 500 m a.s.l., 50% of the area lies below 210 m a.s.l.. Vegetation belongs to the northern boreal forest type, with pine forest as the main type in the lower areas, and mountain birch forest in the higher areas. The tree line of pine forest is 350 m.a.s.l. The majority of lower altitude pine forest is utilised by forest industry and, many higher pine forest areas have been protected because of their extremely difficult regeneration. During winter reindeer mainly used forestland pastures while in summer season reindeer also used high elevation open land and mires. There was no clear pasture rotation system in the Ivalo district during the study.

The climate of the study area is sub-arctic, characterised by a long cold winter and a short, relatively warm summer. Continuous snow cover prevails for seven months (mid October to mid May). For the period 1971 - 2000, the mean temperature of the coldest month, January, was -13.6 °C, and the warmest month, July, 13.9 °C, the mean annual temperature being -0.8 °C. Yearly precipitation was 435 mm, monthly values varied between 23 mm (January) and 66 mm (August). Maximum average snow depth was 67 cm in March. (Ivalo Airport Meteorological Station, Drebs *et al.*, 2002)

Snow measurements

We selected five areas for snow and digging condition measurements (Fig. 1). They were located on state owned land managed by the state enterprise, Metsähallitus (Finnish Forest and Park Service). The snow measurement sites were placed in areas where all forest development (age) classes, as well as the entire variation in height (under 350 m a.s.l.) within pine forestland could be found. In addition, the local herders evaluated how snow conditions differ generally in the Ivalo district and we took into account these differences when establishing our measurement areas.

We used equilateral triangles for snow measurements, since a triangle shaped line represents better both general age structures of forests and snow conditions within a certain limited measurement area than a straight line.

Each triangle was measured during three winters (1999-2002), three times in each winter (December, February and April). In December 1999, we used triangles with seven kilometres long sides and made snow measurements at one kilometre intervals. This proved to be too time consuming, and a smaller triangle was adopted. In the second measurement (February, 2000), we used triangles with sides of 3.5 km long and measurements at 0.5 kilometre intervals. Each of these triangles had 21 measurement sites (first measurement sites were located 250 meters from the corners). Two of the triangles were located in too difficult terrain, and had to be relocated during the second measurement. From the second measurement onwards, all snow measurements were made using the same triangles. The mean altitude of 21 sites in a snow measurement triangle varied considerably being in Alttojärvi 169 ± 4.1 (variarion 150-215) m, in Rajajooseppi 209 ± 4.6 (variation 170-248) m, in Kettujärvi 222 ± 4.9 (variation 190-272) m, in Kuttura 289 ± 3.8 (variation 270-325) m and in Nellim 200 ± 6.6 (variation 162-252) m a.s.l., respectively.

The locations of the sample sites in the triangles were measured using GPS receivers. The sites were visited using snowmobiles and GPS navigation. The measurements of all five triangles took five days, which was important for the comparability of snow conditions between measurement areas. All measurements were taken during the same week in clear weather with no snowfall. At each site snow depth was measured after digging a hole through the snow. Thereafter the vertical hardness and thickness of bottom and top layers as well as the hardest mid layer was measured. For hardness measurements we used a penetrometer made for this purpose (see Kumpula, 2001). Circular plates were pushed vertically against the snow layer and the pressure breaking the layer with a certain sized plate was registered. The hardness of each snow layer (g/cm^2) was then calculated from the "breaking force" and the size of a plate. For measuring the density of the entire snow layer (g/dm^3) a tube with 10.5 cm diameter was forced through the snow and the snow core was weighed.

The following landscape variables were determined from each measurement site: measurement area (Fig. 1), habitat class, height above sea level (m a.s.l.), and slope aspect. The habitat class was determined from forest stand maps produced and maintained by Metsähallitus and it included the following classes: felling area (age about 0 - 10 years old), sapling stand area (11 - 35 years old), young cultivation forest (36 - 80 years old), mature cultivation forest (81 - 140 years old), old growth forest (mainly over 140 years old, but often over 200 years old), forest stand with a diverse age structure, high elevation open land/open forestland, mire and gravel pit/forest roads/power lines. A forest stand with a diverse age structure refers to a forest, which, in addition to old growth trees, consists of young trees of varying maturity. This class was combined with old growth forests in the data. Open forestland refers to scrubby forestland where the annual growth rate of forest is very low and which is mainly located at high elevation. Open land means the high elevation land (land above the tree line), which is treeless or almost treeless. The altitude of the measurement site was determined from digital elevation data (DEM with spatial resolution of 25 meters for xy and 0.1 meters for z) produced by the National Land Survey of Finland. The slope aspect was determined from topographical maps (1:50 000) having contour lines at intervals of ten metres. If the vertical drop of terrain was less than five percent, the slope type was classified as flat. All steeper slopes were classified according to the main compass directions into four aspect classes (northern, southern, eastern and western slopes).

The effects of year, the measurement area, the habitat class, the altitude and the slope aspect on snow characteristics were analysed with the multivariate General Linear Model (GLM) application by SYSTAT (Version 10) in each measurement month separately during the winters 1999-2002. The dependence of snow depth, density and hardness on the altitude of the measurement site in each measurement month for each year separately was also analysed using linear regression models.

Altitudinal selection

Since altitude of forestland seemed to be the most important landscape factor determining snow conditions we studied the altitudinal selection of pastures by reindeer using the GPS tracking data. This data was collected for studying the habitat selection of reindeer in more detail. From December 1999 to February 2002, we tracked a total of 29 female reindeer using GPS collars (model types: GPS 2000 and GPS PLUS; weight of collar: 550 to 700 g; produced by VECTRONIC Aerospace GmbH in Germany) programmed to measure the position of a reindeer at intervals of eight hours. The location was stored in the GPS memory and downloaded following retrieval of the collars. As there were some problems with the GPS engineering (mainly battery life), the total number of locations collected by an individual reindeer varied from 32 to 1075 locations. The oldest type of our

GPS-collars was programmed to indicate accuracy of individual positions only as validated or invalidated. Positions are valid if at least five satellites were received and the DOP-value was below ten (accuracy of position ±15 m). The same criteria were used for the newer type of collar and only positions with a DOP value below ten were used. Altogether 10977 locations were obtained with the collars (Fig. 2), of which 9229 were located on state land for which we had digital forest habitat maps from Metsähallitus.

We first divided the entire GPS-location data into three seasonal periods according to the main seasonal cycle of reindeer (the first period from November to January, the second from February to April and the third from May to October). On the basis of the snow measurements presented here and a long-term snow data (see Kumpula & Colpaert, 2003) we know that our GPS tracking period consisted of three winter seasons with different snow and digging conditions (difficult: 1999-2000; easy: 2000-2001 and average: 2001-2002). This assessment was also confirmed by the reindeer herders. Therefore our GPS tracking period covers equally all different snow conditions and represents average snow conditions as a whole in the study area. However, the number of locations per winter is limited and we were not able to analyse possible changes in altitudinal selection by reindeer between winters. Still, we can detect effects of changes in snow conditions on altitudinal selection by comparing early-mid and late winter periods. Results from the analysis in the early-mid winter period represent altitudinal selection in easy/moderate snow conditions while results form the late winter period correspond to difficult snow conditions.

For the comparisons of altitudinal selection by reindeer we first defined the entire roaming area for all reindeer as the Minimum Convex Polygon (MCP) area (Mohr, 1947) by employing the Animal Movement application in Arc View 3.2 software. Then 1526 random points within this MCP-area were generated using GIS software. The elevation and forest class for each random and real (observed) GPS-point were defined using the digital elevation model and the forest stand map. Finally, using the random and the observed points we compared how the average altitude used by the study reindeer differs from the average altitude within the entire MCP area in each seasonal period. In the same way in each seasonal period, we compared how the average altitude used by the study reindeer within each habitat class separately differs from the average altitude of this habitat class in the entire MCP area. The significance of the difference between the random and observed tracking points in the average altitude was calculated using the *t*-test employing the SYSTAT statistical software (Version 10).

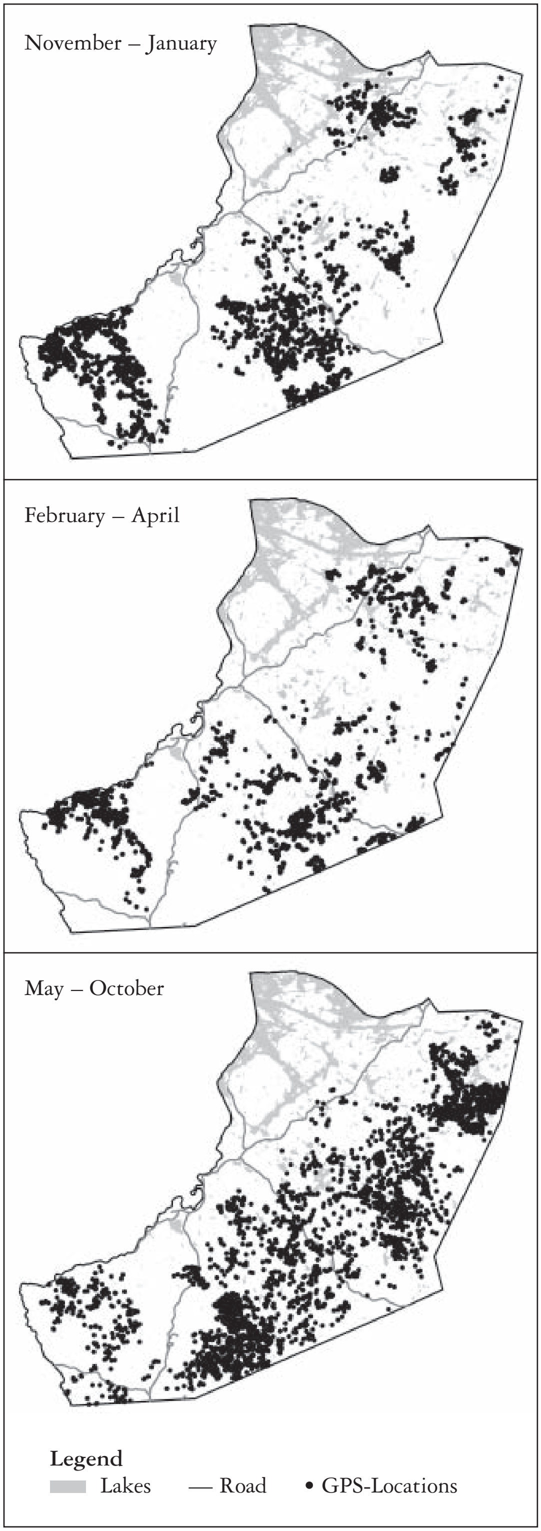

Fig. 2. All locations of GPS-tracked female reindeer (n=29) from 1999 - 2002 (10 981 locations) in the Ivalo reindeer herding district.

Table 1. Effect of different variables on snow depth (cm) in the Ivalo reindeer herding district during three successive winters (1999 - 2002). Multivariate GLM.

		December		February		April	
Variable	*df*	*F-ratio*	*P*	*F-ratio*	*P*	*F-ratio*	*P*
Winter	2	311.97	0.000	755.11	0.000	293.48	0.000
Area	4	5.41	0.000	7.50	0.000	9.14	0.000
Altitude	1	2.19	0.141	3.84	0.051	5.15	0.024
Slope aspect	4	1.03	0.395	2.59	0.037	3.46	0.009
Habitat class	5	1.55	0.175	0.55	0.735	0.53	0.756
		R^2=0.846; N=206		R^2=0.877; N=293		R^2=0.757; N=293	

Results

During three successive years the variation in monthly snow depth was dependent in December on winter (P<0.001) and area (P<0.001), in February on winter (P<0.001), area (P<0.001), altitude (P=0,051) and slope aspect (P=0.037), and in April on winter (P<0.001), area (P<0.001), altitude (P=0.024) and slope aspect (P=0.009). Habitat type, which included all forest age classes, had no significant effect on snow depth in the measurement months (P≥0.175). In February and April western slopes had lowest snow depths while northern slopes had the greatest snow depths (Table 1, Fig. 3).

Although altitude seems to have a relatively slight effect on snow depth in the GLM analysis, we observed that snow depth in each month and each year was always significantly positively dependent on altitude (P<0.001) in simple regression models (Fig. 4). In these models altitude explained in December 36.5-76.6%, in February 21.0-50.8% and in April 19.4-44.9%, of the variation in monthly snow depth, respectively. The general elevation of a snow measurement area and the altitude of a snow measurement site are partly interlinked, which reduces the explanation power from altitude in the GLM analysis, although altitude strongly affects snow depth both through the general elevation of a measurement area (the effect of area) and the altitude of a measurement site (the effect of altitude). This was indicated also by the fact that the average snow depth of a measurement area (indicated as Least square means, LS) was significantly positively dependent on the general elevation of a measurement area (calculated as a mean altitude of 21 measurement sites in each triangle) in two of three measurement months (simple regressions in December R^2=990, n=5, P<0.001, in February R^2=958, n=5; P<0.001 and in April R^2=687, n=5, P=0.083).

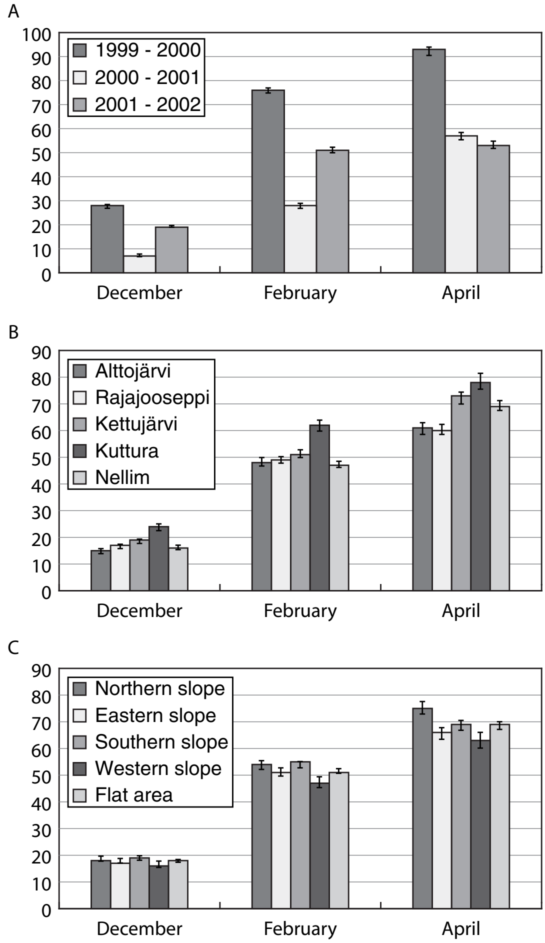

Fig. 3. Snow depth (cm, LS (Least Squares) mean ± SE (Standard Error)) a) in different months, b) in different measurement areas and c) according to the slope aspect during winters 1999 - 2002 in the Ivalo reindeer herding district.

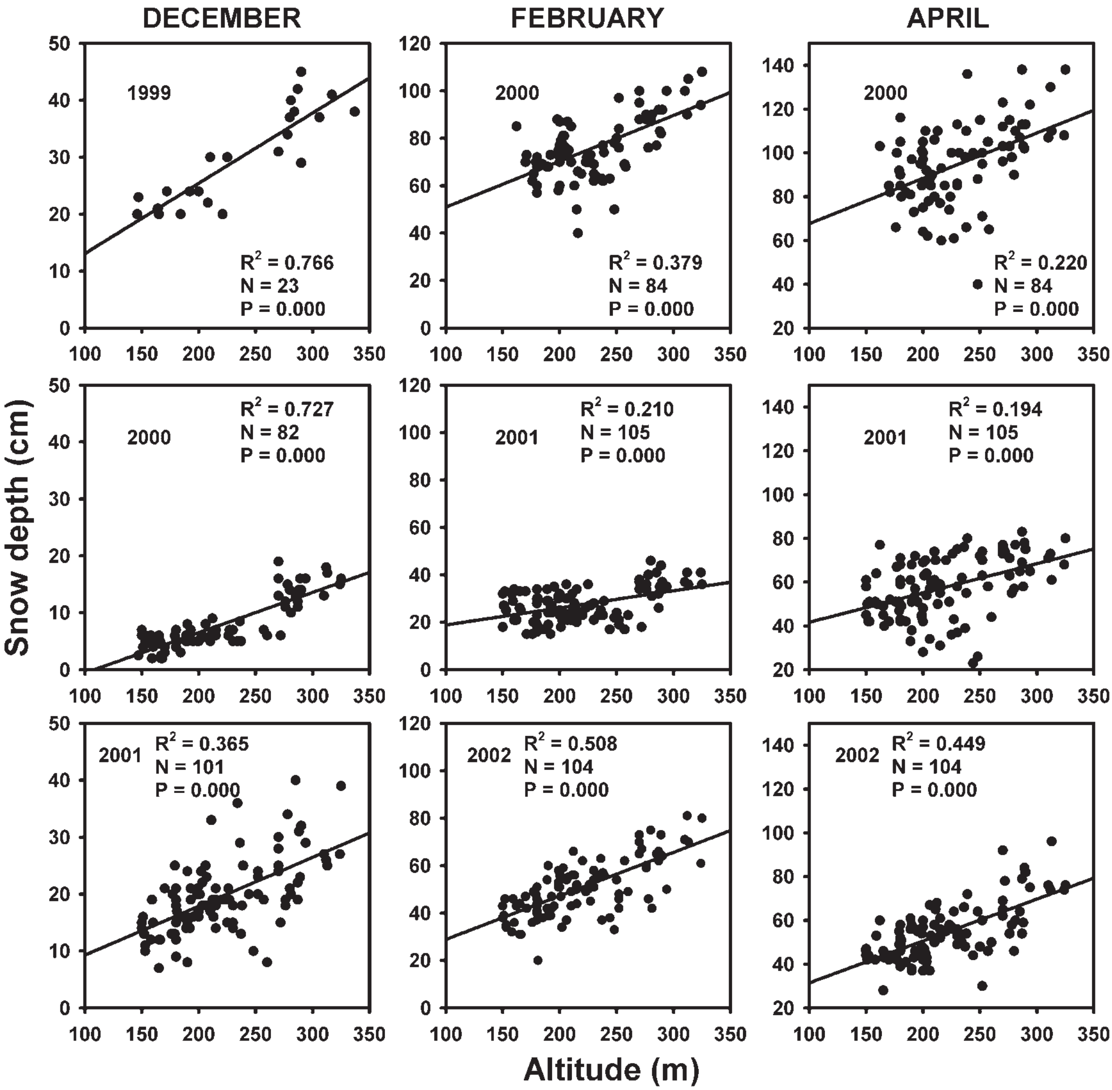

Fig. 4. Dependence of snow depth (cm) on altitude (m a.s.l.) in different months in the Ivalo reindeer herding district during winters 1999 - 2002. Simple regression model.

In the GLM analysis, snow density was in each month significantly dependent on the parameter, winter ($P<0.001$), but the parameter, area, also affected snow density, slightly in December ($P=0.075$) and clearly in February ($P=0.004$), (Table 2, Fig. 5). On the basis of simple regression models, snow density was positively dependent on the altitude of a measurement site ($P<0.05$) in four out of eight measurement cases (Fig. 6). Snow density was also slightly positively dependent on the general elevation of a measurement area in April ($R^2=0.768$, $n=5$; $P<0.051$) but not in December ($R^2=0.094$, $n=5$; $P<0.616$) and in February ($R^2=0.003$, $n=5$; $P<0.928$).

In the GLM analysis, hardness of the hardest snow layer was dependent in each month on the parameter, winter ($P\leq0.001$), but also area and altitude affected hardness of snow, the first one in December ($P=0.020$), and the second one in February ($P=0.012$), (Table 3, Fig. 7). In simple regression models, the hardness of the hardest snow layer was positively dependent on the altitude of a measurement site only in two out of eight cases (December 2001: $R^2=0.113$, $n=101$ and $P=0.001$ and February 2000: $R^2=0.124$, $n=84$ and $P=0.001$) but it was also negatively dependent on altitude in one case (April 2002: $R^2=0.039$, $n=104$ and $P=0.046$).

Since snow conditions, especially snow depth and density, were dependent on the general elevation of the landscape, we studied how reindeer used different altitudes generally in the study area and separately

Table 2. Effect of different variables on snow density (g/dm³) in the Ivalo reindeer herding district during three winters (1999 - 2002). Multivariate GLM.

		December		February		April	
Variable	*df*	*F-ratio*	*P*	*F-ratio*	*P*	*F-ratio*	*P*
Winter	1	29.36	0.000	68.36	0.000	57.92	0.000
Area	4	2.17	0.075	3.91	0.004	0.65	0.628
Altitude	1	1.43	0.234	1.66	0.199	0.77	0.382
Slope aspect	4	0.95	0.436	0.32	0.862	0.61	0.659
Landscape class	5	1.09	0.369	0.97	0.436	0.47	0.801
		R^2=0.399; *N*=162		R^2=0.401; *N*=293		R^2=0.321; *N*=293	

within each habitat class in different seasonal periods. During the period November-January, reindeer used higher altitudes than the average altitude in the entire MCP area for all reindeer was [Random: 229.2 ± 1.66 m (1526 locations); Observed: 242.2 ± 1.06 m (2963 locations); t=-6.580, df=2788.1, P<0.001]. In contrast during February-April, reindeer used lower altitudes than the average altitude was [Observed: 214.8 ± 1.25 m (3049 locations); t=6.917, df=3216.1, P<0.001]. However, again during May-October reindeer used higher altitudes than the average altitude was [Observed: 243.7 ± 1.19 m (3221 locations); t=-7.917, df=3105.5, P<0.001].

Within the habitat classes and from November to January, reindeer selected higher than average altitudes in mature cultivation forests, old growth forests and mires (for all P<0.001), but lower altitudes only in high elevation open land/open forestlands (P<0.001). In all other forest and landscape classes during the same period, reindeer did not show selection according to altitude. In contrast, from February to April reindeer selected lower than average altitudes in sapling stands (P<0.001), in young and mature cultivation forests (P<0.001 and P=0,028, respectively) and in old growth forests (P=0.019), but higher altitudes only in felling areas (P=0.015). From May to October reindeer again selected higher than average altitudes in mature cultivation forests (P=0.019), old growth forests (P<0.001), high elevation open land/open forestland (P=0.001) and mires (P=0.051), but lower altitudes only in felling areas (P=0.031) (Table 4).

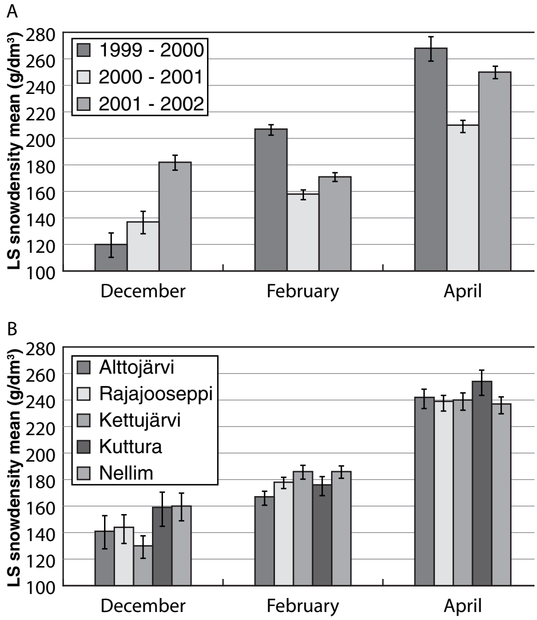

Fig. 5. Snow density (g/dm³, LS (Least Squares) mean ± SE (Standard Error)) a) in different months and b) in different measurement areas during winters 1999 - 2002 in the Ivalo reindeer herding district.

Discussion

The variation of snow conditions in the pine forest area can be divided into two partly interacting sources: the interannual weather variation and certain landscape factors. This study and several others (Post & Stenseth, 1998; Mysterud *et al*., 2000) show that the interannual weather variation clearly dominates the factors that influence snow conditions. The large-scale climatic oscillation in the North Atlantic area expressed by the NAO (North Atlantic Oscillation) index usually predicts how mild and rainy/snowy winters are in Scandinavia (Post & Stenseth, 1999; Mysterud *et al*, 2000; Helle *et al*., 2001; Ottersen *et al*., 2001). Usually positive or negative NAO winters

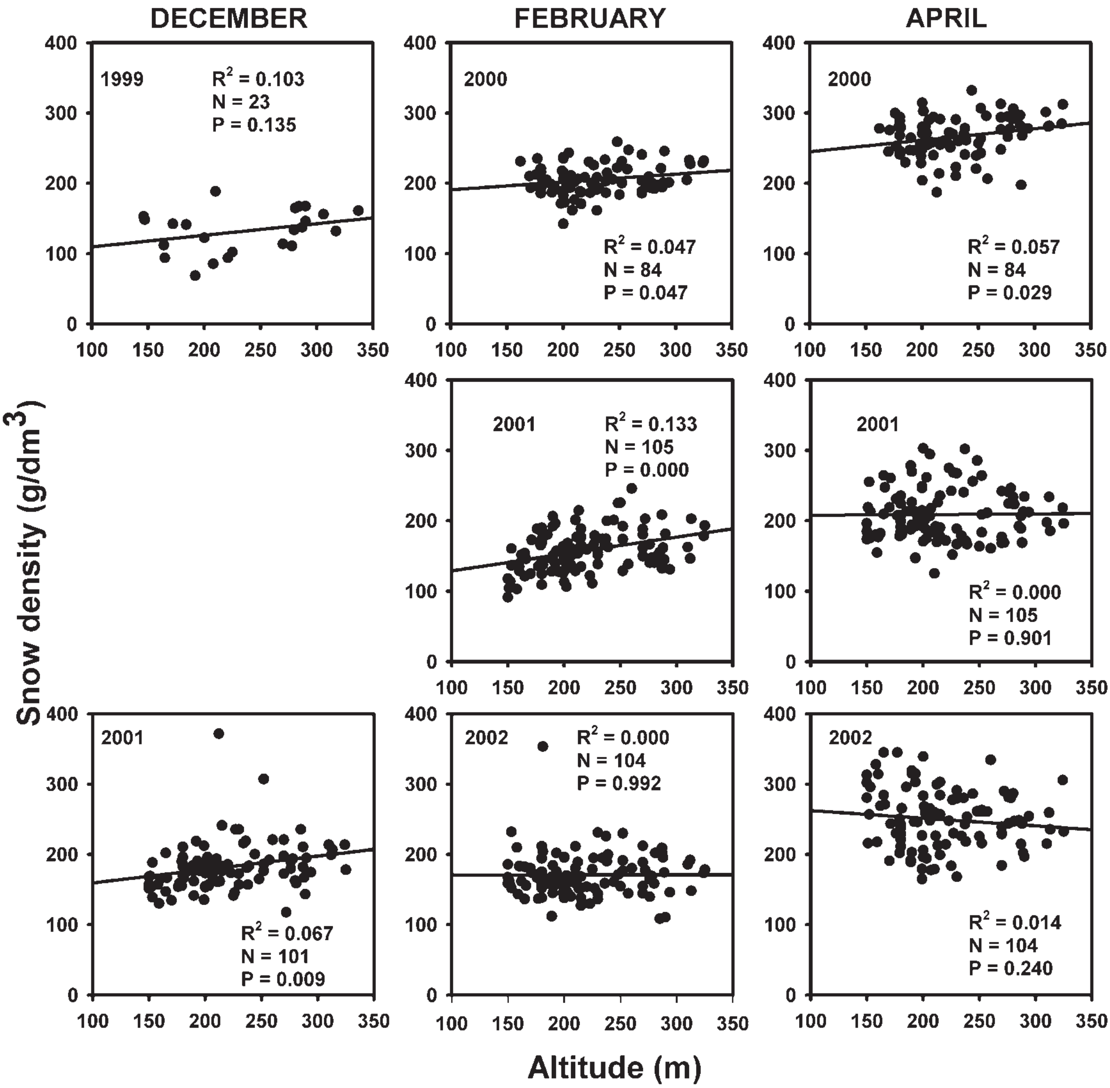

Fig. 6. Dependence of snow density (g/dm³) on altitude (m a.s.l.) in different months in the Ivalo reindeer herding district during winters 1999 - 2002. Simple regression model.

fluctuate in a more or less clear series (see e.g. Ottersen *et al.*, 2001), but as this study also showed, there can be remarkable differences in snow conditions between successive winters.

At the landscape level, the general elevation of the terrain seemed to be the most important factor determining the local snow conditions in our study area followed by slope aspect. In contrast, forest age class seemed to have little effect on snow cover characteristics. This snow condition pattern is surprisingly similar as observed in a study made in southeast British Columbia where elevation was the most important factor affecting local snow depth; followed by slope aspect and canopy cover (D'Eon, 2004). Also in our study area, the higher the average elevation of the terrain, the deeper and partly also denser the snow layer was. This factor clearly affects the winter grazing value of forestland pastures for reindeer in different altitudes and areas. Although the average altitude in our snow measurement areas varied only from 169 to 289 m, snow and digging conditions for reindeer in high elevation forest areas were still very different from those in low elevation forest areas. This observation also confirmed the statements from many local reindeer herders based on their own long-term experience.

Deeper snow in the high elevation forest areas is probably due to the formation of orographic precipitation from moist air coming from the Norwegian coast. Especially the Kuttura area lying on the watershed between the Barents Sea and the Baltic Sea

Table 3. Effect of different variables on snow hardness (g/cm²) in the hardest snow layer in the Ivalo reindeer herding district during three successive winters (1999 - 2002). Multivariate GLM.

		December		February		April	
Variable	*df*	*F-ratio*	*P*	*F-ratio*	*P*	*F-ratio*	*P*
Winter	1	6.87	0.001	16.10	0.000	40.66	0.000
Area	4	3.00	0.020	1.83	0.124	2.03	0.091
Altitude	1	0.50	0.482	6.43	0.012	0.70	0.404
Slope aspect	4	1.08	0.368	0.55	0.700	0.66	0.622
Landscape class	5	1.49	0.194	1.87	0.099	1.32	0.258
		R^2=0.323; N=206		R^2=0.207; N=293		R^2=0.260; N=293	

receives higher than average precipitation. It is probable that changing climatic conditions can affect winter grazing value of these high elevation boreal forest areas, if the phenomenon that Mysterud *et al*. (2000) observed at the Norwegian coast also applies to inland areas. They found that winters with a high positive NAO index, which have been more frequent during recent decades, produce much snow at high altitudes (above 400 m) but less snow at lower altitudes. Hence the climatic change may also give weather with more winter precipitation to our study region, and especially high elevation forestland areas will become more difficult to use in winter for reindeer than today.

Slope aspect also seems to affect snow depth in the pine forest area especially towards the end of winter. In general, the western slopes had the thinnest snow layer and the northern slopes the thickest. The direction and moisture of winds and the amount of solar radiation together probably affect the thickness of snow layer on each slope type. In our study area the prevailing winds in winter comes clearly from southwest (Atlas of Finland 1987). Hence, in rugged forestland areas, snow can accumulate more easily on the wind sheltered slopes than on slopes facing the wind. Towards the end of the winter, solar radiation hastens the melting process of snow especially on western slopes, which get much more solar radiation than northern slopes. This promotes warming and melting processes, which reduces the snow layer and create the first snow-free patches on western slopes during late winter. Early melting of snow may then bring reindeer to graze on western slopes in late winter since digging conditions and availability of food together affect feeding site selection by reindeer and caribou in winter (Skogland, 1978; Helle & Tarvainen, 1984; Adamczewski *et al*., 1988; Rominger & Oldemeyer, 1990; Collins & Smith, 1991; Kumpula,

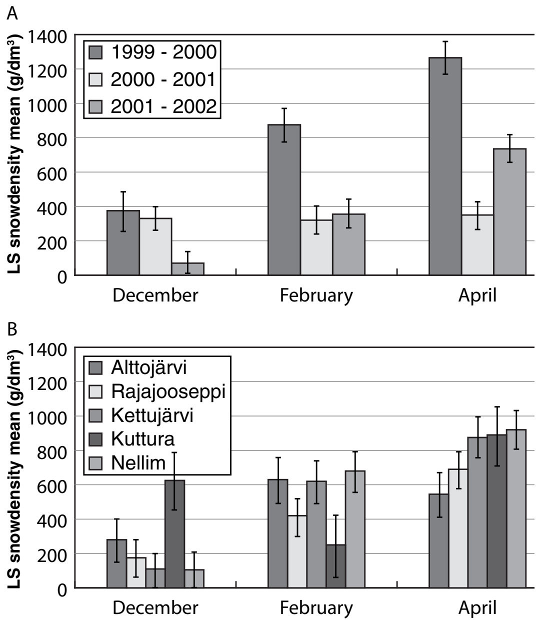

Fig. 7. Snow hardness (g/cm², LS mean ± SE) a) in different months and b) in different measurement areas during winters 1999 - 2002 in the Ivalo reindeer herding district.

2001). In general, the winter grazing value of rugged terrain is higher than that of flat terrain since there are many hillsides with favourable snow conditions in rugged terrain (Nellemann & Thomsen, 1994; Nellemann, 1996).

According to our data, the forest development class had no clear effect on snow conditions. However, we still cannot argue that forest harvesting does not have any altering effect on local snow conditions. The larger open areas forest industry forms, the more likely snow conditions in these open areas will

Table 4. Difference in mean altitude (m) between expected (random) and observed (GPS tracking of reindeer) locations within each forest and landscape class and seasonal period (*N*, *Mean*, SE (Standard Error) and *P*-values in *t*-test).

	Felling area				Sapling stand			
	N	*Mean*	*SE*	*P*	*N*	*Mean*	*SE*	*P*
Expected	106	244.9	5.38		317	218.6	2.22	
Observed								
November-January	169	240.1	3.94	0.467	680	220.1	1.72	0.587
February-April	126	270.2	8.83	0.015	805	196.6	1.63	0.000
May-October	173	230.3	4.06	0.031	900	220.9	1.30	0.360
	Young cultivation forest				Mature cultivation forest			
	N	*Mean*	*SE*	*P*	*N*	*Mean*	*SE*	*P*
Expected	129	239.9	4.10		120	229.6	5.06	
Observed								
November-January	267	244.7	3.25	0.363	410	260.2	2.53	0.000
February-April	176	200.5	2.93	0.000	418	216.9	2.78	0.028
May-October	252	239.2	2.60	0.875	198	244.8	3.91	0.019
	Old growth forest				High elevation open forestland/open land			
	N	*Mean*	*SE*	*P*	*N*	*Mean*	*SE*	*P*
Expected	365	213.2	2.85		111	347.7	4.46	
Observed								
November-January	797	228.0	1.85	0.000	156	321.6	3.12	0.000
February-April	798	205.1	1.97	0.019	155	341.3	6.74	0.430
May-October	578	232.7	2.15	0.000	353	367.0	2.32	0.000
	Mire				Gravel/roads/lines			
	N	*Mean*	*SE*	*P*	*N*	*Mean*	*SE*	*P*
Expected	174	204.3	4.90		10	195.8	11.89	
Observed								
November-January	224	245.2	5.15	0.000	5	191.6	10.89	0.799
February-April	266	212.3	5.41	0.274	24	180.2	10.56	0.337
May-October	488	215.5	2.94	0.051	31	199.9	7.63	0.775

change (see Eriksson, 1976; Kirschhoff & Schoen, 1987; Koivusalo & Kokkonen, 2002). Changes in wind and solar radiation conditions may make snow denser in large open felling areas and snow depth can also vary much like snow conditions vary in open tundra landscapes (see Adamczewski *et al.*, 1988; Collins & Smith, 1991; Larter & Nagy, 2001). However, if forest harvesting causes changes in snow conditions in our study area, these effects are much less pronounced than the effects caused by interannual weather variation or altitude and slope aspect. The current size of felling areas is generally less than ten hectares and limited approximately to 20 hectares at maximum (Pertti Heikkuri, pers. comm.), which also probably reduces the effect of present forest harvesting practices on snow conditions.

During the snow-free season (from May to October), reindeer selected average or higher than average altitudes within most forest and landscape classes (with the exception of felling areas). Factors, which affect the selection of the altitude, obviously vary within the snow-free period. Especially during spring and summer, higher altitudes may have numerous advantages. In the springtime, reindeer usually search for places with an abundance of good quality food (Van der Wal *et al.*, 2000). Later in summer they may search for both fresh green vegetation and relief from insect harassment and heat in areas with higher altitudes (Hagemoen & Reimers 2002; Anderson *et al.*, 2001; Skarin *et al.*, 2004). Contrastingly, in autumn, reindeer can use varying altitudes when searching for mushrooms and gathering in rutting groups.

In early and mid winter (from November to January) reindeer still preferred higher than average altitudes in mature cultivation forests, old growth forests and mires but lower altitudes only in high elevation open forestland/open land. During the study, snow conditions in early and mid winter were relatively favourable (with the exception of winter 1999 - 2000), which made it easier in general for reindeer to find winter forage also at higher altitudes. Especially the foraging conditions of mature and old growth forests located at high altitudes could be favourable since the amount of reindeer lichens within these forest classes in the Ivalo district was also measured to be higher than in other forest classes (Kumpula *et al.*, 2003). Reindeer could also search for dwarf shrubs, lichens and sedges from the hummock surfaces of the high elevation mires.

In late winter, the selection of altitude was, however, contradictory. Reindeer used lower than average altitudes in sapling stands, young and mature cultivation forests and in old growth forests but higher altitudes in felling areas. It is likely that in late winter when snow conditions and food availability were most difficult, reindeer preferred the lower elevation forestland because snow and digging conditions were easier there than in higher altitudes. At low altitudes, reindeer probably could also search for arboreal lichens, which grow most abundantly in old growth forests with humid microclimates located in river valleys and close to lakesides and mires.

Although lichen ranges can be considered heavily worn-out in our study area (Kumpula *et al.*, 2000; 2004b) and reindeer herders had to give supplementary feed to reindeer in the field from mid to late winter, especially in the southern and central part of the Ivalo district, reindeer herders assured that they selected feeding places in the same areas where reindeer actually would have independently grazed during that time. It would be unreasonable, indeed, not to follow the normal pasture rhythm of reindeer when the aim is to keep reindeer in good physical condition on natural pastures, where reindeer, despite supplementary feeding, still have to obtain clearly the majority of their food from natural vegetation.

This study showed that interannual weather variation and certain natural factors are primary sources causing variation and differences in local snow conditions in the boreal forest area. Although forest industry operates intensively in this area it does not seem to change snow conditions as much as has been earlier assumed or claimed. On the other hand, forest harvesting alters reindeer pastures in a number of other ways. The amount of arboreal lichen reduces significantly in felling areas, but terrestrial lichens may also suffer from mechanical logging and cultivation practices (Kumpula, 2003). The felling residue can also disturb the growth of forage plants and hamper digging for food plants by reindeer in winter. Besides this, forest harvesting causes fragmentation of the landscape, which has been observed to change the selection of home range areas by caribou (Smith *et al.*, 2000). For this reason also reindeer are quite reluctant to graze in new felling areas in wintertime, although they may use intensively sapling stands where the felling residue is sufficiently decomposed and growth of terrestrial lichens or hays is improved (Kumpula, 2003; Kumpula *et al.*, 2003).

Since forest harvesting markedly changes the winter grazing value of forestland pasture, the variation of snow conditions between different pasture areas should also be taken into consideration when evaluating the total impact of forest harvesting on the use of pastureland by reindeer (see e.g. Rominger & Oldemeyer, 1990). From the perspective of reindeer herding, the most valuable winter pastures are located in forestland areas where snow conditions are most favourable for reindeer especially in late winter, and therefore the low elevation forestland areas have a high winter grazing value. However, forest industry also has to operate most intensively at the low elevation forestland areas where regeneration and growth of trees is better than in high elevation forestland areas. This contradiction obviously poses more challenges for the co-operation between different land use requirements.

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Lumiolosuhteet ja laidunten käyttöarvo poronhoidossa pohjoisella havumetsäaluella

Abstract in Finnish / Tiivistelmä: Lumiolosuhteiden vaihtelua ja porojen (*Rangifer tarandus tarandus*) laidunalueen valintaa maaston korkeuden perusteella tutkittiin vuosina 1999–2002 metsätalouden hyödyntämällä mäntymetsäalueella Ivalon paliskunnassa, Pohjois-Suomessa. Lumiolosuhteet mitattiin kolme kertaa kunakin kolmena talvena käyttämällä mittaukseen tasasivuisia kolmioita (sivu 3,5 km). Porojen laidunalueen valintaa korkeusvyöhykkeen mukaan tutkittiin käyttämällä porojen GPS seurannan aineistoja 29 vaatimesta (yhteensä 10 977 paikannusta). Vuosien välinen säävaihtelu vaikutti eniten lumen paksuuteen, tiheyteen ja kovuuteen tutkitulla alueella. Maisematasolla lumen paksuus ja tiheys lisääntyivät alueen korkeuden kasvaessa metsämaalla. Ohuin lumikerros mitattiin länsirinteillä ja paksuin kerros pohjoisrinteillä. Sen sijaan metsien käsittelyllä ei näyttänyt olevan selvää vaikutusta lumiolosuhteisiin. Keväästä syksyyn porot käyttivät pääosin ylemmillä korkeusvyöhykkeillä sijaitsevia laitumia. Alku ja keskitalvella, jolloin lumiolosuhteet olivat vielä verrattain helpot, porot suosivat edelleen ylemmille korkeusvyöhykkeille sijoittuvia laitumia, mutta lopputalvella lumiolosuhteiden ja ravinnonsaannin ollessa vaikeimmat, porot suosivat alempien korkeusvyöhykkeiden laitumia. On todennäköistä, että erityisesti ylemmillä korkeusvyöhykkeillä olevat metsämaan laitumet voivat tulla vaikeammaksi käyttää poroille talvella, mikäli ilmastonmuutos aiheuttaa talvisadannan lisääntymisen pohjoisella havumetsäalueella. Yleisesti alemmille korkeusvyöhykkeille sijoittuvilla metsämaan laidunalueilla on ensisijainen talvilaidunarvo poronhoidolle, mutta myös metsätalous hyödyntää näitä alueita intensiivisesti.