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Winter grazing of reindeer in woodland lichen pasture Effect of lichen availability on the condition of reindeer

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Abstract

Winter grazing of semi-domesticated reindeer (*Rangifer t. tarandus*) was investigated at the woodland lichen pasture (lichen approximately 550 kg DM ha^{-1}) in Kaamanen, northern Finland during the winter 1996–1997. Nine female reindeer mainly dug their food in the snow for 122 days (3 December–4 April) in a fenced area of 36.3 ha. Over half of the fenced area was lichen dominated dry pine forest. The amount of lichens in lichen forest inside the fence was estimated before and after grazing. Area of grazed and condition of reindeer as well as snow conditions were monitored. Reindeer grazed over the whole area of lichen forest in early winter but from mid-winter they tended to graze on the areas with the greatest lichen abundancy. The amount of lichens measured decreased in the latter areas by 40% and in the other part of the lichen pasture by 17%, respectively. In both of these areas the residual amounts of lichens left after grazing were similar. Of the dominant lichens, the amount of *C. stellaris* decreased the most and the amount of *Cl. uncialis* the least. During the study, the estimated average daily area grazed varied from 4 to 87 m^2 per reindeer. It was calculated that individual reindeer obtained 2.6 kg of lichen DM per day during the most intensive digging period when the body condition score and weight of reindeer increased. Otherwise, the body condition score and weight decreased. Reindeer finished foraging for ground lichens and started to search for arboreal lichens in mid-March when the snow layer was 70–80 cm thick and contained some hard snow layers which lifted reindeer. Both the amount of lichens in the pasture and the snow conditions essentially affect the nutritional status of reindeer in the woodland region during winter. Assuming that a reindeer is able to graze around 30 m^2 per day in the snow during mid and late winter, there should be, on the basis of energy demand and grazing behaviour of reindeer as well as the nutritive value of lichen, an estimated 1000 kg lichen DM ha^{-1} available in a good condition woodland lichen pasture.

Keywords: Reindeer; Lichen; Nutritional need; Grazing; Digging

1. Introduction

Lichens (*Cladonia* spp.) form an essential part of the winter nutrition of reindeer (*Rangifer tarandus*). During their long adaptation, reindeer have evolved to effectively utilise food composed of lichens, dwarf shrubs, sedges and grass hay by foraging in the snow. Lichens contain a lot of easily digestible carbohydrates (Russell and Martell, 1984) and a diet containing lichens is effectively fermented by reindeer and promotes the digestion of plant fibre in the rumen (Aagnes et al., 1995). The body structure and digging technique of reindeer have both evolved to save energy when foraging in the snow (Thing, 1977; Fancy and White, 1985).

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The management of semi-domestic reindeer in Scandinavia has been traditionally based on a sustainable use of natural plants fodder produced in the pasture land. However, during the last decades the increase in reindeer stock number, changes in management methods and also the increase in uses of land for other purposes have caused a decrease in the availability of pasture land for reindeer and the deterioration of pasture conditions. This has created problems in the productivity and profitability of reindeer production in many areas in Scandinavia (Kumpula et al., 1998; Kumpula, 1999; Gaare et al., 1999). The decrease in winter pasture resources and the deterioration in the lichen pasture conditions have been compensated for by supplementary feeding of reindeer in Finland, but as feeding has increased, the condition of lichen pastures has continuously decreased (Mattila, 1988, 1996).

Reindeer management based on the sustainable utilisation of natural pastures requires a knowledge of its utilisation, productivity and recovery after grazing. The aim of this work was to investigate the winter grazing of reindeer on a relatively heavily stocked woodland lichen pasture. Effects of grazing on the lichen pasture condition were monitored, and the size of the daily grazing area and the amount of lichens utilised by reindeer were evaluated. The effects of the size of the grazing area and the amount of lichens acquired by digging on the body condition of reindeer were also studied. Finally, on grounds of the digging ability and nutritional demands of reindeer in mid and late winter in woodland regions, a sufficient condition level of lichen pastures was assessed.

2. Material and methods

This work was carried out in a fenced area of the Reindeer Research Station in Kaamanen, northern Finland, in the winter 1996–1997. The size of the fenced area was 36.3 ha, of which 55% was lichen dominated dry pine forest, 39% submesic pine and mixed birch forest dominated by dwarf shrubs and mosses. The remaining 6% of the fenced area was covered by mire. Of the forest land inside the fence, 25% was over 100 years old, while the rest was 50–100 years old. On the basis of the measurements made in this study and the lichen growth model presented by Kumpula et al. (2000), the average lichen biomass in dry pine forest inside the fenced area was around 20% of the optimum and 8% of the climax stage lichen biomass in lichen pasture.

Nine semi-domesticated female reindeer were kept within the fenced area, freely grazing from 3 December to 4 April (122 days). A small amount of dry grass hay and concentrate feed was offered weekly to females during the experiment. In each grazing period the average daily energy content (MJ) of the feed offered was calculated per reindeer. Before and repeatedly during the experiment the females were weighed and their body condition was estimated by the body condition scoring. Body condition scoring was partly adapted from the method of Gerhart et al. (1996) with the values 1–8. The condition index of the reindeer was evaluated by palpating the back of the animal above and in front of the hips.

In order to investigate the effects of reindeer grazing on lichen cover, a total of 30 stakes were first placed randomly in the lichen dominated forest inside the fenced area in autumn 1996. At 2 m from each stake, metallic markers which did not interfere reindeer grazing, were pushed into the soil at the four main compass points. This metallic marker was the centre of the four squares with size 0.25 m^2. The base map of the location of the squares was drawn and an ID-number was given to each square. The lichens within the squares were studied first before reindeer grazing in September 1996 and then after grazing in June 1997. However, if there were any large rocks, trees or tree stumps inside a square, it was not studied.

The average percentage cover (%) of lichen stand formed by the four dominant species (*Cladina stellaris*, *C. mitis*, *C. rangiferina* and *Cladonia uncialis*) were first estimated inside each square and after that the proportion of each species per lichen stand. The average height of each of the lichen species was systematically measured and the weighted mean height of the whole lichen stand was calculated in one of the four squares. The biomass estimates of lichens (g DM 0.25 m^{-2}) in these squares were calculated from the base of the average percentage cover and the height of the lichen stand according to the biomass equation presented by Kumpula et al. (2000). The percentage cover of other *Cladonia* spp. and *Stereocaulon* spp. — species was also estimated inside each square. Those squares inside of which clear tracks of reindeer grazing were found were registered on June 1997. The handling of the data was done by comparing the differences in the percentage cover, height and biomass of lichens in the fenced areas between September 1996 and June 1997 by the paired *t*-test. The dependence of the lost biomass grazed by reindeer on the initial lichen biomass in the squares was tested by Pearson's correlation.

During the experiment the average depth of the snow was measured repeatedly at sites selected randomly. The average vertical hardness of the snow for two hardest layers at each measurement sites was taken by a penetrometer. The size of the digging and grazing area during each period was evaluated as follows. Parallel routes, for which the distance was around 80 m, were driven by a snowmobile inside the fence. Along these routes the percentage cover (%) of all digging and grazing tracks was evaluated inside squares (size: 30 m × 30 m), which were located at a distance of 80 m from each other. The location of each square was placed on the vegetation map which was produced before the experiment. The average percentage cover of all digging and grazing tracks inside the entire fenced area and inside the lichen dominated forest was calculated.

On the basis of the entire fenced area and the area of lichen dominated pine forest, these percentage covers were then converted for the total areas (m^2) of tracks. However, the area (m^2) of all digging and grazing tracks in March and April was evaluated from direct measurements because there were so few tracks at these times. The age of the tracks in days was calculated from the period of days during the course of which the total snow accumulation was less than 5 cm. Since the bottom area of craters for grazing dug by reindeer was considerably smaller than the entire area of all digging and grazing tracks, altogether 40 craters (grazing hollows) with their surrounding areas were studied in January 1997 and the whole area of all tracks and the bottom area of the crater was measured. The proportion (%) of the actual grazing area of all digging tracks was calculated. According to this percentage and the total area of all tracks, the daily grazing area per single reindeer (m^2 per reindeer per day) was calculated during each grazing period.

The proportion of different vegetation groups in winter food available for reindeer in the lichen pasture in question was evaluated one year after grazing by randomly collecting 12 vegetation samples from the lichen dominated forest in February 1998. First, a hollow whose bottom area was 25 cm × 25 cm (625 cm^2), was dug in the snow. All available vegetation was collected from this area and stored in paper bags. Samples were afterwards cleaned and sorted into the main vegetation groups in the laboratory and then oven-dried at 105°C for 24 h. The amount of main vegetation groups was weighed (g DM) for each sample.

The dependency of the change in the body condition score and weight of reindeer on the daily grazing area, the amount of lichen acquired in this area and on the energy content of these lichens was tested by Pearson's correlation. The effect of depth and hardness of snow on the grazing behaviour of reindeer was assessed by comparing the daily grazing area per reindeer during each period to the results of the snow measurements.

3. Results

Reindeer grazed nearly the whole area of lichen dominated forest in early winter but from mid-winter they tended to graze mainly in the areas with the most abundant lichen cover. The amount of lichens decreased due to grazing in the lichen pasture between the inventories (Table 1). The average decrease in lichen coverage measured in the sample squares was 2.7% and the average decrease in lichen height 7.2 mm. Reindeer grazing decreased the computational biomass of lichens in the squares on an average 4.3 g DM 0.25 m^{-2} (31%). Of the four most dominant lichen species, the amount of *C. stellaris* decreased the most and the amount of *Cl. uncialis* the least. Grazing also decreased the amount of other lichen species (*Cladonia* spp. and *Stereocaulon* spp.).

Those squares which were noted to be grazed clearly by reindeer had a considerably higher coverage percentage of lichens before grazing than the other squares (Table 2). The average decrease in lichens in these intensively grazed squares was 6.4 g DM 0.25 m^{-2} (40%) while it was 1.8 g DM 0.25 m^{-2} (17%) in the rest of the squares. The remainder of the biomass of lichens after grazing in these two square groups was nearly the same. The previous figures did not represent exactly the lichen biomass utilised by

Table 1
Average percentage cover (%), height (mm) and biomass (g DM 0.25 m^{-2}) of lichens (mean ± S.E.) and their changes (Δt) in the squares (0.25 m^2) studied before and after reindeer grazing in the lichen pasture inside a fence

Lichen species	Variable	September 1996 (mean ± S.E.)	June 1997 (mean ± S.E.)	Change Δt	n	P[a]
Dominant lichens	(%)	24.8 ± 0.75	22.0 ± 0.63	−2.8	416	<0.001
	(mm)	34.2 ± 0.58	27.0 ± 0.52	−7.2	106	<0.001
	(g DM 0.25 m^{-2})	13.7 ± 0.96	9.4 ± 0.62	−4.3	106	<0.001
C. stellaris	(%)	7.2 ± 0.30	5.4 ± 0.21	−1.8	416	<0.001
	(mm)	35.6 ± 0.69	28.3 ± 0.62	−7.3	97	<0.001
C. mitis	(%)	6.5 ± 0.23	5.9 ± 0.20	−0.6	416	<0.001
	(mm)	33.3 ± 0.72	27.3 ± 0.63	−6.0	96	<0.001
C. rangiferina	(%)	7.2 ± 0.26	6.6 ± 0.22	−0.6	416	0.061
	(mm)	37.5 ± 0.85	28.2 ± 0.85	−9.3	100	<0.001
Cl. uncialis	(%)	3.9 ± 0.24	4.1 ± 0.21	+0.2	416	<0.001
	(mm)	25.0 ± 0.92	21.1 ± 0.58	−3.9	66	<0.001
Cladonia spp.	(%)	0.8 ± 0.12	0.4 ± 0.06	−0.4	416	<0.001
Stereocaulon spp.	(%)	0.3 ± 0.09	0.2 ± 0.62	−0.1	416	<0.001

[a] Significance of differences by paired t-test.

reindeer m^{-2} grazed, however, since an estimation of the grazed area inside each square was not made. However, it can be seen that reindeer consumed 50–70% of the total biomass of lichens in the areas with the most abundant lichens (Fig. 1).

The total amount of available vegetation in winter, one year after grazing was on an average 58 g DM m^{-2} in the lichen dominated pine forest (Table 3). Of this amount, 70% was lichens, 20% dwarf shrubs, 2% grass hay and 10% moss, respectively. During the whole experiment, reindeer tended to graze mainly in the lichen dominated forest (Table 4). However, during the most intensive digging period, in February, reindeer also grazed in a relatively large area of submesic forest. The actual grazing area was on an average 38.7% (S.D. $= 13.3, N = 40$) of all digging and grazing tracks. This percentile was used when the real grazing area per reindeer for each period was calculated from the estimations of all digging and grazing tracks (Table 5).

The body condition of the reindeer did not decrease directly as the snow conditions became more difficult,

Table 2
Average percentage cover (%), height (mm) and biomass (g DM 0.25 m^{-2}) of a lichen stand (mean ± S.E.) formed by the four dominant lichen species and their changes (Δt) in the squares (0.25 m^2) studied before and after reindeer grazing. The squares were divided into two groups according to clear grazing tracks noticed in each square in June 1997

Variable	Clear grazing tracks	September 1996 (mean ± S.E.)	June 1997 (mean ± S.E.)	Change Δt	n	T	P[a]
Percentage cover (%)	No	20.7 ± 1.06	20.4 ± 0.90	−0.3	196	0.39	0.701
	Yes	28.3 ± 1.06	23.5 ± 0.88	−4.8	219	4.97	<0.001
Height (mm)	No	34.3 ± 0.74	28.3 ± 0.73	−6.0	48	6.44	<0.001
	Yes	33.9 ± 0.92	25.7 ± 0.70	−8.2	58	8.82	<0.001
Biomass (g DM 0.25 m^{-2})	No	10.9 ± 1.28	9.1 ± 1.11	−1.8	48	2.30	0.026
	Yes	16.1 ± 1.33	9.7 ± 0.66	−6.4	58	4.85	<0.001

[a] Significance of differences by paired t-test.

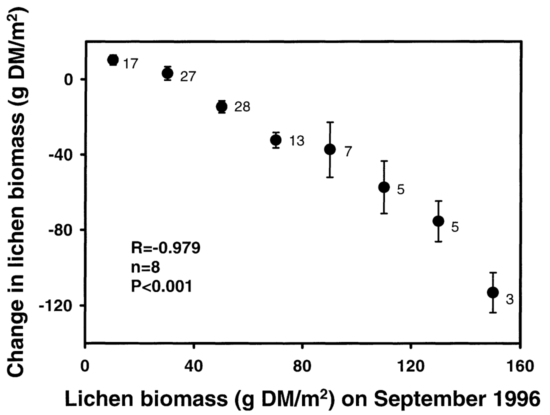

Fig. 1. Dependence of the lichen biomass grazed by reindeer during winter on the initial biomass of lichens before grazing in the squares (g DM 0.25 m^{-2}).

but it was clearly linked to the grazing area and thus the amount of lichens and other plants utilised by reindeer until the end of March (Table 5, Fig. 2). Change in the body condition score per day was correlated clearly to the daily grazing area ($R = 0.992, N = 4, P = 0.008$), the calculated amount of lichens utilised per day and the calculated energy content of these lichens (both of the latter correlations: $R = 0.993, N = 4, P = 0.007$) before mid-March, even though the amount of data was small. On the contrary, all of the latter variables did not correlate so well with the change in weight per day during this same period (for all of these correlations: $P < 0.195$).

Reindeer did not do much digging from the middle of March but obtained their food mainly by foraging arboreal lichens from trees. Digging was inhibited in the lichen pasture in question by a 80 cm thick snow cover. Snow cover also contained some hard snow layers which lifted reindeer. It was calculated, according to the estimates made on the size of the grazing area for each grazing period that reindeer had grazed around 24% of the whole area of lichen dominated pine forest within the fence until the mid of March.

Table 3
Biomass of different vegetation groups in the samples ($N = 12$) collected in February 1998 from the grazed lichen pasture inside the fence. The samples were collected from the hollows (25 cm × 25 cm) dug in the snow

Variable	625 cm^2 (25 cm × 25 cm) g DM (mean ± S.E.)	Calculated to 1 m^2 g DM	% of total biomass
Lichens	2.51 ± 0.714	40.16	69.3
Dwarf shrubs	0.69 ± 0.146	11.04	19.1
Grass hays	0.06 ± 0.043	0.96	1.7
Mosses	0.36 ± 0.149	5.76	9.9
Together		57.92	100.0

Table 4
Percentage cover (%, mean ± S.E.) of all digging and grazing tracks within the fence during the grazing periods for which the length (days) was estimated according to snowfall. Total area (m^2) of tracks and proportion (%) of the tracks in the lichen pasture are given. Percentage cover of the tracks in the first four periods was estimated on the basis of squares 30 m × 30 m but after that the whole area (m^2) of the tracks was directly estimated

Period	Length of period (days)	Percentage cover f all tracks		Squares of *n*	Area of all tracks		Tracks in lichen pasture (%)
		%	±S.E.		m^2	m^2 per day	
3/12–9/12	6	2.98	0.861	61	10705	1784	100.0
14/12–3/1	20	4.57	0.645	58	16589	829	91.5
12/1–30/1	18	3.14	0.389	68	11381	632	91.8
4/2–11/2	7	3.91	0.487	80	14164	2023	86.6
10/3–12/3	2	0.28	–	–	1003	502	100.0
19/3–21/3	2	0.05	–	–	194	97	100.0
31/3–1/4	1	0.01	–	–	48	48	93.8

Table 5
Body weight and condition index of the reindeer, length of grazing periods, size of area grazed, calculated intake of lichens, energy contents of these lichens and of supplementary feed offered, and finally the snow measurements during the study

Variable	Dates					
	2/12	3/12–7/1	7/1–31/1	31/1–14/2	14/2–12/3	12/3–4/4[a]
Body weight[b] (kg, mean ± S.E.)	72.8 ± 2.22	70.6 ± 1.91	67.2 ± 1.82	69.2 ± 1.95	69.1 ± 2.45	69.2 ± 2.35
Body condition index[b] (mean ± S.E.)	5.0 ± 0.69	4.4 ± 0.53	3.7 ± 0.62	3.8 ± 0.62	3.1 ± 0.59	2.9 ± 0.56
Length of period (days)		35	24	14	26	23
Grazed area (m^2 per reindeer per day)						
Within the whole fence		45.1	27.2	87.0	21.6	3.5
Within lichen pasture		42.1	25.0	75.3	21.6	3.3
Lichens[c] (kg DM per reindeer per day)		1.47	0.88	2.64	0.76	0.12
Lichens[d] (MJ per reindeer per day)		15.88	9.50	28.51	8.21	1.30
Supplementary feed[d] (MJ per reindeer per day)		4.6	0.9	1.8[e]	4.2	4.0
Snow depth[f] (cm)		38.4	51.3	68.7	79.8	82.7
Snow hardness[f] ($g\ cm^{-2}$)		739	508	839	878	77[g]

[a] Reindeer obtained their food after 15 March 1997 mainly by taking arboreal lichens.
[b] Reindeer were weighed and the body condition index was evaluated on the last day of each period.
[c] The average lichen biomass utilised by a reindeer in the area dug and grazed was estimated at 35 g DM m^{-2}.
[d] Energy contents used in the calculations: lichens 10.8 MJ kg^{-1} DM, dry hay 8.8 MJ kg^{-1} DM and concentrate feed 10.9 MJ kg^{-1} DM (Isotalo, 1974; Salo et al., 1982; Nieminen and Heiskari, 1989).
[e] Reindeer consumed very little of the supplementary feed offered.
[f] Depth and hardness of the snow were measured on the next days: 3/12–4/12 (9 measurements), 9/1 (7 measurements), 18/2 (10 measurements), 12/3 (4 measurements) and 1/4 (8 measurements).
[g] The whole snow layer was softened by warm weather. Before this the upper layer of the snow beared the reindeer.

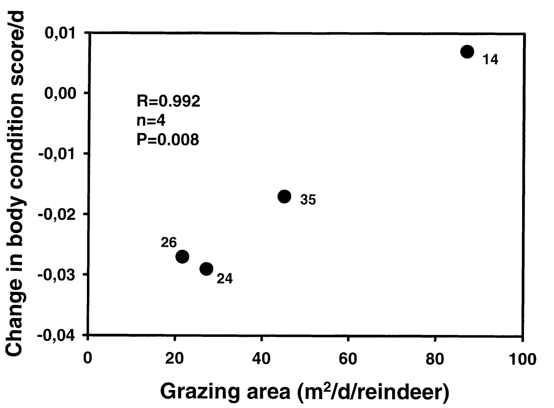

Fig. 2. Effect of the size of a grazing (digging) area by a reindeer per day during each grazing period on the daily change in the body condition score. Length of each grazing period (days) has been marked near each data point.

4. Discussion

Reindeer are selective while grazing on lichen pasture in winter. When grazing even in 70 cm of snow in winter, semi-domesticated reindeer (*R. t. tarandus*) and wild forest reindeer (*R. t. fennicus*) are able to find the areas with the most abundant lichens in the pasture with the aid of their sense of smell (Helle, 1980, 1984). Thus they can optimise the nutritional benefit achieved by cratering (digging work). It is probable that the coverage of lichens is the most important fact when a reindeer selects a place to dig in thick snow. During this study, it was also noted as earlier (Helle, 1980, 1984), that reindeer dug very long, canal like hollows while grazing in a thick snow. This is a reasonable way to behave since opening a new crater consumes a lot of energy. Reindeer also have to utilise lichens and other plants dug out effectively while grazing in thick snow (Helle, 1984). According to Helle (1980, 1984), the semi-domesticated reindeer and the wild forest reindeer may consume over 80% of the total biomass of lichens within a crater while grazing in a thick snow. In this work, the average amount of lichens decreased 50–70% in the areas with the most abundant lichens.

At the beginning of winter or if snow conditions later in winter are easy, semi-domesticated reindeer as well as caribou graze in the areas where there are fewer lichens and more dwarf shrubs, sedges and grass hays (Miller, 1978; Adamczewski et al., 1988).

Depending on snow conditions, the size of a crater is usually quite small in early winter (Helle, 1980, 1984; Russell and Martell, 1984) and reindeer also tend to migrate more than later in winter. Since reindeer grazing is selective in lichen pastures especially during mid and late winter, the average decrease in percentage cover and height of lichens measured in this study did not represent the whole picture of the change which occurred in the lichen pasture due to reindeer grazing. It is obvious that the amount of lichens within the actual craters grazed in a thick snow in particular, decreased considerably while the area immediately surrounding these craters was left untouched. Therefore a lichen pasture only grazed by reindeer in mid and late winter, is always formed by small mosaic-like sites (areas cratered by reindeer in different winters) inside of which the succession level of lichens varies. This makes the evaluation of the productivity of lichens within the grazed lichen pastures more complicated than on ungrazed lichen areas.

The same change in lichen cover which can be seen inside each crater in all lichen pastures after reindeer winter grazing will occur over the whole area of lichen pasture if winter grazing is too heavy or too frequent or, on the contrary, lichen pasture is grazed and trampled during the summer season. The traditional way to use winter ranges in which reindeer were only allowed to graze lichen pastures in the best condition in mid and late winter, and after which a lichen pasture was left for 3–5 years to recover (Alaruikka, 1964; Andreyev, 1977), seems a very rational adaptation of utilising lichen ranges.

The average amount of lichens in dry pine forest within the fenced area was, before grazing, around 550 kg DM ha^{-1} and after, around 380 kg DM ha^{-1}. According to the model of lichen growth and recovery presented by Kumpula et al. (2000), it would take $2\frac{1}{2}$ years before the average amount of lichens would be at the initial level. Since the amount of lichens has not decreased evenly throughout the lichen pasture, recovery of the most intensively grazed areas would probably need a longer time. The average initial lichen biomass in the most heavily grazed areas was, before grazing, 640 kg DM ha^{-1}, and after, 390 kg DM ha^{-1}. According to the model presented previously, the recovery of lichen cover to the initial lichen biomass in this area would need $3\frac{1}{2}$ years. Equivalently, if the average initial biomass of lichens is 1000 kg DM ha^{-1} and 80% of this biomass is grazed, it would take 10.5 years for lichens to recover to the initial level.

The conditions of lichen pastures and snow essentially affect how well a reindeer is able to get through a winter in a good body condition. The less natural food a reindeer is able to utilise from a cratered area and the harder the snow conditions are, the less the nutritional needs of reindeer are satisfied. Digging demands more energy as the snow layer increases and becomes harder (Thing, 1977; Fancy and White, 1985). It is obvious that an increase in the size of cratering areas in less rich lichen pastures will have a similar effect. Depending on both the conditions of pastures and the snow, reindeer will reach a certain limit after which obtaining food by digging will be impossible. When lichen pastures are overgrazed, this limit will be reached much faster than if lichen pastures are in good condition. After reaching this limit the nutritional status of reindeer is much affected by the availability of arboreal lichens in the pasture area. It seems evident that due to the increased energy demands, the reindeer in this study were unable to keep digging constantly effective enough in order to get enough food from the lichen pasture in relatively difficult snow conditions.

The metabolisable energy need for maintenance of reindeer and caribou females in winter has been estimated to vary between 20.5 and 23.0 MJ per day per animal (McEwan and Whitehead, 1970; Boertje, 1985). Increasing activity and the development of a foetus increase the need for energy during late winter (Adamczewski et al., 1993). The actual need for metabolisable energy by reindeer or caribou foraging under difficult snow conditions has been estimated 33.4 MJ per day per animal (McEwan and Whitehead, 1970). In this study, the maximum estimated energy intake from lichens utilised was 28.5 MJ per reindeer per day during the most intensive digging period when reindeer had to work very hard. Reindeer probably also consumed a considerable amount of other food plants (dwarf shrubs, sedges and grass hays) during this period because 13% of their digging occurred in the submesic forest or mire. As a result of the intensive grazing the body condition of reindeer improved. Otherwise, the body condition score and weight decreased during the experiment. It has to be pointed that the change in the weight of female reindeer from mid-winter did not represent very well the real change in the body condition since the development of a foetus took an increasing proportion of the body weight of a female.

The method used to estimate the daily grazing (digging) area of a reindeer is relatively rough and probably overestimates to some extent the real size of this area. Comparing the amount of digging area measured in this study with earlier literature is enabled best by illustrating the length of time which would have been needed to perform the maximum daily digging. Thing (1977) and Collins and Smith (1991) measured the speed of cratering by caribou and noticed that they make on an average two strokes per second during the actual digging in shallow snow. Thing (1977) also estimated that caribou can move snow from a crater on an average 3.75 dm^3 per one stroke. If the smaller values are used for reindeer in the next calculation (speed of digging: one stroke per second; amount of snow moved from crater: 2.0 dm^3 per stroke), the minimum speed of digging by reindeer would be around 5 min m^{-2} in snow of a depth of 60 cm. On the basis of this calculation, the length of time needed to perform the digging alone of 87 m^2 in this kind of snow would be 7 h and 15 min at least, or in other words, 30% of the whole time budget per day.

It can be estimated that the previous amount of digging evidently takes too much of time and energy for reindeer per day since the acquisition of food (digging work + grazing) usually accounts for 41–69% (9 h 50 min–16 h 34 min) of the whole time budget for caribou or reindeer per day (Russell and Martell, 1984; Collins and Smith, 1991). When snow conditions become harder the proportion of the pure digging increases and can be 14–17% (3 h 35 min–4 h 10 min) of the whole time budget of a caribou per day (Collins and Smith, 1991). Thus, it can be estimated that the maximum reasonable size of a digging area by reindeer would be between 25 and 35 m^2 per day in the snow conditions which usually prevail in mid and late winter in the woodland regions of Finland.

In relatively good pasture conditions during winter, the proportion of lichens usually forms 50–80% of all food dug and grazed by woodland reindeer and caribou (Avramchik, 1939; Scotter, 1967; Miller, 1978; Russell and Martell, 1984; Kojola et al., 1995). The metabolisable energy content of lichens is around 10.8 MJ kg^{-1} DM and of dwarf shrubs 5.0–7.0 MJ kg^{-1} DM (Isotalo, 1974; Salo et al., 1982; Nieminen and Heiskari, 1989). If the total energy need of a reindeer foraging in thick snow is 25.0–28.0 MJ per day and if the proportion of lichen in reindeer nutrition is 70%, a reindeer has to acquire 1.9–2.1 kg DM of lichens per day in order to satisfy the total energy need. In this kind of situation, a reindeer would satisfy around 80% of the whole daily energy budget with lichens. Based on the studies on the consumption of lichens (Hanson et al., 1975; Holleman et al., 1979), the previous amount of lichens presented are, however, even smaller than estimated to be consumed by reindeer or caribou grazing freely in good pasture conditions.

Estimating that, when a reindeer consumes 70% of the entire amount of lichens within the actual cratered (grazed) area, satisfies its energy need (25.0–28.0 MJ per day), and can dig and graze 30 m^2 per day, then, on an average, 90–100 g DM m^{-2} of lichens should be available. This is a prerequisite fact that a reindeer is able to satisfy its energy needs from the digging and grazing area presented (30 m^2). According to the model presented by Kumpula et al. (2000), the amount of lichen, 1000 kg DM ha^{-1}, represents on an average around 50% coverage and 30 mm height in a lichen stand, and is equivalent to the earlier level presented of lichen biomass (Kumpula et al., 1997, 1998) which can be considered good in a woodland lichen pasture for a secure winter nutrition of reindeer. However, the average lichen biomass on lichen ranges in the Finnish reindeer management districts in the middle of 1990s was only 350 kg DM ha^{-1} (Kumpula et al., 2000) which makes most of these lichen ranges heavily overgrazed and increases the need to compensate natural winter fodder by supplementary feed.

5. Conclusions

This work indicates that both the amount of lichens in pasture and snow conditions essentially affect the body condition of reindeer via the quantity and quality of natural food acquired by reindeer in the woodland region during winter. Lichens should form a certain part of the winter diet that reindeer are able to satisfy their energy needs and maintain good body condition. The sufficient part of lichens in winter nutrition of reindeer is probably considerably dependent on the fact what are the benefits compared to the costs of acquisition of food by digging. The worse both the condition of lichen pastures and snow conditions are the harder reindeer have to work to acquire enough food by digging.

In several studies made earlier, both the importance of the condition of lichen pastures and the size of the digging and grazing area in various snow conditions on the energy and nutrition budget of reindeer and caribou in winter have often been forgotten. It is obvious that these questions should be focused on more in the future.

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