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Vegetation Changes in the Nordic Mountain Birch Forest: the Influence of Grazing and Climate Change

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Abstract

The study focuses on vegetation changes in the Nordic mountain birch forest in northern Norway, covering a period of more than 40 yr. The study area comprises the municipalities of Kautokeino and Karasjok on Finnmarkskvidda; it is predominantly covered by lichen and dwarf shrub vegetation. Sizes of various vegetation classes were estimated by the use of remote-sensing techniques and ground surveys. A significant change in vegetation cover during the study period was registered in the whole study area. Vegetation types dominated by bilberry (*Vaccinium myrtillus*), wavy hair-grass (*Deschampsia fleuxuosa*), the dwarf cornel (*Cornus suecica*), and mosses have tripled in abundance compared to 40 yr ago. In contrast, lichen-dominated heaths and woodland (forests), preferred by the reindeer stocks intensively utilizing these areas of Finnmarksvidda, have decreased by approximately 80% in abundance during the same period. Correspondingly, there has been a significant increase in the extent of birch forests especially in Kautokeino (90% increase). The reason for the steep decline in lichen-dominated areas appears to be a direct consequence of the intensive grazing by the increasing reindeer population in the period 1961–1987, but climate change (increased precipitation), caterpillar attacks, and long-transported air pollution (e.g., nitrogen) may also have accentuated the increase of forests and other vegetation types.

Introduction

The Nordic mountain birch (*Betula pubescens* ssp. *czerepanovii*) forming alpine or arctic treelines is unique to northwestern Europe (including Fennoscandia, Iceland, and Greenland). One reason for the success that the birch has had in these rather extreme environments is that it has evolved through introgressive hybridization between the downy birch (*Betula pubescens*) and the dwarf birch (*B. nana*) (Väre, 2001). This is probably also the reason for a large variability in many characteristics among the trees in mountain birch forests. There are two rather distinct growth forms of birch; one-stemmed (monocormic) and multistemmed (polycormic) trees. The latter dominate dry heath forests and the former moist, nutrient-rich forests. Areas with a dry, continental climate are dominated by poor heath–forest communities, while the wetter coastal areas are dominated by meadow forests (Wielgolaski, 2001a). Low summer temperature limits the distribution of mountain birch forests with latitude and altitude, but the Nordic mountain birch normally grows at lower summer temperatures than both the spruce and pine in Fennoscandia (Helland, 1912). Several explanations have been suggested for the distribution and growth of the mountain birch forest. For instance, Odland (1996) suggested that the best temperature measure for determining the mountain birch forest line is the average maximum temperature isotherm 13.2°C of the four warmest months. Furthermore, the decreasing height of individual trees with increasing elevation is suggested to be determined by strong winds and reduced length of the growing season (Wielgolaski, 2001a). The nutrient and water conditions may also determine growth. Generally, there is a strong decrease in nitrogen availability, as well as humus content in the soil, with increasing elevation, thus causing a low water-holding capacity, which influences the living conditions for trees. Increased precipitation, favoring birch growth, may also increase the sprouting of mountain birch (Sveinbjörnsson et al., 2002; Linderholm et al., 2003). Finally, the present distribution of the mountain birch may also reflect the limited invasion by other tree species, creating less competition (Hämet-Ahti, 1963).

The most common species in the understory of the mountain birch forests in northern Fennoscandia are the crowberry (*Empetrum hermaphroditum*), cowberry (*Vaccinium vitis-idea*), bilberry (*V. myrtillus*), the dwarf shrub *Betula nana*, and a few grass species (*Deschampsia flexuosa*, *Festuca ovina*). The main difference in the bottom layer is between lichen- and moss-rich formations. Fruticose lichen (*Cladonia* spp.)-rich formations of birch forests are most common in the northeastern inland districts and in the inner parts of the mountain region. These birch communities are characterized by low production, an average tree height of only 2 to 3 m, a low number of vascular species, and a dense carpet of lichens in the ground layer. In this type the tree heights are on average 4 to 7 m (Wielgolaski et al., 1981; Wielgolaski, 2001a), with the mosses *Hylocomium splendens* and *Pleurozium schreberi* as common species in the ground layer. An even higher production is normally found in the meadow forests on meso- to eutrophic subsoil in the subalpine mountain region of Norway. These forest formations are characterized by low and tall herbs, several grass species, and a poorly developed ground layer (Wielgolaski, 2001a).

In the fragile and poor lichen-rich mountain birch woodland, intensive reindeer grazing and browsing may cause a degradation of the vegetation. In the inner continental parts of Finnmarksvidda in northern Norway, the lichen vegetation has been reduced significantly during the last decades (Tømmervik and Lauknes, 1987; Käyhko and Pellikka, 1994; Johansen and Karlsen, 1998, 2000; Gaare and Tømmervik, 2000; Löffler, 2000). Damage to the vegetation cover, often visible as vegetation-free patches on sandy soils, moraines, and ridges with subsequently erosion and soil loss, is detectable over large areas in the winter grazing area, partly due to trampling and illegal grazing by reindeer of the lichen pastures during summer and autumn, which occurred in the 1980s–1990s (Käyhko and Pellikka, 1994; Johansen and Karlsen, 1996; Evans, 1996; Käyhko and Pellikka,

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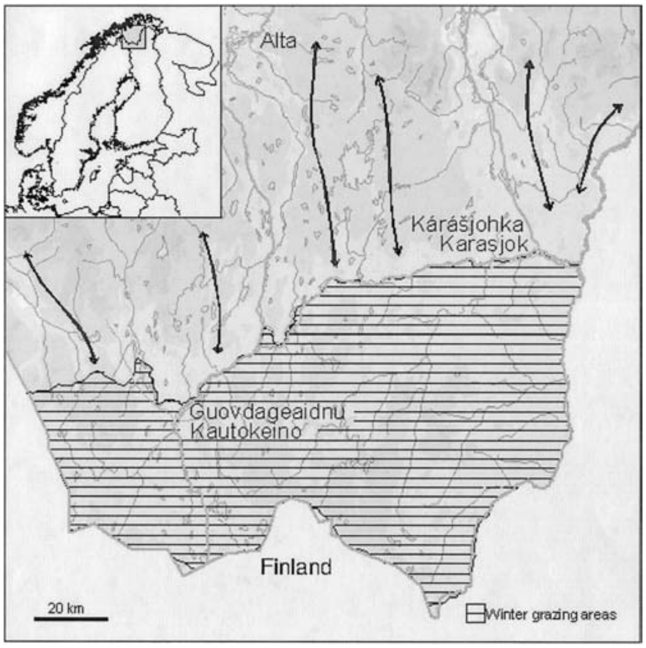

FIGURE 1. The study area at Finnmarksvidda, northern Norway, comprising the municipalities Kautokeino and Karasjok. The size of the area is about 17,000 km^2. The winter grazing area used from December to April is emphasized. The main migration routes for the reindeer are marked with arrows.

1994). The exposition of sand and gravel may start eolian processes, a phenomenon reported from several locations in the mountain birch woodland and treeless tundra north of the Scots pine (*Pinus sylvestris*) forest zone in Fennoscandia (Käyhko et al., 1999). In studies on Ifjordfjellet, eastern part of Finnmark county in Norway, Evans (1996) describes vegetation damage and erosion problems along reindeer fences, on steep slopes, and in areas where reindeer are concentrated along route-lines by topography and water bodies.

In the present study, we focus on the changes in vegetation on the Finnmarksvidda plateau during the period 1961 to 2001. In contrast to previous studies, we use a long-term data set covering an extensive area of Finnmark, especially evaluating the changes in lichens and mountain birch forest, as well as other vegetation types. By the use of remote sensing techniques and ground surveys, we analyze these changes and evaluate their relationship to the intensity of reindeer grazing, climate change, long transported pollution, and discuss the combining influence of these.

Study Area and Methods

FINNMARKSVIDDA

The Finnmarksvidda (Fig. 1) is located in the transition zones between suboceanic and continental climates. The continental influence is strongest, however, which is expressed through the annual extremes like hot summer periods and winters with strong radiation weather conditions. The mean annual precipitation is about 325 mm (standard normal 1961–1990) in Kautokeino, of which 50% falls between June and August (Alm, 1991). During the last 40 yr the annual means of precipitation have risen while evapotranspiration has been reduced due to stronger cloudiness (Tveito et al., 2001; Thannheiser et al., 2005). Thus, at present, the summer months have more precipitation, and the suboceanic influence has shifted from the coastal region to the interior, having an impact on large portions of the northern Finnmarksvidda (Alm, 1991). The Precambrian bedrock of Finnmarksvidda was reshaped by glacier activities during the Pleistocene. Glaciofluvial deposits created a hilly landscape with moraines (Wielgolaski, 2001a).

In the present study we focus on two parts of Finnmarksvidda: Karasjok and Kautokeino. These areas are the two main reindeer districts in Finnmark.

REMOTE-SENSING DATA

Satellite image–aided analyses for forest monitoring provide a spatially complete coverage that can be used to interpolate traditional ground-based observations (Myneni et al., 1997). Satellite sensors are capable of measuring broad-scale changes in the landscape that can be associated with changes in biomass, vegetation specific plant crops, or land cover types, and therefore describe the land-cover condition and phenological stage.

In the study we have used black and white (BW) aerial photographs from 1954–1960, Landsat MSS data from 1973, 1980, and Landsat TM data from 1987, 1990, 1996, and 2000 (Landsat ETM+). Both the aerial photographs and the satellite images cover the entire study area including the total area of Kautokeino and Karasjok municipalities. The satellite data were provided in a radiometrically corrected format. The selection of the satellite images was based on the following ideal criteria: availability of high-quality satellite imagery with minimal cloud coverage, coverage of the study area before and after the presumed dates of the worst vegetation degradation (before 1974 and after 1988, see later), similarity in annual precipitation patterns, coincidence with the peak vegetation growth period of the area (mid July), and finally, application of a new as possible set of data for monitoring recent trends.

SATELLITE DATA PROCESSING

Preprocessing of the Satellite Data

The MSS and the TM satellite images were georeferenced separately to the UTM map format by locating approximately 50 to 70 corresponding points in each image and the reference map. The Landsat MSS-images (1973, 1980) were geocorrected to a pixel size of 75 m, while for the Landsat TM/ETM+ images (1987, 1990, 1996, 2000) of 30 m spatial resolution were selected. During the comparison of the whole time-series, a resolution of 75 m was used for all the images. The geometric registration accuracy (root mean square) was within one pixel. The images were not radiometrically enhanced before the classification in order to not interfere with the spectral information. Each satellite image was processed following the procedure in Tømmervik et al. (2003). This procedure consist of a preclassification stage, a postclassification stage, and finally the standardization of the resultant images.

Preclassification Unsupervised Image Classification

The unsupervised spectral clustering is a method used to establish statistically distinct spectral classes. In the spectral classification of Landsat TM/ETM+ images we used the spectral bands 1–5 and 7. For the Landsat MSS images we used all available channels. The images were clustered into a different number of classes, using the unsupervised k-means algorithm (Maxwell, 1976; Niblack, 1986). Next, the spectral similarity between the cluster centers was computed based on Euclidian distance. The result was represented in a similarity matrix containing the spectral distances between the classes. Based on this matrix, data were aggregated in a dendrogram reflecting the relationship of similarity and thereby groups of spectral classes at different levels. The average-linkage method (Gauch and Whittaker, 1981) was used to merge similar spectral classes to tight clusters. The spectral information of each class and the spectral relationship between classes were used in a first-order interpretation and labelling of the preclassified products.

Postclassification: The Contextual Correction Process

Experiences from several projects dealing with vegetation mapping based on satellite images (e.g., Tømmervik et al., 2003) have demonstrated the difficulty in obtaining distinct vegetation units based on spectral-only information. Depending on the topographic location, underlying geology, elevation, and vegetation complexity, a spectral class may be representative for quite different land-cover types. To minimize the contextual errors associated with the spectral classes, a contextual correction system was conducted for reallocation of subclasses. The contextual correction system was implemented in a geographical information system (GIS). The actual contextual correction was undertaken at the spectral subclass level. The process was done stepwise, starting with the identification of subclasses that occurred out of their proper context. Secondly, decision rules for inclusion or exclusion of subclasses were formulated. The third step was to perform corrections to the classes considered as misclassified. To identify misclassified classes, the pixel membership for each spectral class was cross-tabulated with available land-cover layers (water, forest, mires, agricultural areas, open areas). The following guideline was taken into account when corrections of classes are considered. If pixels from one particular spectral class consistently fell within one single standard cover type, then all the pixels in the class were considered inside a proper context of that particular class. Spectral classes having a large number of pixels in different land-cover layers, were considered mixed classes of various vegetation types and reallocated to already existing classes or defined as new vegetation entities.

Standardization of Classes to Vegetation Entities

After the contextual correction of classes, it was apparent that several of the classes reflect much of the same vegetation unit compared to the traditional vegetation scheme for the study area (Haapasaari, 1988; Fremstad, 1997; Moen, 1999). The final stage in the map production process then comprises renumbering of the new classes to relate them into vegetation scheme valid for the study area. During this standardization process, a map legend was worked out and the vegetation content in each classes were described.

FIELD INVENTORY STUDY

Reindeer Pasture Monitoring

The region of Finnmarksvidda was monitored in the period 1960–2000 using field assessments, aerial photographs (Lyftingsmo, 1965), and satellite images (Landsat MSS/TM). The total area is about 17,000 km^2. Field work using transects and visual interpretation of BW-photographs and satellite images has been carried out by the authors and other scientists in 1961 (Lyftingsmo, 1965), 1965 (Thannheiser, 1975, 1977), and in the period 1989–2002 (Johansen and Tømmervik, 1990; Johansen and Karlsen, 1998, 2000; Gaare and Tømmervik, 2000; Thannheiser et al., 2005). The basic sampling unit of the current reindeer range inventory of the winter grazing areas in Figure 1 (Gaare and Tømmervik, 2000) is a small grid made of five small quadrats (field plots). Medium-scale gradients were sampled using up to 13 stations spread along five transects from the border between Norway and Finland towards north. The distance between the transects is 30 km. The quadrats have a size of 80 × 120 cm^2, in a group (locality) of six; one of these is protected against grazing. Groups of plots are set at 10-km intervals along the transects. Three hundred and thirty-six plots in 56 localities were sampled in 1998/99. The sampling is nondestructive, and all plots are positioned by modern GPS equipment and marked with aluminum poles for discovery. The field work for the remote-sensing part comprised more than 500 field plots scattered all over the study area.

Satellite image interpretations and analyses were conducted on Landsat MSS/TM images from 1973, 1980 and 1988 (Johansen and Tømmervik, 1990), and on Landsat TM/ETM+ images from 1996 and 2000 (Johansen and Karlsen (1996, 1998, 2000)

Vegetation Surveys

In 1964 and 1965 vegetation surveys of the birch forests in the area around Kautokeino were conducted by Thannheiser (1975, 1977). The field work was carried out along 19 west–east transects crossing the Alta-Kautokeino river channel and its tributaries. The vegetation was studied at 164 localities. In each locality, criteria for gradation were defined according to the five-level scale of Hult-Sernander (Du Rietz, 1930), and the results were published in plant sociological tables (Thannheiser, 1975, 1977). In 2001 the same sites were revisited and a six-levelled scale based on a method of Braun-Blanquet (1964) was applied. In order to obtain comparative values, the results of 1964/65 were recalculated using Braun-Blanquet's scale and entered into a constancy table. The tables presented in the present study are only partial constancy tables that express the differences in plant communities, species coverage and frequency for the two survey years.

Statistical Analyses

The satellite images and ground surveys enable us to produce size estimations of various vegetation classes, such as lichen- or bilberry-dominated areas and forest coverage. Such estimations, done by BW-aerial photo interpretations and satellite images, are available from 1961, 1973, 1980, 1987, 1996, and 2000. We then used corresponding reindeer numbers for the same years. Since the number of reindeer increased until 1987 and decreased thereafter, we separated the vegetation data in before and after the peak in 1987.

REINDEER DATA, DEPOSITION DATA, WEATHER, AND FOREST DATA

Reindeer population data (number of reindeer) were extracted from a report (Ims and Kosmo, 2001) and statistics provided by the Directorate for Reindeer Management in Norway. Deposition (air pollution) data were extracted from statistics in Aas et al. (2003) and Semb (1978), based on the monitoring station for long-transported air pollution in Jergul/Karasjok. Precipitation and temperature data were provided by The Norwegian Meteorological Institute (DNMI) and extracted from the Nordklim data set (Tuomenvirta et al., 2001). Forest survey data were obtained from forest statistics (Statistics Norway, 1979) and a report from the County Forest board in Finnmark (Fylkesmannen in Finnmark, 2002).

Results

CHANGES IN FIVE VEGETATION CLASSES

The following vegetation classes are relevant for the present study: birch forests (*Vaccinium myrtillus* and *Cornus suecica* types), lichen-rich Empetrum birch forest (lichen cover >50%), dwarf birch–*Empetrum–Vaccinium myrtillus* heaths, and two classes of dwarf birch–lichen heaths separated by various degree of lichen coverage.

Figure 2, showing the municipality center of Kautokeino, illustrate the main changes in vegetation cover from 1973 (Fig. 2a) to 2000 (Fig. 2b). The increase in forest coverage is shown in green, demonstrating a significant decrease of lichen dominated heaths and forests.

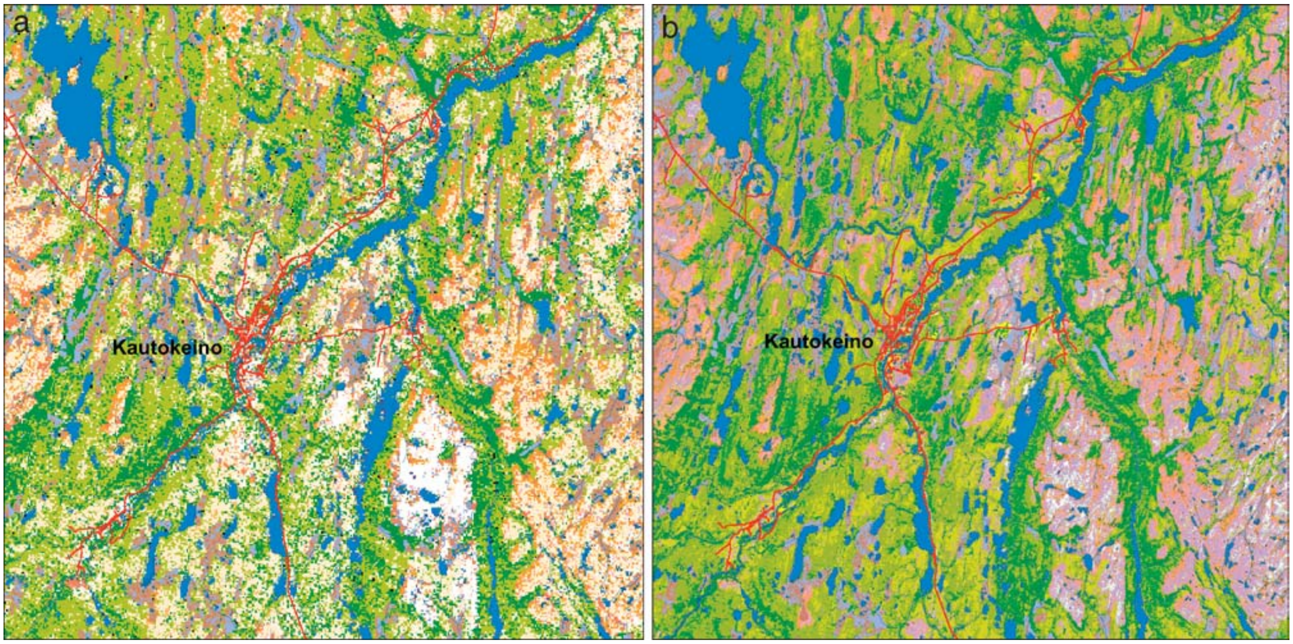

FIGURE 2. Vegetation cover maps from Kautokeino in (a) 1973 and (b) 2000. Lichen communities are presented in yellow and white colours while forests and bilberry communities are presented in green colours. Violet and brown coloured areas indicate vegetation cover types dominated by dwarf shrub (bilberry) and dwarf birch communities.

Figure 3 illustrates the changes in Kautokeino for the various vegetation classes considered in the present study. The *Vaccinium myrtillus* and *Cornus suecica* birch forest type has doubled in size from 1961 to 2000. The lichen-rich birch forest increased in the same matter as the reindeer number increased, but decreased after the peak in reindeer number (1987). The two heath classes have followed a trend opposite to each other. The dwarf birch–*Empetrum–Vaccinium myrtillus* heaths have almost doubled in size, whereas the dwarf birch–lichen heaths have been through a tenfold reduction (Fig. 3). Areas of heavy grazed heaths with lichen coverage less than 25% appeared in 1987 and have increased ever since.The pattern recorded in Kautokeino is also observed in Karasjok, although at a smaller scale (Fig. 3). The *Vaccinium myrtillus* and *Cornus suecica* birch forest type has almost doubled in size over the study period, whereas both the heath classes have decreased considerable. The dwarf birch–*Empetrum–Vaccinium myrtillus* heaths have been reduced by almost 50%, whereas dwarf birch–lichen heaths have disappeared almost entirely (24.7 km^2 in 2000). Also in Karasjok, a "new" vegetation class, the heavily grazed dwarf birch–lichen heaths, appeared in 1987.

FLORISTICAL CHANGES IN THE LICHEN-RICH EMPETRUM BIRCH FOREST

The shortened constancy table (Table 1) demonstrates that the bush layer of young birch increased during the study period. Changes can be noticed in the herb layer as well. The densities of *Vaccinium vitis-idaea* and *Festuca ovina* decreased in the period, while we can observe an increase for *Phyllodoce caerulea* and *Juncus trifidus*. In addition, wavy hair-grass (*Deschampsia flexuosa*) and bilberry (*Vaccinium myrtillus*) appeared during the study period. The moss layer has slightly expanded, and the lichen layer has changed from being dominated by *Cladonia stellaris* to a more complex community consisting of *C. stellaris*, *C. mitis*, *C. rangiferina*, *Stereocaulon pashale*, and a few other lichens. The lichen species dominance of *C. stellaris* is considerably reduced in cover (up to 75%) in 1964/65 only to cover up to 25% in 2001 (Table 1). The lichens *Stereocaulon* spp. and *C. uncialis* were not present in 1964/65 but they emerged and were abundant in 2001 (V and IV) and covered up to 50% of the field plots. We also observed an emergence of some specimens of the fruticose

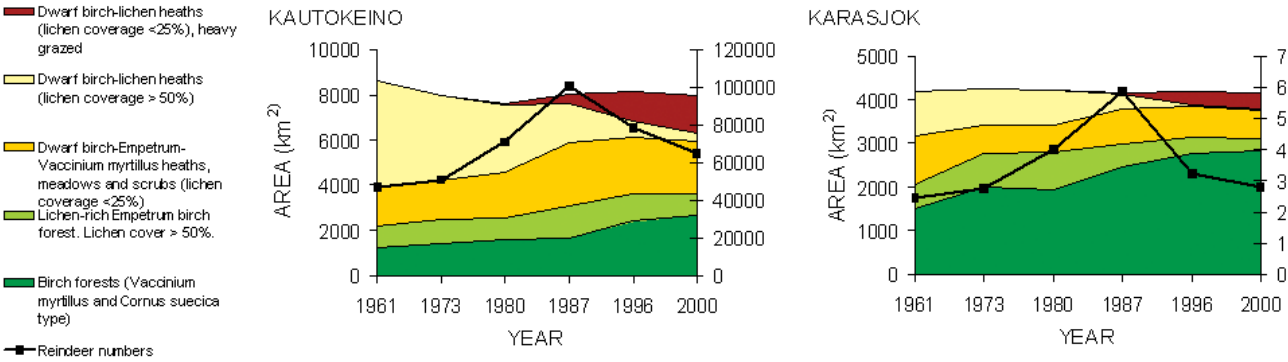

FIGURE 3. Area plots showing the cover of vegetation classes and reindeer numbers from 1961 to 2000 in Kautokeino and Karasjok, northern Norway.

TABLE 1

Shortened constancy table of the lichen-rich Empetrum birch forest and of the moss-rich Empetrum birch forest in the Kautokeino area, Finnmarksvidda, northern Norway. Constancy (degree of presence): + = 1–10%, I = 11–20%, II = 21–40%, III = 41–60%, IV = 61–80%, and V = 81–100%. In parentheses the cover-abundance scale which is divided in following categories: + = few with small cover, 1 = numerous (1–5% cover), 2 = 5–25% cover, 3 = 25–50% cover, 4 = 50–75% cover and 5 = >75% cover

Empetrum-Birch forest Number of plots Date	Lichen-rich 9 1964/65	Lichen-rich 9 2001	Empetrum-Birch forest Number of plots Date	Moss-rich 5 1964	Moss-rich 5 2001
Tree layer			Tree layer		
Betula pub. ssp. *czerepanovii*	V (2)	V (2–3)	*Betula* pub. ssp. *czerepanovii*	V (2–3)	V (3)
Shrub layer			Shrub layer		
Betula pub. ssp. *czerepanovii*		III (±1)	*Betula* pub. ssp. *czerepanovii*		IV (1–2)
Herb layer			*Juniperus communis*		V (1–2)
Vaccinium vitis-idaea	IV (±3)	III (1–2)	Herb layer		
Festuca ovina	IV (±1)	II (±1)	*Vaccinium myrtillus*	I (+)	V (2–3)
Phyllodoce caerulea	II ('+)	V (1–3)	*Cornus suecica*	I (+)	V (1–2)
Juncus trifidus	I (+)	IIII (±1)	*Trientalis europaea*	III (+)	V (1)
Deschampsia flexuosa		III (±1)	*Deschampsia flexuosa*	I (+)	V (1)
Vaccinium myrtillus		III (±2)	Moss layer		
Moss layer			*Pleurozium schreberi*	V (2–3)	V (3–4)
Dicranum scoparium	II (+)	IV (±1)	*Barbilophozia lycopodioides*	III (±1)	V (1–2)
Pleurozium schreberi	II (+)	III (±2)	*Hylocomium splendens*	II (+)	V (1–2)
Polytrichum alpinum/commune		III (±1)	*Polytrichum juniperinum/strictum*	III (+)	V (1–2)
Lichen layer			*Polytrichum alpinum/commune*	II (+)	V (±1)
Cladonia stellaris	V (1–4)	V (±2)	Lichen layer		
Cladonia crispata	IV (±1)	II (+)	*Cladonia rangiferina*	V (2–3)	III (+)
Cladonia deformis	IV (±1)	II (+)	*Cladonia stellaris*	V (±3)	III (+)
Cetraria cucullata	III (±1)	I (1)	*Cladonia mitis*	V (±1)	II (±1)
Stereocaulon alpinum/paschale		V (2–3)	*Nephroma arcticum*	III (±1)	
Cladonia uncialis		IV (±2)	*Cladonia deformis*	III (+)	
Cladonia mitis		V (±2)	*Cladonia bellidiflora*	II (+)	
Cladonia rangiferina		IV (1)	*Cladonia coccifera*	II (+)	
			Cladonia cornuta	II (+)	
			Cladonia ecmocyna	II (+)	
			Cetraria nivalis	III (±1)	V (1–2)
			Peltigera aphtosa	II (+)	IV (±1)
			Peltigera spec.	III (+)	IV (±1)

lichens *C. rangiferina* and *C. mitis* in 2001, species not present in 1964/65.

FLORISTICAL CHANGES IN THE MOSS-RICH EMPETRUM BIRCH FOREST

This forest community tends towards the *Vaccinium myrtillus* birch forest based on physiognomic, ecological, and phytosociological characteristics. The birch patches of this community are closer together. Mosses achieve higher congruence values, but the dominance of lichens is not that strong as in the previous community. The modest but constant snow cover in winter is a determining factor for the development of the herb layer.

Table 1 includes only those plant species for which the proportions have changed during the last four decades. As in the lichen-rich Empetrum birch forest, a stronger growth of young bushes of birch is noticeable. A significant increase in species density of *Vaccinium myrtillus*, *Cornus suecica*, *Trientalis europaea*, and *Deschampsia flexuosa* in the moss rich Empetrum-Birch forests (Table 1) is apparent in the herb layer. Also the much stronger dominance of the mosses *Pleurozium schreberi* and *Hylocomium splendens* in the bottom layer in 2001 compared with 1964/65 is noteworthy (Table 1). In the monitoring part we have merged together Empetrum- Birch forests together with *Vaccinium myrtillus* and *Cornus suecica*-dominated forests and named the new category: Birch forest (*Vaccinium myrtillus* and *Cornus suecica* type).

THE RELATIONSHIP BETWEEN FOREST AND LICHENS

Figure 4 presents the correlation between the total area of lichen-dominated areas vegetation formations and the total area of forests in Kautokeino and Karasjok. Although sample sizes are small (only 6 yr

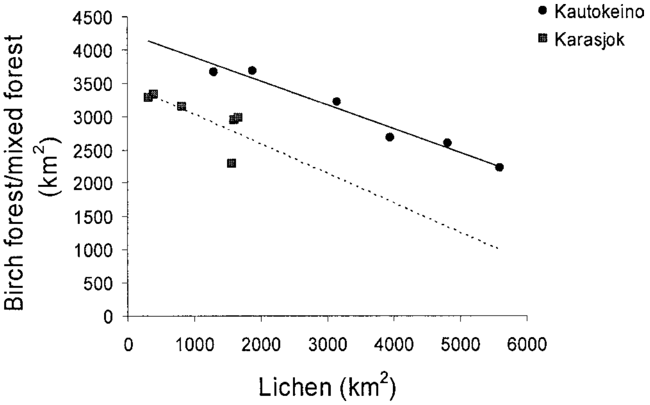

FIGURE 4. Regression plots showing the relation between the lichen-dominated heaths/forests and the total area of forests in Kautokeino and Karasjok, Finnmarksvidda, northern Norway. Symbols represent the 6 yr, 1961, 1973, 1980, 1987, 1996, 2000 of data acquisition (Kautokeino: Y = *4238.1 – 0.4*X, n = *6,* r^2 *= 0.97,* P = *0.0004, Karasjok:* Y = *3466.2 – 0.4*X, n = *6,* r^2 = *0.54,* P = *0.096).*

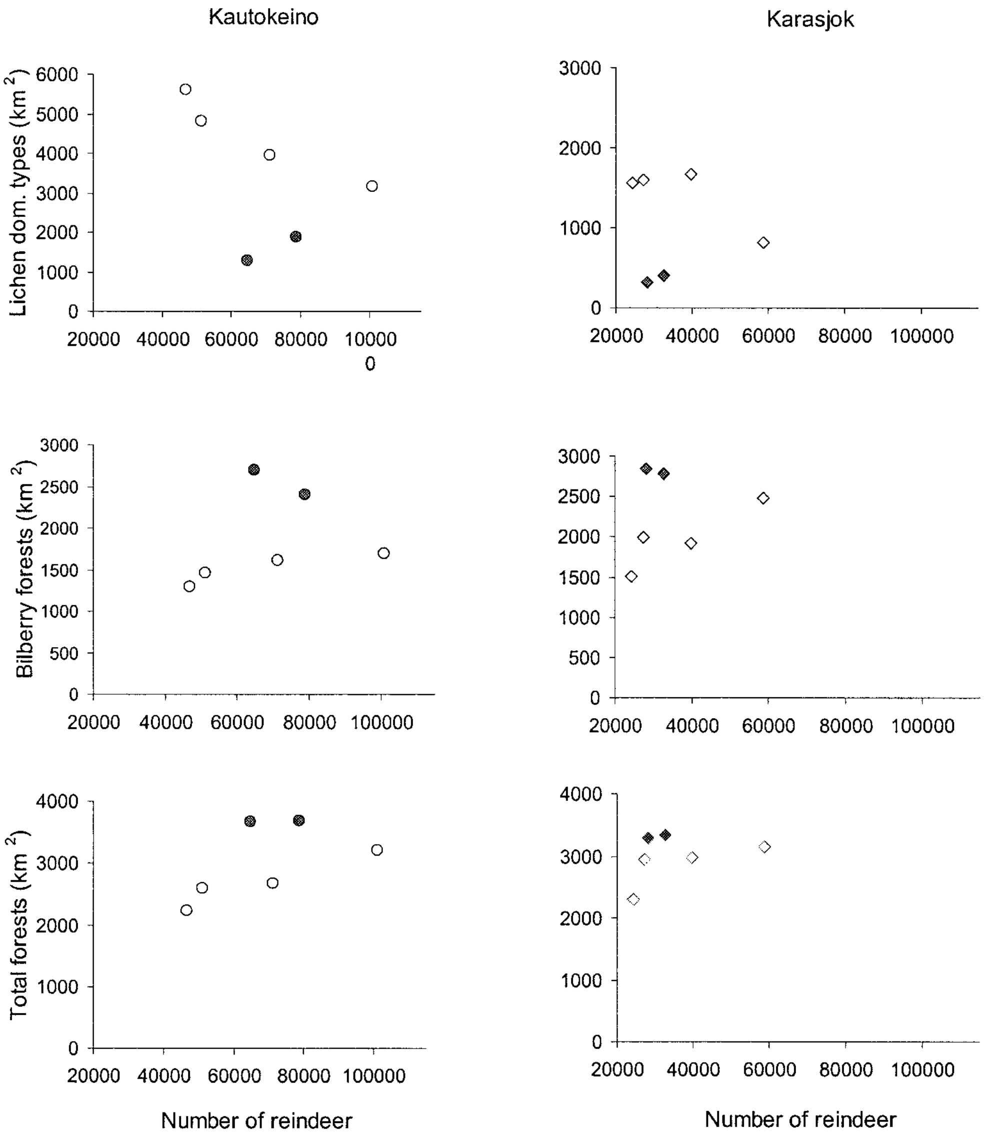

FIGURE 5. The relationship between vegetation cover (lichens, bilberry, and forest) and reindeer numbers, before (1961–1987) and after (1988–2000) the reindeer peak number at Finnmarksvidda, northern Norway. Plots are shown for Kautokeino and Karasjok separately. Filled symbols represent data after peak in reindeer numbers.

of data dispersed over the total study period), the relationship was negative and highly significant for Kautokeino ($r^2 = 0.97$, $n = 6$, $P = 0.0004$), whereas in Karasjok a similar pattern was registered although not significant ($r^2 = 0.54$, $n = 6$, $P = 0.096$). Combining both areas revealed a strong and significant correlation ($Y = 7844.7 - 0.4075X$, $n = 6$, $r^2 = 0.93$, $P = 0.0021$).

THE RELATIONSHIP BETWEEN VARIOUS VEGETATION CLASSES AND REINDEER POPULATION

The relationship between number of reindeer and area of various vegetation classes are presented in Figure 5. The pattern was rather consistent for both areas. Before the peak in reindeer numbers, a decrease in lichen-dominated vegetation classes was recorded as reindeer numbers increased. This was most profound for Kautokeino. Bearing in mind the limited sample size, a linear regression revealed a significant relationship (Kautokeino: $Y = 7158 - 0.04X$, $R^2 = 0.91$, $n = 4$, $P = 0.04$, Karasjok: $Y = 2233 - 0.02X$, $R^2 = 0.73$, $n = 4$, $P = 0.14$). Likewise, the cover of the two forest categories increased in size as reindeer numbers increased (all R^2-values > 0.8, all P-values < 0.11). Data after the peak in reindeer numbers do not follow the same pattern, suggesting a lag in vegetation response when reindeer numbers decrease (Fig. 5).

The correlation between NO_3 in precipitation and total precipitation per year at one location, Jergul/Karasjok, was highly significant ($r^2 = 0.65$, $n = 26$, $P = 0.0001$, Fig. 6), stating that increased precipitation results in a higher wet deposition of NO_3 (in mg m^{-2}).

Discussion

The advantage of using high-resolution multitemporal data for monitoring land-use/land-cover changes has been demonstrated in other studies in Finnmark county, Northern Norway (Tømmervik et al., 1997; Tømmervik et al., 2003). Land-cover changes have long been viewed as being continuous, but in fact they form a disjunctive process, with periods of rapid shifts (Grace et al., 2002; Löffler, 2000; Tømmervik et al., 2003). The process is often triggered by external events, which can initiate a cascade of changes in the ecosystem. Several case studies from the reindeer range areas in northern

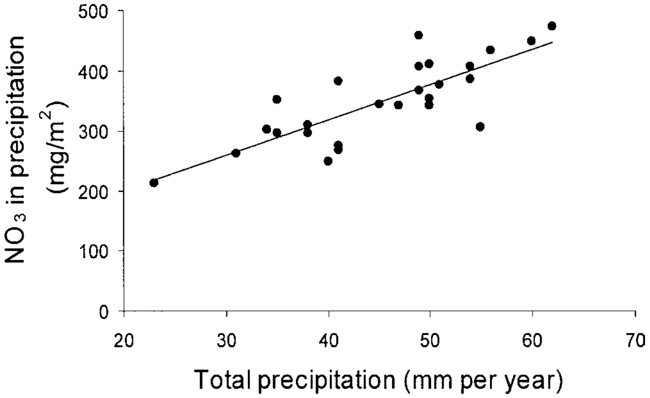

FIGURE 6. The relationship between the deposition of NO_3 from precipitation and the total precipitation per year for the EMEP station in Karasjok (Jergul), Finnmarksvidda, northern Norway ($Y = 6.70 + 0.11X$, $r^2 = 0.65$, $n = 26$, $P = 0.0001$).

Fennoscandia, have shown a dramatically decrease in the lichen-rich vegetation types for most of the area (Johansen and Karlsen, 1996, 1998, 2002; Löffler, 2000, Moen and Danell, 2003; Colpaert et al., 1995, 2003; present study). An increase in the reindeer population during the 1980s is regarded as the main explanation to the land-cover change. In the present study, the negative correlation between lichen cover and reindeer number was profound. Today the reindeer population size is reduced for most of the area, but the lichens still have difficulty in recovering (Gaare and Tømmervik, 2000; Kumpula et al., 2000). This is also suggested by the data gathered on vegetation cover after the peak in reindeer numbers (Fig. 5). A change in climate conditions during the last 20 yr, with higher amounts of precipitation and nitrogen, that appears to be significantly linked (Fig. 6), have in several studies been suggested as a possible explanation for the lack in lichen recovery (Gordon et al., 2001; Sedia and Ehrenfeld, 2003).

The significant increase of the forests in Kautokeino and Karasjok is in agreement with data from Statistics of Norway (Statistics Norway, 1979) and data from the County Forest Board in Finnmark (Fylkesmannen i Finnmark, 2002). The mountain birch forests in Kautokeino increased from approximately 1900 km^2 in 1957, based on estimations using aerial photographs and field inventory, to approximately 3550 km^2 in 2001 (Statistics Norway, 1979; Fylkesmannen i Finnmark, 2002), a value close to our estimate of 3600 km^2.

In the late 1990s, some of the mountain birch forests in the area were defoliated and damaged by caterpillars (geometrid moths) (Tømmervik et al., 2001). Accordingly, the increase in birch forests may have been reduced due to this damage, indicated in Figure 3, suggesting an even larger potential for forest expansion if caterpillar defoliation is avoided.

POSSIBLE CAUSES FOR THE CHANGE IN FOREST COVER

A greening trend in the high northern latitudes, associated with a gradual lengthening of the growing season, has been demonstrated in studies providing photographic evidence (Grace et al., 2002; Lucht et al., 2002), as well as studies based on satellite observations (Menzel and Fabian, 1999; Myneni et al., 2001; Zhou et al., 2001; Høgda et al., 2002; Lucht et al., 2002). These trends are suggested to be associated to elevated temperatures during the last decades (Groisman et al., 1994). However, Høgda et al. (2002) reported a stable or an even shorter growing season for the continental parts of northern Fennoscandia and Kola Peninsula. Sturm et al. (2001) reported increasing shrub abundance in the Arctic, and suggested climate change as the main driving force. Increased summer temperature and precipitation may influence the extent of forest cover, as well as elevated CO_2 and nitrogen deposition, advancing the timberline (altitudinal limit of trees in close canopy and that grow erect and tall–harvestable trees) in the northern forests (Grace et al., 2002; Kusnierczyk and Ettl, 2002; Linderholm et al., 2003). An advance of the treeline (altitudinal limit of stunted but upright tree growth) would be predicted with elevated temperatures if we assume that growth and reproduction are controlled by temperature (Grace et al., 2002). No specific relationship between vegetation cover and temperature has been found for Karasjok and Kautokeino (unpublished data), but increased precipitation during the last decades and its link to nitrogen deposition may be a plausible explanation for the increase in forest cover for the region.

In regions inhabited by grazing animals such as Finnmark and Lapland, the advance of timberline can be curtailed by trampling and grazing of reindeer. However, the growth of trees between the tree- and the timberline will substantially increase. The trampling and grazing of reindeer in the lichen-dominated birch forests of Finnmark may also change the forest structure (see Evans, 1996, Löffler, 2000). When lichens, functioning as a "barrier" (Sedia and Ehrenfeld, 2003), are removed, birch seeds may successfully germinate and sprout (Houle and Filion, 2003; Thannheiser et al., 2005). This again, leads to an elevation of the timberline by filling the gaps between the treeline and timberline with forest (Sveinbjörnsson et al., 2002), thereby increasing the cover of forest in a region. On the other hand, reindeer can hinder the advance of the timberline due to browsing and grazing of birch seedlings, shoots and leaves (Sveinbjörnsson et al., 2002; Olofsson et al., 2001), but this occurs mainly in the summer grazing areas (Olofsson et al., 2001) and presumably not in the winter grazing areas in our study.

TABLE 2

The Standard Normals of precipitation (mm/yr) for the meteorological observation stations in Finnmarksvidda, Northern Norway, in the period 1901–2000 (Data provided by DNMI)

	Suolovuobmi	Kautokeino	Sihcajavri	Karasjok	Mean Finnmarks-vidda
Standard Normal 1901–1930				318	
Standard Normal 1931–1960	403	317	369	356	361
Standard Normal 1961–1990	456	325	366	457	401
Standard Normal 1991–2000	496	432	413	425	442
Change (mm) 1991–2000 versus 1901–1930				107 (34%)	
Change (mm) 1991–2000 versus 1931–1960	93 (23%)	115 (36%)	44 (12%)	69 (19%)	81 (20%)
Change (mm) 1991–2000 versus 1961–1990	40 (8%)	107 (32%)	47 (13%)	−32 (−7%)	41 (10%)

VEGETATION COVERS AND FLORISTICALLY CHANGES

The coverage of fruticose lichens (*Cladonia* spp.) in the bottom layer has decreased significantly in Kautokeino and Karasjok during the study period. Our analyses show a negative relationship between reindeer numbers and cover of lichen-dominated vegetation, and a positive relationship between reindeer numbers and birch forest. Not all correlations were significant, but this is probably due to limited sample sizes and *r*-square values were high.

Some of the mountain birch forests in Finnmark were defoliated by caterpillars (mainly the geometrid moth *Epirrita autumnata*) in 1954–1956, 1964–1965, and 1994–1996 which have led to a change in the floristic composition of the birch forests (Kallio and Lethonen, 1975; Neuvonen et al., 1999; Tømmervik et al., 2001). Accordingly, the floristic changes observed in the present study may have been influenced by such processes, obscuring other influences, such as grazing and climate, on vegetation changes.

The trend towards a shift in lichen-dwarf shrub dominated forests to more grass- and herb-dominated forests, reflects a situation where lichens, crowberry (*Empetrum hermaphroditum*), and cowberry (*Vaccinium vitis-idaea*) are declining. These species are slow-growing and adapted to nutrient-poor systems (Lipson et al., 1996; Nordin et al., 1998). Olofsson et al. (2001) investigated the effect of reindeer grazing, in a long-term experimental study with fences, on tundra heath vegetation in northern Norway, and they reported that intensive grazing can promote a transition of lichen–moss-rich heath tundra into productive, graminoid-dominated steppe-like tundra vegetation.

A situation with increased nitrogen deposition through precipitation and/or deposition of manure (feces) from the reindeer may create unfavorable living conditions for such species. On the other hand, the amount of nitrogen (Aas et al., 2003) did not the reach the critical load for nitrogen deposition for most species and types of arctic vegetation, 500–2000 N m^{-2} yr^{-1} (Bobbink et al., 1998; Aerts and Bobbink, 1999).

The increase of mosses in earlier lichen-rich heaths and forests could also be a result of decreased grazing of mosses by lemmings and voles during the last decades (Ekerholm et al., 2001). The lichens *Stereocaulon* spp. and *Cladonia uncialis*, which were not present in 1964/65, are abundant in 2001 that may be interpreted as a sign of overgrazing the last decades (Evans, 1996; Kumpula et al., 2000). On the other hand, the emergence of some specimens of the fruticose lichens *Cladonia rangiferina* and *C. mitis* in the lichen-rich Empetrum birch forests which were not present in 1964/65, can be interpreted to be a reduction in grazing the last decade (Johansen and Karlsen, 2000; Thannheiser et al., 2005).

THE EFFECTS OF INCREASED PRECIPITATION

The suboceanic species dwarf cornel (*Cornus suecica*) is mainly found on moist but free-draining soils and can act as an indicator of oceanic influence (Taylor, 1999). This species also increased significantly in bilberry- and moss-dominated forests in the period 1964/65 to 2001 in Kautokeino (Table 1). This is probably related to the increased precipitation the last decades measured by several meteorological stations within the study area, as well as in adjacent areas (Tveito et al., 2001). The increase was significant higher in Kautokeino than in Karasjok (Table 2), and this is probably due to the fact that the areas in Kautokeino are more exposed to western winds and accordingly more influenced by oceanic climate.

Additional climate factors like cloud cover, evaporation, and depth of snow cover may also influence the formation of a suboceanic climate. Particularly, increased precipitation in early spring together with higher temperatures might cause ice crusts in the snow cover, detrimental to most fruticose lichens (Wielgolaski, 2001b). Also deeper snow cover, as observed in the birch forest, has been documented (Thannheiser et al., 2005). This condition contributes to changes in the spring water budget for the soil (Thannheiser et al., 2005).

The reason for the increase in abundance of the mosses *Pleurozium schreberi* and *Hylocomium splendens* from 1964/65 to 2001 (Table 1) could be due to an increase in precipitation (Phoenix et al., 2001). Increased summer precipitation, especially for Kautokeino, has been reported (Tveito et al., 2001). This will have an impact on the water budget and is probably the main reason for the significant increase also for the species *Cornus suecica*, *Trientalis europaea*, *Vaccinium myrtillus*, and *Deschampsia flexuosa* and mosses in the moss-rich Empetrum–birch woodland (Table 1). They are all species that may hinder the re-establishment of lichen species (Sedia and Ehrenfeld, 2003), probably acting as the direct cause for the lack of lichen recovery registered in the present study.

Conclusions

The steep decline in lichen-dominated areas appears to be a direct consequence of the intensive grazing and browsing by the increasing reindeer numbers until late 1980s (Figs. 3, 5). When reindeer numbers later decreased substantially, an immediate response in lichens was lacking. This was presumably due to (1) removal of the "lichen barrier," allowing for successfull germination and sprouting of birch seeds, which has led to an elevation of the timberline by filling the gaps between the treeline and timberline with forest, (2) the increase of other vegetation types dominated by, e.g. bilberry (*Vaccinium myrtillus*), wavy hair-grass (*Deschampsia fleuxuosa*), and dwarf cornel (*Cornus suecica*) that increased under such, for them favorable, conditions, and (3) increased precipitation and deposition of nitrogen during the decade after peak reindeer numbers, further favoring the expanding vegetation classes dominated by dwarf shrubs, graminoids, and herbs. In addition, caterpillar attacks by *Epirrita autumnata* may have contributed to the change in vegetation on Finnmarksvidda. The observed expansion of dwarf cornel (*C. suecica*) and other species of herbs and grasses in the forest floor has to be further investigated and monitored. We suggest that the combined effects of large reindeer populations and the factors mentioned above have induced a situation at Finnmarksvidda where the carrying capacity for reindeer has decreased significantly compared to the situation in the early 1960s. When managing Finnmarksvidda, considering future practice in reindeer herding as well as the conservation of the total ecosystem, these findings should be considered.

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References Cited

Aas, W., Solberg, S., Berg, T., Manø, S., and Yttri, K.E., 2003: Overvåking av langtransportert forurenset luft og nedbør. Atmosfærisk tilførsel, 2002. *NILU Report,* OR 23/2003 TA-1968/2003: 1–162.

Alm, T., 1991: Floraen in Finnmark. *Polarflokken,* 15: 45–98.

Aerts, R. and Bobbink, R., 1999: The impact of atmospheric nitrogen deposition on vegetation processes in terrestrial, non-forest ecosystems. *In* Langan, S. J. (ed.), *The Impact of Nitrogen Deposition on Natural and Semi-Natural Ecosystems.* Dordrecht: Kluwer Academic Publishers, 85–122.

Bobbink, R., Hornung, M., and Roelofs, J. G. M., 1998: The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. *Journal of Ecology,* 86: 717–738.

Braun-Blanquet, J., 1964: *Pflanzensoziologie*. Wein: Springer. 865 pp.

Colpaert, A., Kumpula, J., and Nieminen, M., 1995: Remote sensing—A tool for reindeer range land management. *Polar Record*, 31: 235–244.

Colpaert, A., Kumpula, J., and Nieminen, M., 2003: Reindeer pasture biomass assessment using satellite remote sensing. *Arctic*, 56: 147–158.

Du Rietz, G., 1930: *Vegetationsforschung auf soziationsanalytischer*

Grundlage: Handbuch der biologischen Arbeitsmethoden. Vol. 11. Berlin and Wien: Aberhalden, 293–480.

Ekerholm, P., Oksanen, L., and Oksanen, T., 2001: Long-term dynamics of voles and lemmings at the timberline and above the willow limit as a test of hypotheses on trophic interactions. *Ecography,* 24: 555–568.

Evans, R., 1996: Some Impacts of Overgrazing by Reindeer in Finnmark, Norway. *Rangifer,* 16: 3–19.

Fremstad, E. 1997: *Vegetasjonstyper i Norge. Trondheim: NINA Temahefte* 12: 1–279.

Fylkesmannen i Finnmark, 2002: *Årsmelding for skogbruket i Finnmark 2001.* 24 pp.

Gaare, E. and Tømmervik, H., 2000: Monitoring of lichen grazing areas in Finnmark. *NINA Assignment Report,* 638: 1–33.

Gauch, H. G. and Whittaker, R. H., 1981: Hierarchical classification of community data. *Journal of Ecology,* 69: 135–152.

Gordon, C., Wynn, J. M., and Woodin, S. J., 2001: Impacts of increased nitrogen supply on high Arctic heath: the importance of bryophytes and phosphorus availability. *New Phytologist,* 149: 461–471.

Groisman, P. Y., Karl, T. R., and Knight, R. W., 1994: Observed impact of snow cover on the heath-balance and the rise of continental spring temperatures. *Science,* 263: 198–200.

Grace, J., Berninger, F., and Nagy, L., 2002: Impacts of climate change on the tree line. *Annals of Botany,* 90: 537–544.

Haapasaari, M., 1988: The oligothrophic heath vegetation of northern Fennoscandia. *Acta Botanica Fennica*, 135: 1–219.

Hämet-Ahti, L., 1963: Zonation of the mountain birch forests in northernmost Fennoscandia. *Annales Botanici Societatis Zoologicae Botanicae Fennicae Vanamo,* 34: 1–127.

Helland, A., 1912: Trægrændser og sommervarmen. *Tidsskrift for Skogbruk,* 20: 131–146,169–175, 303–313.

Houle, G. and Filion, L., 2003: The effects of lichens on white spruce seedling establishment and juvenile growth in a spruce-lichen woodland of subarctic Quebec. *Ecoscience,* 10: 80–84.

Høgda, K. A., Karlsen, S. R., Solheim, I., Tømmervik, H., and Ramfjord, H., 2002: The start dates of birch pollen seasons in Fennoscandia studied by NOAA AVHRR NDVI data. *Proceeding of IGARSS 24–28 June 2002,* Toronto, Ontario, Canada. ISBN 0-7803-7536-X.

Ims, A. Aa., and Kosmo, A., 2001: *Høyeste reintall for distriktene i Vest. Finnmark, Høringsdokument.* Alta-Norway: Reindriftsforvaltningen. 153 pp.

Johansen, B. and Tømmervik, H., 1990: Mapping winter grazing areas for reindeer in Finnmark county, Northern Norway, using Landsat 5/TM data. *In: Proceedings, International Geoscience & Remote Sensing Symposium 1990.* Vol. I: 613–616.

Johansen, B. and Karlsen S. R., 1996: *Reingjerder i Finnmark – virkning på flora, vegetasjon og endringer av vegetasjonsdekket.* Tromsø: Report NORUT Informasjonsteknologi. 123 pp.

Johansen, B. and Karlsen, S. R., 1998: Endringer i lavdekket på Finnmarksvidda 1987–1996 basert på Landsat 5/TM data. Tromsø-Norway: *NORUT IT/Rapport,* IT475/1–98: 1–12.

Johansen, B. and Karlsen, S. R., 2000: Finnmarksvidda - kartlegging og overvåking av reinbeiter - status 1998. Tromsø-Norway: *NORUT IT Rapport,* IT546/1-2000: 1–68.

Johansen, B. and Karlsen, S. R., 2002: Finnmarksvidda changes in lichen cover 1987–2000. In: Programme and abstracts. 12th Nordic Conference on Reindeer Research. *Rangifer Report,* 6: 65–66.

Kallio, P. and Lehtonen, J., 1975: On the ecocatastrophe of birch forests caused by *Oporinia autumnata* (Bkh.) and the problem of reforestation. *In* Wielgolaski, F.E. (ed.), *Fennoscandian Tundra Ecosystems.* Part 2. *Animals and Systems Analysis.* Ecological Studies, 17. Berlin-Heidelberg-New York: Springer-Verlag, 174–180.

Käyhko, J. and Pellikka, P., 1994: Remote sensing of the impact of reindeer grazing on vegetation i Northern Fennoscandia using SPOT-XS data. *Polar Research,* 13: 115–124.

Käyhko J., Vuorela, A., and Pye, K., 1999: Landsat TM mapping of evidence for current wind activity in northern Fennoscandia. *International Journal of Remote Sensing,* 20: 421–443.

Kumpula, J., Colpaert, A., and Nieminen, M., 2000: Condition, potential recovery rate, and productivity of lichen (*Cladonia* spp.) ranges in the Finnish reindeer management area *Arctic,* 53: 152–160.

Kusnierczyk, E. R. and Ettl, G. J., 2002: Growth response of ponderosa pine (*Pinus ponderosa*) to climate in the eastern Cascade Mountains, Washington, USA: Implications for climatic change. *Ecoscience,* 9: 544–551.

Linderholm, H. W., Solberg, B. O., and Lindholm, M., 2003: Tree-ring records from central Fennoscandia: the relationship between tree growth and climate along a west-east transect. *Holocene,* 13: 887–895

Lipson, D. A., Bowman, W. D., and Monson, R. K., 1996: Luxury uptake and storage of nitrogen in the rhizomatous alpine herb, *Bistorta bistortoides. Ecology,* 77: 1277–1285.

Löffler, J., 2000: High mountain ecosystems and landscape degradation in northern Norway. *Mountain Research and Development,* 20: 356–363.

Lucht, W., Prentice, I. C., Myneni, R. B., Sitch, S., Friedlingstein, P., Cramer, W., Bousquet, P., Buermann, W., and Smith, B., 2002: Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. *Science,* 296: 1687–1689.

Lyftingsmo, E., 1965: *Norske fjellbeite Bind XIV Oversyn over Fjellbeite i Finnmark.* Mosjøen-Norway: Det Kgl. Selskap for Norges Vel. 367 pp.

Maxwell, E. L., 1976: Multivariate system analysis of multispectral imagery. *Photogrammetric Engineering & Remote Sensing,* 42: 1173–1186.

Menzel, A. and Fabian, P., 1999: Growing season extended in Europe. *Nature,* 397: 659.

Moen, A., 1999: *National Atlas of Norway*: *Vegetation.* Hønefoss-Norway: Norwegian Mapping Authority. 200 pp.

Moen, J. and Danell, Ö., 2003: Reindeer in the Swedish mountains: An assessment of grazing impacts. *Ambio,* 32: 397–402.

Myneni R. B., Keeling, C. D., Tucker C. J., Asrar G., and Nemani R. R., 1997: Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature,* 386: 698–702.

Myneni, R. B., Dong, J., Tucker, C. J., Kaufmann, R. K., Kauppi, P. E., Liski, J., Zhou, L., Alexeyev, V., and Hughes, M. K., 2001: A large carbon sink in the woody biomass of Northern forests. *Proceedings of the National Academy of Science,* 98: 14784–14789.

Neuvonen, S., Niemelä, P., and Virtanen, T., 1999: Climatic change and insect outbreaks in boreal forests; the role of winter temperatures. *Ecological Bulletin,* 47: 63–67.

Niblack, W., 1986: *An Introduction to Digital Image Processing.* London: Prentice-Hall International (UK) Ltd. 215 pp.

Nordin, A., Nasholm, T., and Ericson, L., 1998: Effects of simulated N deposition on understorey vegetation of a boreal coniferous forest. *Functional Ecology,* 12: 691–699.

Odland, A., 1996: Differences in the vertical distribution pattern of *Betula pubescens* in Norway and its ecological significance. In Frenzel, B. (ed), *Holocene Treeline Oscillations, Denrochronology and Paleoclimate.* G. Fischer, Stuttgart, 43–59.

Olofsson, J., Kitti, H., Rautiainen, P., Stark, S., and Oksanen, L., 2001: Effects of summer grazing by reindeer on composition of vegetation, productivity and nitrogen cycling. *Ecography,* 24: 13–24.

Phoenix, G. K., Gwynn-Jones, D., Callaghan, T. V., Sleep, D., and Lee, J. A., 2001: Effects of global change on a sub-Arctic heath: effects of enhanced UV-B radiation and increased summer precipitation. *Journal of Ecology,* 89: 256–267.

Sedia, E. G. and Ehrenfeld, J. G., 2003: Lichens and mosses promote alternate stable plant communities in the New Jersey Pinelands. *Oikos,* 100: 447–458.

Semb, A., 1978: Deposition of trace elements from atmosphere in Norway. Oslo-Ås: *SNSF FR: 13/78.*

Sturm, M., Racine, C., and Tape, K., 2001: Climate change: Increasing shrub abundance in the Arctic. *Nature,* 411: 546–547.

Sveinbjörnsson, B., Hofgaard, A., and Loyd, A., 2002: Natural causes of the Tundra-Taiga boundary. *Ambio*, 12: 23–29.

Statistics Norway, 1979: *Landbrukstelling 1979 Skogbruk, Finnmark and Troms.* Census of Agriculture and Forestry 1979. Vol. VII Forestry.

Taylor, K., 1999: *Cornus suecica* L. (*Chamaepericlymenum suecicum* (L.) Ascherson & Graebner). *Journal of Ecology,* 87: 1068–1077.

Thannheiser, D., 1975: Vegetationsgeographische Untersuchungen auf der Finnmarksvidda im Gebiet von Masi/Norwegen. *Westfälische Geographishe Studien,* 31: 1–178.

Thannheiser, D., 1977: Subarctic birch forests in Norwegian Lappland. *Naturaliste Canadien,* 104: 151–156.

Thannheiser, D., Tømmervik, H., and Wehberg, J., 2005: The vegetation changes and recent impact on mountain birch forest during the last 40 yr. In:Wielgolaski, F.E. (ed), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests.* Ecological Studies, 180. Berlin: Springer-Verlag: 235–254.

Tømmervik, H. and Lauknes, I., 1987: Mapping of reindeer ranges in the Kautokeino area, Northern Norway, by use of Landsat 5/TM data. *Rangifer,* 2: 2–14.

Tømmervik, H., Johansen, B., and Lauknes I., 1997: Use of airborne CASI spatial mode data for mapping of Sub-Arctic mountain heaths in Pasvik, Northern Norway. *Canadian Journal of Remote Sensing,* 23: 230–242.

Tømmervik, H., Høgda, K. A., and Karlsen, S. R., 2001: Using remote sensing for detection of caterpillar outbreaks in mountain birch forests, a new interesting approach. *In* Wielgolaski, F. E. (ed.), *Nordic Mountain Birch Ecosystems.* Man and the Biosphere Series, 27. Paris: UNESCO and London.: The Parthenon Publishing Group, 185–194.

Tømmervik, H., Høgda, K. A., and Solheim, I., 2003: Monitoring vegetation changes in Pasvik (Norway) and Pechenga in Kola Peninsula (Russia) using multi-temporal Landsat MSS/TM data. *Remote Sensing of Environment,* 85: 370–388.

Tuomenvirta, H., Drebs., Førland, E., Tveito, O. E., Alexandersson, H., Vaarby Laursen, E., and Jonsson, T., 2001: *Nordklim data set 1.0. Description and illustrations.* Oslo: DNMI – KLIMA, Report 08/01. 26 pp.

Tveito, O. E., Førland, E. J., Alexandersson, H., Drebs, A., Jonsson, T., Tuomenvirta, H., and Vaarby Laursen, E., 2001: Nordic climate maps. Oslo: *DNMI-Report*: 06/01: 1–28.

Väre, H., 2001: Mountain birch taxonomy and floristics of mountain birch woodlands. *In* Wielgolaski, F. E. (ed.), *Nordic Mountain Birch Ecosystems.* Man and the Biosphere Series, 27. Paris: UNESCO and London.: The Parthenon Publishing Group, 35–46.

Wielgolaski, F. E., Bliss, L. C., Svoboda, I., and Doyle, G., 1981: Primary production of tundra. *In* Bliss, L. C., Cragg, J. B., Heal, D. W., and Moore, J. J. (eds.), *Tundra Ecosystems: A Comparative Analysis.* International Biological Programme, 25. Cambridge: Cambridge University Press, 187–225.

Wielgolaski, F. E., 2001a: Vegetation sections in Northern Fennoscandian mountain birch forests. *In* Wielgolaski, F. E. (ed.), *Nordic Mountain Birch Ecosystems.* Man and the Biosphere Series, 27. Paris: UNESCO and London: The Parthenon Publishing Group, 115–126.

Wielgolaski, F. E., 2001b: Field- and bottom layer vegetation mat transplantation. A method to simulate possible effects of climate change? *Skogræktarritið,* 2001: 167–170.

Zhou, L., Tucker, C. J., Kaufmann R. K., Slayback, D., Shabanov, N. V., and Myneni R. B., 2001: Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999, *Journal of Geophysical Research,* 106: 20069–20083.

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