High Mountain Ecosystems and Landscape Degradation in Northern Norway

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The influence of reindeer pasturing on high mountain ecosystems in northern Norway was investigated using a landscape-ecological analysis. The most visible impacts of overgrazing are on the vegetation. In addition, soils and humus have been changed due to morphodynamic processes induced to a large extent by reindeer pasturing. Degradation of the high mountain landscapes within the last 30 years is described on 3 spatial levels: large-scale effects at specific localities, linear effects along reindeer fences, and small-scale effects on the altitudinal zonation of entire mountain systems. The structure of the ecosystem has changed completely due to reindeer pasturing, which has resulted in landscape degradation under great pasturing pressure. The processes that influence the ecosystem as a function of different pasture intensities are described and show a complex correlation and interaction between the ecofactors. These include destruction of vegetation cover, reduction of root density, erosion of humus and mineral soil horizons, reduction of soil moisture and soil stability, and changes in plant species composition. On the whole, degradation leads to a depression of the altitudinal belts, indicated by the new organization of the ecosystems. It can be concluded that reindeer herding at current levels is a destructive form of land use in the northern Norwegian high mountains and hence is not sustainable. The author believes that destruction of the natural environment could be reversed, although this is not to be expected.

***Keywords**: Landscape ecology; high mountains; reindeer; herding; grazing; landscape degradation; Norway.*

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Introduction

Due to their geographical position, ranging from the Arctic Circle northward to about the 71st parallel, the northern Norwegian high mountain landscapes comprise an ecotone between the northern boreal and the arctic zones. Northern boreal and subpolar altitudinal zonation can be differentiated on a small scale. Moreover, an oceanic-continental gradient leads to 3 climatically influenced mountain regions: the coastal mountain region, with a pronounced oceanic climate; the mountains of the inner fjord regions, with a suboceanic climate; and the (sub-)continental mountain regions. Alpine zonation thus differs in terms of the altitudinal extension of the alpine belts and in the regional characteristic of the floristic spectrum (Moen 1999). While coniferous forest is widespread at lower altitudes in the northern boreal zone, followed by birch forest in the subalpine belt, in the subpolar zone, the vegetation consists of birch forest that reaches sea level. Alpine altitudinal zonation itself can be divided into the low alpine belt, dominated by shrub and ericaceous heath communities; the midalpine belt, dominated by grassy vegetation, which becomes narrower toward the coasts and the north; and the high alpine belt, with scattered and patchy vegetation extending up to the summits of the highest mountains (Dahl 1975). In northern Norway, the highest peaks reach elevations between 610 m (Kjöltindan, Varanger) and 1833 m (Jiekkevarre, Lyngen).

Investigations using a large-scale mapping method for vegetation, soils, morphodynamics, and hydrology on the ecosystem structure of the northern Norwegian high mountain landscapes show hardly any difference between the ecosystems of the different regions (Löffler 1999). Changes in ecosystems exhibit regional differences due to parent material and resulting pH. Locally, the ecosystems can be described as extremely large-scale in structure due to relief conditions as well as resulting snow and drainage patterns.

Although it has a very low population density, the northern Norwegian high mountain landscape shows the effects of human influence. Reindeer herding has been carried out for hundreds of years, primarily by the Saami population (Bernes 1993: 99). Its scale and intensity have gradually increased in recent decades. Environmental surveillance by satellites (Norut 1999) shows that "before 1974 nature was fresh and beautiful [...] the brush and trees were intensely green and the white-yellow lichen, much favored by the reindeer, covered the ground like a delicate carpet." By comparison with 1988, the same areas showed a decrease of lichen-dominated vegetation of 85% within 15 years.

In this rough and unproductive northern landscape, food production based on reindeer herding has been a necessity for human survival. However, herding has not been increasing due to population growth but as a result of the fact that a few herders own increasing numbers of reindeer, which they use to generate income by selling meat and hides. This development caused the political authorities in Norway to reduce and seriously control the quantity of reindeer. Beginning in 1985, when the nuclear accident in Chernobyl led to the slaughtering of a large number of reindeer, the total number of reindeer continued to increase until 1989, after which it decreased continuously due to governmental control (Figure 1).

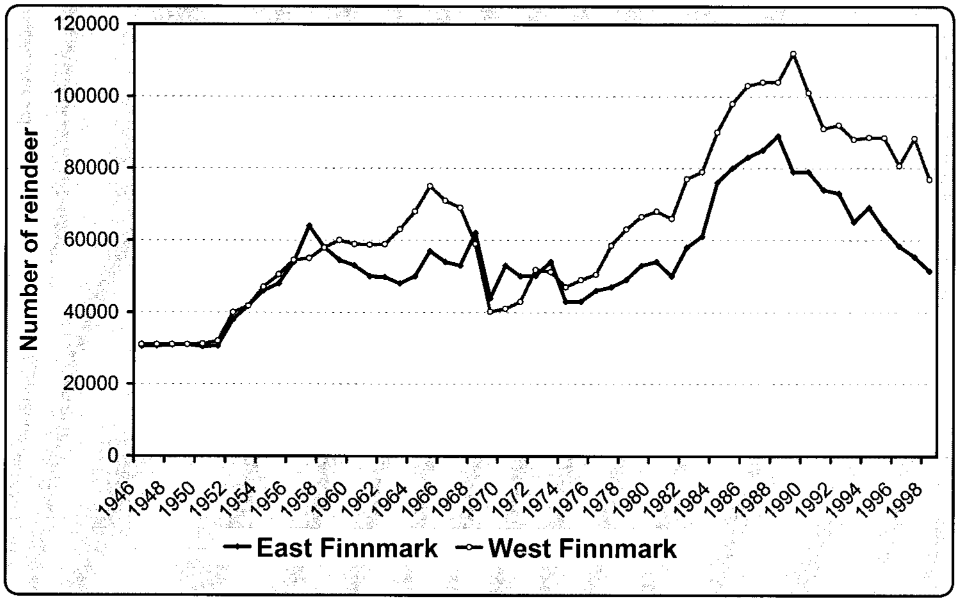
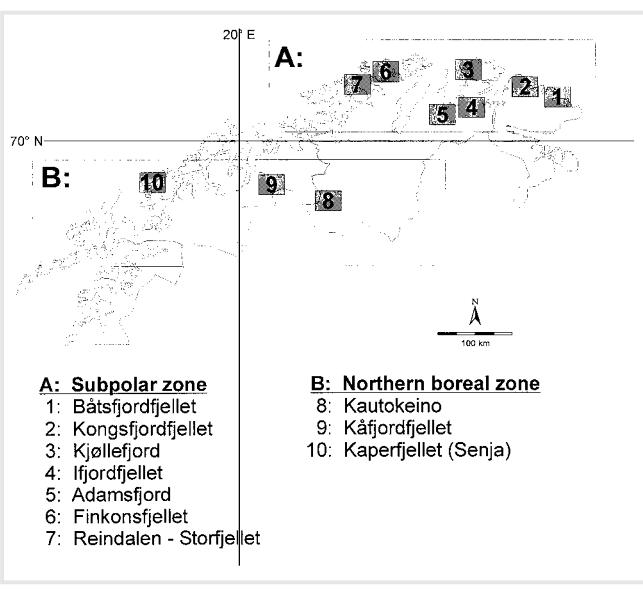


FIGURE 1 Fluctuations in the reindeer population in Finnmark, northern Norway, from 1946 to 1998. (Source: Hemmer 1985; Reindriftsforvaltningen 1999)

In general, an increase in the reindeer population puts pressure on the high mountain ecosystems of northern Norway. This phenomenon is accompanied by the practice of fencing the pasturing districts in Norway in order to prevent conflicts between settlers and pastoralists. In particular, reindeer fences have been built across the high mountain landscape to separate summer and winter pastures and direct the animals to the slaughter stations. These fences were in use prior to 1970, as they are already mentioned in topographical maps. The fences are of methodological significance in the present study because they are considered in the context of a comparison of low and high pasturing pressure on the ecosystems.

Geoecological investigations have been conducted in several high mountain regions in northern Norway since 1998 to analyze the ecological impact of reindeer grazing on the alpine environment. The present study focuses on the question of landscape degradation due to pastoral land use and the regeneration potentials of high mountain landscapes. The results are discussed in the framework of recent debate on sustainable high mountain development (eg, Messerli and Ives 1997).

FIGURE 2 Study areas in northern Norway. (Map by J. Löffler and D. Wundram)



Methods and materials

Figure 2 shows 10 regions where investigations took place along 2 west–east gradients. The 2 profiles cover the subpolar (1–7) and northern boreal (8–10) altitudinal zonation of northern Norway (see above).

The investigations were carried out in several small catchment areas of the low and midalpine belt of each region. Approximately 1550 stands were analyzed in order to characterize relief (slope aspect, slope gradient, slope shape, and hillslope-profile position), elevation (m), drainage, soil moisture status, depth to water table, vegetation (phytosociological relevés according to Braun-Blanquet [1964] and vegetation disturbance index [Figure 5]), parent material and bedrock, percentage of coarse surface fragments, soil profile (horizon combination, thickness, pH value [Munsell 1992], hue, value, and chroma), soil texture, roots, and soil temperature at a depth of 50 cm. The methodology, terminology, and classification were carried out according to Löffler (1998) if not otherwise specified. This concept employs a differentiated mapping hierarchy to distinguish several scales and dimensions of landscape examination. The larger the scale, the smaller the spatial dimension and the more detailed the investigation of each ecological factor. Three dimensions were used: site, catchment area, and entire landscape within an altitudinal belt. A classification is given for each ecological category (eg, relief, vegetation, humus, soil, etc) and subdivided into these 3 categories of landscape

FIGURE 3 Damage to *Betula nana* at Syltefjordfjellet (Varanger, northern Norway, August 1998). (Photo by A. Blume)

dimension. The main techniques and tools of landscape analysis are applied and structured after AG Boden (1994) and Bastian and Schreiber (1994).

Results

The effects of reindeer grazing on the ecosystems can be described on 3 scales: (a) large-scale effects at local sites, (b) linear effects along a reindeer fence, and (c) small-scale effects on entire mountain systems.

Large-scale effects at local sites

Figure 3 shows the effects of reindeer grazing on shrubs. Browsing and treading on boughs and branches lead to complete destruction of woody plants (especially *Empetrum hermaphroditum* and *Betula nana*). This effect is very common on medium-shaped slopes (<10° slope) in the low and midalpine belts characterized by a thin snow cover in winter. On peaks without snow cover, only special shrubs (especially *Loiseleuria procumbens* and *Diapensia lapponica*) occur under these harsh conditions within a carpet of lichens and/or mosses. The effects of browsing and treading produce a fragmentary vegetation structure. Most of the damaged shrubs die and the dead branches are covered by the lichen *Ochrolechia frigida.*

At first, the lichen cover is nearly removed, exposing the open ground to wind erosion and sheet wash. All well-drained sites that were covered by a more or less dense lichen layer of *Cladonia* ssp, especially *Cladonia stellaris* or *Cetraria nivalis* in earlier times (eg, Thannheiser 1975), now show either a gray-colored arrangement of *Ochrolechia frigida,* covered branches of dead shrubs and a degraded soil surface, or a nearly completely denuded surface of stones, blocks, or massive bedrock. In the next stage, woody plants are replaced by sparse vegetation in large areas (eg, *Ochrolechia frigida, Juncus trifidus, Deschampsia flexuosa, Luzula* ssp, *Carex bigelowii*) and annual species due to grazing pressure. In these places, the ground is locally exposed to frost so that solifluction and cryoturbation have become more common, sometimes even leading to devastation of the vegetation as a result of self-intensifying processes. In the snow beds of the low alpine belt, usually characterized by the dominance of *Vaccinium myrtillus,* grazing often caused unstable conditions so that *Salix herbacea* replaced the previous vegetation. In the poorly drained sites, covered by dense bog vegetation, pure peat can be found, mostly as a result of cattle trampling. Furthermore, soil development in general is influenced by eroded peat or humus layers and mineral topsoil layers, with the result that hardly any undisturbed profile can be found. In particular, Podzols, as one of the most common and characteristic soil types at the well-drained sites in the low alpine belt, are replaced by other soil profiles often similar to arctic/alpine brown soil. Moreover, sheet wash plays an important role. Many soil surfaces in hollows and depressions are covered by fine mineral material due to accumulation of sediment or are enriched by residual skeleton material at the surfaces of ridges and slopes due to erosion of humus and fine mineral material.

Linear effects along a reindeer fence

The effects of reindeer herding become obvious along the fences at different sites on both sides. Figure 4 shows the difference between the summer and winter grazing areas.

Figure 5 summarizes the influence of intensive pasturing on the vegetation. The table shows plant species compositions at 6 sites (3 each on both sides of the fence), their cover-abundance index on a 10-point scale (black beams), and their anthropogenic disturbance index on a 5-point scale (gray beams). The percentage of the total vegetation cover has also been calculated. Correspondingly, Figure 6 shows the ecological impact of different pasturing intensities on roots, morphodynamics, humus, soil pH, and soil moisture. In both Figures 5 and 6, the 3 columns on the left side of the fence show the less pastured sites while the 3 columns on the right show the heavily pastured sites under the same ecological conditions.

The density of the vegetation cover can be as low as 55% due to reindeer pasturing, and a remarkable

FIGURE 4 Reindeer fence at Ifjordfjellet (northern Norway, September 1998). (Photo by J. Löffler)

change in plant species composition can be observed. Some woody plants (especially *Empetrum hermaphroditum*) show an extremely high disturbance index on both sides of the fence, indicating their susceptibility even to slight pasturing pressure. In general, *Betula nana* is strongly affected and its abundance is reduced at ridge sites, whereas it is completely superseded on the southern slope. *Vaccinium myrtillus* is heavily reduced in the snow beds but shows no damage at any site; under pasture, it appears with some species in an elevated position where it does not usually occur. *Rubus chamaemorus* is reduced at those sites where it is usually present under less pasture, probably due to less soil moisture availability. *Salix herbacea* shows hardly any individual change with regard to abundance and disturbance but becomes a major species while others are extremely reduced. The vegetation at ridge sites on the pastured side of the fence can almost be described as a snow-bed community.

Under these unstable conditions (especially due to deflation), a complete change in species pattern has occurred, with the effect that, at these sites, only specific plant species are now competitive. Some annual species missing on the less disturbed side are found on the heavily pastured side of the fence. The remarkable change in the grassy vegetation is obvious: there is a general increase in abundance of all grassy species present and a distinct appearance of grassy species that were formerly absent. In summary, it can be said that all sites are becoming grassy under reindeer pasturing. These plants can cope with the stressful conditions of deflation, sheet wash, cryoturbation, and solifluction, as these morphodynamics are present at all sites in the midalpine belt where these species usually occur in great abundance. Hepatics, common on the left side, are completely absent under heavy pasturing. Other mosses only show a slight decrease in abundance. The most visible effect of pasturing on the vegetation cover is the disturbance of lichens and their reduced abundance. Nearly all species are damaged on both sides of the fence; many of them show an extremely high percentage of destruction.

The ridge sites formerly characterized by 12 lichen species even lost a total of 5 species, 2 of which were among the most abundant ones (*Cetraria nivalis* and *Ochrolechia frigida*). In general, the presence of *Ochrolechia frigida* at the less pastured sites is an indicator of reindeer pasturing on vegetation in those areas. The suppression of this lichen species at sites under high pasturing pressure is an indicator of overgrazing, resulting in completely disturbed and unstable ecological conditions. The site that slopes to the south has lost nearly all lichen species present on the left side of the fence. The few species to be found under pasturing at sites with northern exposures are mostly reduced in abundance and are extremely disturbed. On the whole, the changes in vegetation structure and composition, species cover abundance, and disturbance of species do not correlate with the number of species. Moreover, the resulting combination of plant species under high pasturing pressure does not fit into the Norwegian system of well-known plant associations (Dahl 1987).

As shown in Figure 6, a decrease in fine roots is recognizable due to increasing pasture intensity. In general, sites with a vegetation cover of nearly 100% on the less pastured side of the fence show a dramatic decrease of roots in the upper 15 cm of the soil. At ridge sites, there is a complete loss of roots at greater depths and few roots in the upper 5 cm. This change in root density is one of the major causes of further erosion processes, as humus and soil stability are heavily reduced. Morphodynamic processes are dominant at ridge sites and on medium-shaped sites with southern exposures. Slopes exposed to the north often show relatively dense vegetation with more or less stable root conditions in places where vegetation is present (otherwise, the surface is completely eroded to blocky and stony fragments). The layers of humus that formerly covered

FIGURE 5 Influence of different pasturing intensities on the vegetation on two sides of a reindeer fence in the Ifjordfjellet region, northern Norway. Black beams show species abundance on a 10-point scale, grey beams their anthropogenic disturbance index on a 5-point scale. (Sketch by A. Blume and J. Löffler)

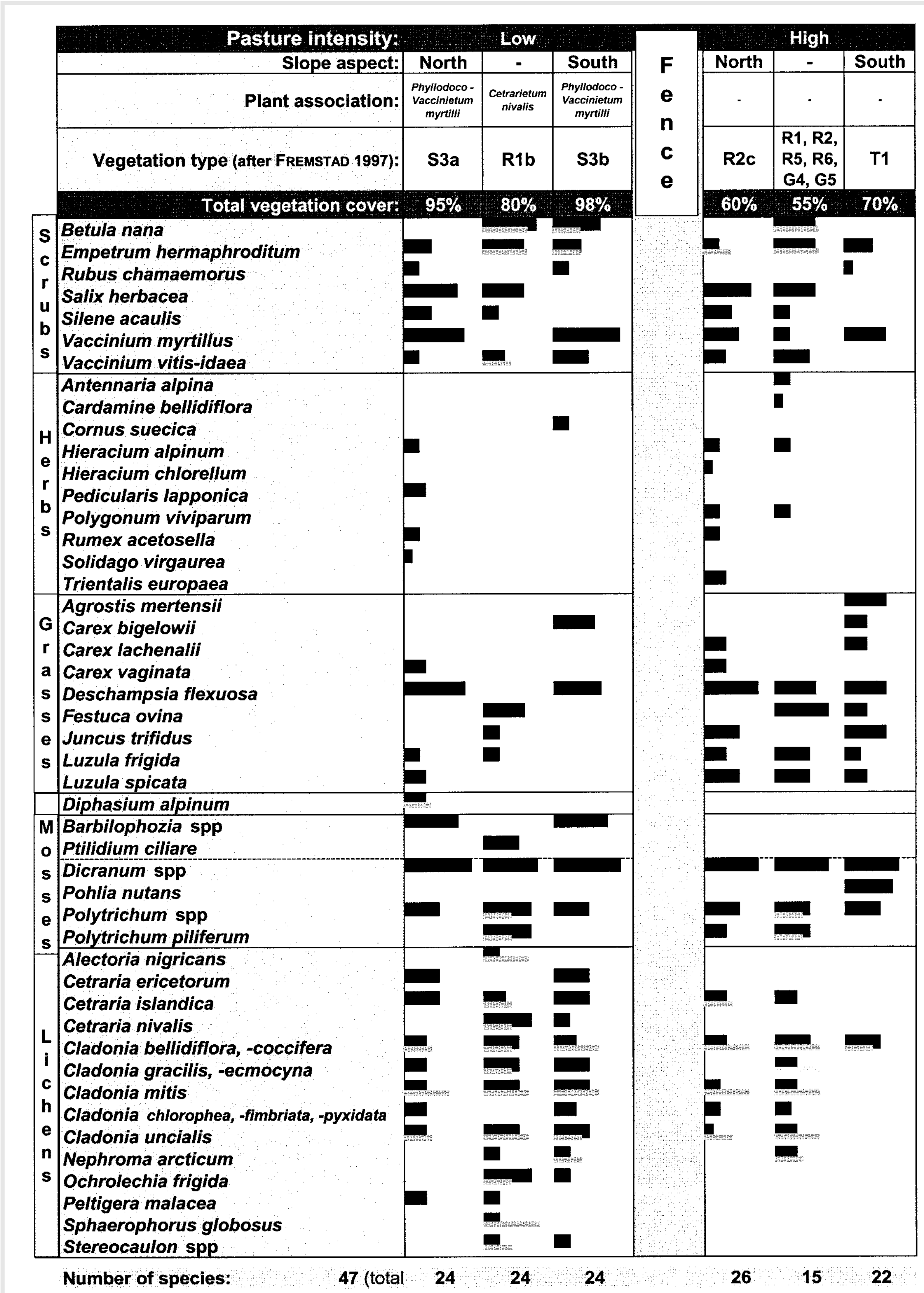
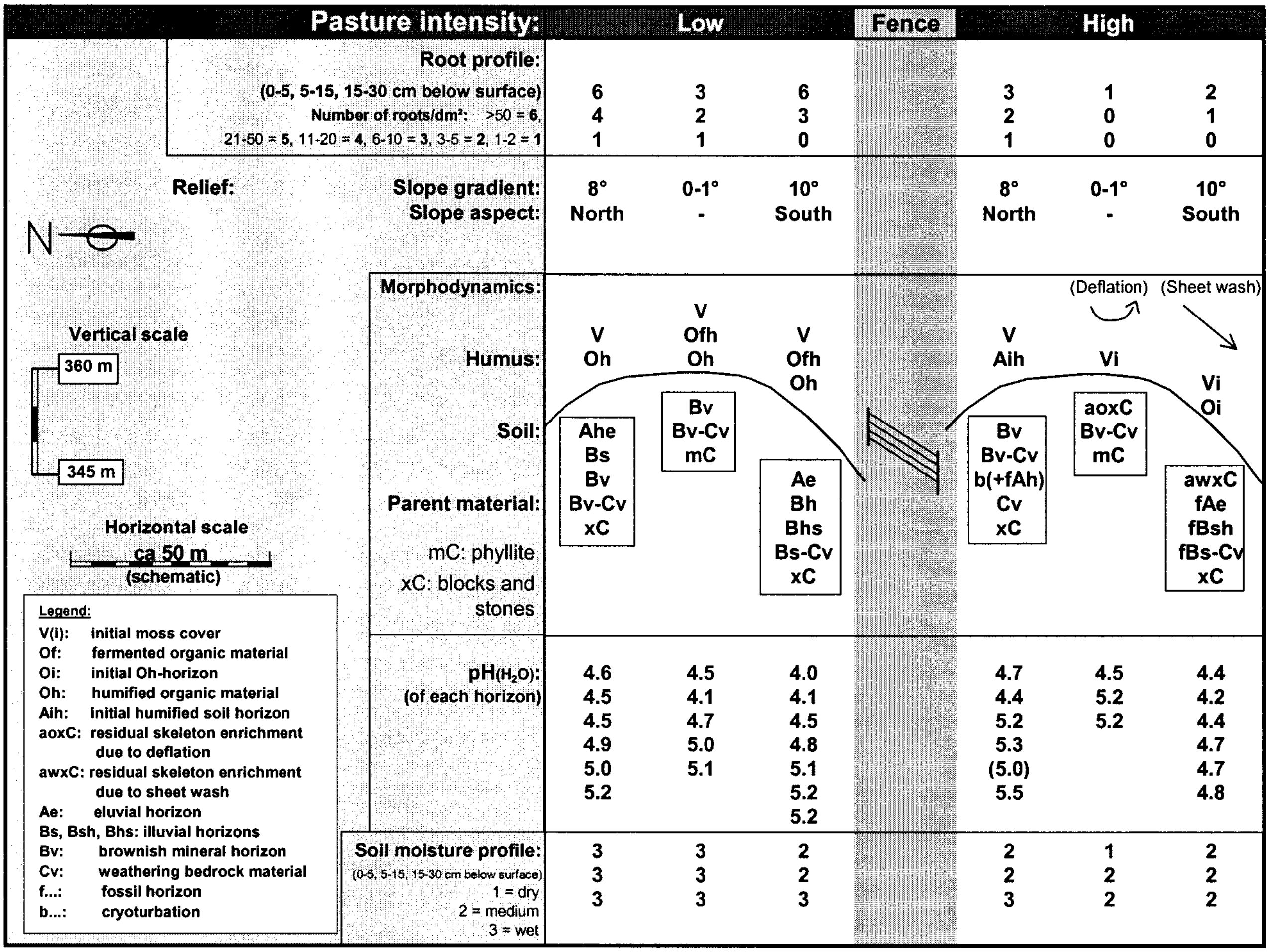


FIGURE 6 Influence of different pasturing intensities on root profile, morphodynamics, humus, soils, pH and soil moisture on two sides of a reindeer fence in the Ifjordfjellet region, northern Norway. (Sketch by A. Blume and J. Löffler)



almost the entire surface under lower pasturing intensity show a clear change to initial moss cover, with thin initial layers of humus under high-intensity pasturing.

The underlying soil profile is also affected in combination with these processes of humus erosion. Remarkably developed Podzol profiles are reduced to a brown soil profile formerly present under the Podzol horizons (mostly found at sites with northern exposure) or to a skeleton sheet wash surface covering the fossil Podzol horizons. At ridge sites, brown soil profiles are largely reduced to a skeleton surface due to deflation covering some relics of the former soil profile. Sometimes cryoturbation has influenced the soil profile, and fossil layers of humus are found within the B horizons. Recent pH values for the humus and soil horizons do not show any great changes due to pasturing intensity, but they do show a general increase in soil depth (as usual), with almost the same trends in nutrient status and medium acidification. Soil moisture is heavily affected due to destruction of primary vegetation through reindeer pasturing followed by root destruction and erosion of humus and soil. Even the deeper layers are affected, showing drier conditions under high-intensity pasturing. All these changes in ecological site conditions influence vegetation succession. On the one hand, recent conditions under intense pasturing cause stress with which most plant species cannot cope. On the other hand, many other plant species that are tolerant of unstable ecological conditions formerly absent because of weak concurrence have a chance to establish themselves under high pasturing pressure.

Small-scale effects on entire mountain systems

As a result of this environmental stress, extended changes in ecosystem structure can be summarized as a depression of the alpine altitudinal belts (Löffler 1999). Taking the processes of complex landscape-ecological change in ecosystem structures into consideration, many indicators can be found to prove that this environmental change is the result of reindeer herding. The distance between the forest line and the tree line is generally very great, while the distance between the tree line and the upper limit of the low alpine belt is often relatively small. It can thus be concluded that the birch forest has been depressed to lower altitudes. The fact that some of the highest sites with young trees or

FIGURE 7 View of the low alpine landscape of Ifjordfjellet at about 200-400 m, facing south (northern Norway, September 1998). (Photo by J. Löffler)

tree groups are found at high altitudes shows that the tree line ecotone has been enlarged at the same time. The former low alpine belt has been depressed from higher altitudes and recently replaced by a midalpine environment. In these areas, fossil Podzol profiles often buried under erosion or solifluction material are found along with relics of a dense low alpine vegetation surrounded by extremely scarce vegetation, which has usually developed under recent mid- or high-alpine conditions. The spectrum and abundance of plant species have therefore changed completely, and many species (especially the grassy vegetation) from higher altitudes have invaded the lower regions. The less pastured winter grazing landscape can be seen in Figure 7. Figure 8 gives a schematic summary of the phenomenon of depression of altitudinal belts in the northern Norwegian high mountains, using vegetation, soils, and morphodynamics as indicators.

Conclusions

Land use in northern Norway can be characterized to a great extent as intensive pastoralism. On the one hand, reindeer herding is the only practical way to produce food above the alpine tree line. On the other hand, intensification of this economic sector has caused alarming pressure on the environment. The fragile high mountain ecosystems suffer from overgrazing, and there has been a dramatic change in ecosystem structure and function. The present state of the landscape can be described as a partial or complete change in ecological characteristics due to stress that exceeds the carrying capacity. The processes that have caused local changes in species composition, linear destruction of ecosystem structures along fences, and a depression of altitudinal belts over widespread areas can be summarized as landscape degradation.

From an ecological point of view, the long-term perspective under stable conditions can be assessed as problematic. Nevertheless, this type of land use does not compete with other interests in northern Norway, with the exception of nature conservation. But in the case of national parks where reindeer herding is not forbidden, it will be difficult to halt this process without fencing the entire park area.

The high mountain landscape has been subjected to unlimited exploitation by means of reindeer pasturing in alarming proportions. Though there appears to be an abundance of land, the carrying capacity has obviously been exceeded. The recent reindeer population has averaged about $4/km^2$ in northern Norway, with local variations. The carrying capacity of the northern Norwegian high mountain landscape has not been assessed as a whole. But in the absence of concrete data, Hemmer (1985) has noted the possibility of redistribution within northern Norway. It is now obvious, however, that the entire mountain landscape has suffered from overgrazing for a long time, so it is unlikely that any balance in the intensity of pressure on the landscape can be expected.

Recent land use patterns in northern Norway will not be sustainable over the long term for the following reasons:

- Recent land use obviously leads to environmental destruction, which is likely to result in a desert-like mountain landscape in the future.
- Economic short-sightedness will lead to a natural decline in the animal population due to the reduced productivity of the land resources.
- Sociocultural changes have accompanied modern development in Norway. These changes have brought problems that disrupt the traditional society of the Saami population (unemployment, alcoholism, etc).

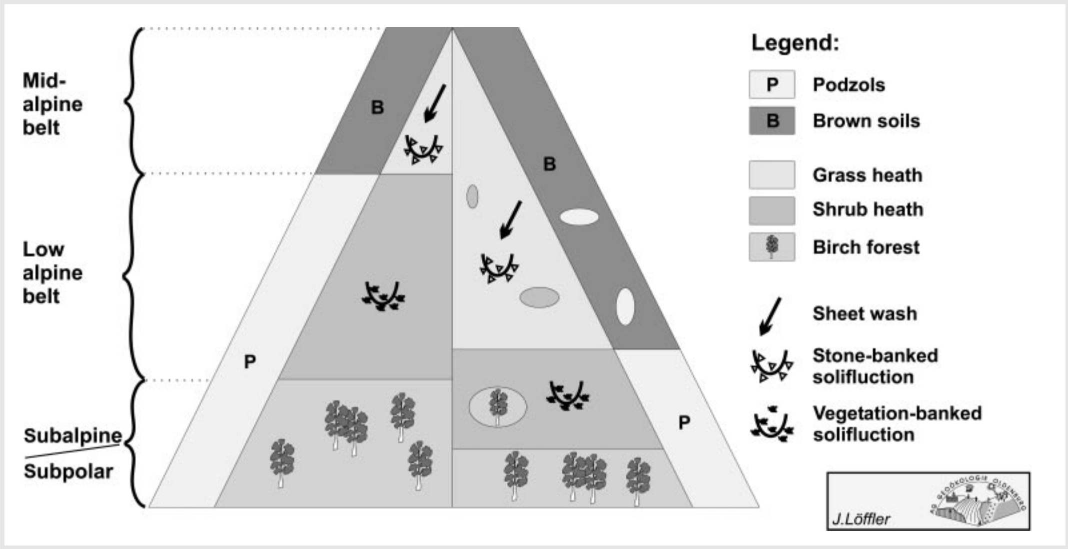


FIGURE 8 Depression of altitudinal zonation due to overgrazing in the northern Norwegian mountains.

Processes that destroy the natural environment could be reversed with a large-scale decrease in the intensity of pasturing. This has been shown in a few places where pasturing was abandoned some years ago. Regeneration of some lichen species is apparent at some sites, as well as germination of birches (*Betula pubescens*) above the recent tree line. Thus, for instance, Thannheiser (2000) describes the succession of birches in the inner *Finnmarksvidda* as the result of a decrease in the intensity of pasturing. But sustainable mountain development cannot be expected in northern Norway under current conditions due to the lack of alternatives to this type of land use.

AUTHOR

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