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Lichens, a unique forage resource threatened by air pollution

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Abstract: Lichens are the primary winter forage for most mainland caribou and reindeer herds in North America and for the majority of domestic and wild reindeer in Siberia and northern Europe, collectively totaling in excess of 5 million animals. Lichens represent a unique forage resource throughout much of the circumpolar North that cannot effectively be replaced by vascular plants. Lichens are particularly sensitive to the effects of air pollution. The increased pace of exploitation and processing of minerals and petroleum resources throughout the circumpolar North, with associated introduction of pollution products into the atmosphere has already resulted in losses of lichens and their reduced productivity in extensive areas adjacent to large metallurgical complexes in the Taimyr of Siberia, on the Kola Peninsula, and in adjacent parts of Finland. Losses of terricolous lichens in the Taimyr from pollution generated by the Norilsk metallurgical complex have been nearly complete within a 300,000 ha area closest to the pollution source and damage and reduced growth extends over an area in excess of 600,000 ha. The Arctic also is a sink for atmospheric pollution generated in the heavily industrialized north temperate regions of the world. Assessment of the effects on lichens of this global scale increase in air pollution is difficult because of the lack of representative controls.

Keywords: lichens, pollution, sulfur dioxide, caribou, reindeer, Soviet Union, Arctic pastyres, winter

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Introduction

Lichens are a primary winter food for over 5 million caribou and reindeer (both *Rangifer tarandus*) that occupy the northern boreal forest of North America, the taiga of Eurasia, and their adjacent tundra areas (Andreev 1977, Klein 1982). Lichen-dominated plant communities occupy vast regions of the northern portions of North America and Eurasia (Andreev 1977, Kershaw 1977) (Figure 1). Lichens are a unique forage that, unlike vascular plants, accumulate living plant tissue over several years that is available as winter forage (Klein 1982). Although lichens contain unique acidic compounds that act as chemical defenses against most herbivores (Rundel 1978), caribou and reindeer are well adapted to use many arboreal and terricolous lichen species as forage. The primary value of lichens for reindeer and caribou is in their high content of available energy which is the major dietary requirement of these northern ungulates in winter. Thus the abundance and availability of lichens at high northern latitudes enables successful overwintering of

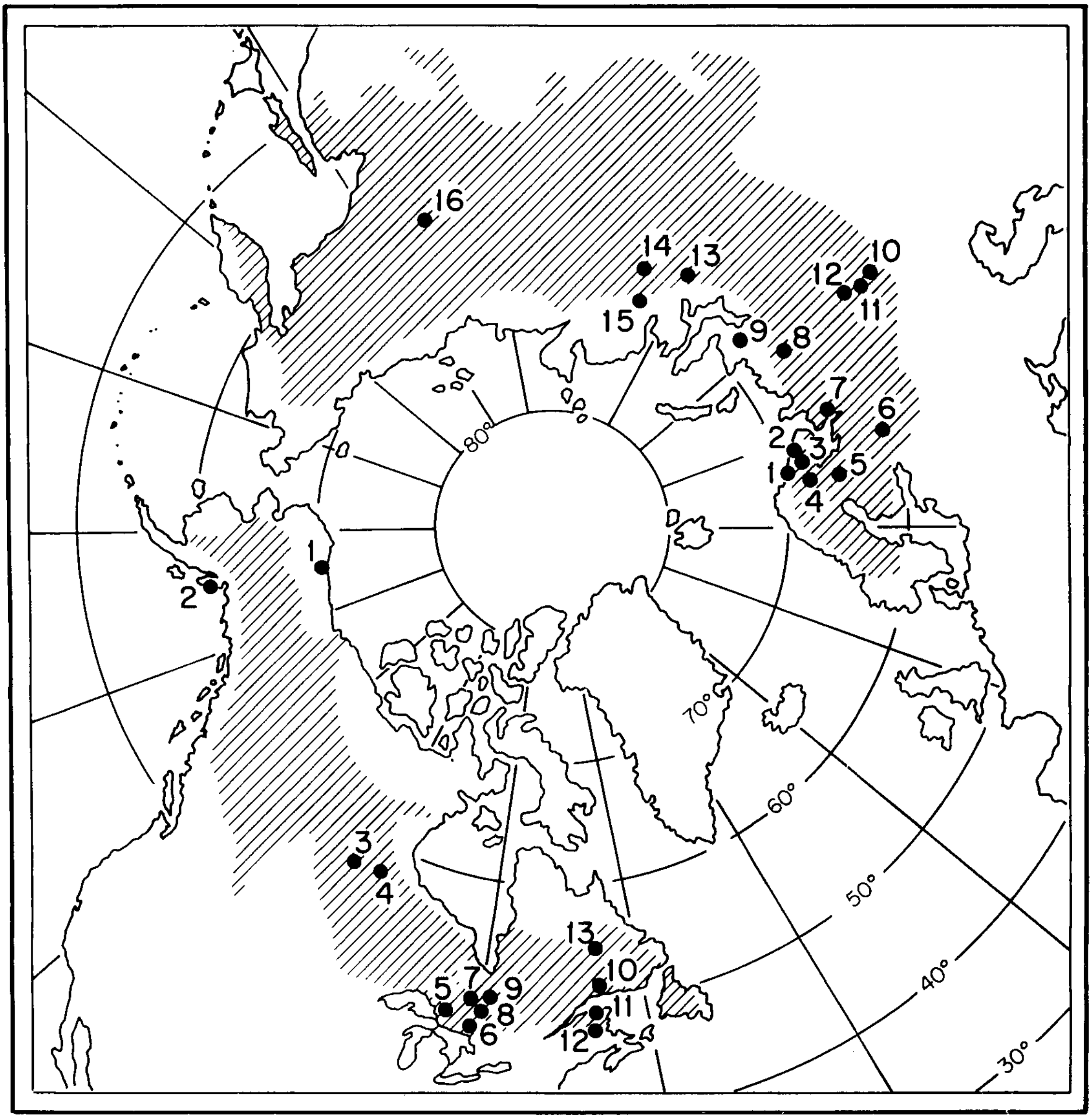

Fig. 1.

large herds of migratory caribou and domestic reindeer. Suitable areas with high lichen biomass for winter grazing by reindeer or caribou occupy 30–40% of the land area of the northern regiaons of North America and Eurasia (Andreev 1977, Kershaw 1977).

The uniqueness of lichens, in contrast to vascular forage plants, derives from their structure, physiology, and ecology as a function of the symbiotic union of fungi and blue green algae. The structure of lichens is formed by the fungal component, which provides an interstitial environment favorable for blue green algae. When sufficient moisture and light are available, the algae are able to photosynthesize and draw on nutrients from the atmosphere, including trace nutrients, that become sequestered in the fungal tissues. The photosynthates that are produced are then available for growth of both the algal and fungal components as a symbiotic "organism." Lichens have no roots and hence derive virtually all of their requirements for growth from the atmosphere; their porous structure also results in their capture of particulate material falling from the atmosphere (Hawksworth 1971). Because of this characteristic lichens also accumulate pollutants from the atmosphere.

Fig. 1. Major point sources of atmospheric pollution in and adjacent to the boreal and taiga forests (Boreal and taiga forest zone shown as crosshatching from Ahti *et al.* 1968; pollution sources from Norwegian Institute for Air Research 1984 and Canada Department Energy, Mines and Resources 1988).

North America
1. Oil field complex, Prudhoe Bay, Alaska
2. Petrochemical industries, Kenai, Alaska
3. Copper-zinc smelting, Flin Flon, Saskatchewan
4. Nickel smelting, Thompson, Manitoba
5. Iron sintering plant, Wawa, Ontario
6. Nickel-copper smelting, Sudbury, Ontario
7. Zinc-copper-cadmium smelting, Timmins, Ontario
8. Iron sintering plant, Kirkland Lake, Ontario
9. Copper smelting, Noranda, Quebec
10. Iron-titanium agglomerate plant, Port Cartier, Quebec
11. Copper smelting, Murdockville, Quebec
12. Lead-silver-copper smelting, Belledune, New Brunswick
13. Iron sintering plant, Labrador City, Labrador

Eurasia
1. Iron smelting, Sydvaranger, Norway
2. Copper-nickel smelting, Nikel-Zapolyarni, Kola Peninsula, U.S.S.R.
3. Copper-nickel smelting, Monchegorsk, Kola Peninsula, U.S.S.R.
4. Iron smelting, Kostomuksha, U.S.S.R.
5. Coal-fired pulp and paper production, Svetogorsk, Kola Peninsula, U.S.S.R.
6. Iron smelting and steel production, Cherepovets, U.S.S.R.
7. Coal-fired power and paper production, Arkangelsk, U.S.S.R.
8. Coal-fired power and paper production, Ikhta, U.S.S.R.
9. Coal-fired power and paper production, Vorkuta, U.S.S.R.
10. Copper-nickel smelting, Sverdlovsk, U.S.S.R.
11. Steel production, Nishniy Tagil, U.S.S.R.
12. Steel production, Serov, U.S.S.R.
13. Oil-gas field complex, Samotlor, U.S.S.R.
14. Wood products and paper production, Igarka, U.S.S.R.
15. Nickel-copper smelting, Norilsk, U.S.S.R.
16. Coal-fired power and paper production, Yakutsk, U.S.S.R.

Response of lichens to air pollution

Erasmus Darwin, the grandfather of Charles Darwin, observed in the 19th century in England that lichens were sensitive to air pollution, and deterioration of the lichen flora around London during the industrial revolution was noted by several English botanists (Hawksworth and McManus 1989). Similarly, the lichen flora of southern Sweden, which suffers from acid precipitation from heavy industrial activity in northern Europe, declined markedly in species diversity and biomass over several decades (Arup *et al.* 1989). In Canada, atmospheric pollution from the large nickel smelting complex in the Sudbury district of Ontario has had a long history of negative effects on vegetation on the region, most lichens were eliminated within several kilometers downwind of the pollution sources (LeBlanc and Rao 1966). Sulfur, in varying forms, is the primary pollutant responsible for the decline of the lichen flora around Sudbury, and laboratory studies confirmed the sensitivity of lichens to sulfur dioxide and its derivatives in acid precipitation (Hawksworth 1971, Pucket *et al.* 1973).

Point sources of pollution from industrial development have increased markedly in northern regions in the latter half of this century (Figure 1). Little effort has been expanded on evaluation of the direct effects of atmospheric pollution on lichens as a forage for reindeer and caribou. In addition to the economic and socially important role of reindeer husbandry in the past several decades in the Soviet Union, Finland, Sweden, and Norway, caribou and wild reindeer have been equally important in the subsistence economy of northern peoples in the Soviet Union, Greenland, Canada, and Alaska (Klein 1989). Only during the past two decades, as international concern over the deterioration of the world's environment mounted, have efforts been expanded at assessing losses of lichen species diversity and biomass as forage for reindeer and caribou in areas of heavy atmospheric pollution.

Air pollution from smelting of nickel and copper at Monchegorsk and Nickel on the Kola Peninsula, of U.S.S.R. resulted in sulfur fallout measured by Helle *et al.* (1990) in adjacent areas of northern Finland of 1.0–1.2 g/m^2, and to 0.4 g/m^2 in western Lapland. In spruce *(Picea abies)* stands at 67°50′N and 65°44′N, where these authors began studies of aboreal lichens in 1976, lichen biomass had been reduced by 50% up to 1988 at the more southern site and by 75% at northern site under sulfure fallout levels of about 0.6 g/m^2.

Pollution from the Norilsk complex

In the Taimyr region of north central Siberia, pollution from the huge metallurgical complex of Norilsk has had serious consequences for lichens in an area that has been heavily used by both domestic and wild reindeer (Vlasova *et al.* 1991). Norilsk, lying in the Arctic at nearly 70°N is a city of 260,000 people. Founded in the mid-1930's in association with development of the world class copper-nickel sulfide deposits in the region, Norilsk supplies about two thirds of the total Soviet production of nickel and is the largest nickel producer in the world. The source of power for mining, smelting, the city of Norilsk, and satellite mining centers was originally coal from local mines. In the late 1960's hydroelectric development of the Khantayka and Kureyka rivers lessened dependence on coal. Construction of natural gas pipelines to the area during 1969–1973 further reduced the need for coal, but also enabled construction of a second smelter. The discontinued dependence on coal resulted in some reduction of atmospheric pollution. Growth in the industrial complex, however, increase in sulfur content of the ore processed, and introduction of an autogenous fusion processing method increased the proportion of sulfur component in discharge gasses from 5% in 1981 to about 50% by 1989 (Vlasova *et al.* 1991). The Norilsk complex now accounts for roughly 4.5 million metric tons of atmospheric pollution annually (Saunders 1990). This includes nitrogenous and anhydrous sulfur components that readily convert to acids in contact with rain or surface water and substantial amounts of heavy metals (Kovalev and Filipchuck 1990). Sulfur dioxide emissions alone equal about 2.2 million metric tons per year, an amount about equal to the total of all combined Canadian output (Saunders 1990).

Studies of pollution effects from the Norilsk metallurgical complex on vegetation of the region were initiated in 1976 by Soviet scientists from the Far North Institutes for Agricultural Research in Norilsk jointly with specialists from the Forest Resources Section of the

Table 1. Effects of atmospheric pollution from the Norilsk metallurgical complex on vitality, species composition, percent ground cover, and biomass of lichens in the region (data from Vlasova *et al.* 1991; pollution zones are referenced in Fig. 2).

Degree of Pollution	Vitality of lichens	Number of species	Percent cover	Biomass (100 kg/ha)
Maximum	Absent, or only fragments remaining	0–4	<	<1
Severe	Heavily damaged, morphological changes of up to one half of the thalli	5–20	<20	1–5
Moderate	Stressed, less than average size, changes in color of thalli	21–34	>20–40	>5–10
Slight	Normal, average size	>34	>40–70	>10–15
Relatively clean	Good condition	>34 (up to 96)	>70–90	>15

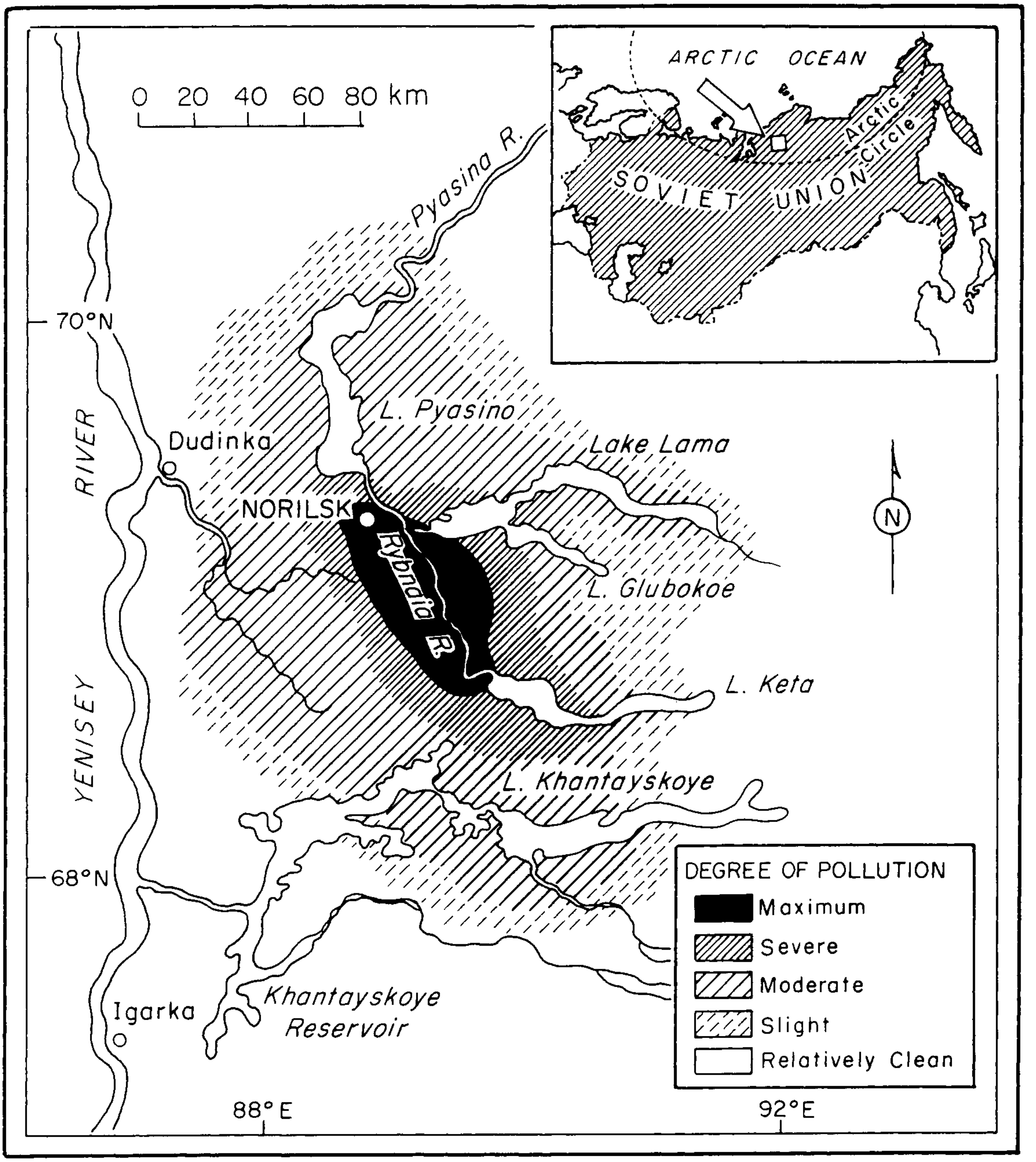

Fig. 2. Degree of pollution in zone radiating from the Norilsk metallurgical complex as reflected in condition of lichens (from data in Table 1).

Union Scientific Research Institutes in Moscow and Bryansk (Vlasova *et al.* 1991). In the zone of fallout of atmospheric pollution during summer, vegetation over an area of 565,000 ha showed various levels of damage and deterioration when surveyed in 1989 (Vlasova *et al.* 1991) (Figure 2). This compares to 457,000 ha in this category in 1986 and 323,000 ha in 1976, thus the annual increase in area affected changed from 13,400 ha/yr from 1976 through 1986 to 36,200 ha/yr in the following 3 years. Forests, dominated by *Larix sibirica,* and most lichens have been killed in an area of over 300,000 ha closest to the pollution source and extending obliquely over 50 km to the southeast (Figure 2) (Table 1).

The pattern of the response by lichens to pollution is consistent with distribution of the plume of summer pollution from the Norilsk metallurgical complex, which in turn is the product of seasonal wind patterns. Topographic features, however, also have an important influence on distribution of pollutants. The Putorana Mountains lying east and southeast of Norilsk are a partial barrier to penetration of airborne pollutants although major river valleys and associated large lake basins serve as channels for movement of polluted air into lower lying areas in this mountain range.

The extensive area over which lichens have been eliminated or their biomass greatly reduced as a consequence of pollution from the Norilsk metallurgical complex has been an important wintering area for domestic and wild reindeer. Wild reindeer from the Taimyr herd, numbering close to 600,000, winter in the Putorana Mountains mostly east of the polluted area, however, tens of thousands of animals from this herd extend their winter grazing into slightly to moderately polluted areas. Domestic reindeer husbandry has been much more severely affected by the loss of lichens. Winter grazing of domestic reindeer in areas of maximum and severe pollution was discontinued and herd numbers have declined accordingly since the mid-1970's. Because the polluted areas are expanding, the available lichen forage continues to decline through death of lichens and decreased lichen growth rates. The future of reindeer husbandry and of the wild reindeer population in the Taimyr is therefore seriously threatened.

Concluding remarks

Will the current political and economic reforms in progress in the Soviet Union lead to realistic efforts to reduce pollution emissions from the Norilsk metallurgical complex? Technology exits in the West to improve efficiency of the smelting process at Norilsk. Recently initiated exchanges of representatives from the Norilsk complex and Canada's Inco nickel production facilities at Sudbury, Ontario and Thompson, Manitoba, may ultimately lead to assistance in the adoption of new technology at Norilsk (Saunders 1990). Even if emissions of sulfur components are reduced in the future, recovery of vegetation in severely damaged areas will require a long time. Lichens, in particular, must undergo a long sequence of recovery, including the establishment of pioneering forms that are little used by caribou and reindeer, which ultimately leads to a climax or terminal lichen complex dominated by species of most importance as forage (Kershaw 1977). This entire sequence requires a minimum of 20 to 25 years following fire (Andreev 1977), and much longer if no living lichens remain in the area or vascular plant succession becomes stagnated in a grass or sedge stage (Klein 1982, 1987).

Widespread deterioration and death of lichens in the Taimyr as a consequence of pollution from the Norilsk metallurgical complex is a catastrophic loss of a major forage resource, and has markedly limited productivity of the region for reindeer. Sensitivity of lichens to air pollution has been well demonstrated in the Taimyr at the cost of loss of biological diversity, disruption of ecosystems, and reduced productivity of the land. Increased exploitation of mineral resources in the circumpolar North and associated industrial development, expansion of human populations, pollution from point sources, and global increases in atmospheric pollution pose a major threat to lichens and their use as food for the world's population of reindeer and caribou.

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