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SPOROPHYTE ABNORMALITIES AS A CAUSE FOR DECLINE AND DISAPPEARANCE OF MOSSES IN POLLUTED AREAS

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SUMMARY — Mosses that survive in polluted areas usually represent common, widespread and tolerant species; they may serve as an example for studying and explaining some reasons for the decline of mosses. For this purpose, species of Pohlia *were collected during a period of three years (1990-1992) from heavily polluted to presumably less influenced areas in different directions (50-300 km SSE, 10-150 km E-NE) from a huge metallurgical complex at Norilsk in the northern subarctic areas of the Krasnoyarsk region in Siberia. Sporophyte deformity of the pollution tolerant* Pohlia nutans *and of the endangered* P. elongata *are examined and related to different distances to the pollution source. In addition, morphological deviations and reproductive features of some tolerant species, such as* P. nutans, P. cruda *and* P. proligera, *are discussed.*

KEYWORDS — Morphological deviations, peristome deformity, pollution, Siberia, bryophytes

ZUSAMMENFASSUNG — Missbildungen an Sporophyten als Ursache für Rückgang und Verschwinden von Laubmoosen in verschmutzten Gebieten

Laubmoose, die in verschmutzten Gebieten überleben, gehören zu häufigen, weit verbreiteten und unempfindlichen Arten. Sie können als Objekte für die Untersuchung und Erklärung einiger Ursachen des Arten-Rückganges bei Laubmoosen dienen. Zu diesem Zweck wurden während dreier Jahre in verschieden stark verschmutzten Gebieten der nördlichen Subarktis Sibiriens Pohlia*-Arten gesammelt. Sie stammen aus der weiteren Umgebung eines riesigen Verhüttungswerkes in Norilsk im Gebiet um Krasnojarsk. Missbildungen am Sporophyten der verschmutzungsresistenten* Pohlia nutans *und der gefährdeten* P. elongata *wurden untersucht und mit den verschiedenen Distanzen von der Verschmutzungsquelle in Verbindung gebracht. Ausserdem werden morphologische Abweichungen und generative Merkmale einiger toleranter Arten wie* Pohlia nutans, P. cruda *und* P. proligera *diskutiert.*

Introduction

There are many characteristics of plant species that respond to air pollutants, such as population structure, morphology and physiology, or cellular characteristics. The use of measurable attributes of affected plants has limitations (Belnap & al. 1993) some of which are: a) difficulties in identifying the best indicator species for a particular study; b) difficulties in demonstrating that the observed changes of plants reflect pollution stress and not other abiotic or biotic factors, for example drought or ageing. In pollutant-related studies little attention is usually paid to the morphological appearance of the common, widespread and tolerant species which may be found in polluted areas. The morphological condition of survivors may help to explain why some mosses decline. For these purposes it is necessary: a) to demonstrate whether selected morphological abnormalities attributed to pollution fall outside the normal variation caused by non-pollution-related environmental factors, b) to demonstrate that the selected morphological abnormalities are really caused by pollution.

Materials and Methods

Study area and studied species

The study area includes the north-western, western and south-western parts of the Putorana plateau (Fig. 1). It has been chosen in order to show that pollution influences the mosses significantly more than natural environmental conditions because this region has been subjected to increasing emissions from a huge metallurgical complex at Norilsk since the mid 1930's.

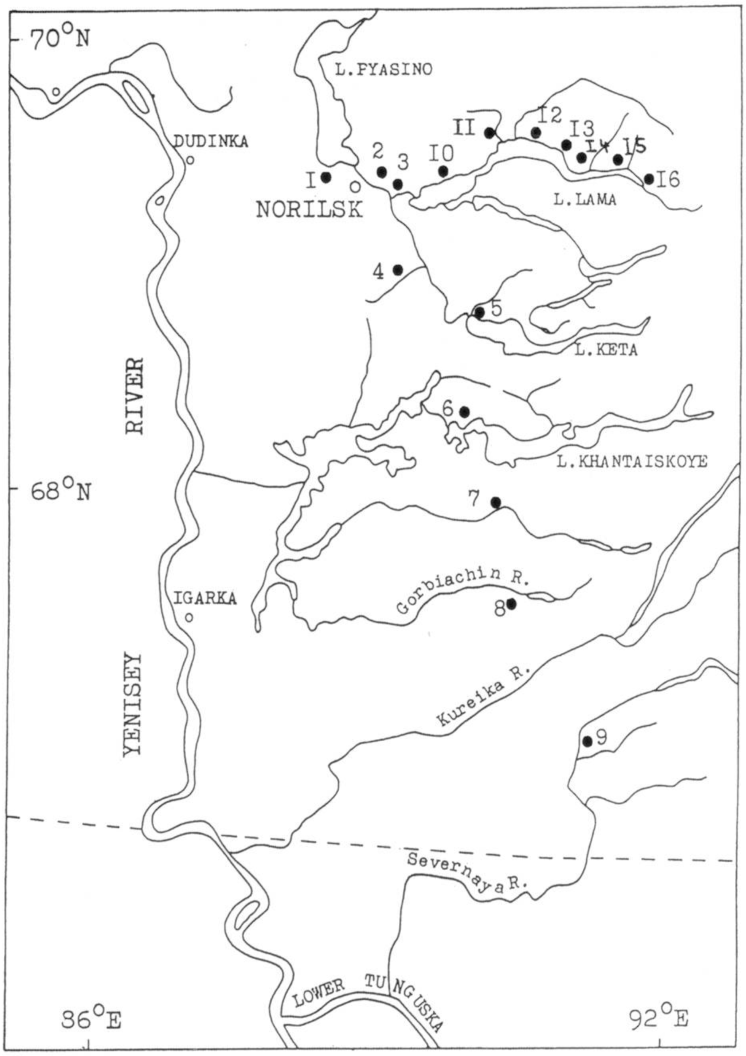

FIGURE 1. Map of the Norilsk region (Siberia, Russia), showing the collecting sites.

Negative effects of gases containing sulphur from the Norilsk industrial region on the vegetation have been reported in the literature (Vlasova & al. 1991; Klein & Vlasova 1992). In 1989, more than 2.2 million tons of sulphur compounds were emitted from a point source. At present, more than 300.000 hectares of natural vegetation around Norilsk are considered to be damaged (Vlasova & al. 1991). Also remote, previously undisturbed areas around Norilsk are increasingly affected by the long range transport of pollutants. The pattern of air pollution damage in the surrounding region is mainly influenced by the prevailing winds from northwest and by topographic features such as major river valleys and large lake basins, which serve as channels for the polluted air from Norilsk.

During the period 1990-1992, mosses were collected from heavily polluted to presumably less influenced areas in different directions from the Norilsk pollution source (50-300 km south-southeast, 10-150 km east-northeast; Fig. 1 and Tab. 1). The sites are located in the river valleys and watershed slopes which are covered by open woodlands and tundra vegetation. The species sets of the study sites and the investigated features of the collected specimens are related to the distance from the Norilsk's point source. Unfortunately, no direct measurements of pollution levels are available in such remote areas.

Eight Pohlia species are known to occur in the north-western part of the Putorana plateau: *P. andrewsii, P. bulbifera, P. cruda, P. drummondii, P. filum, P. nutans, P. proligera* and *P. sphagnicola* (Czernyadjeva 1990; Czernyadjeva & Ignatov 1991; nomenclature follows Shaw 1982).

About 300 samples of P*ohlia* species were analysed from the study area (Fig. 1) and eight *Pohlia* species were identified. *P. cruda, P. elongata, P. longicollis* and *P. nutans* were found with sporophytes. Of the propaguliferous species, *P. andrewsii, P. drummondii, P. filum* and *P. proligera* were observed. *P. nutans* and *P. elongata* were selected for detailed investigation.

Studied structures

The presence of sporophytes and of asexual propagation units in the collected moss specimens were recorded. Sporophyte abundance was quantified using four categories: O = no, Sg = single, M = in moderate number, N = numerous sporophytes present. In the propaguliferous taxa, the number of propagules was classified into three categories : Sc = scattered occurence, M = moderate amount, N = numerous. The peristomes of the collected specimens of *Pohlia nutans* and of *P. elongata* were examined. The degree of exostome deformation was estimated in comparison with normally developed peristomes according to few categories: + = no, Sl =

slight, Md = moderate, St = strong deformation. Special attention was paid to exostome teeth anastomosing at their base.

Results

Fig. 2 shows a normally developed peristome where the exostome teeth are loosely attached to the capsule mouth. Abnormally developed peristomes lack this property as a result of partial (Figs 3, 4 and 5) or complete (Fig. 6) anastomosing of exostome teeth at the base or in the upper part.

Tab. 1 gives an overview of the occurrence of different *Pohlia* species at the study sites. At the sites 1-3 around Norilsk (Fig. 1) and at site 4, 50 km south-east of Norilsk, only *P. nutans* and *P. proligera* occur. The number of species generally increases with increasing distance from the source of pollution (Tab. 1).

No.	Locality	Distance	Date	Species
1	Kaijerkan	10 km NW	1991	Pn, Pp
2	Talnach	10 km NE	1991	Pn, Pp
3	Talaya R.	25 km E	1992	Pn, Pp
4	Chopko R.	50 km SE	1990	Pn, Pp
5	Keta-Irbo R.	80 km SSE	1990	Pc, Pn, Pa, Pp
6	L. Khantaiskoye	105 km SE	1990	Pc, Pn, Pa, Pf, Pp
7	Kulyumbe R.	145 km SE	1991	Pc, Pn, Pa, Pd, Pp
8	Gorbiachin R.	190 km SE	1991	Pc, Pe, Pn, Pa, Pp
9	Severnaya R.	300 km SSE	1991	Pc, Pe, Pl, Pn, Pa, Pd, Pf, Pp
10	L. Melkoye	50 km E	1992	Pc, Pn, Pp
11	Neralakh R.	80 km NE	1991	Pc, Pn, Pa, Pd, Pp
12	Mikchanda R.	110 km NE	1992	Pc, Pn, Pa, Pf, Pp
13	L. Kapchuk	125 km NE	1992	Pc, Pn, Pa, Pp
14	Kapchuk R.	130 km E	1992	Pc, Pn, Pa, Pp
15	Bucherama R.	140 km E	1992	Pc, Pe, Pl, Pn, Pa, Pd, Pp
16	Bunisyak R.	150 km E	1992	Pc, Pe, Pl, Pn, Pa, Pp

TABLE 1. Study sites and studied species.

Numbers refer to the collecting sites shown in Fig. 1. Distances and directions from the Norilsk point source. Pc = *P. cruda*; Pe = *P. elongata*; Pl = *P. longicollis*; Pn = *P. nutans*; Pa = *P. andrewsii*; Pd = *P. drummondii*; Pf = *P. filum*; Pp = *P. proligera*.

	Locality								
Species	1	2	3	4	5	6	7	8	9
P. nutans	+	+	+	St	St-Md	Md	Sl	+	+
P. elongata	-	-	-	-	-	-	-	+	+

TABLE 2. Different degrees of peristome deformity of *Pohlia nutans* and *P. elongata* in relation to the distance from the Norilsk metallurgical complex according to the direction of prevailing winds from north-west. Locality numbers refer to the collecting sites shown in Fig. 1 and Tab. 1. St = strong; Md = moderate; Sl = Slight; + = specimen without damage on sporophytes; - = no collections.

Species	Locality 10	11	12	13	14	15	16
P. nutans	+	+	+	St	St-Md	Md	Sl
P. elongata	-	-	-	-	-	St	St-Md

TABLE 3. Different degrees of peristome deformity of *Pohlia nutans* and *P. elongata* in relation to the distance from the Norilsk metallurgical complex along a topographic gradient (up Lake Lama). Locality numbers refer to the collecting sites shown in Fig. 1 and Tab. 1. St = strong; Md = moderate; Sl = slight: + = specimen without damage on sporophytes; - = no collections.

	Species	Locality 1	2	3	4	5	6	7	8	9
a)	*P. cruda*	-	-	-	-	Sg	M	Sg	M	Sg
	P. elongata	-	-	-	-	-	-	-	M	M
	P. longicollis	-	-	-	-	-	-	-	-	M
	P. nutans	N	N	N	Sg	M	M	M	M	M
b)	*P. andrewsii*	-	-	-	-	M	M	M	Sc	Sc
	P. drummondii	-	-	-	-	-	-	Sc	-	Sc
	P. filum	-	-	-	-	-	Sc	-	-	-
	P. proligera	N	N	N	N	N	M	M	M	Sc

TABLE 4. Abundance of sporophytes and asexual propagules of *Pohlia* species in relation to the distance from the Norilsk metallurgical complex. Locality numbers refer to the collecting sites shown in Fig. 1 and Tab. 1. a) Sporophytes: N = numerous; M = moderate; Sg = single. b) Asexual propagules: N = numerous; M = moderate; Sc = scattered; - = no collections.

	Species	Locality 10	11	12	13	14	15	16
a)	*P. cruda*	0	0	0	Sg	M	M	N
	P. elongata	-	-	-	-	-	Sg	Sg
	P. longicollis	-	-	-	-	-	Sg	-
	P. nutans	N	N	M	M	M	M	M
b)	*P. andrewsii*	-	Sc	M	N	N	M	M
	P. drummondii	-	Sc	-	-	-	Sc	-
	P. filum	-	-	Sc	-	-	-	-
	P. proligera	N	N	N	N	N	M	M

TABLE 5. Abundance of sporophytes and asexual propagules of *Pohlia* species in relation to the distance from the Norilsk metallurgical complex. Locality numbers refer to the collecting sites shown in Fig. 1 and Tab. 1. a) Sporophytes: N = numerous; M = moderate; Sg = single; 0 = without sporophytes. b) Asexual propagules: N = numerous; M = moderate; Sc = scattered; - = no collections.

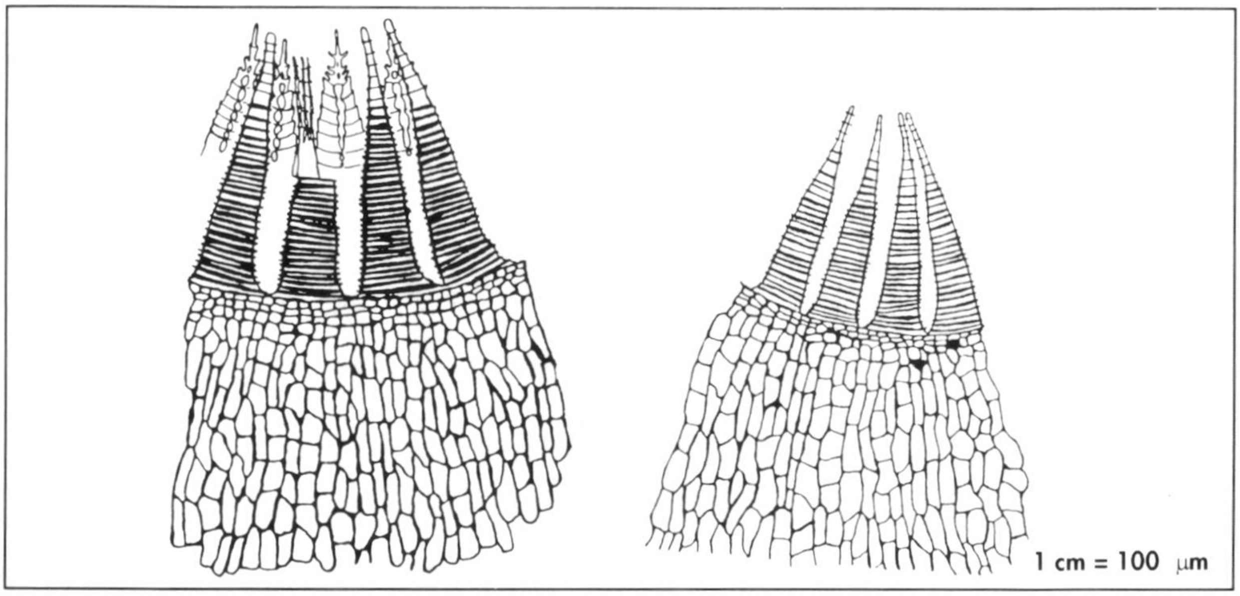

FIGURE 2. *Pohlia nutans*. Normally developed peristome (parts, at right endostome removed).

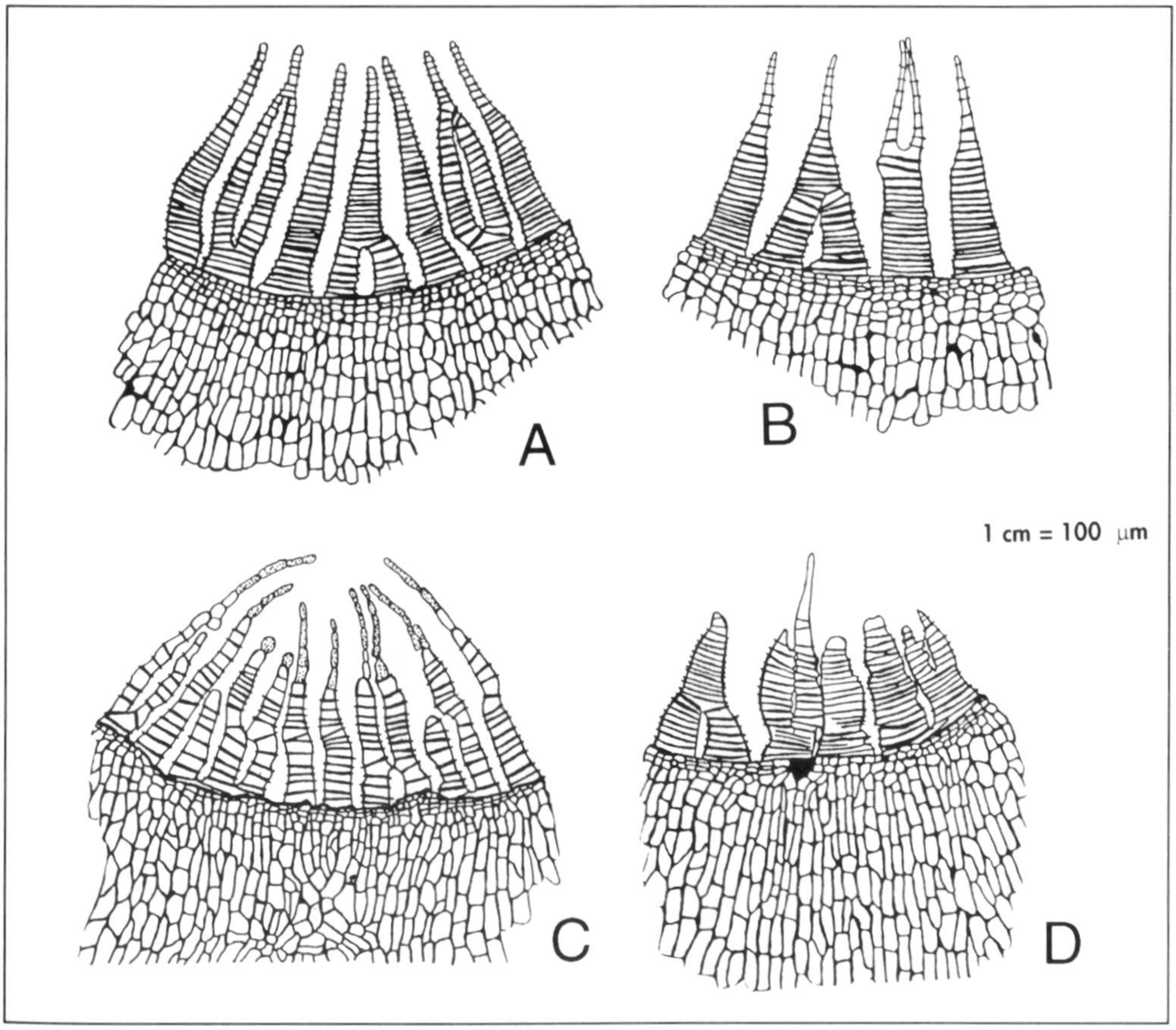

FIGURE 3. *Pohlia nutans*. Examples of peristomes with exostome teeth deformity (parts, endostome removed). A, B - slightly deformed teeth, C - moderately deformed teeth, D - strongly deformed teeth.

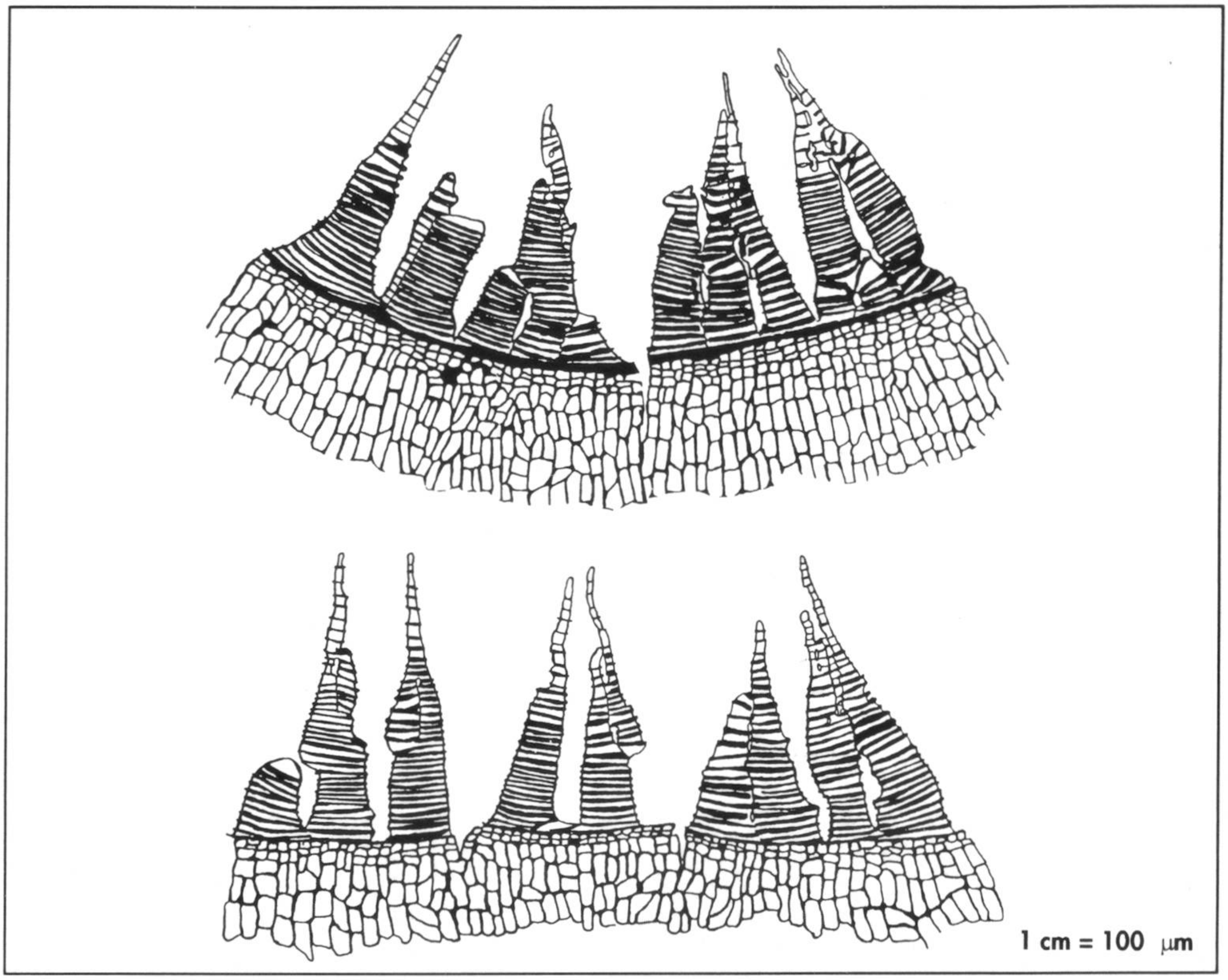

FIGURE 4. *Pohlia nutans.* Peristome with strongly deformed exostome teeth. The two halves of one peristome are shown (endostome removed).

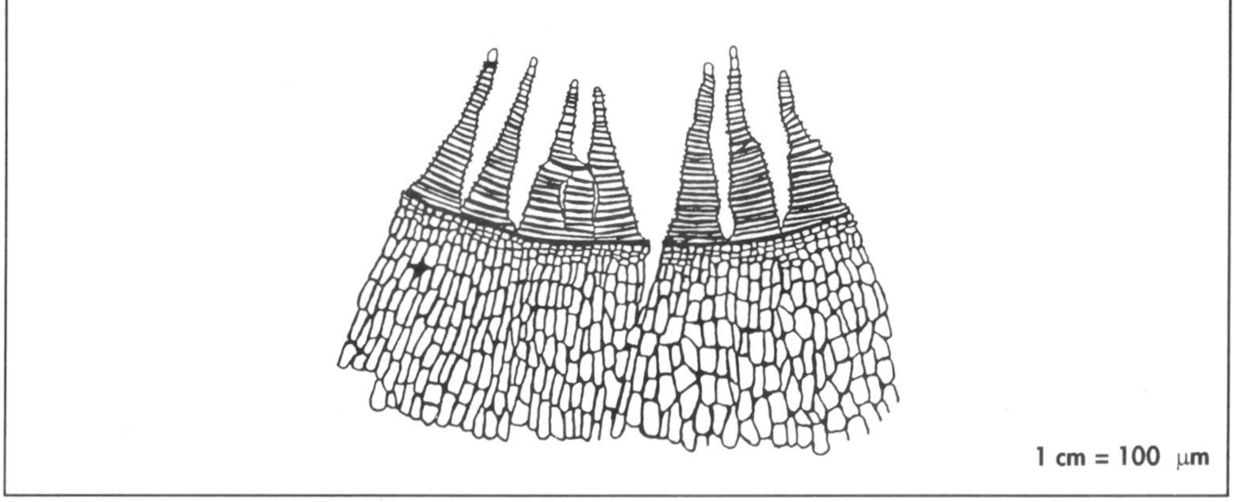

FIGURE 5. *Pohlia elongata.* Example of a moderate deformity of the exostome teeth.

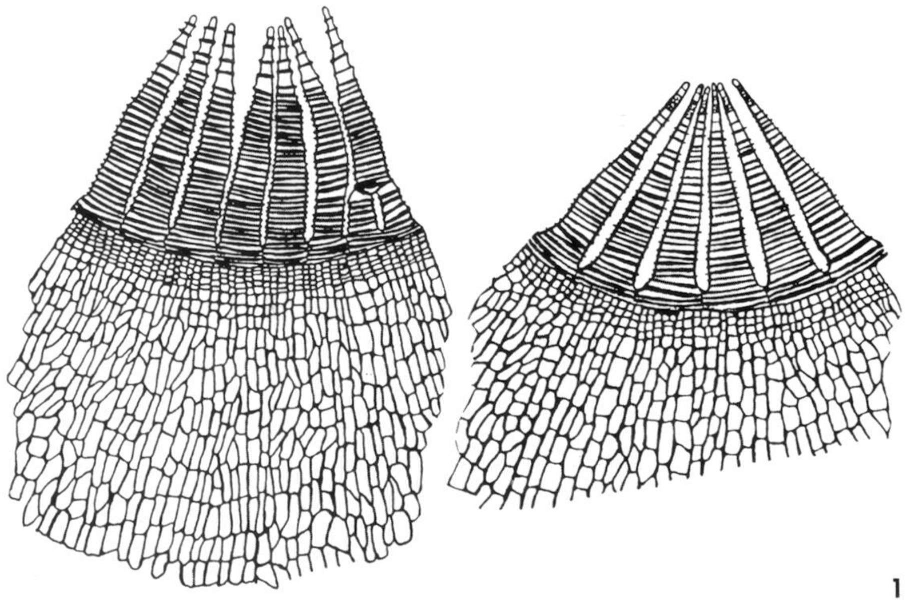

FIGURE 6. *Pohlia elongata.* Two examples of exostomes (parts) with teeth not separated at the base.

The relation between the degree of peristome deformity and the distance from the Norilsk point source is presented in Tabs 2 and 3. No damage of sporophytes was observed at the sites closest to the metallurgical industry (1-3 and 10-12). Further away, however, the severity of peristome derformations shows a decreasing tendency both along the investigated sites in the direction of the prevailing northwestern winds (4-9) and along those in the major river valleys (13-16). Sporophyte abundance of *P. cruda* increases along the site sequence 10 to 16, parallelling the distance from the pollution source. In *Pohlia nutans* it tends to decrease with increasing distance, at least in eastern direction, as well as the number of asexual propagules in *P. proligera* in both directions and to some extent in *P. andrewsii* (Tabs 4 and 5). At sites 1-3 close to the metallurgical complex, however, *P. nutans* sporulates abundantly and *P. proligera* produces a large number of propagules. Gametophytes of *P. nutans* lack any vegetative propagules.

Discussion

As no direct measurements of pollutant loadings are available, the morphological deviations cannot directly be correlated with the level of pollutant exposure. However, there is evidence from the relevant literature (e.g., Roberts & al. 1979) that the greatest impact from a single source of pollution occurs near that source. The severity of effects usually declines with increasing distance from the source.

No statistical analysis was performed with the present data. Therefore, the present study is basically a description of a phenomenon, namely morphological changes of widespread moss species with respect to pollution which is hardly reported on in the literature so far.

It is interesting to notice that sporophytes of P. *nutans* lack morphological deviations at sites 1-3 within a radius of 10-25 km around Norilsk (Fig. 1, Tab. 2). In a previous report (Otnyukova 1994), it was concluded from these observations that *Pohlia nutans* never changes sporophyte morphology in any condition of pollution. However, the absence of morphological sporophyte deformity of *P. nutans* may be explained by the composition of polluted compounds deposited here. It is well known from the literature that heavy metal deposition prevails at sites closest to the pollution sources (e.g., Lyanguzova 1990). The secondary pollutants such as sulphates are deposited at some distance as a result of long range transport of air pollution (e.g., Stolte & al. 1993). Sulphur compounds are more harmful for bryophytes (Nash & Nash 1974; Rao 1982).

The occurence of only two *Pohlia* taxa, namely *P. nutans* and *P. proligera*, 50 km south-east of Norilsk (Fig 1 site 4) is presumably caused by the heavy pollution by sulphates. The observed peristome abnormalities, however, do not appear to have a negative effect regarding spreading and flourishing of *P. nutans* here. It bears fragile leading buds on sterile shoots for vegetative reproduction. The other species, *P. proligera*, is also flourishing here.

P. nutans and *P. elongata* exhibit moderate and strong exostome deformity (Figs 5 and 6) at different distances from the pollution source (Tabs 2 and 3). Of both species, samples with different degrees of gametophyte and sporophyte deterioration were collected, *P. nutans* at sites 4-7 and 13-16, and *P. elongata* at sites 15-16 (Fig. 1).

The alterations of morphological features in the investigated *Pohlia* species seem to be in accordance with Zubareva's (1993) territory zonation based on the content of sulphur compounds in vascular plants: relatively clean area (Fig. 1, sites 8 and 9), slightly polluted (sites 7 and 13-16), moderately polluted (sites 5-6 and 11-12), and severely polluted areas (sites 1-4 and 10).

It is interesting to notice that peristome alterations such as exostome deformity and exostome teeth anastomosing (knitting) at the base have been found in appearingly healthy and well developed capsules. It is assumed that peristome deformity prevent spore dispersal. Capsules with abnormal exostomes contain two kinds of spores: a majority of healthy spores, but also underdeveloped, flattened and shrunken spores. In the case of strong exostome deformity many spores germinate within the capsules. Therefore, the peristome deformity observed may serve as the earliest sign of sporophyte damage that in the end may result in the disappearance of some *Pohlia* species.

Other investigated species such as *P. cruda* and *P. longicollis* lack visible morphological changes. However, *P. cruda* produces as many sporophytes as *P. nutans* only 100 or more km away from Norilsk (sites 6 and 14, Tabs 4 and 5). Among the propaguliferous species, *P. proligera* produces propagules in larger amounts than *P. andrewsii* at sites closest to the metallurgic complex (Tabs 4 and 5). Under slight and moderate degree of pollution *P. andrewsii* produces as many propagules as *P. proligera* (sites 5-7 and 11-16, Tabs 4 and 5). Only at relatively clean sites more than 190 km away from the pollution source *P. andrewsii* produces propagules in small amounts as it does usually in normal environmental conditions (sites 8-9, Tabs 4 and 5). The high production of sporophytes in *P. nutans*, or propagules, respectively in *P. proligera*, close to the pollution source is possibly an effect of stress due to the heavy pollution, as enhanced fertility has been interpreted as a reaction to environmental stress in many plant species.

Concluding, I suggest that behavior and response of tolerant *Pohlia* species (e.g., *P. nutans* and *P. cruda*) to increasing pollutant loadings may be used as examples to outline the problem of decline and disappearance of mosses in affected areas. Peristome deformity, probably caused by pollution, possibly hinder an effective spore dispersal. Species with the possibility of vegetative reproduction, such as *P. nutans* and propaguliferous species, seem to be less affected. They seem to be able to produce large quantities of asexual propagules and buds also in polluted areas. An increase in pollutant loadings, however, may lead to gametophyte deterioration of propaguliferous species and ultimately to their elimination. The disappearance of *P. cruda* gametophytes close to Norilsk may serve as an example. The same probably happens with usually sexually reproducing species, such as *P. longicollis* and *P. elongata*, after suppression of sporophytes.

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