The use of lichens to monitor terrestrial pollution and ecological impacts caused by oil and gas industries in the Pechora Basin, NW Russia

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Air pollution was assessed by investigating the chemistry of lichens in the Pechora Basin, NW Russia. Differences were sought between industrial and background sites in lichen biodiversity to yield information on air pollution impacts. Only limited modifications in the chemistry and biodiversity of lichens were found close to a large oil and gas complex, near the Kolva River, suggesting signs of an early indicator of industrial activity. All other sites remained unmodified and reflected background concentrations, with low ecological impacts of the measured pollution loads.

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Die Luftverunreinigung im Pechora Becken, nordwestliches Russland, wurde durch eine Untersuchung der chemischen Zusammensetzung von Flechten abgeschätzt. Es wurden Unterschiede in der Flechtendiversität zwischen industrienahen und industriefernen Standorten gesucht, um Informationen über die Auswirkungen der Luftverunreinigungen zu erhalten. Nur in der Nähe eines großen Öl- und Gaskomplexes nahe dem Fluss Kolva wurden beschränkte Veränderungen der chemischen Zusammensetzung und der Biodiversität der Flechten festgestellt, die als frühe Zeiger industrieller Aktivität gelten können. Alle anderen industrienahen Standorte blieben unverändert und zeigen dieselben Konzentrationen wie an den industriefernen mit geringen ökologischen Auswirkungen durch die gemessene Schadstoffbelastung.

Key words: Komi Republic, lichen biodiversity, lichen chemistry, soil chemistry, petrochemical industries.

Introduction

The Russian Arctic, a vast sparsely populated wilderness, is generally regarded as a fragile environment (ROVINSKY et al. 1995). Despite its daunting size, some regions are beginning to display signs of degradation (VIRTANEN et al. 2002, WALKER et al. 2003a, 2003b), such as reduced plant diversity and increased heavy metal contamination of soil, rivers and precipitation, as a consequence of resource-exploitation, e.g. the mining and metallurgical industries in the Kola Peninsula (REIMANN et al. 1999). Historically, exploitation of coal has been a major element of industrial activity in the Russian Arctic (REVICH 1995), but more recently, gas and oil recovery has shown signs of expansion (LOCATELLI 1999), e.g. the oil and gas exploration of the Timan-Pechora province (LAUSALA & VALKONEN 1999). According to PELLEY (2001) the Timan-Pechora province is the third most important oil-producing region in Russia and is reputed to contain some of the World's richest deposits. Recently, the oil and gas industries have boomed and are expected to expand, bringing about significant risks of environmental pollution, e.g. from gas flaring and oil spills (VILCHECK & TISHKOV 1997). However, it should be emphasised that vast areas of the Russian Arctic appear close to pristine (ROVINSKY et al. 1995). Due to their susceptibility to SO_2 and other phytotoxic air pollutants, epiphytic lichens have been used for decades to monitor air pollution (HAWKSWORTH & ROSE 1970).

The objective of this study was to see whether pollution impacts are already detectable and to seek evidence of environmental impacts in the vicinity of oil and gas industries in the Pechora region. This data provides a baseline against which the extent of pollution in the future can be gauged. This was achieved by quantifying the chemical status of terricolous mat-forming lichens and and by measuring alpha (α) biodiversity of epigeal lichens (in sample plots in the tundra) and epiphytic lichens (on trunks of *Picea obovata*) in close proximity to both potential pollution 'hot spots' and unpolluted 'reference' sites with comparable communities.

Methods

Problems exist when monitoring pollution deposition in remote regions as air and precipitation chemistries show high temporal and spatial variation. In such cases, approaches include: (i) analysis of ecological materials that accumulate contaminants (see REIMANN et al. 1999) and (ii) use of bio-indicators, the distribution of which become modified by exposure to pollution. These ecological assessments were undertaken at eight sampling sites. Details of industrial developments and pristine sites are given in Table 1. Sampling sites were chosen to quantify environmental impacts in close proximity to industrial installations and in unpolluted reference sites of broadly comparable community structure. Across the Pechora Basin, 'industrial' sites (e.g. $F1_i$) and unpolluted 'reference' sites (e.g. $F2_r$), comprised of the following: Ukhta area ($F1_i$), Belaya Kedva river ($F2_r$), Ortina river ($F3_i$), Neruta river ($F4_r$), Svetly Vuktyl ($F5_i$), Maly Patok ($F6_r$), Upper Kolva ($F7_i$) and Moreyu river ($F8_r$). There are a variety of human impacts in the region with relatively uninhabited 'pristine' areas and a few densely populated regions. Field-work was carried out during spring across two seasons.

Lichen abundance and species diversity was determined on epigeals in the tundra and epiphytes in the taiga. Nine mature spruce trees (*Picea obovata*) were selected ≥ 100 m apart from each other at each forested study site. An estimate of abundance and cover of each lichen species was made on trunks and branches, up to a height of 1.7 m, using the scale of KAUPPI & HALONEN (1992): 7 = >50 %, 6 = 26–50 %, 5 = 11–25 %, 4 = 3–10 %, 3 = poor cover, <3 %, 2 = little, many specimens, but not constituting any real cover, 1 = extremely little, only one or two specimens per trunk. Lichens were identified using (DOBSON 1979, MOBERG & HOLMÅSEN 1982, GOWARD et al. 1994, GILBERT 2000) and all the species are recorded in the provisional list of lichens for the Komi Republic by HERMANSSON et al. 1998.

Unidentified specimens were collected and returned to the Institute of Biology, Komi Science Centre, Syktyvkar for detailed examination and identifications made by Tatyana N. Pystina and Olga Lavrinenko. In the tundra 5 quadrats (2 m^2), separated by >100 m, were randomly chosen in lichen rich sub-sites which were dominated by dwarf birch (*Betula nana* L.) at each of the study sites. The number and percentage cover of epiphytic and epigeal lichen species were again recorded on Kauppi & Halonen's 1–7 point scale.

At least one species of terricolous mat-forming lichen of the genera *Cladonia* (*C. stellaris* or *C. arbuscula*) or *Flavocetraria* (*F. cucullata*) was collected, subject to availability to provide biological material for chemical analysis. At each site three sub-sites were selected, >500 m apart, at which 6 replicate samples of lichen material was collected at distances >10 m apart. Details of sampling and analysis for lichen chemistry are given in WALKER et al. (2003a, 2003b, 2005). Elements measured in lichens were: total N; major cations: Mg^{2+}, Ca^{2+} and K^{+}; and Pb, undertaken using atomic absorption spectrophotometry (GF-AAS and F-AAS).

Statistical analysis: Unless otherwise indicated, significant differences between sites were determined by one-way-ANOVA followed by Tukey's test (n = 18).

Results and Discussion

The objectives of the study were to produce a benchmark survey of chemical contamination in the Pechora region, against which effects of future developments can be assessed. A small pollution signature was detected at the Upper Kolva River site ($F7_i$), where oil and gas operations produces gas flares. Here, a suite of minor shifts in environmental chemistry and lichen abundance (which are in broad agreement) were recorded. The abundance and diversity of lichens differed significantly between sites (Fig. 1). Among the tundra sites, $F7_i$ had a markedly lower abundance and diversity of epigeals and lower abundance of epiphytes. Complete listings of epigeal lichen species and epiphytic lichen species are given in Tables 2 and 3. The effect of reindeer grazing and trampling were marked to severe at $F3_i$, $F4_r$ and $F8_r$. Complete listings of epiphytic lichen species assessed on the trunks and branches of *P. obovata* are given in Table 4. The first record of *Ramalina obtusata* in the Komi Republic was made at the Izhma River, ($F1_i$) (WALKER & PYSTINA 2005). A voucher specimen of *R. obtusata* has

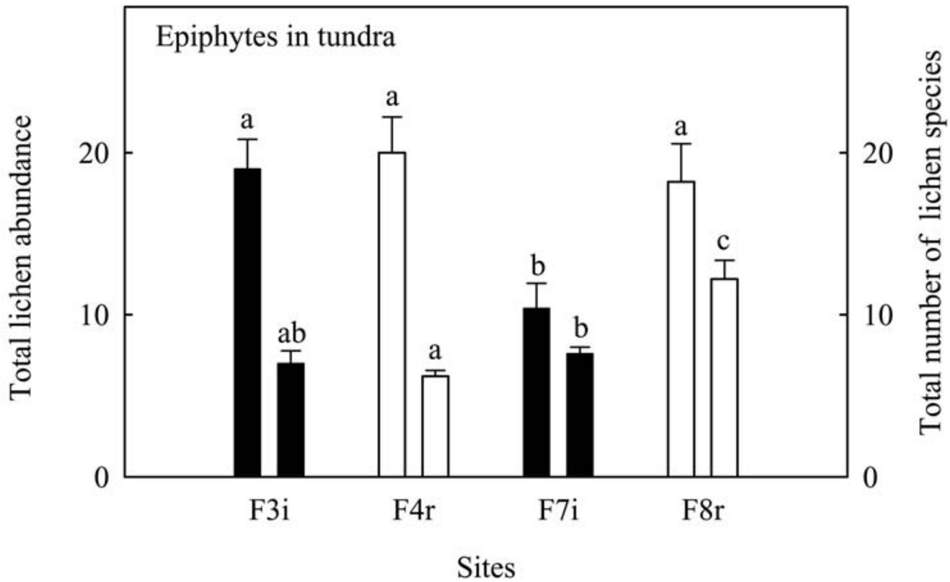

Fig. 1: Mean values of total abundance (left hand column) and total number of epiphytic lichen species (right hand column) at each tundra site. Filled and open columns indicate 'industrial' and 'reference' sites respectively. Plotted values are means ± SE (n = 5). Significant differences were determined by one-way-ANOVA followed by Tukey's test; within each measured attribute sites with the same letters were not significantly different and sites with different letters were significantly different at the $P < 0.05$ level. Modified from WALKER et al. (2005).

been deposited in the herbarium at the Institute of Biology - Komi Science Centre, Syktyvkar. Identification was made in the field by Tatyana N. Pystina and was verified in Syktyvkar by Olga Lavrinenko. Mean abundance of epigeal (Fig. 2a) and epiphytic (Fig. 2b) species at $F7_i$ and $F8_r$ were compared for the purpose of highlighting species with markedly different abundance values. *Alectoria nigricans*, *A. ochroleuca*, *Bryocaulon divergens* and *Sphaerophorus globosus* were common at $F8_r$ but were poorly represented at $F7_i$. With the exception of *A. ochroleuca*, these species were also well represented at $F4_r$, although this site was not chosen as a comparable 'reference' site for $F7_i$. *Cetraria nigricans* and *Ochrolechia frigida* were common at $F8_r$ but were poorly represented at $F7_i$ and *O. frigida* was also common at $F4_r$. There was no evidence of deleterious industrial impacts on epiphytic lichens at taiga sites while values of lichen abundance and α-diversity were lower at industrial tundra sites, most notably at $F7_i$. However, interpretation of these data must take into consideration the potential confounding effects of other man-made disturbances such as forestry around the industrial sites producing younger, more open forests and reindeer husbandry. Since little data exist on the pollution sensitivity of epigeal lichens, and the tundra sites were subject to heavy reindeer grazing, greater emphasis was placed on data for epiphytic species for which more information exists on pollution sensitivity. The abundance and α-diversity of lichens varied significantly between sites. Among taiga sites differences were small, with 'reference' sites having the lower values. Site $F7_i$, appeared to be less disturbed by reindeer. This might be because roads and pipelines restrict the movement of reindeer herds, or because reindeer herdsmen avoid industrial sites where the occurrence of discarded debris on the tundra can injure animals. The epigeal lichens here formed much deeper mats, and hence greater biomass but comprised fewer species. By contrast, sites $F3_i$, $F4_r$ and $F8_r$ had more epigeal species, and hence greater diversity, but low biomass due to heavy grazing and trampling by reindeer. Epigeal lichen species which were present at $F8_r$ and $F4_r$, but were absent or poorly represented at $F7_i$, included species that are known to be pollution-sensitive according to Gilbert (2000) viz. *Alectoria nigricans*, *Bryocaulon divergens* and *Sphaerophorus globosus.*

An additional objective of this study was to seek changes in lichen chemistry at 'industrial' sites that might be caused by air pollution. Lichens in the genera *Cladonia* (*Cladonia arbuscula* or *C. stellaris)* or *Flavocetraria* (*F. cucullata*) were widespread and locally abundant in the Pechora Basin. Cover was generally poor in the tundra due to grazing and trampling by reindeer, except for site $F7_i$. There was some variation in the concentrations and concentration ratios of cations in the apices of *C. arbuscula*, *C. stellaris* and *F. cucullata*. There were some marked and significant differences between comparable 'industrial' and 'reference' sites, e.g. site $F7_i$ compared to site $F8_r$ in both *C. arbuscula* and *F. cucullata*, and $F5_i$ compared to $F6_r$ in *C. arbuscula*. Lead was selected as an additional analyte because it was one of several trace metals found to contaminate snow and soils locally in the tundra around Vorkuta (Walker et al. 2003b). Walker et al. (2005) found that whilst absolute concentrations are low in all species there may be localised elevation of $[Pb]_{apices}$ in *C. arbuscula* and *F. cucullata* at $F7_i$ where concentrations were 3–4 times greater than at $F8_r$ and also found a strong relationship between $[Pb]_{apices}$ in *C. arbuscula* and concentrations of Pb in soil ash ($[Pb]_{soil\ ash}$). In the same study there was little evidence of elevated $[N]_{apices}$ in *C. arbuscula* at 'industrial' sites with the exception of $F7_i$ which had the highest values for the tundra sites and significantly greater than the value for $F8_r$. There were significant differences in $[N]_{apices}$ and $[N]_{base}$ in *F. cucullata* between 'industrial' and 'reference' sites. The ratio of $[N]_{apices}$: $[N]_{base}$ in *F. cucullata* was significantly higher at $F7_i$ than at the other tundra sites (Walker et al. 2005). Amongst tundra sites, values of $[N]_{apices}$ were greatest at $F7_i$ and the value of $[N]_{apices}$:$[N]_{base}$ in *F. cucullata* was significantly

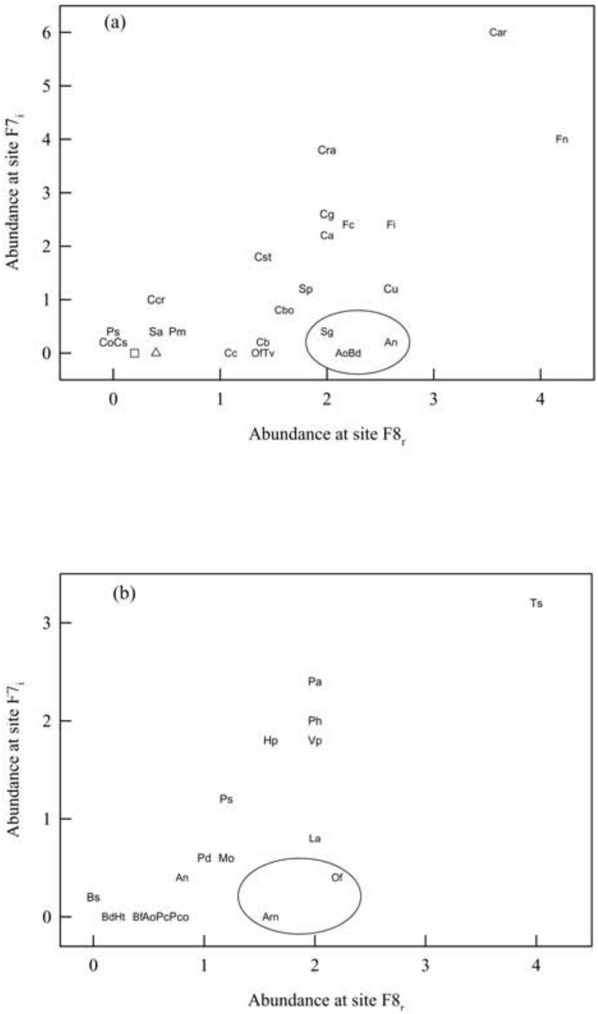

Fig. 2a: Comparisons of mean cover abundance of epigeal lichen species between sites $F7_i$ and $F8_r$. Species denoted as: (An), *Alectoria nigricans*; (Ao), *A. ochroleuca*; (Bd), *Bryocaulon divergens*; (Fn), *Flavocetraria nivalis*; (Fc), *F. cucullata*; (Fi), *Cetraria islandica*; (Ca), *Cladonia amaurocraea*; (Car), *C. arbuscula*; (Cb), *C. bellidiflora*; (Cbo), *C. borealis*; (Cc), *C. chlorophaea*; (Ccr), *C. crispata*; (Cg), *C. gracilis*; (Co), *C. coniocraea;* (Ccr), *C. cornuta*; (Cra), *C. rangiferina*; (Cst), *C. stellaris*; (Cs), *C. subfurcata*; (Cu), *C. uncialis*; (Ie), *Icmadophila ericetorum*; (Of), *Ochrolechia frigida*; (Pm), *Peltigera malacea*; (Ps), *P. scabrosa*; (Sg), *Sphaerophorus globosus*; (Sa), *Stereocaulon alpinum*; (Sp), *S. paschale*; (Tv), *Thamnolia vermicularis*; (□), *Cetraria nigricans*, *Cladonia cervicornis*, *Peltigera neckeri*, *Pertusaria coccodes*; (Δ), *Cladonia pleurota*, *C. sulphurina*, *Hypogymnia physodes*, *Pertusaria panygra*. Specimens, but not constituting any real cover, 1 = extremely little, only one or two specimens.

Fig. 2b: Comparisons of mean cover abundance of epiphytic lichen species between sites $F7_i$ and $F8_r$. Species denoted as: (An), *Alectoria nigricans*; (Ao), *A. ochroleuca*; (Arn), *Cetraria nigricans*; (Bd), *Bryocaulon divergens*; (Bf), *Bryoria fuscescens*; (Hp), *Hypogymnia physodes*; (Ht), *H. tubulosa*; (La), *Lecanora argentata*; (Mo), *Melanelia olivacea*; (Of), *Ochrolechia frigida*; (Ps), *Parmelia sulcata*; (Pa), *Parmeliopsis ambigua*; (Ph), *P. hyperopta*; (Pc), *Pertusaria corallina*; (Pco), *P. coccodes*; (Pd), *P. dactylina*; (Ts), *Cetraria sepincola*; (Vp), *Vulpicida pinastri*. Circled species denotes those present at site $F8_r$ but were absent or rare at site $F7_i$**.** Estimates were made using the abundance scale of KAUPPI & HALONEN (1992): 7 = >50 %, 6 = 26–50 %, 5 = 11–25 %, 4 = 3–10 %, 3 = poor cover, < 3 %, 2 = little, many specimens, but not constituting any real cover, 1 = extremely little, only one or two specimens.

Table 1: Summary of the main sampling sites within the Pechora region.

Site	Name of site	Co-ordinates	Type of industry and status
$F1_i$	Izhma river (near Suz'u river mouth), Ukhta area	63°44'10''N, 53°42'57''E,	Oil and gas recovery, forestry, fragmented lowland taiga
$F2_r$	Belaya Kedva river	64°19'27''N, 53°03'39''E,	Pristine lowland taiga
$F3_i$	Ortina river, Narjan-Mar area	67°55'59''N, 54°02'33''E,	Oil and gas recovery, tundra delta area
$F4_r$	Neruta river, Malozemelsk tundra	68°00'10''N, 52°24'16''E,	Reindeer herding, pristine tundra, partly protected, coastal
$F5_i$	Svetly Vuktyl river, Vuktyl area	63°47'42''N, 57°32'36''E,	Gas industry, fragmented lowland taiga
$F6_r$	Maly Patok river	64°18'54''N, 59°04'40''E,	Pristine taiga in Ural foothills, protected Yugyd Va national park
$F7_i$	Kolva river (near the Kharayaha river mouth)	67°08'22''N, 56°41'41''E,	Large oil industrial complex, tundra
$F8_r$	The Moreyu river (near the Syamayu river mouth)	67°52'51''N, 59°43'21''E,	Reindeer herding, pristine tundra, partly protected, coastal

Table 2: Epiphytic lichen species and their mean cover abundance recorded growing on *Betula nana* in five × 2 m^2 plots in the tundra.

Species	**Sites**			
Epiphytes	**$F3_i$**	**$F4_r$**	**$F7_i$**	**$F8_r$**
Alectoria nigricans *	-	-	0.4	0.8
A. ochroleuca *	-	-	-	0.6
Cetraria nigricans	0.2	-	-	1.6
C. sepincola	2.8	4.2	3.2	4.0
Bryocaulon divergens *	-	-	-	0.2
Bryoria fuscescens *	-	-	-	0.4
B. simplicior *	-	-	0.2	-
Hypogymnia physodes	3.2	1.6	1.8	1.6
H. tubulosa	-	-	-	0.2
Lecanora argentata	0.4	-	0.8	2.0
Melanelia olivacea	1.8	-	0.6	1.2
Ochrolechia frigida	3.0	4.0	0.4	2.2
Parmelia sulcata	-	-	1.2	1.2
Parmeliopsis hyperopta	3.4	3.6	2.4	2.0
Pertusaria corallina	2.6	3.6	2.0	2.0
P. coccodes	-	-	-	0.6
P. dactylina	0.6	1.0	0.6	1.0
Vulpicida pinastri	1.0	2.0	1.8	2.0
Sum of mean abundance	**19**	**20**	**10.4**	**18.2**
Mean number of species	**7**	**6.2**	**7.6**	**12.2**

* Species which are pollution sensitive according to HAWKSWORTH & ROSE (1970).

Table 3: Epigeal lichen species and their mean cover abundance recorded in five × 2 m^2 plots in the tundra.

Species	**Sites**			
Epigeal	**$F3_i$**	**$F4_r$**	**$F7_i$**	**$F8_r$**
Alectoria nigricans *	1.4	2.6	0.2	2.6
A. ochroleuca *	0.4	0.8	-	2.2
Bryocaulon divergens *	1.0	1.0	-	2.2
Flavocetraria nivalis	4.8	6.2	4.0	4.2
F. cucullata	1.8	3.4	2.4	2.2
Cetraria islandica	2.8	3.2	2.4	2.6
C. nigricans	0.4	-	-	0.2
Cladonia amaurocraea	0.8	1.0	2.2	2.0
C. arbuscula	4.6	5.2	6.0	3.6
C. bellidiflora	0.6	0.4	0.2	1.4
C. borealis	-	-	0.8	1.6
C. cervicornis	0.2	-	-	0.2
C. chlorophaea	-	0.4	-	1.2
C. coccifera	0.6	1.4	-	-
C. coniocraea	-	-	0.2	-
C. cornuta	-	0.4	0.2	-
C. crispata	0.4	1.0	1.0	0.4
C. gracilis	2.2	3.0	2.6	2.0
C. furcata	0.2	0.2	-	-
C. macrophylla	-	0.2	-	-
C. pleurota	0.4	-	-	0.4
C. rangiferina/stygia	2.8	4.0	3.8	2.0
C. stellaris	0.4	1.2	1.8	1.4
C. subfurcata	0.6	0.2	0.2	-
C. sulphurina	0.2	-	-	0.4
C. uncialis	2.0	3.6	1.2	2.6
Hypogymnia physodes	-	-	-	0.4
Icmadophila ericetorum	-	-	0.2	0.2
Nephroma arcticum *	-	1.6	-	-
Ochrolechia androgyna	0.2	-	-	-
O. frigida	1.0	0.4	-	1.4
Peltigera neckeri	-	-	-	0.2
P. malacea	-	-	0.4	0.6
P. scabrosa *	0.2	1.2	0.4	-
Pertusaria coccodes	-	-	-	0.2
P. panyrga	-	-	-	0.4
Sphaerophorus globosus	0.8	1.4	0.4	2.0
Stereocaulon alpinum *	0.2	1.2	0.4	0.4
S. paschale *	1.6	3.4	1.2	1.8
Thamnolia vermicularis	1.0	2.0	-	1.4
Sum of mean abundance	**33.6**	**50.6**	**32.2**	**44.4**
Mean number of species	**15.6**	**18.4**	**12**	**20.8**

* Species which are pollution sensitive according to GILBERT (2000).

Table 4: Epiphytic lichen species and their mean cover abundance recorded on between nine *Picea obovata* trunks and branches up to 1.7 m.

Species	Sites			
Epiphytes	**$F1_i$**	**$F2_r$**	**$F5_i$**	**$F6_r$**
Alectoria sarmentosa *	-	0.1	-	0.1
Bryoria capillaris *	3.6	2.4	3.7	2.0
B. furcellata *	1.0	-	0.8	0.6
B. fuscescens *	4.5	3.1	4.1	1.1
B. fremontii *	0.1	-	-	-
B. nadvornikiana *	0.3	0.4	1.4	0.7
B. simplicior *	-	0.3	-	-
Cetraria chlorophylla	1.8	1.7	2.1	2.0
C. sepincola	0.4	0.1	-	-
Evernia divaricata	-	-	-	1.3
E. mesomorpha	1.8	0.8	0.8	0.2
E. prunastri	0.3	-	-	-
Hypogymnia bitteri	0.5	0.4	0.3	0.7
H. physodes	4.5	4.9	4.0	4.1
H. tubulosa	2.0	2.4	1.9	3.4
Imshaugia aleurites	0.4	-	0.1	-
Melanelia exasperatula	0.5	0.1	0.7	-
M. olivacea	1.6	3.0	2.8	2.0
Parmelia sulcata	2.8	3.8	3.0	2.0
Parmeliopsis ambigua	1.0	0.7	1.0	2.4
P. hyperopta	1.0	0.3	0.9	2.4
Physcia aipolia	-	0.1	-	-
Plastimatia glauca	1.0	0.2	0.8	1.4
Ramalina dilacerata	1.4	2.7	1.8	0.1
R. obtusata †	0.1	-	-	-
R. roesleri	0.4	0.9	0.2	-
R. thrausta	0.8	0.2	0.8	-
Usnea filipendula *	3.0	2.2	4.2	1.7
U. glabrescens *	0.1	0.8	2.3	-
U. lapponica *	0.9	1.1	0.8	0.6
U. scabrata *	-	-	0.1	1.0
U. subfloridana *	2.0	2.6	3.7	0.9
Vulpicida pinastri	1.0	1.2	1.3	2.1
Sum of mean abundance	**38.5**	**36.7**	**43.6**	**32.9**
Mean number of species	**17.6**	**15.3**	**17.2**	**15.1**

† First record in the Komi Republic.
* Epiphytic species which are pollution sensitive according to Hawksworth & Rose (1970).

higher here than at other sites (Walker et al. 2005). Hyvärinen & Crittenden (1998), demonstrated a strong relationship between N deposition and [N] in the common heathland mat-forming lichen *C. portentosa*. Their study in the British Isles, revealed that [N] in the apical 5 mm of thalli ($[N]_{apices}$) and in a deeper stratum 35–50 mm from the apices ($[N]_{base}$) were both significantly positively correlated, and that the ratio $[N]_{apices}$:$[N]_{base}$ was negatively correlated, with N deposition. Since Hyvärinen & Crittenden (1998) found the concentration ratio

$[N]_{apices}$:$[N]_{base}$ to be negatively correlated with N deposition in *C. portentosa*, the higher value of the ratio at $F7_i$ is difficult to interpret; it may reflect a subtle physiological perturbation. There are no data for N deposition around $F7_i$, but gas flaring was observed at the industrial complex. Elevated values of $[N]_{apices}$ in *C. arbuscula*, and *F. cucullata*, at $F7_i$ might result from local NO_x emissions due to waste gas combustion at this site. Slightly elevated $[Pb]_{apices}$ values were recorded at $F7_i$, probably derived from local oil and gas industries (WALKER et al. 2005). It is noteworthy that GARTY et al. (1998) found elevated concentrations of Pb in *Ramalina lacera* at a site close to an oil combustion plant.

The mean pH values and concentrations of metal elements of top-soil in another study were all uniformly low (WALKER et al. 2005) and were comparable with values reported at pristine sites in the Usa Basin (RUSANOVA 1995) and on the Chukotka peninsula (ALEXEEVA-POPOVA et al. 1995). However, Ba, Ca and Ni in soils were significantly greater at $F7_i$ than at $F8_r$ and were highly positively correlated (WALKER et al. 2005), but, concentrations of Ba in soil ash close to Vorkuta were six times greater than at $F7_i$ (WALKER et al. 2003b). Chemical anomalies at $F7_i$ include high $[Pb]_{apices}$ and low soil pH. Elevated concentrations of in the vicinity of $F7_i$ were probably the result of fuel oil combustion and gas flaring, which occurs around the Kolva site, (VILCHECK & TISHKOV 1997). It is likely that lichens from $F7_i$, and those at other sites in this study, have not been significantly modified and remain close to pristine.

Conclusions

The major findings of the chemical analyses of terrestrial ecological materials collected in this study, provided evidence that large areas of the Pechora Basin remain in a condition close to ‘pristine’. Any contamination that was found was largely confined to local sites, whereas, at sites remote from towns there was little supporting evidence of pollution. The background values of measured variables in this study were broadly comparable with those reported by ROVINSKY et al. (1995) in the Ust-Lena reserve, considered an uncontaminated area of the Russian Arctic. From a chemical standpoint much of the Pechora region remains largely unmodified by pollution and reflects background conditions and concentrations, which further emphasises the need for environmental protection where future industrial exploitation is likely. An exception was the Upper Kolva site ($F7_i$), where a suite of minor shifts in environmental chemistry and lichen abundance might be an early indicator of industrial activity. The semi-pristine nature of much of the Pechora Basin, will mean that increased pollution loads should be readily detected with a high degree of sensitivity, due to favourable signal to noise ratios.

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