Working Papers of the Finnish Forest Research Institute 85

http://www.metla.fi/julkaisut/workingpapers/2008/mwp085.htm
ISBN 978-951-40-2110-7 (PDF)
ISBN 978-951-40-2111-4 (paperback)
ISSN 1795-150X

Current State of Terrestrial Ecosystems in the Joint Norwegian, Russian and Finnish Border Area in Northern Fennoscandia

Edited by John Derome, Tor Myking and Per Arild Aarrestad

METLA www.metla.fi

Working Papers of the Finnish Forest Research Institute publishes preliminary research results and conference proceedings.

The papers published in the series are not peer-reviewed.

http://www.metla.fi/julkaisut/workingpapers/
ISSN 1795-150X

Office
Unioninkatu 40 A
FI-00170 Helsinki
tel. +358 10 2111
fax +358 10 211 2101
e-mail julkaisutoimitus@metla.fi

Publisher
Finnish Forest Research Institute
Unioninkatu 40 A
FI-00170 Helsinki
tel. +358 10 2111
fax +358 10 211 2101
e-mail info@metla.fi
http://www.metla.fi/

Authors

Derome, John, Myking, Tor & Aarrestad, Per Arild

Title

Current State of Terrestrial Ecosystems in the Joint Norwegian, Russian and Finnish Border Area in Northern Fennoscandia

Year	Pages	ISBN	ISSN
2008	98	978-951-40-2110-7 (PDF) 978-951-40-2111-4 (paperback)	1795-150X

Unit / Research programme / Projects

Rovaniemi Research Unit / Research and monitoring of arctic terrestrial ecosystems, 340202, 7157

Accepted by

Pasi Puttonen, Director of Research, April 2008

Abstract

An international EU/Interreg III Kolarctic project "Development and implementation of an environmental monitoring and assessment program in the joint Finnish, Norwegian and Russian border area", was carried out during 2003 – 2006 as a joint undertaking between Norwegian, Finnish and Russian research institutes and environmental authorities. The aim of the terrestrial ecosystem sub-project of the Pasvik project was to develop and implement a monitoring and assessment programme for terrestrial ecosystems in the joint Finnish, Norwegian and Russian border area. The sub-project was carried out in six stages: 1) evaluation of the sufficiency of existing monitoring activities, 2) harmonization of the monitoring and assessment methods (sampling, measurement and observation, laboratory analyses, data analysis, evaluation and reporting) required for monitoring terrestrial ecosystems, 3) development of methods for assessing new parameters depicting terrestrial ecosystem condition and functioning in the region, 4) testing of the integrated monitoring programme, to be implemented by the environmental authorities and organizations of the three countries, during the period when emissions from the Pechenganikel smelter complex are expected to decrease as a result of renovation of the smelter, 5) assessment of the state of terrestrial ecosystems in the region, and 6) compilation of recommendations for a future joint monitoring programme. According to the results of the project, there are signs of a slight recovery in the condition of terrestrial ecosystems in the area around the emission source, e.g. the reappearance of pioneer species of bryophytes and lichens on a number of the Russian plots, and the marked recolonization of epiphytic lichens on the least polluted plots along the transect running to the west of the smelter. Satellite imagery indicates that there has been an increase in lichen coverage in the area from 1994 to 2004, which is related to the reduction in emissions during the past 10 years. Lichens are sensitive indicators of pollution, especially SO_2. Furthermore, there has been an increase in the vitality of birch and bilberry (measured as photosynthetic efficiency) along the transect running to the south of the smelter, as well as a smaller increase along the transect running to the north. In contrast, the accumulation of heavy metals (especially Ni) in mosses has increased during the past 15 years. The continuing emission of heavy metals is clearly reflected in the metal concentrations in mosses up to a distance of ca. 30 km from the smelters. The soil close to the smelter contains extremely high concentrations of a wide range of heavy metals, representing accumulation over the lifetime of the smelters. Elevated heavy metal concentrations also extend up to a distance of 30-40 km from the smelters. Although a relatively high proportion of the metals are in an immobilized form, the concentrations of plant-available metals are still excessively high. Accumulation of metals in the litter and organic layer is reflected in heavy metal concentrations in plants. such as grasses and dwarf shrubs, as well as in the needles and leaves of trees. The soil in the immediate vicinity of the smelter is not suffering from soil acidification, despite the continued relatively high level of SO_2 emissions, due to the abundant occurrence of basic types of bedrock in the area.

Keywords

Air pollution, Cu-Ni smelter, Terrestrial ecosystems, Fennoskandia, Arctic, Heavy metals

Available at

http://www.metla.fi/julkaisut/workingpapers/2008/mwp085.htm

Contact information

John Derome, Finnish Forest Research Institute, Rovaniemi Research Unit, P.O. Box 16, FI-96301 Rovaniemi, Finland. E-mail john.derome@metla.fi

Contents

Institutes:

[1] Finnish Forest Research Institute (Metla); Rovaniemi, Vantaa, Muhos and Parkano research units
[2] Norwegian Institute for Nature Research (NINA), Tromsö
[3] Norwegian Forest and Landscape Institute; Bergen and Ås units
[4] Institute of the Industrial Ecology of the North (INEP), Kola Science Centre, Apatity, Russia
[5] All-Russian Institute for Nature Conservation (VNIIpriroda), Moscow
[6] Svanhovd Environmental Centre, Norway
[7] Institute of Global Climate and Ecology, Moscow
[8] Northern Finland Office of the Finnish Geological Survey (GTK), Rovaniemi
[9] Finnish Meteorological Institute (FMI)

Preface

This report is the main scientific outcome of the work carried out on air quality and terrestrial ecosystems as a part of the international, EU-funded Interreg III Kolarctic project "Development and implementation of an environmental monitoring and assessment program in the joint Finnish, Norwegian and Russian border area" during the period 2003 - 2006. The aim of the report is to present information on the current state of the environment, and on changes that have taken place in recent years, in the border area of the three countries Norway, Finland and Russia. The technical report and recommendations concerning the development and implementation of a monitoring and assessment programme for air quality, water quality and aquatic ecosystems, and terrestrial ecosystems, have already been published in “State of the Environment in the Norwegian, Finnish and Russian Border Area”
(http://www.ymparisto.fi/download.asp?contentid=70351&lan=EN (air quality),
http://www.ymparisto.fi/download.asp?contentid=70353&lan=EN (aquatic),
http://www.ymparisto.fi/download.asp?contentid=70352&lan=EN (terrestrial)).
Approximately 30 researchers from 9 organizations in Russia, Norway and Finland participated in analysing the data and writing this scientific report. Without the support of numerous persons who were involved in the field work, laboratory analyses, and data analyses and related office work at the 9 organizations, the project and report would never have been completed on time. The editors wish to thank all the participants for their dedicated and skilful assistance and input throughout the many stages of the project.

1 Introduction

John Derome[1], Tor Myking[3], Per Arild Aarrestad[2]

From the late 1980's onwards, the effects of emissions from the Pechenganikel and the Zapolyarnij smelters on terrestrial ecosystems in the NW part of the Kola Peninsula and in adjoining parts of Norway and Finland have been monitored and studied in a number of national and international projects (e.g. Finnish Lapland Forest Damage Project, Skogforsk-NINA-VNIIPRIRODA-IGCE Project, NINA-NGU-INEP-METLA Project). The results of these projects have clearly shown that the terrestrial ecosystems in the immediate surroundings of the smelters are severely damaged or even completely destroyed, and that the ecosystems located at greater distances from the smelters are suffering from both visible and non-visible damage.

Trees, vascular plants, mosses and lichens are all affected. Visible injuries to vegetation caused by SO_2 are common, and symptoms are visible on a number of species, including Scots pine (*Pinus sylvestris*), downy birch (*Betula pubescens*), bilberry (*Vaccinium myrtillus*) and dwarf birch (*Betula nana*) (Aamlid 1993). In the immediate vicinity of the smelters the forests are dead or severely damaged (Vassilieva 1992, 1993). The coverage of epiphytic lichens has been drastically reduced (Aamlid and Skogheim 2001), and critical levels of heavy metals are exceeded over more than 3.200 km^2 of the border area (SFT 2002). The coverage of epigeic lichens (reindeer lichens, e.g. *Cladonia arbuscula* and *C. stellaris*) decreased significantly in the area during the period 1973-1999 (Tømmervik et al. 1998, 2003). The functioning of the more sensitive components of the ecosystems is thus seriously disturbed in many parts of the region (Tikkanen and Niemelä 1995, Reimann et al. 1998, SFT 2002). The photosynthetic efficiency of needles/leaves of Scots pine (*Pinus sylvestris*) and birch (*Betula pubescens*) has also decreased along the Russian-Norwegian border due to the effects of air pollutants (Odasz-Albrigtsen et al. 2000). Non-visible symptoms of damage to the cellular tissue in Scots pine needles have been recorded at distances of over 100 km to the west of the smelter (Tikkanen and Niemelä 1995). The vegetation and soil layers are contaminated with heavy metals, and there are clear signs of decreased soil fertility and increased soil acidity probably also affecting the species composition of the ground vegetation (Lukina and Nikonov 1997, Derome et al. 1998, Aamlid et al. 2000, Steinnes et al. 2000). Long-term monitoring of lakes and rivers has also revealed substantial surface water acidification (Traaen et al. 1991). The accumulation of heavy metals has also been reported in small vertebrates, particularly in the vicinity of the smelters (Kålås et al. 1993, Henttonen et al. 2002). Accumulation occurred in the liver of small mammals, particularly in species of the second trophic level e.g. the common shrew (*Sorex araneus*), which feeds on invertebrates living in the soil.

The Nordic Investment Bank and the Norwegian government are supporting the modernisation of the smelter in Nikel. The goal is to reduce the emissions by 90%, and thereby decrease the pollution impact in the region. The sub-project is a synthesis of elements of several previous cross-border projects in the region with the aim of collecting reference data on the state of the terrestrial ecosystem before the modernisation of the smelter. This is of crucial importance for monitoring the future recovery of the environmental condition after emissions have been reduced.

The aim of this part (terrestrial ecosystem sub-project) of the project was to develop and implement a monitoring and assessment programme for terrestrial ecosystems in the joint Finnish, Norwegian and Russian border area. The sub-project was carried out in six stages:

1. Evaluation of the sufficiency of existing monitoring activities.
2. Harmonization of the monitoring and assessment methods (sampling, measurement and observation, laboratory analyses, data analysis, evaluation and reporting) required for monitoring terrestrial ecosystems.
3. Development of methods for assessing new parameters depicting terrestrial ecosystem condition and functioning in the region.
4. Testing of the integrated monitoring programme, to be implemented by the environmental authorities and organizations of the three countries, during the period when emissions from the Pechenganikel smelter complex are expected to decrease as a result of renovation of the smelter.
5. Assessment of the state of terrestrial ecosystems in the region.
6. Compilation of recommendations for a future joint monitoring programme.

2 Establishment of an environmental monitoring network in the joint Finnish, Norwegian and Russian border area, and evaluation of the sufficiency of existing monitoring activities

Per Arild Aarrestad[2]

Background and aims

The primary objectives are to integrate and harmonise the monitoring activities that have already been carried out by Norway, Russia and Finland on the effects of emissions from the Pechenganikel smelter on terrestrial ecosystems in the border area, and to identify relatively sensitive and cost effective parameters for future monitoring activities in the area. In order to fulfil these objectives a terrestrial ecosystem monitoring network (ECM) has been established in Norway, Russia and Finland based on existing monitoring networks. Dormant intensive monitoring plots have been activated, and the measurements and assessments required to up-date the baseline information were carried out in 2004 and 2005.

Establishment of the ecosystem monitoring network (ECM)

The new ecosystem monitoring network (ECM) consists of selected plots from three earlier established forest monitoring networks

7. The Finnish Lapland Forest Damage Project monitoring network, established in 1990-1995
8. The Skogforsk-NINA-VNIIPRIRODA-IGCE monitoring network with eight plots along a transect from the Nikel smelter towards Norway, established in 1994-1998 (Aamlid et al. 2000)
9. The NINA-NGU-INEP-METLA monitoring network with 31 plots along a north-south and a west-east transect running through the Nikel area, established in 2000-2001 (Yoccoz et al. 2001)

In addition to the above plots, studies on bird and small mammals have been carried out along transects running westwards from the River Pas, and these transects were incorporated in the new ecosystem monitoring network. The bird transect had been sampled in 2000, and two different transects for micro-mammalia (rodents *Microtidae* and shrew *Soricidae*) sampled during the period 1985 - 2004. These projects were carried out by the Svanhovd Environmental Centre and Pasvik Zapovednik.

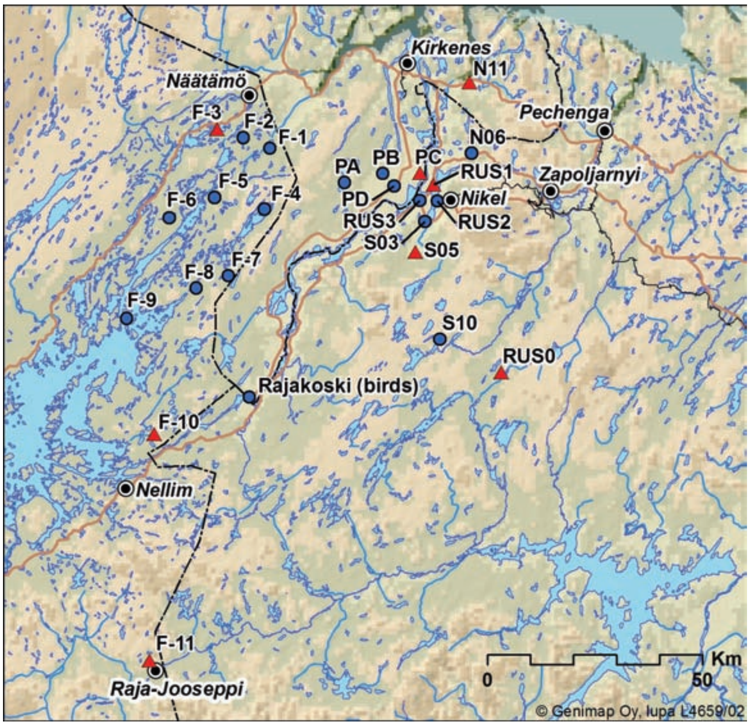
The existing monitoring network included activities on a wide range of terrestrial parameters covering tree crown condition, tree (stand) growth, species composition of ground vegetation, epiphytic lichens on birch and pine stems, plant vitality measured on the basis of photosynthetic efficiency, chemical analyses of mosses, lichens and vascular plants, species composition of hole-nesting passerines (birds) and small mammals (rodents and shrew), chemical properties of the organic and uppermost mineral soil layers, and the chemical composition of bulk deposition and stand throughfall. These networks had a different plot and sampling design (see Section 4.5.1), primarily because they were originally designed to monitor some different components of forest ecosystems. As the distribution of the plots overlapped to some extent, it was considered unnecessary to include all the established plots in the new network.

The new ecosystem monitoring network was established in forested areas (pine and birch forests), and tested in 2004 and 2005 with a total of 23 plots: 10 in Russia, 5 in Norway and 11 in Finland (Fig. 1). The plots represent a north-south and an east-west gradient related to the emission point sources at the Nikel and the Zapolyarnij smelters, and includes both heavily affected areas and undisturbed reference plots. However, the selection of number of plots, as well as the parameters to be measured on the plots, was also based on a cost-benefit evaluation.

Plots PA, PB, PC and PD (in Norway) and RUS0, RUS1 and RUS3 (in Russia) were selected from the Skogforsk-NINA-VNIIPRIRODA-IGCE network. Plots S03, S05, S10, N06 (in Russia) and N11 (in Norway) were selected from the NINA-NGU-INEP-METLA network. Plots F-1 – F-11 were selected from the Finnish Lapland Forest Damage Project. An additional plot was established for bird studies close to Rajakoski in Russia (80 km SSW of Nikel) in order to compare species composition and nesting dates.

We selected, on the basis of the results obtained earlier with the different networks, a list of parameters (Table 1) that should be measured on the new ecosystem monitoring network. Bulk deposition and stand throughfall were to be monitored continually over a period of one year (total of 8 plots; 3 in Russia, 2 in Norway, 3 in Finland). Assessment of tree condition and growth, ground vegetation, epiphytic lichens, metal concentrations in certain plants and the litter and organic layers were carried out on all the plots during one summer, while studies on photosynthetic efficiency, birds and mammals were carried out on a limited number of plots.

Five sites were selected as a minimum number of plots for monitoring bulk deposition and stand throughfall in order to obtain reliable information about the deposition of pollutants within the monitoring area. The plots were located on transects running to the north, south and west of the Nikel smelter (Fig. 1). Two additional plots in Finland were selected as background sites (F-10 and F-11).



© Genimap Oy, lupa L4659/02

Figure 1. Location of the Ecosystem Monitoring Network (ECM) plots in Russia, Finland and Norway monitored during 2004-2005. = Deposition monitoring plot.

Table 1. The plots selected for testing the terrestrial ecosystem monitoring network in Russia, Norway and Finland and the parameters monitored on the plots during 2004-2005. The assessment of birds and small mammals (*) was carried out in the vicinity of the plots.

Country	Plot	Wet dep.	Crown cond.	Stand growth	Ground veg.	Epiphytic lichens	Photo-synth.	Plant chem..	Birds	Small mamm.	Soil
Russia	RUS0	X	X	X	X	X		X			X
	RUS1	X	X	X	X	X		X			X
	RUS2		X	X	X	X		X	X		X
	RUS3								X		X
	S03		X		X	X	X	X			X
	S05	X	X		X	X	X	X			X
	S10		X		X	X	X	X			X
	N6		X		X	X	X	X			X
	Raja-koski								X		
Norway	N11	X	X		X	X	X	X			X
	PA		X	X	X	X		X	X*		X
	PB	X	X	X	X	X		X	X*	X*	X
	PC		X	X	X	X		X	X*		X
	PD		X	X	X	X		X	X*	X*	X
Finland	F-1		X	X	X	X		X			X
	F-2		X	X	X	X		X			X
	F-3	X	X	X	X	X		X			X
	F-4		X	X	X	X		X			X
	F-5		X	X	X	X		X			X
	F-6		X	X	X	X		X			X
	F-7		X	X	X	X		X			X
	F-8		X	X	X	X		X			X
	F-9		X	X	X	X		X			X
	F-10	X									
	F-11	X									

3 Harmonization of the environmental monitoring and assessment methods employed in the sampling, measurement/observation, data analysis, evaluation and reporting stages

John Derome[1], Tor Myking[3], Per Arild Aarrestad[2]

Harmonization was achieved by carrying out joint sampling and assessment exercises at selected sites, inter-laboratory ring tests for the chemical analyses of deposition, plant and soil material, and by drawing up data compilation, data analysis and reporting guidelines and templates for the researchers working in the three countries.

Joint sampling and assessment exercises in the field

Joint sampling and assessment exercises were carried out at sites in Norway and in Russia during establishment of the new ecosystem monitoring network. In addition, a common sampling and assessment course was held at the Rayakoski workshop (2.-3.8.2004) in Russia before the start of the field work, with participating researchers from Norway, Russia and Finland. Determination of critical taxa of bryophytes and lichens and methods of assessing species abundance, crown conditions, stand growth and epiphytic lichens was emphasized.

Inter-laboratory ring tests

The laboratories responsible for analysing the deposition, plant and soil samples in the sub-project were the laboratory of the Norwegian Forest and Landscape Institute (formerly the Norwegian Forest Research Institute, Skogforsk) in Norway, the terrestrial ecosystems laboratory of the Institute of the Industrial Ecology of the North (Kola Science Centre, Russian Academy of Sciences, INEP KSC RAS) in Russia, and the laboratory of the Rovaniemi Research Unit of the Finnish Forest Research Institute (Metla).

Deposition analyses

The three laboratories participated in WRT2005, which was an inter-laboratory ring test for deposition and soil solution samples organized with co-funding from the EU Forest Focus forest monitoring programme, and supervised by the ICP Forests Expert Panel on Deposition. 58 laboratories from most European countries participated in WRT 2005 in May 2005. Five natural deposition samples (bulk deposition and stand throughfall) and 4 synthetic samples were sent to each laboratory for analysis. The analyses performed were pH, alkalinity, dissolved organic carbon (DOC), NH_4, NO_3, total N, SO_4, Cl, PO_4, Ca, Mg, K, Na, Al, Cd, Co, Cu, Mn, Ni, Pb, and Zn. The total number of individual analyses performed on the samples was over 250. The three laboratories performed satisfactorily in the ring test (Fig. 2): for Norway 95% of the results were within the acceptable range for the individual analyses, for Finland 84% and for Russia 81%. However, the results that were outside the acceptable range (Norway 5%, Finland 16%, Russia 19%) were within 5% of the acceptable range.

Plant and humus analyses

The three laboratories also participated in an inter-laboratory ring test arranged as a part of the activities of the sub-project. Samples of the organic layer, bilberry (*Vaccinium myrtillus*) leaves, pine (*Pinus sylvestris*) and birch (*Betula* spp.) leaves were taken during the joint sampling and assessment exercise in the field, carried out at Rayakoski in Russia on 2.-3.8.2004. The site is known to have relatively elevated heavy metal and total sulphur concentrations in the soil and plants, and therefore they were considered representative of the actual field samples collected as a part of the monitoring programme of the sub-project elsewhere in the area. The samples were taken to the laboratory of the Rovaniemi Research Unit (Metla), dried, milled and homogenised. Samples were sent to the three laboratories for analysis of total metals and total S, P, N and C on the plant and humus samples, and pH, exchangeable acidity, cation exchange capacity, base cations, and exchangeable metals on the organic layer sample. All three laboratories used microwave digestion for determining total concentrations in the plant samples, but the individual laboratories used slightly different digestion mixtures (Table 2). The laboratories also used different extractant solutions for determining exchangeable cations (Table 3).

The results for the total analyses on the plant and humus samples by the individual laboratories were relatively compatible, especially in the case of heavy metals such as Cu, Ni, Pb and Zn, which are the major pollutants derived from the smelters and hence important for the monitoring programme (Table 2). The differences between the Cr and Cd concentrations were relatively large but, as these metals were present at very low concentrations, the variation is acceptable. Part of the differences are undoubtedly due to differences between the digestion mixtures used by the individual laboratories, and not to poor quality of the analytical work. The results obtained by the individual laboratories for pH, exchangeable cations etc. of the reference humus sample (Table 3) were very variable, especially for the important base cations (Ca, Mg). The main reason for this is that the laboratories used different extraction solutions.

Data analysis, evaluation and reporting stages

One researcher was responsible for collating and checking, in co-operation with the other researchers, the datasets for each of the groups of monitoring parameters (see Sections 4.2–4.13). The data files for each group of parameters, as well as information about the sampling, chemical analyses etc., were incorporated in the database as both data files and metadata files. One researcher was responsible for preparing an evaluation and report, in co-operation with the other researchers, for each of the individual groups of monitoring parameters.

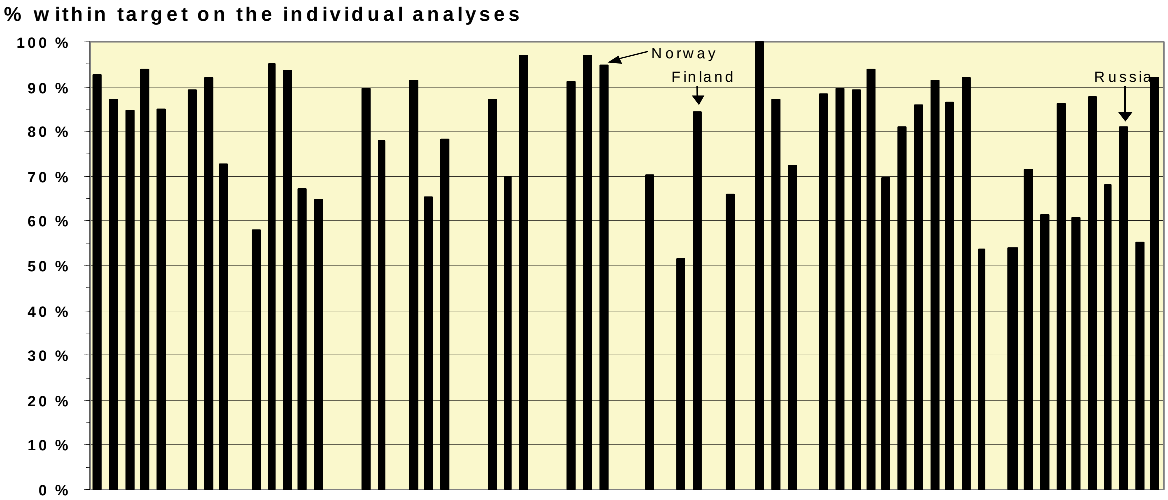


Figure 2. Results of an inter-laboratory ring test (WRT 2005) carried out in May 2005 for deposition and soil solution samples organized with co-funding from the EU Forest Focus forest monitoring programme, and supervised by the ICP Forests Expert Panel on Deposition. The Norwegian, Finnish and Russian laboratories participating in the project are marked on the figure.

Table 2. Total concentrations of heavy metals, macronutrients (Ca, Mg, K) and total phosphorus, sulphur, carbon and nitrogen in reference birch leaves, pine needles, bilberry leaves and humus samples analysed by the Finnish, Norwegian and Russian laboratories in the inter-laboratory comparison exercise. The elements were determined by wet digestion (microwave oven). In Finland a mixture of nitric acid and hydrogen peroxide ($HNO_3 + H_2O_2$) was used as the digestion mixture, in Norway nitric acid and perchloric acid ($HNO_3 + HClO_3$), and in Russia nitric acid (HNO_3). <LOQ = below the Limit of Quantitation. na = not analysed owing to insufficient sample.

	Country	Al mg/kg	Ca mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	K mg/kg	Mg mg/kg	Mn mg/kg	Ni mg/kg	P mg/kg	Pb mg/kg	S mg/kg	Zn mg/kg	Tot-C %	Tot-N %
Birch leaves	Finland	64	8455	<LOQ	1.1	7.8	123	11040	3662	1544	6.7	2405	<LOQ	1713	197	49.1	2.37
	Norway	74	10000	0.2	1.1	7.5	118	10400	4000	1528	5.7	2400	0.4	1600	200	na	na
	Russia	30	9450	0.1	0.9	8.7	132	11175	3259	1405	9.5	2495	0.6	1180	232	48.3	2.43
Pine needles	Finland	266	3332	<LOQ	0.5	3.8	38	4787	878	931	1.7	1342	<LOQ	959	53	51.9	1.31
	Norway	332	3600	0.2	1.1	2.7	39	4600	900	920	1.1	1400	0.4	900	56	51.7	1.12
	Russia	238	3636	0.1	0.3	3.4	42	5024	882	887	1.5	1420	1.2	616	50	56.4	1.21
Bilberry leaves	Finland	145	6143	1.4	<LOQ	10.9	88	10086	2001	848	3.0	1342	<LOQ	1736	11	48.1	1.43
	Norway	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	Russia	103	6047	0.3	0.2	9.5	82	9795	1655	762	2.5	1342	0.6	1368	11	51.8	1.44
Humus	Finland	5567	3324	0.1	137.2	22.5	8769	1442	2029	287	95.9	819	10.7	1007	49.5	30.6	0.82
	Norway	3135	2489	0.2	81.5	21.2	5998	1036	967	236	68.9	842	8.1	921	44.6	34.3	0.83
	Russia	3101	2013	0.1	158.6	18.3	7289	1297	1476	285	87.2	589	9.8	857	43.4	33.0	0.84

Table 3. pH and concentrations of exchangeable Al, Ca, Fe, K, Mg, Mn and Na and exchangeable acidity (EA), cation exchange capacity (CEC) and base saturation (BS) in a reference organic layer samples analysed by the Finnish, Norwegian and Russian laboratories in the inter-laboratory comparison exercise. In Finland the samples was extracted with barium chloride ($BaCl_2$), in Norway with ammonium nitrate (NH_4NO_3), and in Russia with ammonium acetate (CH_3COONH_4).

Country	pH (H_2O)	pH ($CaCl_2$)	EA meq/kg	CEC meq/kg	BS %
Finland	3.99	3.31	130	355	63.4
Norway	3.75	3.27	87	232	59.0
Russia	3.52	3.00	-	-	-

	Al mg/kg	Ca mg/kg	Fe mg/kg	K mg/kg	Mg mg/kg	Mn mg/kg	Na mg/kg
Finland	341	3111	504	727	600	197	42.0
Norway	314	1834	390	794	511	210	39.1
Russia	310	1248	127	748	242	205	36.0

4 Testing the integrated monitoring programme to be implemented by the environmental authorities and organizations of the three countries

4.1 General information about the monitoring plots

Per Arild Aarrestad[2]

The ecosystem monitoring network (ECM) consists of plots from three earlier established monitoring networks, with different plot design.

The eight plots from the Skogforsk-NINA-VNIIPRIRODA-IGCE monitoring network (PA, PB, PC, PD, RUS0, RUS1, RUS2 and RUS3) were established in Scots pine and Norway spruce forests. They all have a rectangular design with a total area of 30 x 50 m (1500 m^2) (Fig. 3). An inner site area of 25 x 40 m (1000 m^2) was intended for non-destructive sampling with a minimum of disturbance (Fig. 3), while the outer buffer zone was mainly established for destructive sampling (cf. Aamlid et al. 2000).

The five selected plots from the NINA-NGU-INEP-METLA monitoring network (S3, S5, S10, N6 and N11) were established in birch forests, and each consists of five sub-plots (A, B, C, D and E) for the assessment of terrestrial parameters (Fig. 4). Each-sub –plot is 15 x 15 m (225 m^2), and the total plot area is 1125 m^2. E is the central sub-plot, and the distance from the centre of E to the centre of each of the other sub-plots is 25 meters (cf. Yoccoz et al. 2001).

The nine clusters selected from the Finnish Lapland Damage Project (F-1 to F-9) were all established in pine forests. Each cluster consists of 3 - 4 circular plots (Fig. 5a). One plot, which represented the ground vegetation of the whole cluster, was selected as a sample plot for the Pasvik project. The size of the plot is 300 m^2, with a radius of 9.8 m (Fig. 5b).

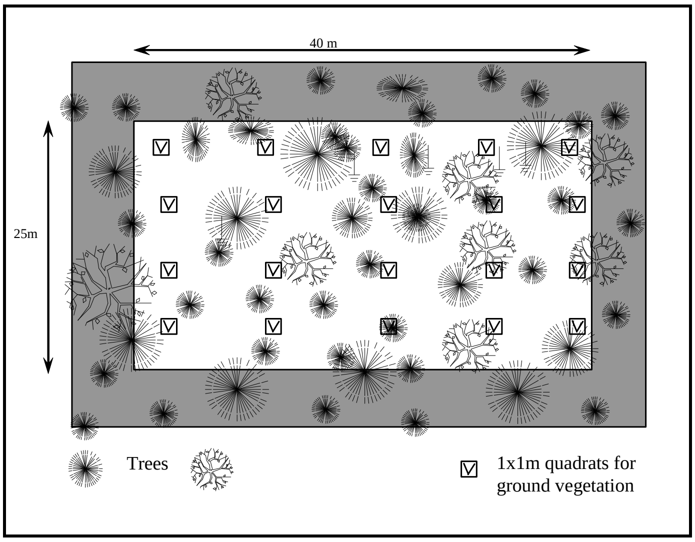


Figure 3. Design of the Skogforsk-NINA-VNIIPRIRODA-IGCE monitoring plots.

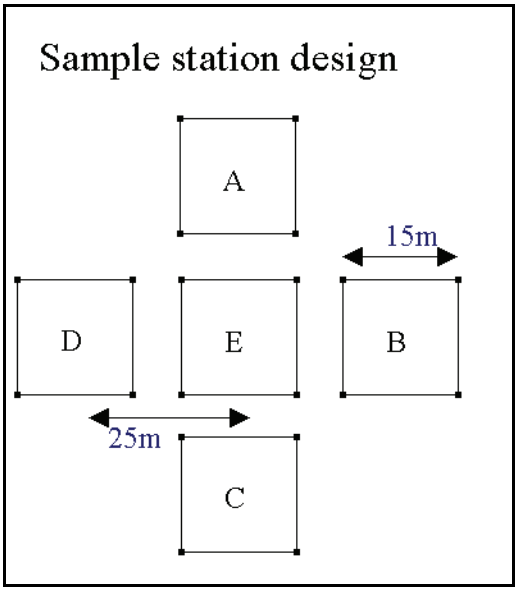


Figure 4. Design of the NINA-NGU-INEP-METLA plots.

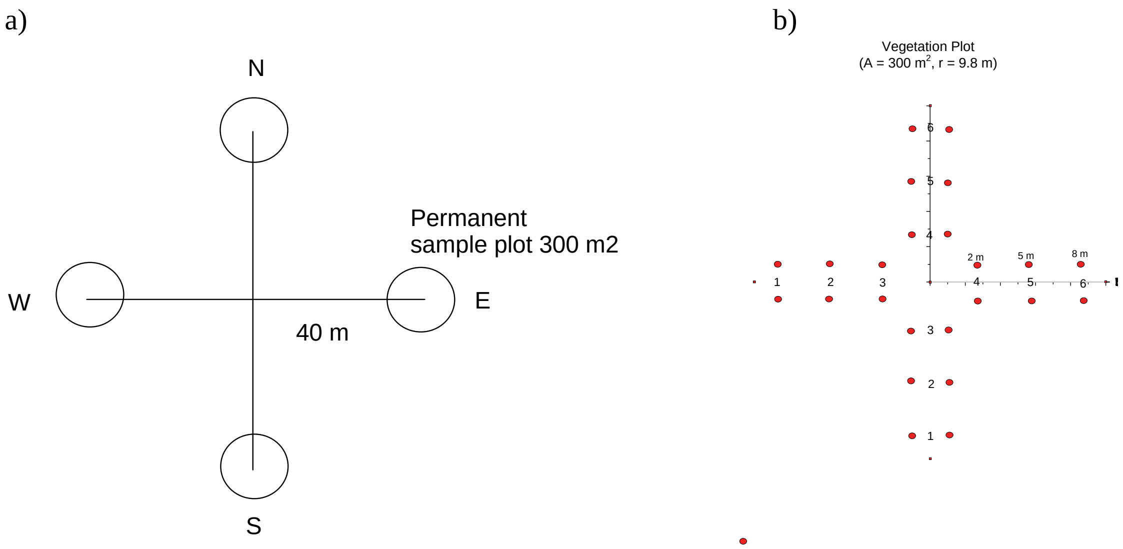


Figure 5. Design of a) the sample clusters, and b) vegetation plots used in the Lapland Forest Damage Project.

4.2 Air quality and deposition

John Derome[1], Tor Myking[3], Ludmilla Isaeva[4], Jussi Paatero[9], Antti-Jussi Lindroos[1], and Ulla Makkonen[9]

The mining and metallurgical industry on the Kola Peninsula is, after Norilsk in eastern Siberia, the second largest source of SO_2 emissions in the Arctic. For this reason the concentration of SO_2 has been monitored at Raja-Jooseppi (68º29' N, 28º18' E, 262 m above sea level) in northern Finland, close to the Finnish-Russian border, for over 15 years. SO_2 concentrations in the air are continuously monitored by a method based on UV fluorescence.

Air quality

The SO_2concentration in the air at Raja-Jooseppi during the period 1992-2004 is presented in Fig. 6. The concentrations are usually close to zero, but high peaks occur sporadically. In 2002, for example, there were 15 episodes with a SO_2 concentration exceeding 10 µg/m^3. These peaks are related to air masses, moving from the metallurgical plants at Nikel and Monchegorsk in a north-easterly and south-easterly direction. Peaks as large as these are rarely found even in industrial areas, and almost never in so-called background areas in Finland. The EU air quality regulations for human health protection allow three exceedances of the daily concentration of 125 µg/m^3 per year. In Finland the EU limits were therefore not exceeded. The reduction in SO_2 emissions from the smelters in recent years are reflected in the SO_2 concentrations: after the year 2000 the peak concentrations tended to be lower than prior to 2000. The impact of the Kola smelters can be seen even in western Lapland, 200 km to the west of Raja-Jooseppi. Hatakka et al. (2003) reported that, during periods with easterly winds, the average SO_2 concentration was 1.7 µg/m^3, while during periods with southerly winds it was 0.7 µg/m^3 and with north-westerly winds 0.3 µg/m^3.

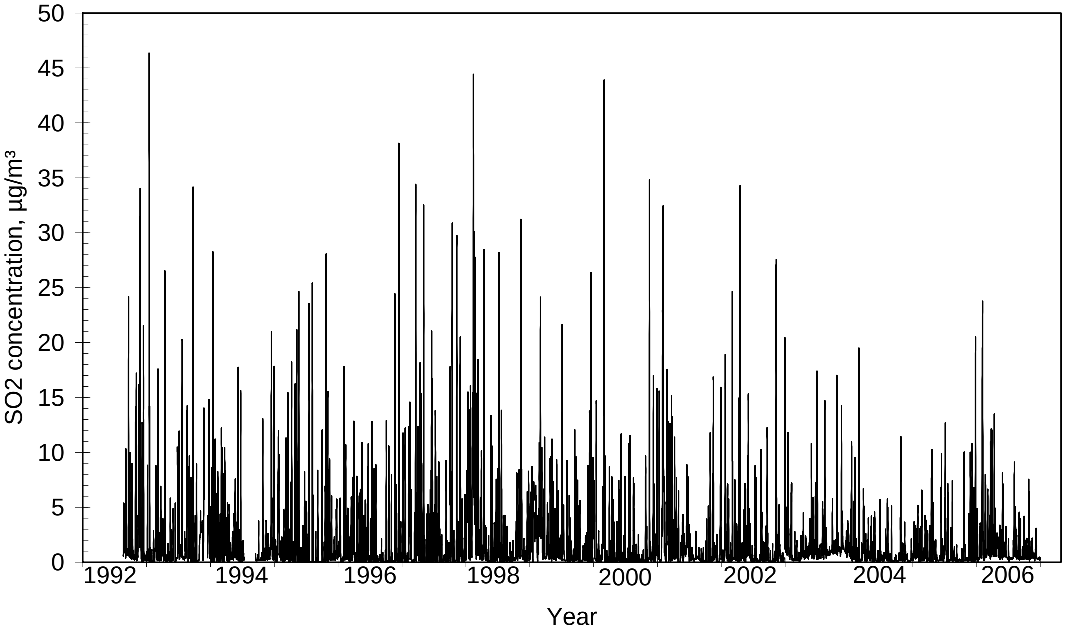


Figure 6. Daily mean sulphur dioxide concentrations (µg/m) at Raja-Jooseppi, northern Finland during 1992-2006.

Sulphate and heavy metal deposition were monitored at two sites in northern Finnish Lapland in accordance with the EMEP protocols (www.emep.int). Weekly deposition samples were pooled to form monthly samples, and analysed for sulphate by IC (ion chromatography) and for heavy metals by ICP-MS. The deposition of sulphate and heavy metals at Sevettijärvi and at Kevo (69º45' N, 27º01' E, 107 m above sea level) in 2005 are shown in Fig. 7. The deposition of metals emitted from the smelters was clearly higher at Sevettijärvi than at Kevo, 80 km to the west. The annual deposition of Ni was five times higher, and of Cu three times higher at Sevettijärvi than at Kevo. In contrast, there was only a small difference in sulphate deposition at the two sites. Evidently the transport time of SO_2 emissions from the smelters in northern Lapland is so short that there is not enough time for the oxidation of SO_2 into SO_4, especially in winter when there is insufficient solar radiation to catalyse the oxidation processes. The deposition values at Kevo were close to the normal background values recorded elsewhere in northern Finland.

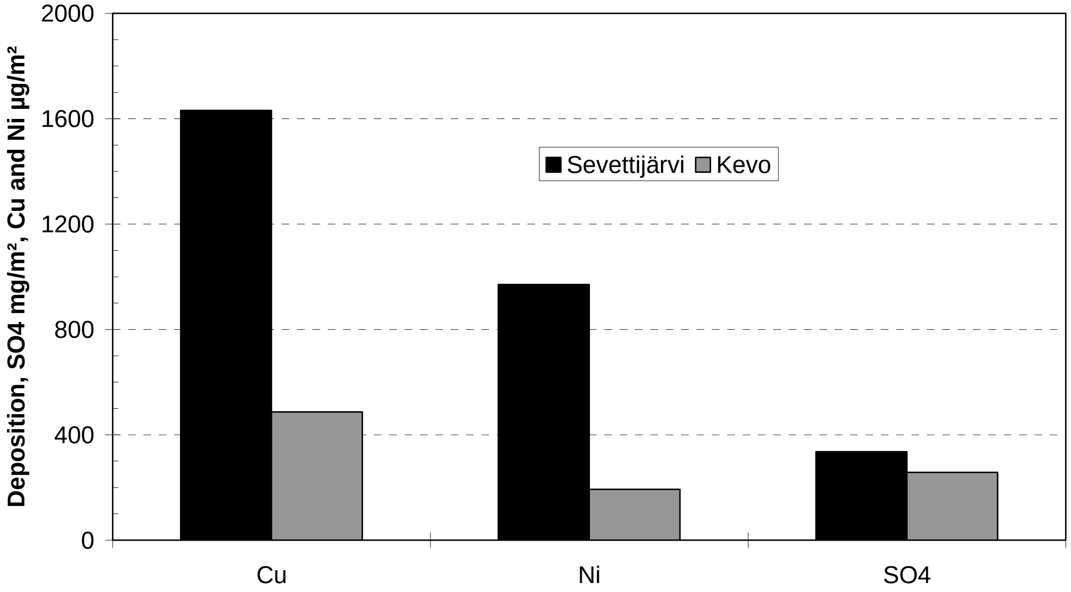


Figure 7. Annual deposition of copper and nickel (*µ*g/m), and sulphate (mg/m) at Sevettijärvi and Kevo in 2005.

Deposition

Bulk deposition and stand throughfall were monitored on a total of 8 plots in Norway, Russia and Finland for a period of one year during 2004-2005. The plot numbers in the individual countries and the sampling periods are given in Table 4. The equipment for collecting the rain and snow samples was the same on all the plots, and was based on the design used in Finland as a part of the Forest Focus/ICP Forest deposition monitoring programmes. Bulk deposition was monitored during the snowfree period using 5 rainfall collectors located in an open area (i.e. no tree cover) close to the plots, and 3 snowfall collectors located at the same points during the winter. Stand throughfall was collected during the snowfree period using 20 rainfall collectors located systematically in a circle inside the stand at a distance of 9.8 m from the centre point of the plot. The collectors were emptied at 4-week intervals. During the snowfree period all the samples from the bulk deposition and stand throughfall collectors were bulked on site to give one composite sample for each type of sample. The total volume of the bulked samples was recorded (determined by weighing, 1 g = 1 ml) in the field, and a sub-sample (1 l) was sent to the laboratory for analysis. During the winter the samples in all the individual collectors had to be transported to the laboratory for thawing, weighing and bulking. Maintenance of the collectors in the field, sampling and transport to the laboratory were carried out in accordance with the field manual of the Finnish version of the Forest Focus/ICP Forests deposition monitoring programme (ICP Forests, 2005).

Table 4. The plots used for monitoring bulk deposition and stand throughfall in Russia, Norway and Finland during 2004-2005.

Country	Plot	Distance from the emission sources, km	Tree species	Sampling period
Russia	RUS0	43	Birch	4.10.04-1.10.05
	RUS1	6	Scots pine	4.10.04-1.10.05
	S05	12	Birch	1.6.04-1.10.05
Norway	N11	30	Birch	1.6.04-8.6.05
	PC	14	Scots pine	1.6.04-8.6.05
Finland	F-3	58	Scots pine	1.6.04-13.6.05
	F-10	90	Scots pine	1.6.04-13.6.05
	F-11	131	Scots pine	1.6.04-13.6.05

The plots in Norway, Finland and one of the plots in Russia (S05) were established at the beginning of June, 2004. For logistical reasons the other two plots in Russia (RUS0 and RUS1) were established at the beginning of October, 2004. Sampling was carried out over a period of approximately one year. Because the sampling period was not exactly one year, the results for annual deposition were adjusted accordingly. The results for bulk deposition (open area collection) on plot S05 are not presented here owing to the fact that a high proportion of the collectors were destroyed by vandalism, and annual deposition values therefore could not be calculated.

The proximity of the sea, and the large variation in topography and the prevailing wind directions, produce relatively high local variation in the annual amount of precipitation. The long-term annual average precipitation for the area varies between 350 and 450 mm, with somewhat higher values close to the coast. The permanent snow cover usually lasts from mid-November to late May. A higher proportion of precipitation falls as snow on the Finnish plots as they are located at higher altitudes inland, and the winter is correspondingly longer. In 2004/5, the annual precipitation on the monitoring plots in Russia and Finland ranged between 420 – 500 mm, which was slightly higher than the long-term average (Table 5). On the two plots in Norway (N11 and PC), which are the closest to the sea, the annual precipitation was 680 and 720 mm.

The bulk deposition of sulphate was relatively high at the two plots (331 and 355 mg SO_4-S/m^2/a) in Norway (Table 5), while on all the other plots sulphate deposition was low (53 – 105 mg SO_4-S/m^2/a) and similar to the deposition level at e.g. Pallasjärvi (average 102 mg SO_4-S/m^2/a during 2001-2004), which is considered to represent background deposition levels (Lindroos et al. 2007). There was no statistically significant relationship between the bulk deposition of sulphate on the plots and the distance to the emissions sources (Fig. 8). The plots

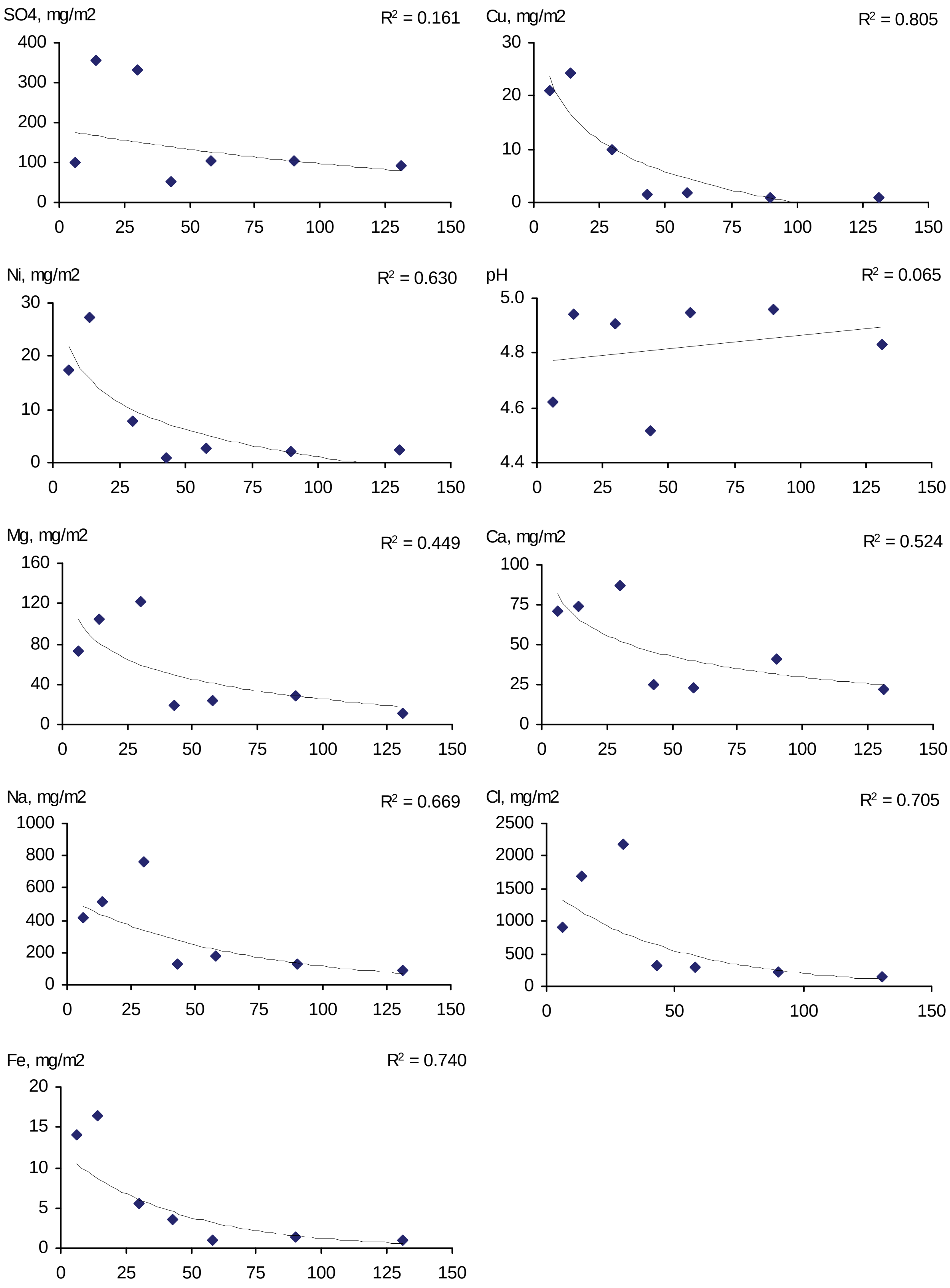


Figure 8. Relationship between the annual deposition of SO4-S, Cu, Ni, Mg, Ca, Na, Cl and Fe and mean annual pH in the open (bulk deposition) and the distance (kilometers) to the Nikel smelters in kilometers.

received sulphate from two sources: the Pechenganikel smelters (gaseous SO_2 and SO_4^{2-}), and sulphate in aerosols from the sea (e.g. as $MgSO_4$). The SO_2 emitted by the Pechenganikel smelters reaches the plots within a relatively short period of time and, in the dry, cold climate, only small amounts of SO_2 will be oxidized to sulphate. Furthermore, during the cold, dark arctic winter there is no solar radiation to catalyze the photochemical oxidation processes of SO_2. The contribution of dry deposition to total (dry + wet) deposition is expected to be high in the Finnmark region due to the relatively high concentrations in the air and low precipitation. At Karasjok in Norway, the contribution of sulphur dry deposition to total deposition is estimated to be 53% in winter and 50% in summer. The lack of statistically significant correlation between sulphate and Cu and Ni deposition and between pH and sulphate deposition, and the significant correlation between sulphate and Mg, Na and Cl deposition (Table 7), strongly suggests that most of the sulphate is derived from marine sources, and not from the smelters.

There was a statistically significant correlation between annual Cu and Fe deposition and the distance to the smelters, and almost significant correlation for Ni (Fig. 8). However, as the plots are located to the north, south and west of the emission sources, and the prevailing wind is from the S/SW, then it is clear that highly significant correlations between deposition levels and distance from the smelters cannot be expected. Despite this, it is clear that the deposition of heavy metals extends, in these directions, only to a distance of less than 50 km from the smelters. There is almost no information available about deposition levels to the E and NE of the smelters.

Table 5. Distance from the emission source, and the annual precipitation (open area), average pH and deposition of metals, cations and anions in bulk deposition at the plots in Russia, Norway and Finland in 2004-2005. nd = no data available.

Plot	Distance, km	Precip. mm	pH	Cu mg/m^2	Ni mg/m^2	SO_4-S mg/m^2	Zn mg/m^2	Fe mg/m^2	Al mg/m^2
RUS1	6	461	4.62	20.9	17.3	102	4.0	14.0	6.3
PC	14	722	4.94	24.4	27.3	355	8.6	16.5	9.8
S05	17	nm	nd	nd	nd	nd	nd	nd	nd
N11	30	678	4.91	10.0	7.8	331	5.8	5.6	10.5
RUS0	43	423	4.51	1.5	0.9	53	4.8	3.7	5.7
F-3	58	485	4.95	1.7	2.7	103	6.2	1.0	7.3
F-10	90	444	4.96	1.0	2.2	105	6.5	1.5	6.7
F-11	131	500	4.83	1.0	2.5	94	6.1	1.0	8.4

Plot	Distance, km	Na mg/m^2	Cl mg/m^2	Ca mg/m^2	Mg mg/m^2	K mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2
RUS1	6	414	898	70.7	73.2	73.7	7.1	51.3
PC	14	517	1686	74.3	104	73.7	57.0	60.5
S05	17	nd	nd	nd	nd	nd	nd	nd
N11	30	763	2188	86.8	123	66.9	61.6	52.7
RUS0	43	130	316	24.7	19.6	22.2	8.6	54.4
F-3	58	175	306	23.4	23.5	27.3	38.4	28.8
F-10	90	131	218	40.9	27.8	69.9	33.5	17.1
F-11	131	84	138	21.7	10.4	28.4	48.5	30.5

Table 6. Distance from the emission source, and annual precipitation (inside the tree stand), average pH and deposition of metals, cations and anions in stand throughfall at the plots in Russia, Norway and Finland in 2004-2005.

Plot	Distance, km	Precip., mm	pH	Cu mg/m^2	Ni mg/m^2	SO_4-S mg/m^2	Zn mg/m^2	Fe mg/m^2	Al mg/m^2
RUS1	6	396	4.60	19.2	13.9	145	4.3	13.7	8.0
PC	14	577	4.81	27.1	30.7	447	25.3	19.8	12.7
S05	17	497	4.57	19.2	13.9	145	4.3	13.7	8.0
N11	30	640	5.04	11.9	12.1	401	4.1	7.4	11.4
RUS0	43	463	4.52	2.2	1.5	116	4.9	7.6	7.2
F-3	58	414	4.83	1.7	2.5	191	6.6	3.1	8.6
F-10	90	431	4.91	0.9	2.2	114	6.9	1.4	6.5
F-11	131	431	4.76	0.9	2.2	102	6.7	1.2	7.3

Plot	Distance, km	Na mg/m^2	Cl mg/m^2	Ca mg/m^2	Mg mg/m^2	K mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2
RUS1	6	378	812	79	77	97	30.4	87.9
PC	14	805	2225	129	148	529	66.0	78.8
S05	17	378	812	79	77	97	30.4	87.9
N11	30	1374	3405	136	215	465	61.8	50.9
RUS0	43	229	492	63	52	136	49.6	160.6
F-3	58	432	810	79	67	295	32.6	19.5
F-10	90	154	269	49	36	154	30.8	13.4
F-11	131	121	198	45	24	110	47.4	25.4

The annual deposition of base cations (Ca, Mg, K and Na) and the anion Cl was considerably higher on the plots closest to the sea, i.e. plots RUS1, PB and N11. However, these plots are also the closest to the smelters. Due to the extremely strong correlation between Ca and SO_4, and between Na and Cl (Table 7), we can assume that most of the Mg and Na is primarily of marine origin. The deposition of Ca and K, on the other hand, is most probably derived from dust emissions from the smelters and power stations at Nikel.

Deposition in the area is characterised by occasional peaks, with relatively high concentrations of Cu, Ni and sulphate (Fig. 9); the peaks are primarily determined by the wind direction. However, on some of the monitoring plots (e.g. plots in Finland), the Cu and Ni concentrations were extremely small, and in many cases below the limit of quantification for the analytical equipment.

Coniferous trees are known to effectively filter dry deposition from the atmosphere, and the concentrations of elements are normally considerably higher (except for nitrogen compounds) in stand throughfall than in bulk deposition. However, there were relatively small differences between the deposition of Cu and Ni in bulk deposition and stand throughfall on the individual plots (Tables 5 and 6), presumably because the stands are of low density and the trees relatively short. Sulphate was an exception to this, almost certainly due to the interception of sulphate containing aerosols of marine origin (Fig. 9).

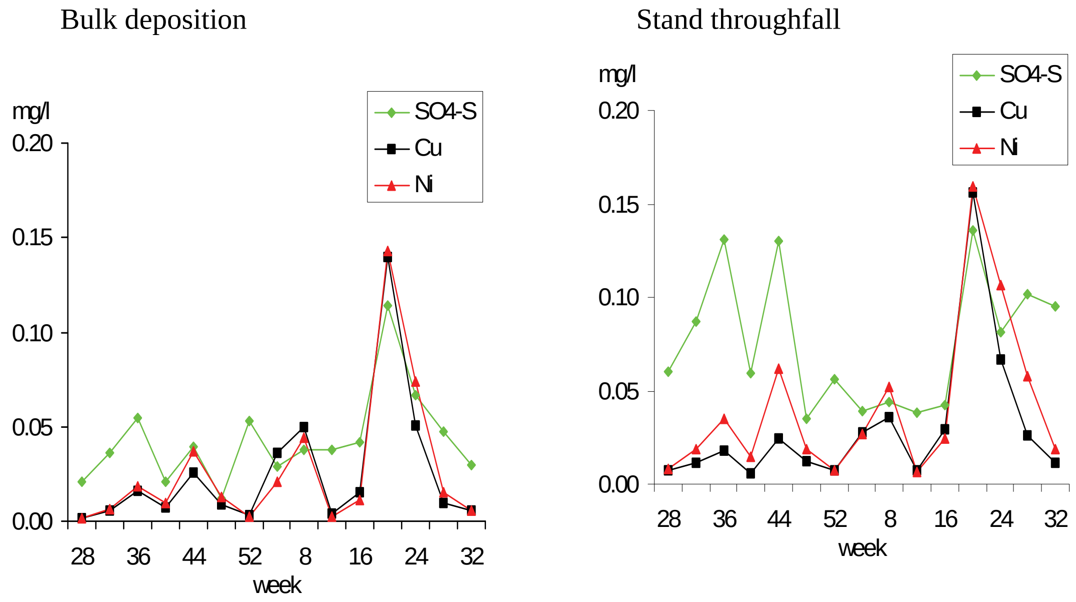
Table 7. Matrix showing the coefficient of determination for the relationships between a number of parameters (mean annual deposition or mean annual pH) in bulk deposition and in stand throughfall. The values in bold are statistically significant at the 5% probability level. n = 8.

Bulk deposition

	Cu	Ni	Fe	SO_4-S	pH	Mg	Ca	Na
Cu								
Ni	**0.974**							
Fe	**0.986**	**0.965**						
SO_4	0.619	0.663	0.547					
pH	-0.019	0.110	-0.132	0.503				
Mg	0.766	0.713	0.697	**0.893**	0.223			
Ca	**0.794**	0.717	0.729	**0.797**	0.162	**0.971**		
Na	0.672	0.596	0.590	**0.857**	0.199	**0.983**	**0.943**	
Cl	0.675	0.631	0.604	**0.923**	0.236	**0.983**	**0.919**	**0.984**

Stand throughfall

	Cu	Ni	Fe	SO_4-S	pH	Mg	Ca	Na
Cu								
Ni	**0.953**							
Fe	0.457	0.296						
SO_4-S	0.601	0.758	0.179					
pH	-0.143	0.045	-0.346	0.547				
Mg	0.557	0.621	0.414	**0.909**	0.518			
Ca	0.676	0.752	0.395	**0.953**	0.417	**0.968**		
Na	0.458	0.530	0.362	**0.887**	0.588	**0.991**	**0.942**	
Cl	0.507	0.595	0.356	**0.922**	0.572	**0.996**	**0.957**	**0.994**


Bulk deposition

Stand throughfall

Figure 9. Copper, nickel and sulphate concentrations in bulk deposition and stand throughfall at Plot PC in Norway during the period 1.6.2004 – 8.6.2005. The measured sulphate concentrations have been divided by 10 in order to make comparison of the timing of the peaks easier.

4.3 Crown condition

Tor Myking[3], Martti Lindgren[1], Michael Gytarsky [7], Rodion Karaban[7] and Vera Kuzmicheva[7]

Crown condition is a term describing the overall vitality of a tree. The main components of crown condition are crown density and crown colour. As there was no variation in crown colour on the plots in the area, only the crown density results are reported here.

Scots pine

The crown density was higher on the moderately polluted Norwegian plots (> 90%) in both 2004 and 2005 than on the heavily polluted Russian plots (< 80%), although relatively low crown density was also recorded on the reference plots in Russia (RUS0) in 2004 and in Finland in 2005 (Table 8).

Table 8. Crown density assessments of Scots pine. These observations were transformed to crown density by subtracting defoliation from full crown density (100% - ds).

	FL-4	FL-5	FL-6	PA	PB	PC	PD	RUS1	RUS2	RUS0
2004				91.8	92.2	93.7	92.5	75.3	79.0	79.0
2005	74.5	79.6	85.3	91.8	92.2	92.5	93.7			
1996*				90.9	95.5	93.6	93.6	**82.9		

* Aamlid et al. 2000 ** 1995 values

The striking cross-border difference in crown density may reflect a combination of differences in climate, soil conditions and pollution. The Finnish plots are the least exposed to the deposition of pollutants. However, compared with the Norwegian-Russian area, they are located in an area with a relatively high elevation and nutrient-deficient bedrock, and this may explain the poor crown condition (Merilä et al. 1998, De Vries et al. 2000, Ewald 2005).

In a previous study including a subset of the plots in Norway and Russia (PA, PB, PC, PD, RUS1), it was concluded that crown condition was negatively affected by pollution (Aamlid et al. 2000). A similar result was obtained in the present survey, and there has also been a reduction in crown density on the plot in Russia subjected to a pollution load (RUS1). The Russian reference plot (RUS0) may not be representative as the trees are relatively old and severely attacked by *Peridermium pini*, which has undoubtedly reduced the overall stand vitality and crown density (Michael Gytarsky, personal communication). Thus, there are indications that pollution has reduced the crown density of Scots pine in the border area (cf. Kandler and Innes 1995), but the data are not conclusive.

Birch

Crown density in birch was, in general, assessed on only a small and varying number of trees on each plot, due to the low presence of birch on many of the plots, especially on the north-south gradient. Therefore the results should be considered as only tentative.

Crown density in birch declined along the west-east gradient and appears to be negatively affected by the emissions (Table 9). The north-south gradient also included plots located close to the smelter (N06, S3, S5), but these plots had comparably high crown density values (Table 10). The results for the two gradients are therefore somewhat conflicting, and the low crown density on the Russian reference plot (RUS0) cannot be explained in terms of the impact of pollution. Thus the question of whether crown density in birch is negatively influenced by pollution on the area is still open. Being a deciduous tree, birch is expected to be less sensitive than pine to SO_2 pollution (Neuvonen 2001, Kozlov 1992), and this may be what our dataset reflects.

Table 9. Crown density assessments of birch, west-east gradient, 1995-2004.

Plot	PA	PB	N11	RUS1	RUS2	RUS0
1995	93.6	94.1		56.2		
1998	91.6	91.9		58.2	59.9	51.1
2004	92.5	91.9	81.0	64.2	64.1	58.3

Table 10. Crown density assessment of birch, north-south gradient in 2004.

	N11	N06	S03	S05	S10
2004	81.0	90.1	91.8	90.6	90.3

4.4 Stand growth

Tor Myking[3], Michael Gytarsky [7], Rodion Karaban[7], Vera Kuzmicheva[7]and Ingvald Røsberg[3]

Growth of the Scots pine stands has been calculated as the relative increase in the increment of basal area, height and volume between 1998 and 2004 (Table 11). The basal area increased by between 10 and 38%. The largest relative increase occurred on plots RUS1 and RUS2 in Russia, close to the smelter at Nikel, and the smallest increase on reference plot RUS0 in Russia. The difference between the plots in Norway was small and unrelated to distance from the smelter. The height increment increased by between 7 and 16%. The highest and lowest increment occurred on the two plots furthest from the emission sources, PA and RUS0, respectively (Table 11). The difference in height increment between the other plots varied by only 4%, the lowest increment occurring on plot RUS1 close to Nikel. The volume increment increased by between 16 and 54%. However, when the volume increment was calculated on the basis of the increment in basal area and height, there was no spatial pattern for this parameter.

In conclusion, despite the large variation between the plots, there are no indications that pollution from the smelters is having a negative effect on the growth of Scots pine, not even on the plots in the immediate vicinity of the smelters. A relatively high correlation has been reported in Norway spruce between crown condition and growth (Solberg 1999). In our data the correlation for Scots pine was extremely low ($r^2 \leq 0.14$), which indicates that crown condition is not related to the growth of Scots pine in the border area.

Table 11. Relative change between 2004 and 1998 for basal area (rBA), tree height (rTH) and tree volume (rV). Different letters show significant differences between plots, same letters (e.g. ab) implies no difference at the 5% level between values with each of individual letters.

	PA	PB	PC	PD	RUS1	RUS2	RUS0
rBA	1.271b	1.257b	1.269b	1.283ab	1.377a	1.338ab	1.0096c
rTH	1.162a	1.144a	1.151a	1.159a	1.122b	1.156a	1.070c
rV	1.431ab	1.369b	1.408c	1.428ab	1.541a	1.478ab	1.160c

4.5 Ground vegetation

Per Arild Aarrestad[2], Vegar Bakkestuen[2], Michael Gytarsky[7], Minna Hartikainen[1], Rodion Karaban[7], Vladimir Korotkov[5], Vera Kuzmicheva[7], Maija Salemaa[1] and Natalia Vassilieva[7]

The ground vegetation, defined as all lichens, bryophytes and vascular plants (for woody species only those with a height below 50 cm), was assessed on the monitoring network in 2004, and then compared with earlier analyses carried out on the original networks (Aamlid et al. 2000, Yoccoz et al. 2001).

4.5.1 Sampling units

The common sample unit for assessment of the species composition and abundance of the ground vegetation on all the plots was a 1 x 1 m quadrat. However the number of quadrats analysed on the individual plots varied between the different networks.

On the eight plots of the Skogforsk-NINA-VNIIPRIRODA-IGCE monitoring network there were originally twenty 1 x 1m quadrats randomly distributed within the inner area (Fig. 3, Section 4.1). Ten of the original 20 quadrats on each of the Norwegian plots (PA, PB, PC and PD) were randomly selected as monitoring sites in 2004, while all of the 20 quadrats were assessed on the Russian plots (RUS0, RUS1 and RUS2). The total number of quadrats was therefore 100. Data from 1994-1996 were available for all the quadrats.

On the 5 plots selected from the NINA-NGU-INEP-METLA monitoring network (S03, S05, S10, N06 and N11) one 1 x 1 m quadrat was marked out at the centre of each sub-plot (A, B, C, D and E), giving five quadrats per plot (Fig. 4, Section 4.1). A total of 25 quadrats were analysed in 2004. Percentage cover data from 2000 were available for all the quadrats.

On the nine selected plots from the Lapland Forest Damage Project network one of the four circular plots forming a cluster (Fig. 5, Section 4.1) was selected for assessment of the ground vegetation. A total of 7 - 12 vegetation quadrats (1 x 1 m) were systematically marked out on the plot along two transects running S-N and W-E. A total of 87 quadrats were analysed in 2004 for the first time.

Thus, a total of 212 vegetation quadrats, covering a gradient ranging from heavily affected areas to areas with almost no pollution impact, were assessed in 2004.

4.5.2 Species composition of the ground vegetation in 2004

The selected plots represented eutrophic dry to medium dry pine and birch forests with naturally occurring *Cladonia* lichens, hepatics mainly *Barbilophozia* spp., *Dicranum* spp. and *Pleurozium schreberi* mosses and small dwarf shrubs of *Empetrum nigrum*, *Vaccinium* spp. and *Ledum palustre*. A number of herbs, such as *Linnea borealis, Listera cordata, Pedicularis lapponica* and *Trientalis europaea,* and the grass *Deschampsia flexuosa,* were the most common species in the medium dry forests, while lichens and bryophytes dominated in the dryer forests.

A detrended correspondence analysis DCA (Hill 1979, Hill & Gauch 1980) of the species on the 212 quadrats showed that there was a gradient in the analysed vegetation from dry vegetation dominated by lichens to medium dry vegetation with more dwarf shrubs and herbs (Fig. 10). The vegetation on the Norwegian plots (PA-PD, N11) was very similar to that on the Russian reference plots (S10 and RUS0), far to the south of the Nickel smelter, and also similar to that on many of the Finnish sample plots. However, several of the Finnish plots reflected a dryer vegetation type more dominated by reindeer lichens and cup lichens. The Norwegian, Finnish and the Russian reference plots all probably represent naturally occurring vegetation with a very low pollution impact.

The species composition of the ground vegetation on the Russian plots in the vicinity of the Nickel melter (RUS1, RUS2, S03 and S05) was, however, very different from that on the other plots in the monitoring network (Fig. 10, red plots). In general, they lacked most of the bryophytes, and the lichen cover was very sparse. This is probably an effect of air pollution on these plots. However, the vegetation on the Russian plot to the north (N6) was distinctly more vigorous, and was dominated by *Vaccinium myrtillus*, *Cornus suecica*, *Gymnocarpium dryopteris* and *Deschampsia flexuosa,* indicating less pollution impact at this site.

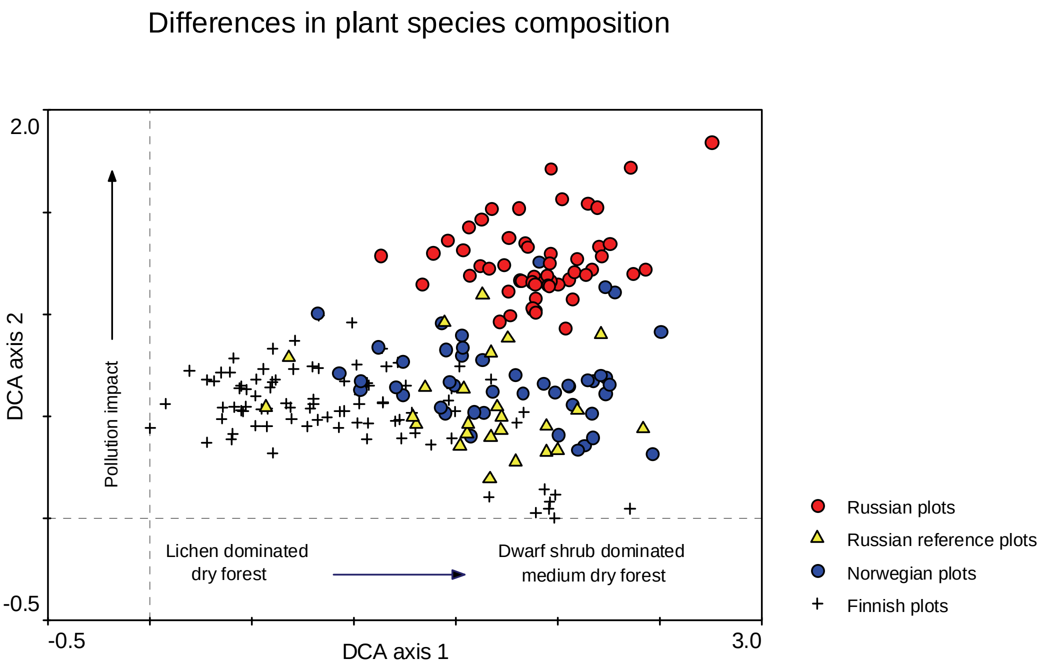
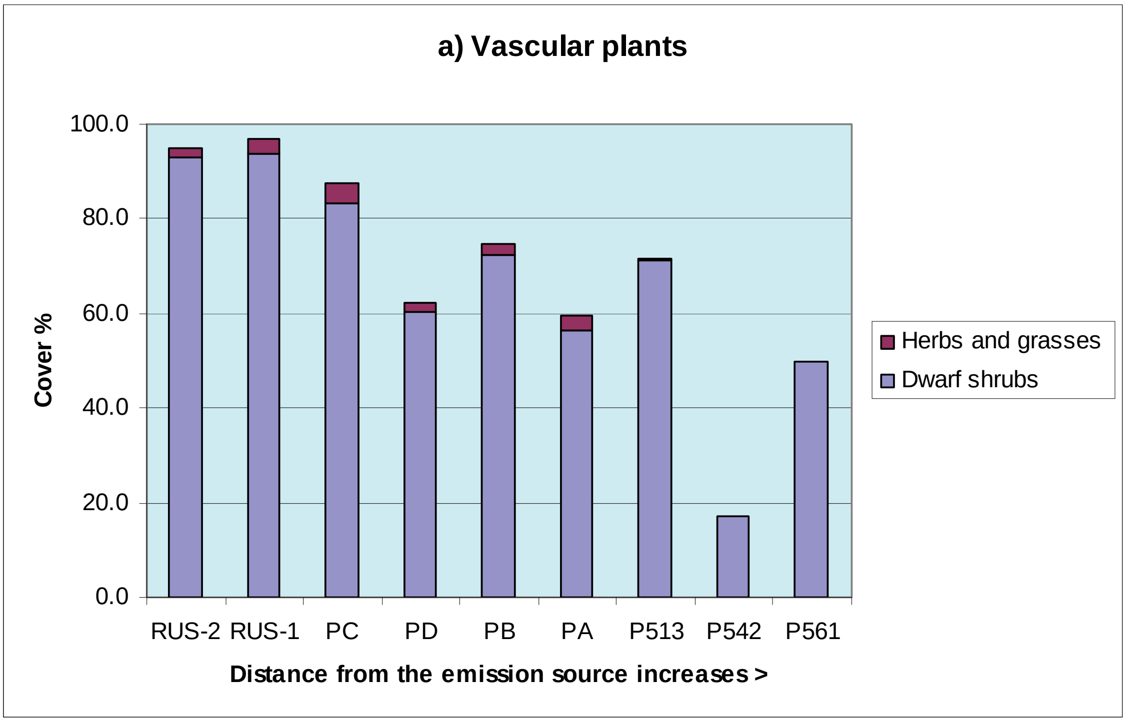


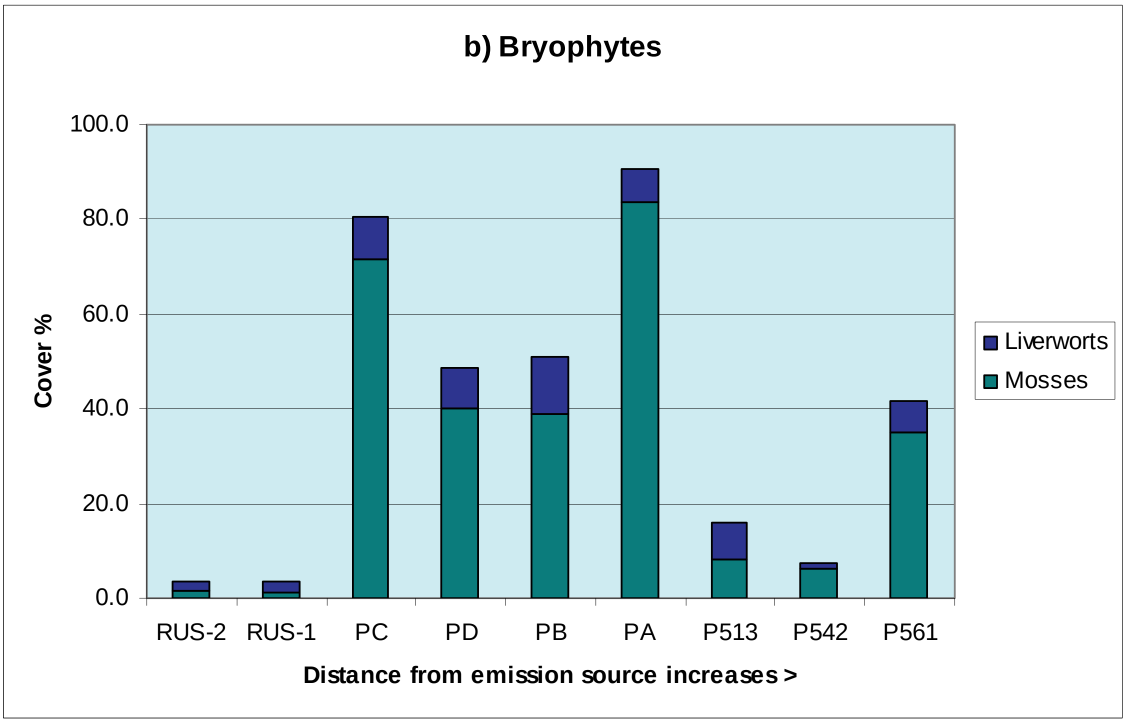
Figure 10. Detrended correspondence analysis (DCA) of the total 212 quadrats (sample plots), axis one and two, performed with CANOCO version 4.5 (ter Braak & Smilauer 2002). Sample plots that are situated close together are very similar in species composition. Sample plots that are far apart are very different in species composition.

4.5.3 Differences in the vegetation along the east-west transect in 2004

The plots along the E-W transect were selected for a more detailed evaluation in order to minimize the effect of bio-geographical variation on the vegetation pattern, and to quantify the impact, if any, of air pollution. The length of the study transect is 63 km, and it runs from the Petchenganikel smelter through eastern Finnmark to Finnish Lapland.

The plotwise average percentage cover was calculated for vascular plants, bryophytes and lichens (Figs. 11a-c). The cover of vascular plants was the highest on the Russian plots and decreased on moving westwards (Fig. 11a). Dwarf shrubs formed the major group within the vascular plants. Herbs and grasses were the most abundant on plots RUS1 and PC, but their percentage cover was very low. Dryer growing conditions explained the lower abundance of vascular plants on the Finnish plots.





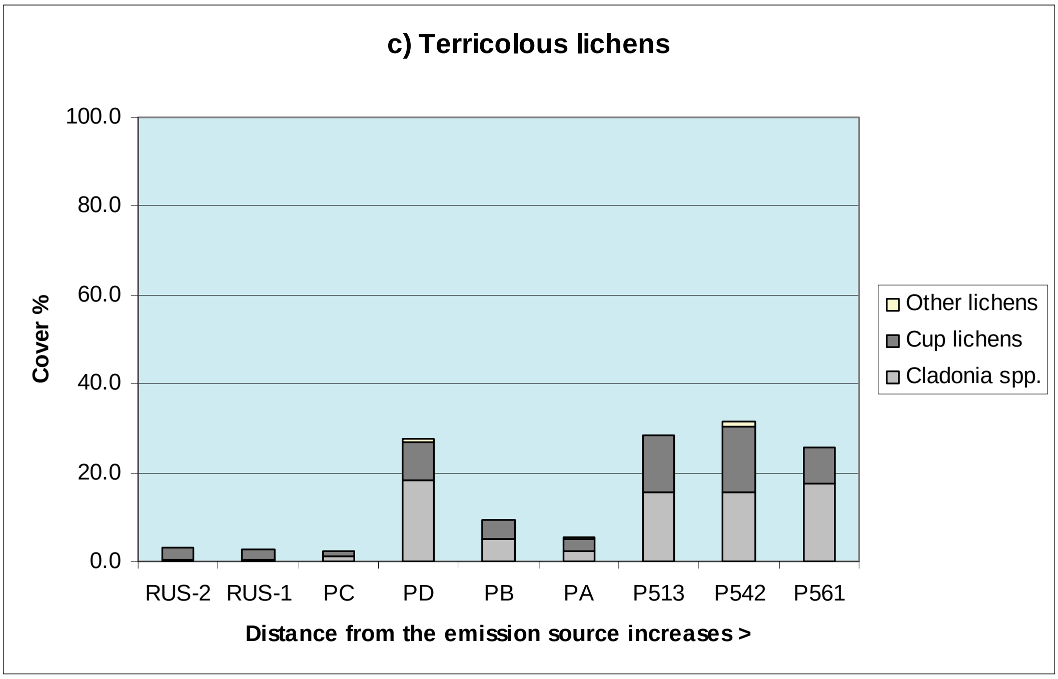


Figure 11. The average cover (%) of a) vascular plants, b) bryophytes (mosses and liverworts) and c) terricolous lichens on the sample plots on the east - western transect.

The abundance of bryophytes was the highest (average cover 40–84%) on the Norwegian plots (Fig. 11b). Similarly, the cover of liverworts was the highest on the Norwegian part of the transect. Bryophytes were almost absent on the Russian plots, indicating an impact of pollutants. However, four taxons of liverworts were found on the two Russian plots, and they had even a higher cover (2%) than that of mosses (1.5%). The cover of the moss layer varied on the Finnish plots depending on the moisture level of the individual sites.

The cover of terricolous lichens increased on moving to the west along the transect (Fig. 11c). The cover of reindeer lichens (*Cladonia* spp.) on the Finnish plots was about 16% and that of cup lichens 12%. In contrast, the lichen layer was very scarce on the Russian plots (3%) and mainly consisted of pioneer cup lichens. The Norwegian plots also had a relatively low abundance of lichens compared to the situation on the Finnish plots. The group of other lichens included leather lichens (*Peltigera* sp.), which occurred sporadically on the plots.

The composition and the relative abundance of the plant species has changed in the vicinity of the Petsenganikel smelter. On the Russian plots, the ground vegetation was characterised by dwarf shrubs, which are relatively resistant to heavy metals and other pollutants. The common forest bryophytes (e.g. *Pleurozium schreberi*) and reindeer lichens, which are known to be affected adversely by air pollutants, were missing on the plots near the smelter. On the other hand, some pioneer bryophytes and cup lichens were growing on the disturbed and polluted soil. The increase in the abundance and number of bryophyte species on the Norwegian plots was probably due to the lower pollution load. The composition and abundance of the species on the lichen heaths on the Finnish plots mainly reflected the characteristics of the dryer growing sites and reindeer grazing, rather than the effect of air pollutants. However, increased heavy metal and sulphur concentrations were found in mosses and lichens on the Finnish plots (see Section 4.8).

4.5.4 Preliminary results of ground vegetation analysis on the long-term sample plots along the east-west transect (1994, 1995, 1998 and 2004 surveys)

The monitoring plots where ground vegetation data were available from 1994, 1995, 1998 and 2004 were located at various distances from the pollution source (see Fig. 1). The plots were RUS0 (the most remote site), PA, PB, PC, PD, RUS1 and RUS2. Analysis of the ground vegetation was carried out once on 20 randomly selected 1 x 1m quadrats on all the plots during 1994-1998. In 2004 the analysis was repeated on all the quadrats on the Russian plots, and on 10 randomly selected quadrats on the Norwegian plots. The analysis included records of the species composition of dwarf shrubs, herbs, grasses, lichens and bryophytes, and their percentage cover. Assessment of the species composition, species abundance (number of species per unit area) and average percentage cover was made for each species community. A species community is defined as a group of species that occupies a similar spatial and temporal location. The following communities were identified: trees and shrubs, dwarf shrubs, herbs and grasses, mosses, liverworts and lichens.

Species composition

The dwarf shrub community on all the sample plots included *Empetrum nigrum* ssp. *hermaphroditum*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea* and *Ledum palustre*. *Vaccinium uliginosum* was also present on plots RUS0, RUS1 and RUS2, although its occurrence and percentage cover were minor. The percentage cover of *Empetrum nigrum* ssp. *hermaphroditum* and *Vaccinium vitis-idaea* was notably higher on plots RUS1 and RUS2 than on the other plots. For herbal communities, *Linnaea borealis* and *Deschampsia flexuosa* had the highest occurrence and percentage cover on all the plots. Low values for percentage cover and occurrence were typical for the other herbal species.

Pleurozium schreberi, *Pohlia nutans* and *Polytrichum juniperinum* were found within the moss communities on all the plots. Their occurrences abruptly dropped in conditions of increased pollution (RUS1 and RUS2 plots). *Pleurozium schreberi* was the most dominant moss on the RUS0, PA, PB, PC and PD plots. However, its percentage cover and occurrence were significantly lower on the RUS1 and RUS2 plots. Some species (*Dicranum* spp., *Hylocomium splendens*, *Plagiothecium laetum*) occurred only on the RUS0, PA, PB, PC and PD plots. The reason for the absence of these species on the RUS1 and RUS2 plots may be the high level of pollution on these plots.

The liverwort community was represented by *Barbilophozia* spp. and *Lophozia ventricosa*, and they occurred on all the plots. However, their occurrence and percentage cover was notably lower on the RUS1 and RUS2 plots.

The lichens *Cladonia arbuscula*, *C. chlorophaea*, *C. crispata*, *C. furcata*, *C. rangiferina*, *C. gracilis* and *C. deformis* were found on all the plots. However, their occurrence and percentage cover significantly decreased on the RUS1 and RUS2 plots. Some lichen species were missing on the RUS1 and RUS2 plots. These changes in lichen community are most probably due to the effects of pollution from the smelters.

Species abundance (number of species per unit area)

The lowest species abundance values occurred on the RUS1 and RUS2 plots, which are the closest to the pollution source. The decrease in total abundance was due to the reduction in the number of lichens, liverworts and mosses (Fig. 12). This is obviously due to the natural succession that occurs in forest ecosystems. In contrast, the percentage cover of lichens, mosses and liverworts decreased on plot RUS1 or remained at approximately the same level on plot RUS2, both of which are subjected to higher levels of pollution (Fig. 12), and reduction in the number of lichens, liverworts and mosses (Table 12). This is clearly evident from the average and maximum number of species per m^2. The species abundance of dwarf shrubs and herbs was relatively constant on all the sample plots. There were only insignificant changes in the species abundance in 2004 compared to the situation in 1994/1995 and 1998. The differences between the abundance values on the Norwegian sample plots in different assessment years were presumably due to the differences in sampling size: only 10 quadrats were analyzed on each plot in 2004, but 20 quadrats in 1994 and 1995.

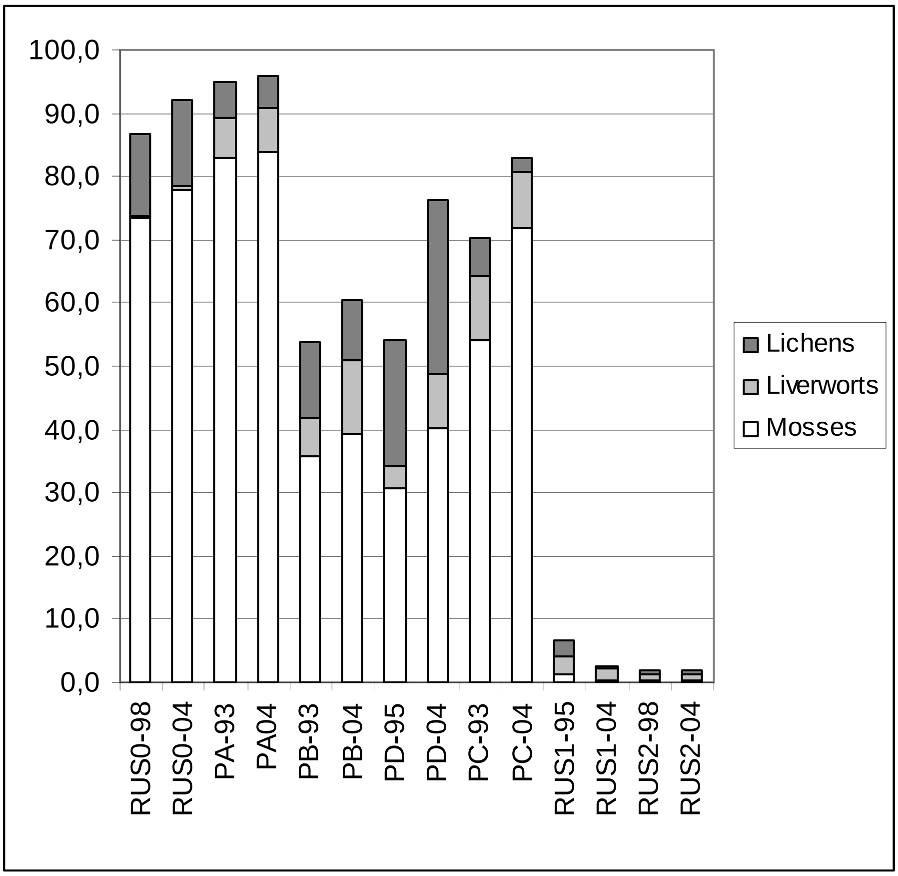


Figure 12. The projective cover of lichens, liverworts and mosses over the plots.

Table 12. Species abundance (number of species per unit area) of different vegetation communities within the plots along the east-west pollution gradient at two different years. Average and maximum (in parentheses) number of species per m^2.

Plot ID	RUS0	RUS0	PA	PA	PB	PB	PD	PD	PC	PC	RUS1	RUS1	RUS2	RUS2
Year	1998	2004	1993	2004	1993	2004	1995	2004	1993	2004	1995	2004	1998	2004
	3.5	3,5	2,9	1,6	3,1	1,6	3,1	1,7	3,4	1,8	4,2	4,2	4	3,9
Dwarf shrubs	(5)	(5)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(5)	(5)	(5)	(5)
	1.9	1.5	1.9	0.6	1.7	0.5	0.8	0.2	1.9	0.6	2	2.1	1.1	1.3
Herbs & grasses	(4)	(4)	(3)	(2)	(4)	(3)	(2)	(1)	(3)	(2)	(3)	(4)	(3)	(2)
	5.1	5.3	4.6	2.3	4.7	2.4	4.7	2.5	4.6	2.2	1.2	1.3	2.1	1.7
Mosses	(7)	(8)	(9)	(7)	(8)	(7)	(6)	(6)	(7)	(6)	(3)	(3)	(4)	(3)
	1.3	1.7	1.5	0.7	2	2.4	1.5	1.8	1.6	1.5	0.7	0.9	1.1	1.5
Liverworts	(3)	(4)	(3)	(2)	(3)	(7)	(3)	(5)	(2)	(4)	(2)	(2)	(2)	(5)
	3.7	4.1	4.1	1.6	7.5	3.2	8.2	4.7	3.9	0.9	2.3	2.8	3.1	3.1
Lichens	(9)	(10)	(9)	(10)	(12)	(12)	(14)	(15)	(9)	(6)	(7)	(7)	(7)	(7)
	15.4	16	14.9	6.7	19.2	9.9	18.7	11.2	15.6	7.1	10.9	11.7	11.5	11.4
Total	(24)	(22)	(30)	(21)	(32)	(27)	(31)	(27)	(26)	(19)	(23)	(17)	(17)	(16)

Average percentage cover of species communities within the plots

There was a decrease in the percentage cover of lichens, liverworts and mosses on the RUS1 and RUS2 plots (Table 12). However, the cover of dwarf shrubs was significantly higher than that on the other plots.

In 2004, the cover of mosses on the RUS0, PA, PB, PC and PD plots, which are subjected to relatively insignificant levels of pollution, had increased higher. The cover of lichens and liverworts changed to only a very small extent (Table 13).

4.5.5 Preliminary results of ground vegetation analysis on the birch plots along the north-south transect (2004 survey)

The ground vegetation was analysed on 5 randomly selected 1 x 1 m quadrats on each plot. The plots (N06, N11) along the N transect were dominated by dwarf shrubs (*Empetrum nigrum ssp. hermaphroditum*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*) and herbs (mainly *Cornus suecica* and *Deschampsia flexuosa*). The cover of mosses and liverworts was low, and the contribution of the lichen community small.

The plots (S05, S10) along the S gradient were characterized by dominant dwarf shrubs and an insignificant cover of herbs. Although the moss, liverworts and lichen communities were abundant under unpolluted conditions, the absolute cover percentages were lower than on the pine plots. There was clear degradation of mosses, liverworts and lichens in the vicinity of the emission source, i.e. a decrease in both the percentage cover and species distribution. The lowest percentage cover and species composition of mosses and liverworts occurred on the S03 plot, adjacent to the pollution source (Fig. 13 and Table 14).

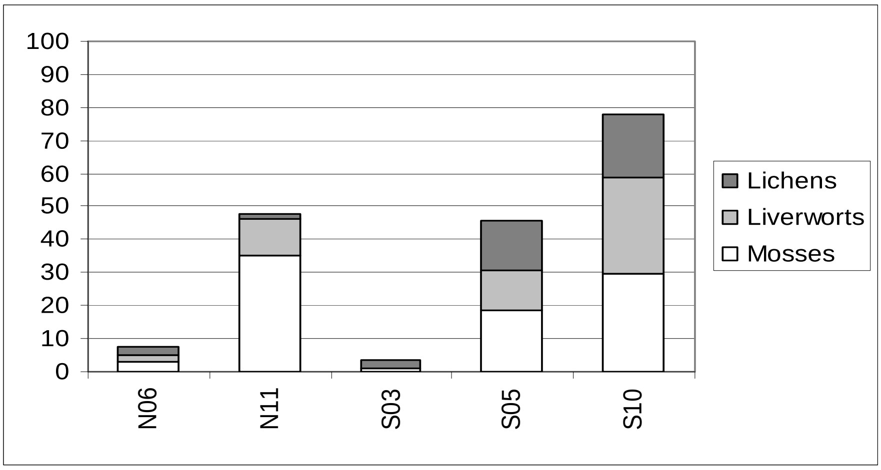


Figure 13. The projective cover of lichens, liverworts and mosses at the investigated sites

Table 13. The average percentage cover of species communities within the plots long the east-west pollution gradient at two different years.

Plot ID	RUS0	RUS0	PA	PA	PB	PB	PD	PD	PC	PC	RUS1	RUS1	RUS2	RUS2
Year	1998	2004	1993	2004	1993	2004	1995	2004	1993	2004	1995	2004	1998	2004
Dwarf shrubs	30.6	48.1	46.9	56.3	52.0	72.3	41.7	57.8	78.7	82.8	96.3	90.2	89.6	93.4
Herbs & grasses	0.6	0.5	4.4	3.4	2.7	2.3	0.9	1.7	4.7	4.3	3.2	2.0	1.1	1.2
Mosses	73.4	78.0	82.8	83.8	35.8	39.1	30.6	40.2	54.2	71.8	1.3	0.3	0.3	0.3
Liverworts	0.5	0.5	6.4	6.9	6.0	11.9	3.7	8.4	10.1	8.9	2.9	1.8	0.9	1.0
Lichens	13.0	13.7	5.6	5.3	12.0	9.4	19.7	27.7	6.1	2.3	2.5	0.3	0.8	0.6

Table 14. Average (maximum) number of plant species per m^2 grouped by community.

Plot ID	N06	N11	S03	S05	S10
Dwarf shrubs	2.6 (3)	3.2 (4)	3.6 (4)	3.0 (4)	3.0 (3)
Herbs & grasses	4.2 (5)	3.2 (4)	0.6 (1)	2.0 (4)	3.8 (4)
Mosses	2.6 (4)	4.8 (7)	0.6 (1)	2.8 (3)	4.6 (6)
Liverworts	1.8 (3)	2.8 (4)	0.4 (1)	3.6 (5)	3.8 (6)
Lichens	2.6 (6)	1.2 (3)	2.0 (6)	8.0 (11)	6.8 (9)
Total	13.8 (21)	15.2 (22)	7.2 (13)	19.4 (27)	22.0 (28)

4.5.6 Changes in species occurrence on the Norwegian and Russian plots during the lasta 4-10 years

The number of quadrats where the species percentage cover had decreased, remained stable or increased since the first analysis (PA, PB, PC in 1994, PD and RUS1 in 1995, RUS0 and RUS2 in 1998, and all the N and S plots in 2000) were calculated separately for the Norwegian and the Russian plots. The overall change (sum of increased and decreased quadrats) for each species is shown in Figs. 14a–f.

Vascular plants

The abundance of vascular plants was relatively stable on both the Norwegian and the Russian plots (Figs. 14 a and b). However, there was a major increase in *Vaccinium vitis-idaea* on all the plots. *Vaccinium myrtillus* and *Linnaea borealis* increased slightly on the Norwegian plots, while *Ledum palustre* increased to some extent on the Russian plots. There was no major decrease in vascular plants, apart form the slight decrease in *Empetrum nigrum* on the Russian plots.

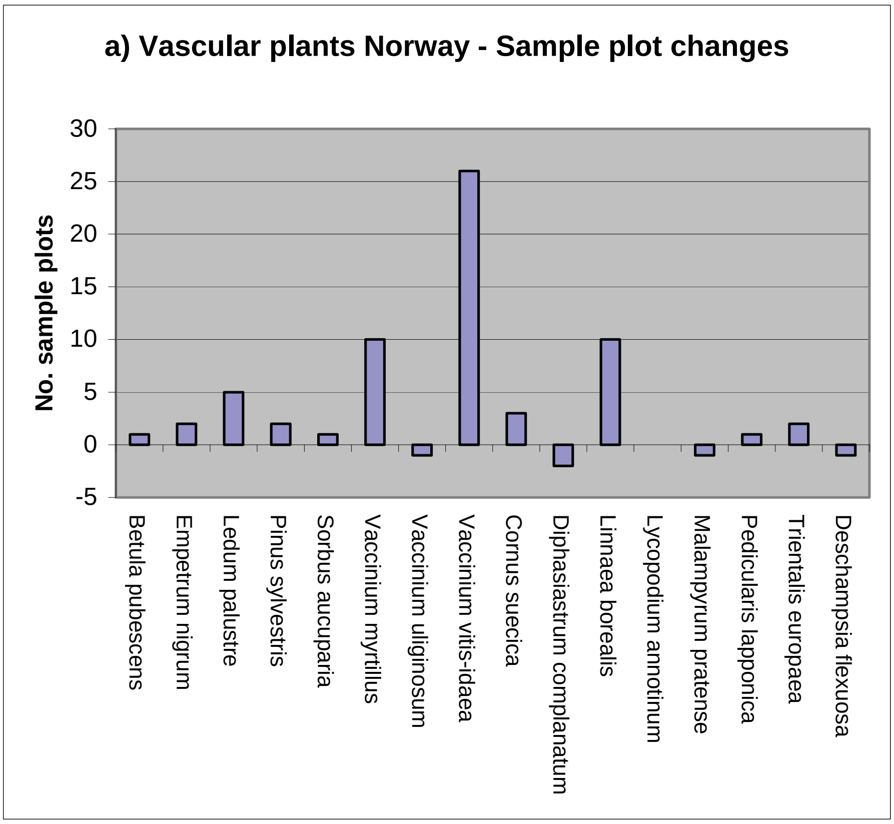
Bryophytes

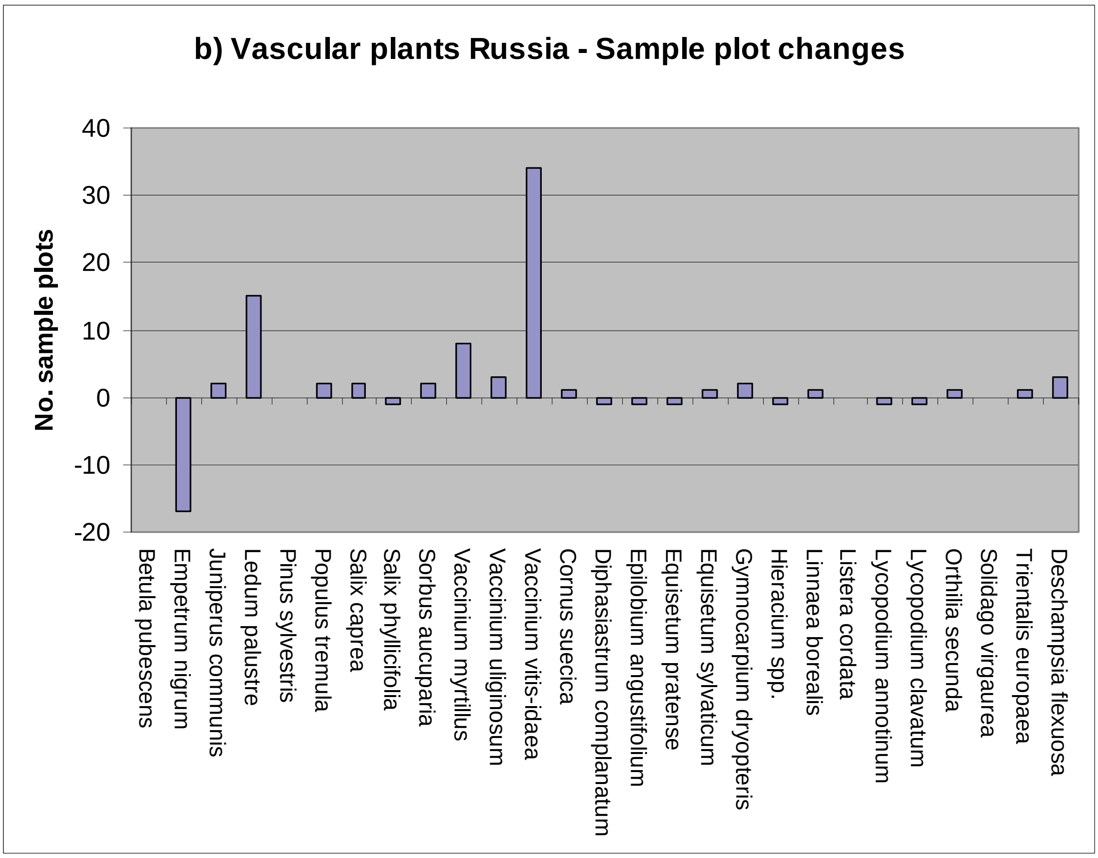
Several bryophytes increased their percentage cover on both the Norwegian and Russian plots, especially the liverworts *Barbilophozia* spp. and *Lophozia* spp. (Fig. 14 c and d). *Pohlia nutans* and *Pleurozium schreberi* also had an increasing cover, especially on the Russian plots, while *Dicranum scoparium* mainly increased on the Norwegian plots.

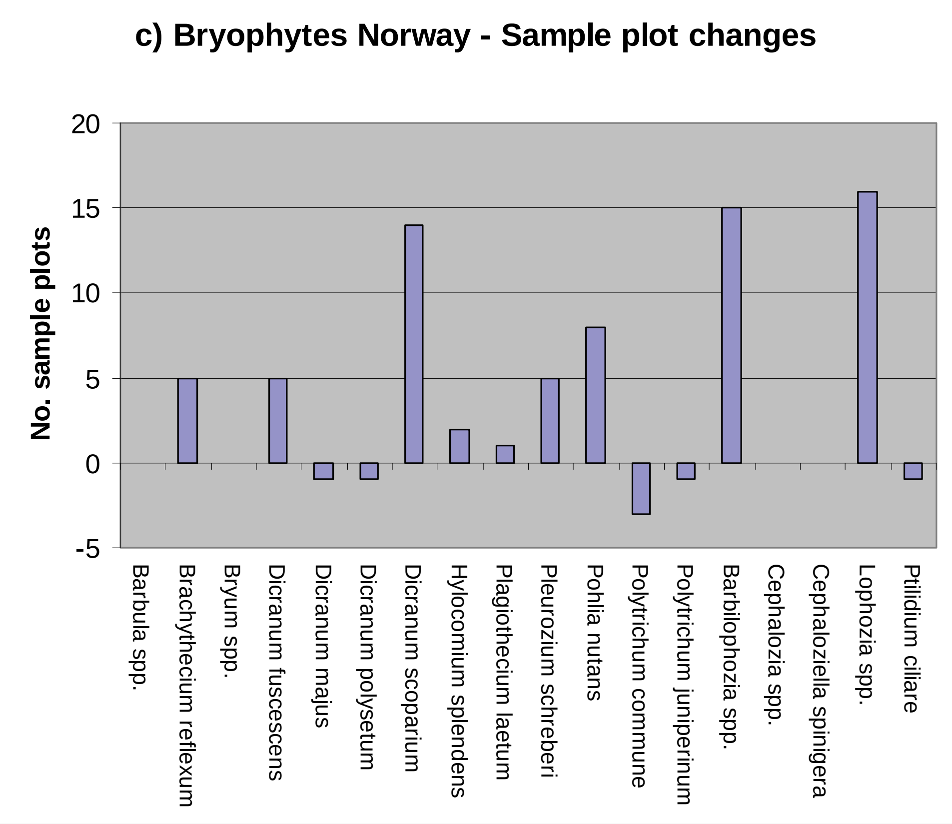
Lichens

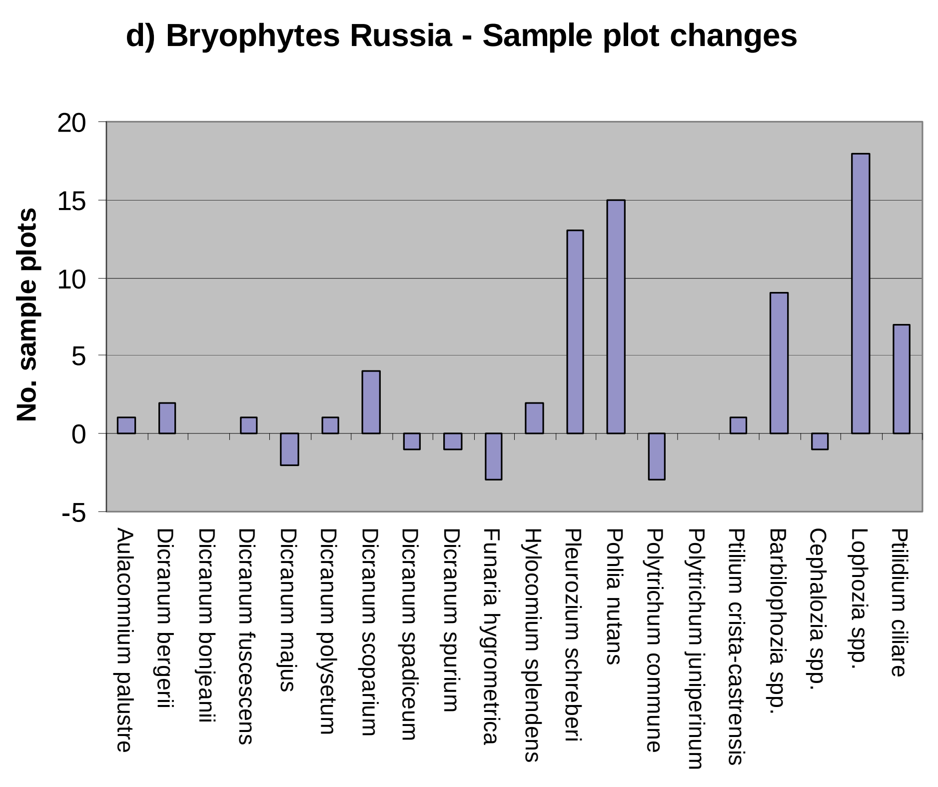
Several lichen species either increased or decreased their cover on the Norwegian plots (Fig. 14e). On the Russian plots, however, the cover of lichens mainly increased (Fig. 14f), especially the small cup lichens *Cladonia botrytes*, *Cladonia carneola* and *C. chlorophaea* coll., and the awl-shaped lichens *Cladonia furcata* and *C. gracilis*.

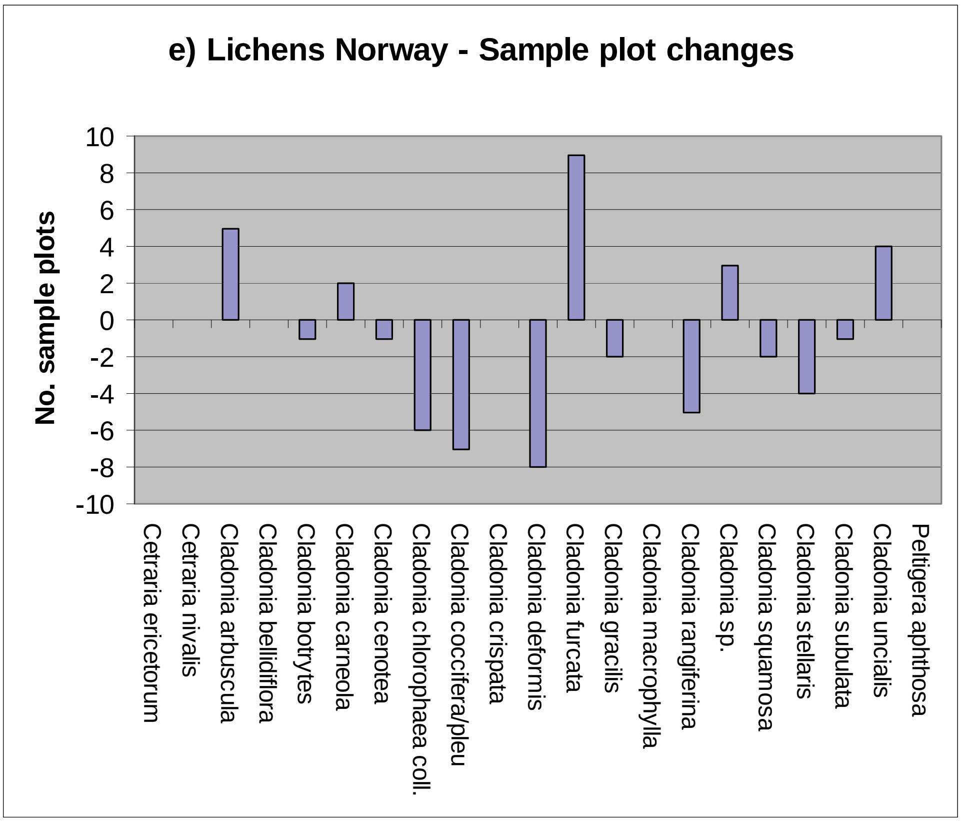
All the minor changes detected between these surveys may be due to year-to-year fluctuations in species abundance or estimation errors in the assessments. However, there are strong indications that several species, especially bryophytes and lichens, are recovering on some of the Russian plots. The changes in the abundance of lichens on the Norwegian plots may also be a result of varying grazing pressure by reindeer.


a) Vascular plants Norway - Sample plot changes
No. sample plots
30
25
20
15
10
5
0
-5
Betula pubescens
Empetrum nigrum
Ledum palustre
Pinus sylvestris
Sorbus aucuparia
Vaccinium myrtillus
Vaccinium uliginosum
Vaccinium vitis-idaea
Cornus suecica
Diphasiastrum complanatum
Linnaea borealis
Lycopodium annotinum
Malampyrum pratense
Pedicularis lapponica
Trientalis europaea
Deschampsia flexuosa

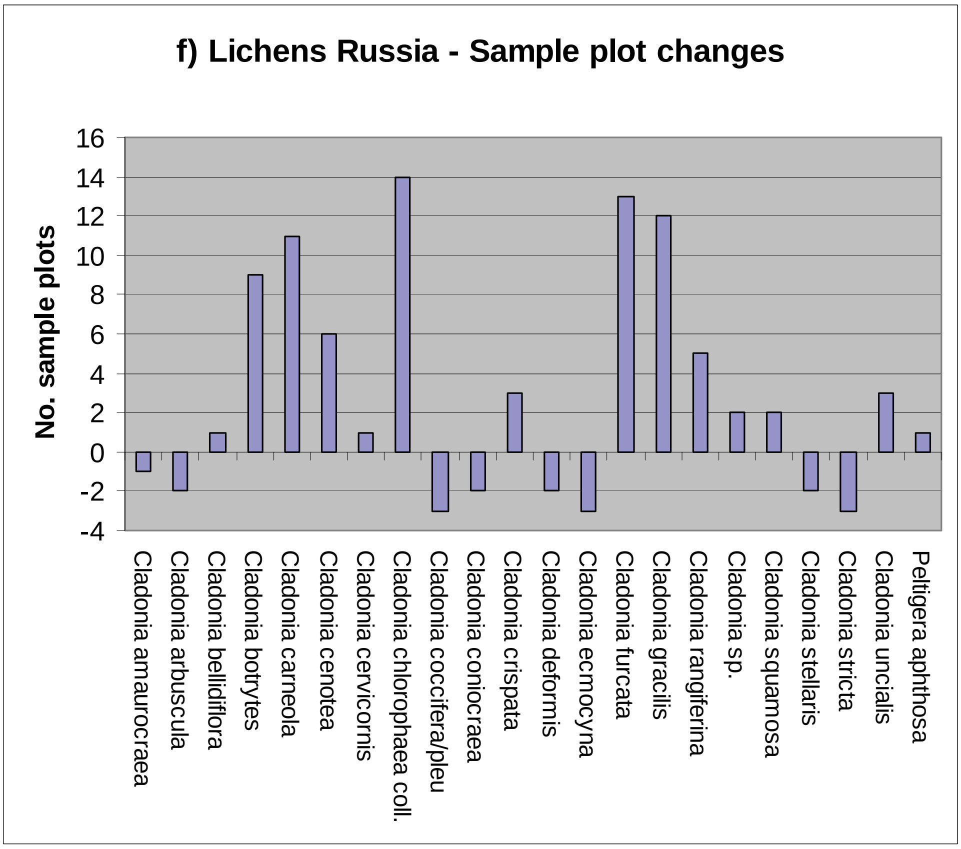

b) Vascular plants Russia - Sample plot changes
No. sample plots
40
30
20
10
0
-10
-20
Betula pubescens
Empetrum nigrum
Juniperus communis
Ledum palustre
Pinus sylvestris
Populus tremula
Salix caprea
Salix phyllicifolia
Sorbus aucuparia
Vaccinium myrtillus
Vaccinium uliginosum
Vaccinium vitis-idaea
Cornus suecica
Diphasiastrum complanatum
Epilobium angustifolium
Equisetum pratense
Equisetum sylvaticum
Gymnocarpium dryopteris
Hieracium spp.
Linnaea borealis
Listera cordata
Lycopodium annotinum
Lycopodium clavatum
Orthilia secunda
Solidago virgaurea
Trientalis europaea
Deschampsia flexuosa


c) Bryophytes Norway - Sample plot changes
No. sample plots
20
15
10
5
0
-5
Barbula spp.
Brachythecium reflexum
Bryum spp.
Dicranum fuscescens
Dicranum majus
Dicranum polysetum
Dicranum scoparium
Hylocomium splendens
Plagiothecium laetum
Pleurozium schreberi
Pohlia nutans
Polytrichum commune
Polytrichum juniperinum
Barbilophozia spp.
Cephalozia spp.
Cephaloziella spinigera
Lophozia spp.
Ptilidium ciliare


d) Bryophytes Russia - Sample plot changes
No. sample plots
20
15
10
5
0
-5
Aulacomnium palustre
Dicranum bergerii
Dicranum bonjeanii
Dicranum fuscescens
Dicranum majus
Dicranum polysetum
Dicranum scoparium
Dicranum spadiceum
Dicranum spurium
Funaria hygrometrica
Hylocomium splendens
Pleurozium schreberi
Pohlia nutans
Polytrichum commune
Polytrichum juniperinum
Ptilium crista-castrensis
Barbilophozia spp.
Cephalozia spp.
Lophozia spp.
Ptilidium ciliare



e) Lichens Norway - Sample plot changes



f) Lichens Russia - Sample plot changes

Figure 14. Changes of the abundance of different species within the quadrats (sample plots) in Norway and Russia, based on two different years of sampling (4-10 year intervals). Number of sample plots shows the overall change (the sum of sample plots where the species has increased or decreased) for a, b) vascular plants, c, d) bryophytes, e, f) lichens.

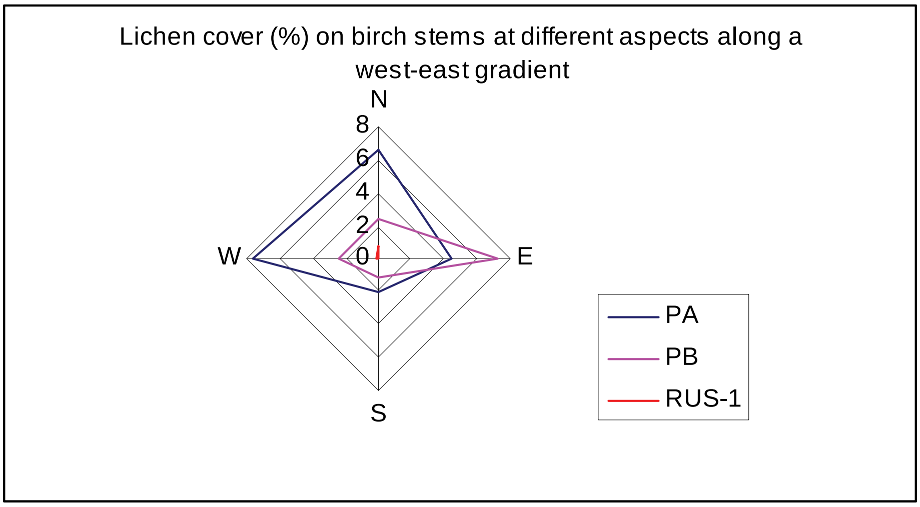
4.6 Epiphytic lichens

Jarle Werner Bjerke[2]*, Tor Myking*[3]*, Hans Nyeggen*[3] *and Hans Tømmervik*[2]

Birch stems

The most common lichens on birch stems in the area were *Hypogymnia physodes* and *Melanelia olivacea*. Epiphytic lichens are sensitive pollution indicators, and the degree of coverage is a reliable measure of the pollution load, especially of SO_2. The lichen cover was recorded on plots along a west-east transect (A) in 1995 and in 2004, and along a north-south transect (B) in 2004 (Fig. 15).

A.



B.

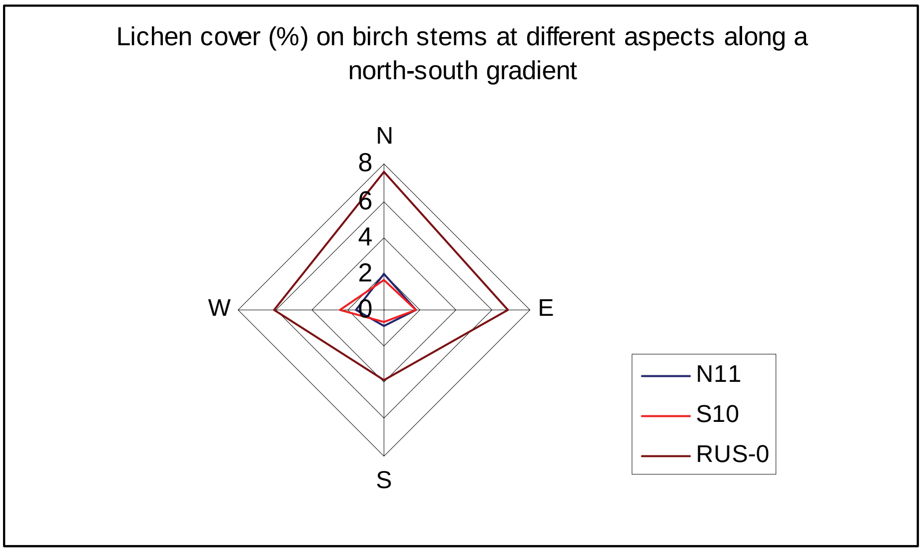


Figure 15. Mean lichen cover in % of total stem circumference, distributed on the different aspects (N, E, S, and W). A: west-east gradient, B: north-south gradient. The data refer to 2004.

A large area was clearly an epiphytic lichen “desert”, and this area corresponded well with the most heavily polluted area surrounding the emission sources in Nikel and Zapoljarni (Fig. 15) (Bruteig 1984, Aamlid and Skogheim 2001). Plots N06, S03, S11 and RUS2 had no epiphytic lichens on birch stems and were hence omitted from the figures (see Table 15). There was a clear increase, with increasing distance to the west, in the lichen cover to more than 20% of the stem circumference (PA). In the northern and southern directions the situation was the opposite; only the most remote plots had any lichen cover (N11 and RUS0, respectively).

Table 15. Mean lichen cover as % of the total stem circumference, and distributed on the different aspects (N, E, S, and W). A: north-south transect, B: west-east transect. The data refer to 2004.

	plot	Total	Total N	Total E	Total S	Total W
A	N11	0.62	0.20	0.17	0.08	0.17
	N06	0.00	0.00	0.00	0.00	0.00
	S03	0.00	0.00	0.00	0.00	0.00
	S05	0.00	0.00	0.00	0.00	0.00
	S10	6.41	1.60	1.79	0.62	2.40
	RUS0	24.23	7.57	6.74	3.84	6.07
B	PA	20.64	6.56	4.46	2.06	7.56
	PB	7.56	2.41	1.81	1.16	2.46
	RUS1	0.79	0.68	0.00	0.00	0.12
	RUS2	0.00	0.00	0.00	0.00	0.00

The southern aspect of the stems had consistently the lowest lichen coverage. On the plots located to the north and north-west of Nikel, pollution may have contributed to this pattern (Aamlid et al. 2000). However, because this is also the case on the reference plot in the south (RUS0), the irradiance level, species composition (cf. Aamlid and Skogheim 2001) or other natural environmental factors may be equally or more important factors determining the distribution of epiphytic lichens on the different aspects of the stem.

Comparison between the first (1995-98) and second (2004) survey of epiphytic lichen cover shows that lichens have recolonised to a substantial extent on the least polluted plots on the east-west transect (PA and PB) within a period of only a few years (Fig. 16, Table 16). The lichen cover may have decreased slightly on the most polluted plots close to the smelters, but these results should be treated with caution due to the low initial coverage. The coverage on the reference plot in Russia (RUS0) has decreased slightly, but it is not likely to be affected by pollution owing to its remote position and the prevailing wind directions from south-southwest (Hagen et al. 2006). The recolonisation of epiphytic lichens found in this survey is in agreement with the reduction in emissions from Nikel and Zapoljarni that has taken place over the last 2-3 decades (Aamlid 2002).

Table 16. % coverage of lichens in 1995-98 and 2004.

1995 PA	2004 PA	1995 PB	2004 PB	1995 RUS1	2004 RUS1	1998 RUS2	2004 RUS2	1998 RUS0	2004 RUS0
12.04	20.64	3.03	7.56	1.86	0.79	1.02	0.00	26.73	24.23

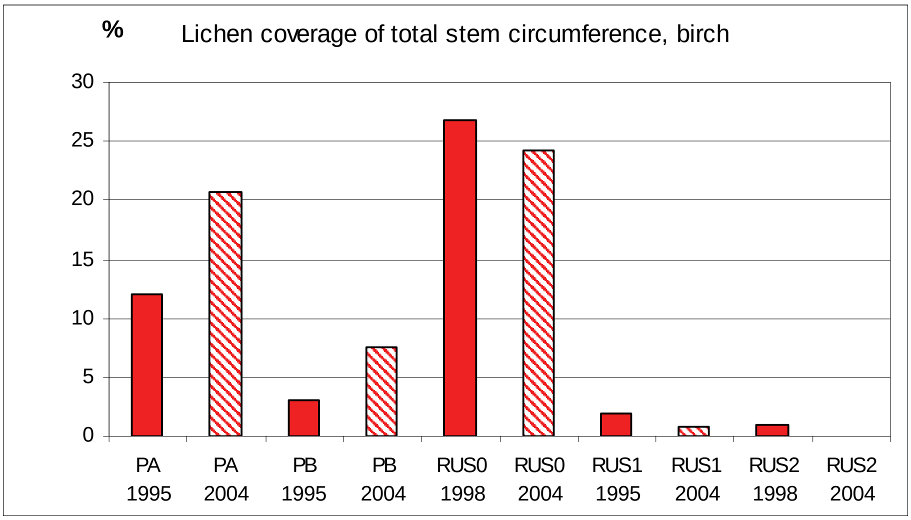


Figure 16. Percent coverage of all lichens of total stem circumference in 1995-98 and 2004.

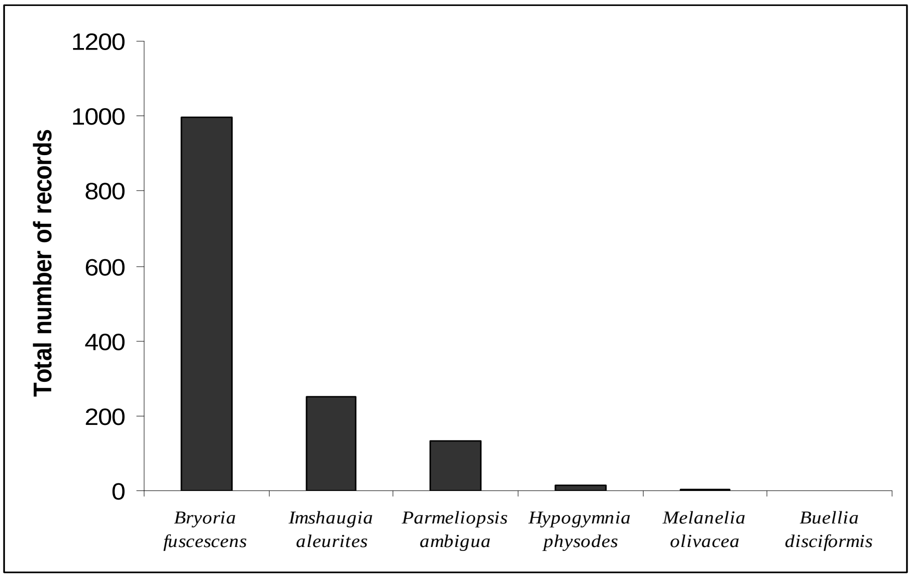


Figure 17. Number of records of lichens on the seven investigated sites around Inari.

Pine stems

The epiphytic lichen cover was surveyed on 7 of the pine plots in Finland in 2005. The plots were species-poor with only five lichen species present. *Bryoria fuscescens,* and probably also a few specimens of other *Bryoria* species, e.g. *B. freemontii* (however, no yellow soralia visible), *B. simplicior* and *B. furcellata*, was by far the most common lichen (Fig. 17). It was recorded four times more frequently than the next lichen on the list, *Imshaugia aleurites*, which in tuen was recorded twice as frequently as the third lichen on the list, *Parmeliopsis ambigua*. *Hypogymnia physodes* was very rare, whereas *Melanelia olivacea* and *Buellia disciformis* were recorded only twice and once, respectively. The plots closest to Nikel had the lowest lichen abundance with less than 10% total cover, whereas the plots farther away from Nikel had up to 23.4 % total lichen cover (Fig. 18).

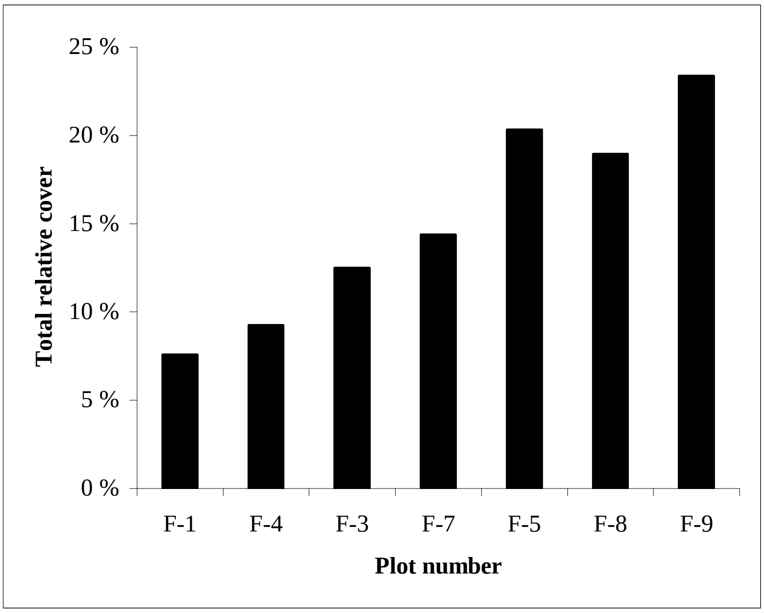


Figure 18. Total lichen cover at the seven investigated sites arranged according to distance from Nikel (site 612 nearest).

There was a strong relationship between the distance to Nikel and the lichen cover (Fig. 19). The N-facing sides of the tree trunks generally had the highest relative lichen cover, and the S-facing and E-facing sides usually had a very low cover or no cover at all (Fig. 19). At the plots closest to Nikel (plots 612 and 513), the E-facing sides of the trunks had no lichen cover, whereas on the three plots farthest away from Nikel, the lichen cover on the E-facing sides contributed 25-30% of the total lichen cover. The lichen cover on the N-facing side was as low as 29% on one plot at intermediate distance from Nikel, but the north-facing side on the two plots closest to Nikel had 68% and 82% of the total lichen cover. Some of the variation in the lichen cover was not related to the distance to Nikel, and was probably more attributable to differences in microclimate between the plots. This is supported by the low correlation for the S-facing side (Fig. 19). The coefficient of determination (R^2) for the total lichen cover is 0.75, whereas for the W, N, E and S directions the values are 0.45, 0.41, 0.64 and 0.03, respectively. Hence, the E-facing side, which is the side facing Nikel, shows the strongest correlation with distance. For the S-facing side, the correlation is non-significant.

The survey on the 7 Finnish plots strongly indicated that the epiphytic vegetation is affected by air pollution from Nikel. Although none of the plots were totally lacking in lichens, there was a strong correlation between the distance to Nikel and the abundance of lichens. As this relationship does not seem to be correlated with any climatic gradient, pollutants from the smelter are the most likely factor accounting for the variation in distribution patterns. The effects of air pollution are further supported by the intra-trunk variation in lichen cover. The side of the trunk facing Nikel in general contributed only a small proportion of the total lichen cover, especially at the plots closest to Nikel. There was probably a larger amount of sulphur and heavy metals accumulated on this side of the trunk than on the other sides. The epiphytic lichen vegetation on the plots farthest away from Nikel did not show any clear response to emissions from Nikel. These plots had a relatively high lichen cover, and the E-facing side of the trunks actually had a higher lichen cover than the W-facing side. This indicates that the accumulation of sulphur and heavy metals on the E-facing side is not greater than on the other sides. The higher lichen cover on the N-facing side is most certainly an effect of the microclimatic conditions. The N-facing side dries out much slower than the other sides, providing suitable moisture conditions for lichen growth. The opposite is the case on the S-facing side, which dries out faster and is therefore less suitable for lichen growth.

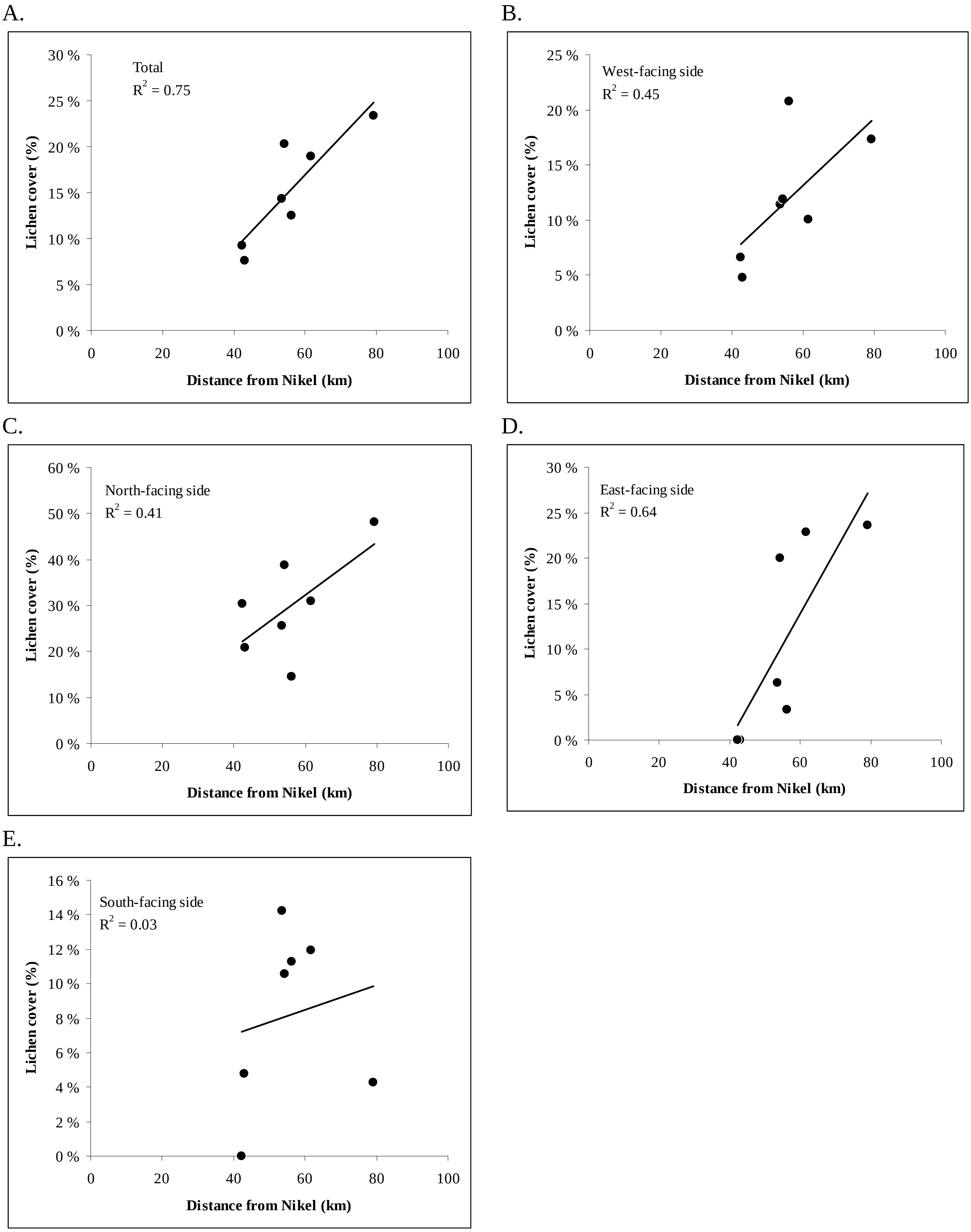


Figure 19. Lichen cover as a function of distance from Nikel. A. Total lichen cover (all directions), B. West-facing side of trunks, C. North-facing side, D. East-facing side of trunks, E. South-facing side of trunks.

4.7 Photosynthetic efficiency

Hans Tømmervik[2]

4.7.1 Estimation of plant vitality by means of fluorescence measurements on the INEP/NINA plots

Airborne pollutants can limit the growth of plants especially at high latitudes. Under such conditions the plants are growing at the limits of their distribution and at the extreme range of their habitat tolerance (Bliss l962). A sustained reduction in the efficiency of photosynthesis system II (PSII) has been reported in many species after exposure to unfavourable conditions (Osmond 1994, Demmig-Adams et al. 1998). Multiple environmental stresses lower the photosynthetic rate and increase the degree to which the absorbed light energy can be excessive and potentially damaging to PSII. The lowered photosynthetic efficiency (Fv/Fm) of PSII in stressed plants is inversely related to the energy release from the conversion states in the carotenoids of the xanthophyll cycle. This cycle, found to be present in all the higher plant species (ca. 30) investigated so far, safely dissipates the potentially destructive excess energy (for a review, see Demmig-Adams and Adams l996). This protective process, termed "photoinhibition" (Demmig-Adams et al. l998; Krause l994) or "photoinhibition of PSII" (Osmond l994), can be quantified on the basis of the ratio of the variable to the maximal chlorophyll fluorescence (Fv/Fm) (Kitajima and Butler l975). Odasz-Albrigtsen et al. (2000) found that the photosynthetic efficiency in birch *(Betula pubescens)* and bilberry *(Vaccinium myrtillus*) was negatively correlated with the concentrations of Cu, Ni, and SO_4, derived from emissions from the Cu–Ni smelters, in birch and bilberry leaves. Measurement of fluorescence in these species was found to be a sensitive indicator of the impact of air-borne pollutants. However, as the measurements and analyses have so far only been performed in the Norwegian part of the region, we considered it important to evaluate the variation in the photosynthetic efficiency of plants growing along the relatively sharp deposition gradients running from Nikel.

The photosynthetic efficiency (fv/fm index) of birch and bilberry, as well as the concentrations of airborne pollutants in the leaves of the same species, was measured at 17 plots along the northern, southern and western transects in 2000. In 2004, the same parameters were measured on the same species (same trees and cluster of plants) on 5 plots (S03, S05, S10, N06 and N11) along the northern and southern transects. In addition, photosynthetic efficiency was measured in lichens (mainly "reindeer lichens; *Cladonia* spp.) and in mosses *(Pleurozium schreberi* and *Hylocomiun splendens*), if present, on the same plots. The photosynthetic efficiency measurements were made with a Hansatech Plant Efficient Analyser. The Hansatech instrument was calibrated with the Plant Stress Meter used in the previous investigations in the area (Odasz-Albrigtsen et al. 2000). The number of trees, plants, mosses and lichens on each plot was 5, and 5 measurements were performed on each tree/plant/moss/lichen. The instrument is specifically designed for measuring plant vitality (chlorophyll fluorescence), expressed as the photosynthetic efficiency fv/fm. Chlorophyll fluorescence was measured in intact leaves on the lower branches of the birch trees, on leaves in the top of the bilberry plants, on the upper half of the thallus of the lichen clusters, and on the upper half of the green leafy moss clusters. Only green leaves were measured, and the leaves were selected at random. However, damaged or discoloured leaves were avoided. We compared the measurements from two years (2000 and 2004) in our study in order to assess whether there has been a change in vitality in the area. Statistical analysis (e.g. correlation analysis) was used to assess the suitability of fluorescence measurements in monitoring plant vitality in the study area.

The measurements of photosynthetic efficiency in 2004 showed that there was an increase in the vitality of birch and bilberry along the southern transect (S03, S05 and S10, negative values) from Nikel (Table 17 and Fig. 20), as well as a smaller increase along the northern transect (N06 and N11, positive values) from Nikel, compared to the situation in 2000 (Yoccosz et al. 2001). Maximum values of fv/fm in both species were obtained on plot S10 on the southern transect, which is located 31 km from the Cu-Ni smelters.

The vitality in 2004 was significantly better than that measured in 2000 (Table 18), indicating that growing conditions for the plants and trees have improved in the area since 2000 (Yoccosz et al. 2001).

Table 17. The photosynthetic efficiency expressed as mean fv/m for birch (B), bilberry (VM), reindeer lichens (Clad) and mosses (Moss).

Station	Transect	Altitude	fv/fm_B	fv/fm _VM	fv/fm_Clad	fv/fm_Moss
N11	N	55	0.70	0.73	0.60	0.66
N06	N	105	0.69	0.70	0.00	0.71
S03	S	40	0.69	0.75	0.00	0.73
S05	S	150	0.73	0.77	0.51	0.66
S10	S	213	0.73	0.79	0.54	0.74

Table 18. The photosynthetic efficiency expressed as mean fv/m for birch (B) and bilberry (VM). The values for S3 in 2000 are the means between S02 and S04, while the values for S05 are the means between S04 and S06, respectively.

Station	Transect	Altitude	fv/fm_B 2000	fv/fm_B 2004	fv/fm _VM 2000	fv/fm _VM 2004
N12	N	45	0.76		0.73	
N11	N	55	0.69	0.70	0.69	0.73
N10	N	65	0.72		0.65	
Zapolyarniy						
N08	N	245	0.60		0.55	
N06	N	105	0.45	0.69	0.58	0.70
N04	N	110	0.61		0.69	
N03	N	65	0.55		0.54	
N01	N	75	0.55		0.58	
Nikel						
S02	N	46	0.54		0.52	
S03	S	40	0.54	0.69	0.52	0.75
S04	S	100	0.55		0.52	
S05	S	150	0.54	0.73	0.49	0.77
S06	S	225	0.54		0.47	
S09	S	268	0.56		0.59	
S10	S	213	0.52	0.73	0.61	0.79

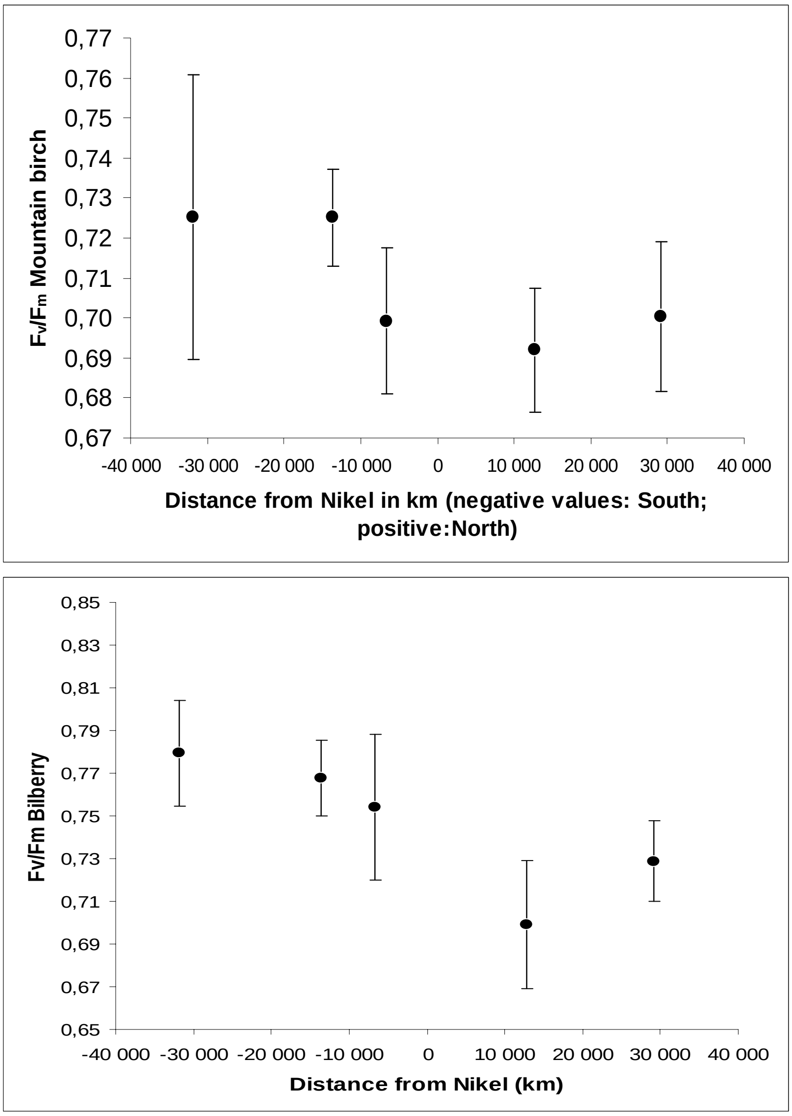


Figure 20. The vitality of the mountain birch *(Betula pubescens* ssp*. czerepanovii)* and the bilberry *(Vacciniun myrtillus)* expressed as the photosynthetic efficiency (fv/fm) was measured along the north-south transects through Nikel. The plots N11 (the most right error bar) and S10 (the most left error bar) are located 29 and 31 kilometres from the smelter in Nikel, respectively.

4.7.2 Relationship between photosynthetic efficiency and Cu and Ni concentrations in birch leaves

The fluorescence measurements were analysed against different environmental parameters and concentrations of heavy metals in the soil and leaves using statistical analysis. A curvilinear, significant relationship was found between the Cu and Ni concentrations in birch leaves and the fv/fm measurements on 17 plots along the northern, southern and western transect on the basis of data from 2000 (Fig. 21). The relationship between the Cu and Ni concentrations in the organic layer at the same sites and the photosynthetic efficiency were weaker but significant.

These results show that the fluorescence method is suitable for the measurement of plant vitality on birch and bilberry, but not on lichens and mosses. Another procedure for lichens and mosses using total wet samples is recommended in the future (Bjerke 2006, oral communication).

Similar conclusions were drawn in a similar study conducted in 1993 by Odasz-Albrigtsen et al. (2000). However, the SO_2 concentration in the ambient air, as well as environmental stress factors, also have a significant effect on plant vitality. The best plant species (indicator) for fluorescence measurements is considered to be bilberry, as concluded by Odasz-Albrigtsen et al. (2000).

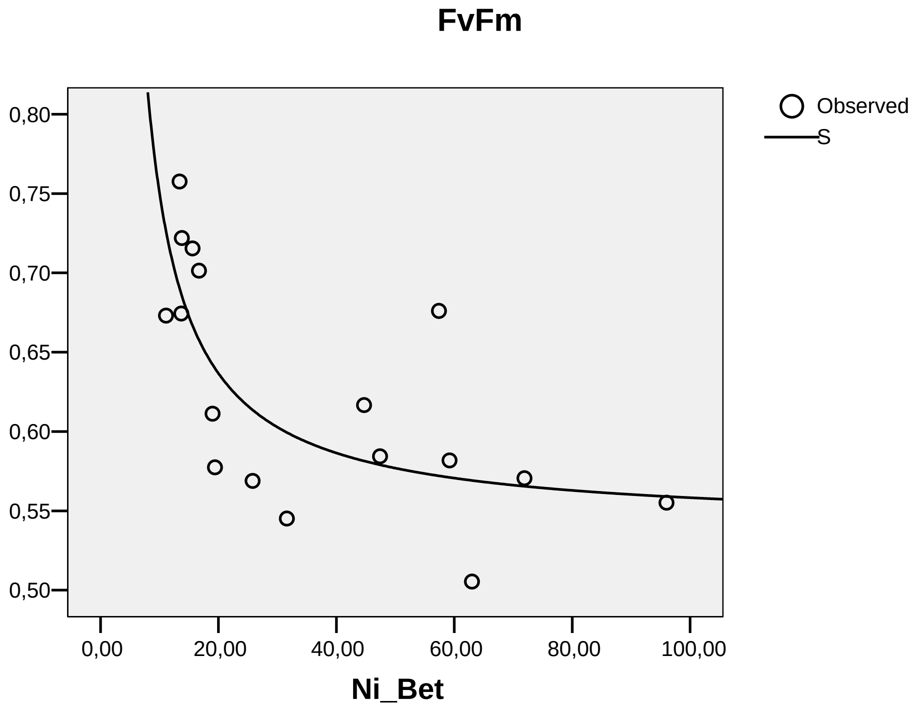


Figure 21. The relationship between the nickel concentration in birch leaves (ppm) and the photosynthetic efficiency (vitality) in birch trees expressed as fv/fm. Data are from year 2000 and are based on 17 plots along the northern, southern and western transects from Nikel.

4.8 Element concentrations in plants

*Ludmilla Isaeva[4], Jarmo Poikolainen[1], Tor Myking[3], John Derome[1],
Tatyana Sukharev[4] and Pasi Rautio[1]*

4.8.1 Mosses

Terrestrial mosses have been widely used as biomonitors in regional heavy metal surveys. They are highly suitable heavy metal biomonitors because they obtain most of their nutrition from wet and dry deposition, and they also have several properties that promote the accumulation of heavy metals. The deposition of heavy metals (Cd, Co, Cr, Cu, Fe, Ni, Pb, Ti, V, Zn) and sulphur in the area affected by emissions from the Nikel smelters was investigated by collecting and analysing moss samples. The samples were collected in August 2004 from 16 plots located at distances ranging from 7 – 72 km from the smelter. The moss species collected on the Finnish plots (9 plots) were *Hylocomium splendens* and *Pleurozium schreberi*, and on the Norwegian plots (5) only *Hylocomium schreberi* and on the Russian plots (2) only *Pleurozium schreberi*. In cases where both moss species were obtained from the same plot, only the concentrations in *Hylocomium splendens* are presented in this report. No moss samples were obtained from the background plot (RUS0).

Metal concentrations in the mosses

The concentrations of most of the heavy metals, especially Ni and Cu, were high at a distance of 10 km from the emission source. The Ni concentration on the plot nearest to the smelter was 517 mg/kg and the Cu concentration 290 mg/kg (Table 19). The Co (14.5 mg/kg), Cd (0.63 mg/kg), Cr (6.2 mg/kg), Fe (1638 mg/kg) and Pb (17.5 mg/kg) concentrations were also relatively high near the smelter, whereas the V, Zn and Ti concentrations were not noticeably elevated. The heavy metal concentrations clearly decreased at distances greater than 25 – 30 km from the smelter The heavy metal concentrations on the Finnish plots were relatively low. The Ni, Cu and Co concentrations decreased the most regularly with increasing distance from the smelter (Fig. 22). The Pb, Cd and Cr concentrations were relatively high near the emission source, but they decreased relatively sharply already at a distance 10 km. There was no decreasing trend in the Mn and Ti concentrations.

The degree and extent to which emissions are spread depends on the type of emission source, the composition of the emissions and the weather conditions. In general, heavy metals are attached to the emitted particles, and the majority of the heavy metal emissions are deposited close to the source. According to the concentrations in the mosses, most of the heavy metals emitted from the Nikel smelter are deposited on the ground and vegetation cover at distances of less than 10 km. The heavy metal concentrations, apart from those of Ni and Cu, on the Finnish plots were at almost the same level as a the median values in the nation-wide surveys in 2000 on mosses in Norway (Steinnes et al. 2001) and in Finland (Poikolainen et al. 2004). In other words, they were close to the so-called background levels. However, the Ni concentrations on the Finnish plots were 5 – 10 and the Cu concentrations 2 – 3 times higher than the median value in the Norwegian and Finnish surveys in 2000. Similar results have also been reported in other surveys on heavy metal concentrations and damage to a number of plant species in the surroundings of the Nikel smelter (Gytarsky et al. 1994, Tikkanen & Niemelä 1995, Aamlid et al. 2000)

Table 19. Heavy metal and sulphur concentrations (mg/kg) in mosses (mean, median, standard deviation, minimum, maximum, correlation, F-value and significance in relation to distance from the smelter).

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Ti*	V*	Zn	S
Mean	0.17	3.02	1.54	57.0	509	522	93.8	4.48	27.7	1.07	34.3	976
Median	0.10	0.85	1.09	18.9	291	467	26.7	3.05	19.1	0.90	27.5	890
Stand dev	0.14	3.98	1.33	76.9	479	235	135.8	3.86	26.5	0.45	15.6	292
Minimum	0.06	0.37	0.83	8.4	136	236	9.7	1.80	4.0	0.62	19.4	657
Maximum	0.63	14.46	6.21	290.2	1638	1212	516.6	17.54	106.0	2.04	77.2	1824
Correlation	-0.722	-0.811	-0.502	-0.776	-0.832	-0.196	-0.763	-0.650	-	-	-0.661	-0.794
F value	14.16	24.94	4.39	19.68	29.32	0.52	18.13	9.53	-	-	10.11	22.22
P	0.002	0.000	0.056	0.001	0.000	0.483	0.001	0.009	-	-	0.007	0.000
Median[1]	0.09	-	0.69	4.26	365	-	1.11	2.70	-	1.36	29.4	-
Median[2]	0.12	-	1.25	3.96	259	-	1.83	3.37	-	1.45	28.8	-

Median[1] = Concentrations in mosses in Norway 2000 (Buse et al. 2003, Steinnes et al. 2001)
Median[2] = Concentrations in mosses in Finland 2000 (Buse et al. 2003, Poikolainen et al. 2004)
* No concentration on the sample plot RUS1

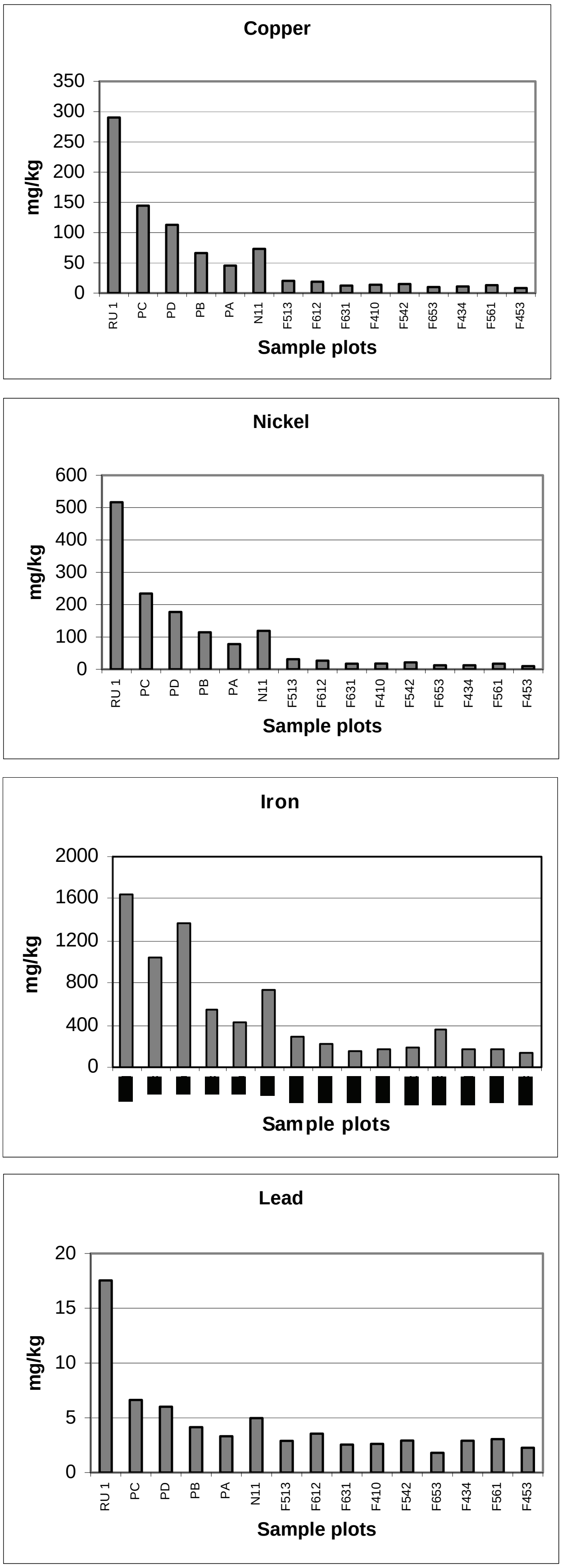


Figure 22. The concentrations of copper, nickel, iron and lead in mosses on the sample plots.

The Ni and Cu concentrations in mosses in 2004 were clearly higher than those reported in the 1990´s on the plots located nearest to the smelter (RUS1), and also slightly higher on some of the Norwegian plots (PC, PD) (Aamlid et al. 2000). The Ni concentration in mosses also increased in NW Finland between 1985 to 2000, but the Cu concentration remained relatively constant during the period 1985 – 2000 (Poikolainen et al. 2004). The year-to-year variation in Cu and Ni concentrations are mainly due the weather conditions and the emission levels, Reimann et al. (1998) found, in their heavy metal studies on the Kola Peninsula, that the concentrations of many of the elements in mosses are probably more closely related to the chemical composition of rainwater than to the annual deposition level.

The heavy metal concentrations in mosses do not directly reflect the total deposition of heavy metals. There are differences in the accumulation of heavy metals in mosses, and the concentrations in mosses are also affected by factors other than atmospheric pollution. Factors affecting the concentrations in mosses, especially in the surroundings of the Nikel smelter, are the weather conditions, the amount of soil dust in the air, and the condition of the mosses. Soil dust has been shown to have a significant effect on the Fe, Ti and Cr concentrations in mosses. However, the Cu and Ni concentrations in mosses are especially good indicators of the spread of Cu and Ni emissions in the surroundings of the Nikel smelter.

Sulphur concentration in mosses

The sulphur concentration in mosses near the smelter was very high (1824 mg/kg). The concentrations on the Norwegian plots ranged from 1010 mg/kg to 1233 mg/kg, and on the Finnish plots from 709 mg/kg to 896 mg/kg. Although the decrease in the sulphur concentration was significantly related to the increasing distance from the smelter (Table 19), the sulphur concentration did not decrease (Fig. 23) as clearly as the Ni and Cu concentrations (Fig. 22).

Mosses are not considered to be especially good biomonitors of sulphur deposition, although sulphur concentrations have been found to reach high levels close to emission sources and to correspondingly decrease with increasing distance from emission sources (Mäkinen 1994, Äyräs et al. 1997). The results of this survey support these earlier findings. The reason why mosses are relatively poor bioindicators may be that sulphur at high concentrations damages the mosses and alters their accumulation capacity. There is also natural variation in the sulphur concentration of plants in the study area, which is due e.g. to the maritime climate (Kashulina et al. 2003). However, the sulphur concentrations in mosses indicate elevated sulphur deposition in the study area, and sulphur emissions from the smelter are clearly distributed over a larger area than the heavy metal emissions. The sulphur concentrations in mosses were now higher than in 1994 on the plots nearest to the smelter (RUS1), and slightly lower on the Norwegian plots (Aamlid et al. 2000).

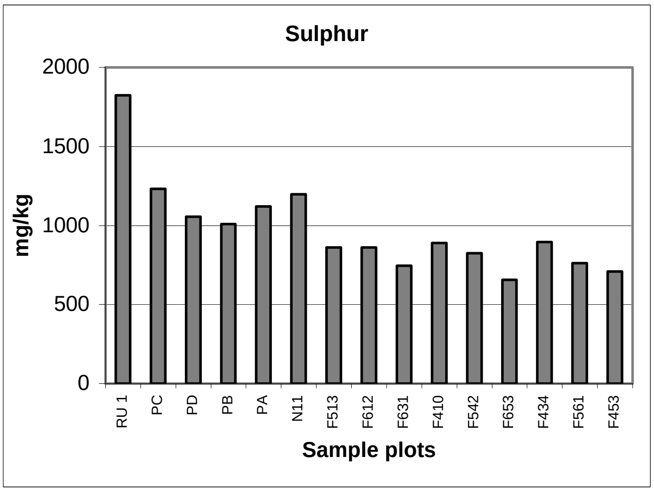


Figure 23. The sulphur concentration in mosses on the sample plots.

4.8.2 Other vegetation

Bilberry leaves (*Vaccinium myrtillus*), wavy hair-grass (*Deschampsia flexuosa*) and reindeer lichen (*Cladonia rangiferina*)

In general, there was a clear gradient in the Cu and Ni concentrations in all three species, with the highest values on the plots close to the smelters (Table 20). In bilberry leaves and wavy hair-grass, the highest Cu and Ni concentrations occurred on the plot to the north of the emission source (N06) and not on the plots close to the smelter (e.g. RUS1), and there were also extremely high Ni concentrations in wavy hair-grass on the Russian reference plot (RUS0). There was no clear pattern for the Zn concentrations, although the highest Zn concentrations in wavy hair-grass occurred in the affected area (e.g. PA, PB) rather than in the reference area (Finland).

Reindeer lichens are unique in their ability to accumulate heavy metals over a period of several years. This phenomenon was reflected in the results of this survey, the Cu and Ni concentrations being about 20 times higher than those in the vascular plants on the most polluted plots. The Cu and Ni concentrations in reindeer lichen were strongly related to the distance from the emission source, the concentrations consistently decreasing on moving to the S, W and N from the emission source. The Co, Cr and Pb concentrations were also strongly elevated on the plots close to the smelters. As for vascular plants, there was no clear gradient in the Zn concentrations in reindeer lichens, although the highest levels occurred in the most contaminated area (N05, N06).

When the Cu and Ni concentrations in reindeer lichen (*Cladonia rangiferina*) in the present survey are compared with the concentrations in *C. stellaris* collected on the same plots 8 years earlier (Aamlid et al. 2000), it is clear that the concentrations of Cu and Ni have increased considerably during the 8-year period. The increase in the Ni concentration on plot PD was two-fold. The gradient in the heavy metal concentrations (PA-PD, RUS1-RUS0) also resembles that reported by Aamlid et al (2000). However, the fact that different species of reindeer lichen were sampled in the two surveys makes this comparison somewhat uncertain.

Table 20. Heavy metal content (mg/kg) in vascular plants (bilberry leaves, wavy hair-grass) and reindeer lichen.

Species	Metal	F-4	F-5	F-6	PA	PB	PC	PD	RUS1	RUS0	N11	N06	S05
Vaccinium	Cu	5.01	5.35	6.23	6.23	5.66	9.28	6.55	11.01	6.14	6.86	17.30	6.71
Myrtillus	Ni	1.73	1.68	1.88	6.99	5.64	15.97	9.92	19.97	4.87	6.69	37.92	13.41
	Zn	11.30	11.06	10.49	11.83	10.72	9.02	8.89	7.15	12.66	11.83	8.11	9.22
Deschampsia	Cu	3.518	3.649	3.337	3.050	3.749	5.020	3.622	7.747	8.830	3.559	7.573	3.715
Flexuosa	Ni	3.329	3.652	3.579	7.750	9.217	12.799	6.634	10.625	22.705	6.693	26.891	10.526
	Zn	15.993	17.164	11.655	20.461	20.003	19.807	13.270	18.025	16.083	14.708	13.909	13.158
Cladonia	Co	0.433	0.612	0.437	1.945	2.534	6.306	3.889	10.493	1.119	2.298		7.634
Rangiferina	Cr	0.617	0.607	0.523	1.090	1.090	1.508	1.090	3.093	0.640	1.090		3.095
	Cu	11.465	13.178	10.827	34.444	48.234	111.403	74.290	147.393	13.774	40.736		98.287
	Ni	12.653	18.280	13.554	56.303	76.264	172.255	110.199	232.237	23.981	63.348		125.694
	Pb	1.613	1.921	2.207	1.450	2.279	3.937	2.693	5.777	1.408	2.072		8.029
	Zn	19.109	17.588	14.772	24.122	19.742	18.957	18.238	24.153	14.758	26.671		25.972

4.8.3 Scots pine and birch foliage

Sulphur and heavy metals are the main pollutants affecting the boreal forests in NW-Russia. In addition to the direct toxic effect of these pollutants on tree foliage, they can also reduce the availability of macro- and micronutrients as a result of leaching from the soil and from the foliage (Lukina and Nikonov 1998, Aber et al., 1989, Darrall 1989, Innes 1995). Disturbances in the nutrient status of the soil take place when acidifying compounds (e.g. SO_2/sulphuric acid, NO_x/nitric acid) displace important macronutrients such as Ca and Mg (as cations, Ca^{2+}, Mg^{2+}) on the cation exchange sites in the soil (Zoettl and Huettl 1991). However, acidifying nitrogen deposition in the region is relatively low. Acidification of the soil may also increase the concentrations of soluble aluminum species (e.g. Al^{3+}) which, in turn, have antagonistic effects with other cations (e.g. Ca), thus reducing the uptake of important nutrient elements (Evers and Huettl 1991).

We studied the chemical composition of pine (*Pinus sylvestris* L.) and birch (*Betula pubescens* Ehrh.) foliage in order to assess the spatial variation in the concentrations of heavy metal and sulphur pollutants, and to assess the possible impact of the pollutants on the nutrient status of the trees. Determination of the element concentrations of tree foliage is one of the most common methods for monitoring forest vitality, assessing the impacts of pollution, and determining the nutrient status of trees (Mitrofanov 1977, Prokushin 1982, Il’in 1991, Huttunen et al. 1985, Helmisaari 1992, Tikkanen and Raitio 1990, Huettl and Fink 1991, Brække 1996).

Material and methods

A total of 20 sampling plots in birch and pine stands were investigated: 9 in Finland, 7 in Russia, and 4 in Norway (see Fig. 1). Needle and leaf samples were collected at the end of the growing period (August). Birch and pine branches (including needles/leaves) were taken in the upper third of the tree crown on 5 trees and then pooled to form one sample per plot. The needle samples were divided into individual age classes and analysed as such. The Ca, Mg, K, Fe, Mn, Cu, Ni, Zn concentrations were determined, following microwave-assisted digestion, by ICP/OES or AAS, and S and P by ICP/OES or photocolorimetrically. Total C was determined on a CHN analyser or by the Tiure method, and total nitrogen on a CHN analyser or by the automated Kjeldal method. The methods used by the laboratories in Norway, Finland and Russia differed to some extent, but all the laboratories participate regularly in international inter-laboratory comparison exercises, with satisfactory results.

Chemical composition of pine needles

Maximum accumulation of heavy metals in current-year pine needles occurred at a distance of 10-15 km from the smelter in both the north-east and south-east directions, and the concentrations generally decreased exponentially with increasing distance from Nikel. The Ni concentration in needles in the “background” part of the study area, i.e. at a distance of 70 – 80 km from the smelter, was less than 3% of the concentrations measured in the immediate vicinity of Nikel (Fig. 24). The spatial patterns for the Cu and Fe concentrations were similar to that of Ni, but for Fe the trend was weaker in the previous-year needles than in the current-year ones (Figs 25 and 26). For all these elements the concentrations of Ni, Cu and Fe were exceptionally high at plot N06 (12 km NE of the smelter). In addition to distance, the wind direction also has a strong effect on the deposition levels. The predominant wind direction in the Paz river valley is from the south-southwest (Bekkestad et al. 1995, Hagen et al. 2006), which means that plots located to the north of Nikel (e.g. N06) receive very high amounts of deposition. It is more difficult to explain the relatively elevated concentrations of Cu, Ni and Fe on plot F4 in Finland, which is located more than 42 km upwind from the smelter; however, natural metal concentrations in the bedrock or soil may be one possible explanation. In general, the concentrations of these heavy metals were lower in current-year needles than in previous-year needles, suggesting that these elements accumulate in the needles over time.

The S concentrations in needles were very variable and there was no clear trend in relation to the distance from the smelters (Fig. 27). The overall reduction in emissions in recent years SO_2 emissions has undoubtedly contributed to this. One important factor affecting the S concentrations is sulphate originating from marine sources: the distance between the individual plots and the Barents Sea strongly confounds the effects of SO_2 emissions from the smelters. Sulphur is also an important macronutrient, and it is metabolized and translocated within the tree.

There was no clear trend in the Al concentrations (Fig. 28). The highest concentration occurred on plot N06, which was also the plot with the highest Ni, Cu and Fe concentrations and relatively low Ca and Mn concentrations (Table 21). This could be related to the accumulation of dry deposition on the needles, as well as to the antagonistic effect of Al on the uptake of Ca and Mn (Løbersli and Steinnes 1988, Lukina and Nikonov 1996). The concentrations of mobile elements (the macronutrients K, P, N, Table 21) in pine needles were either comparable to or below the background values (plot RUS0, 42 km from the smelter), and in many cases below the threshold level for deficiency (cf. Huettl 1993). This was the case despite the relatively concentrations of these elements in the organic horizon of the soil. Increased uptake of Ca and Mn, and decreased uptake of K, P and N, may reflect antagonism processes in the uptake of these elements. Antagonistic relationships often occur between the following pairs of elements: Ca-K. Ca – P, Mn – K, Mn – P.

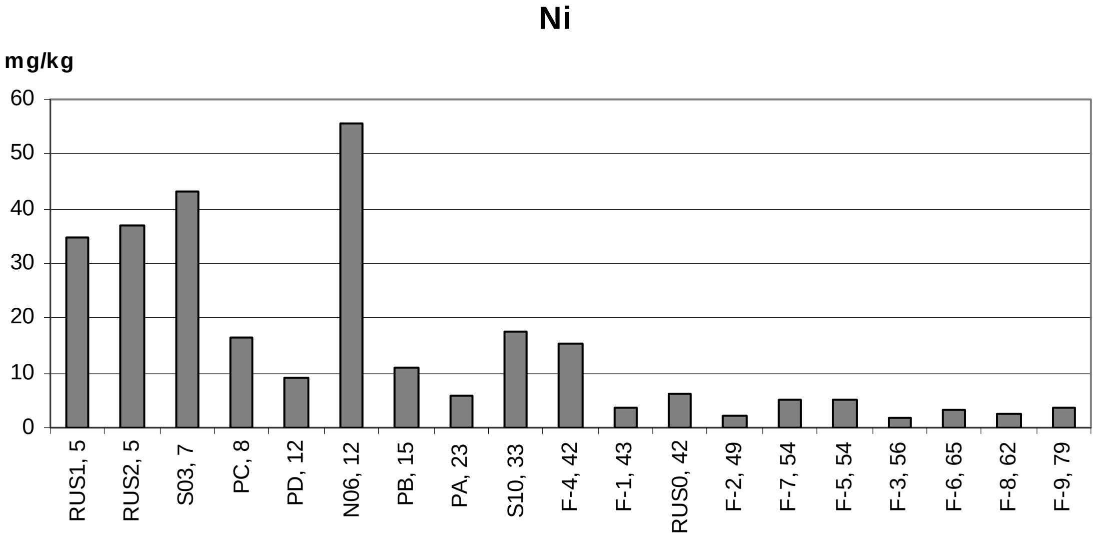


Figure 24. Nickel concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig.1 for the location of the plots. The distance in km is given after the plot code.

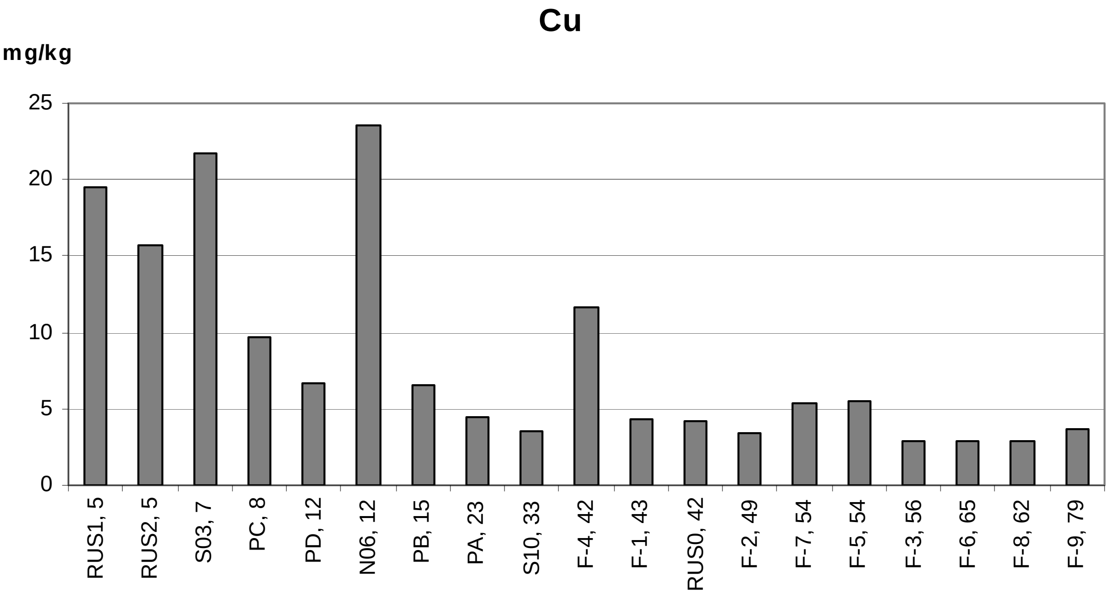


Figure 25. Copper concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

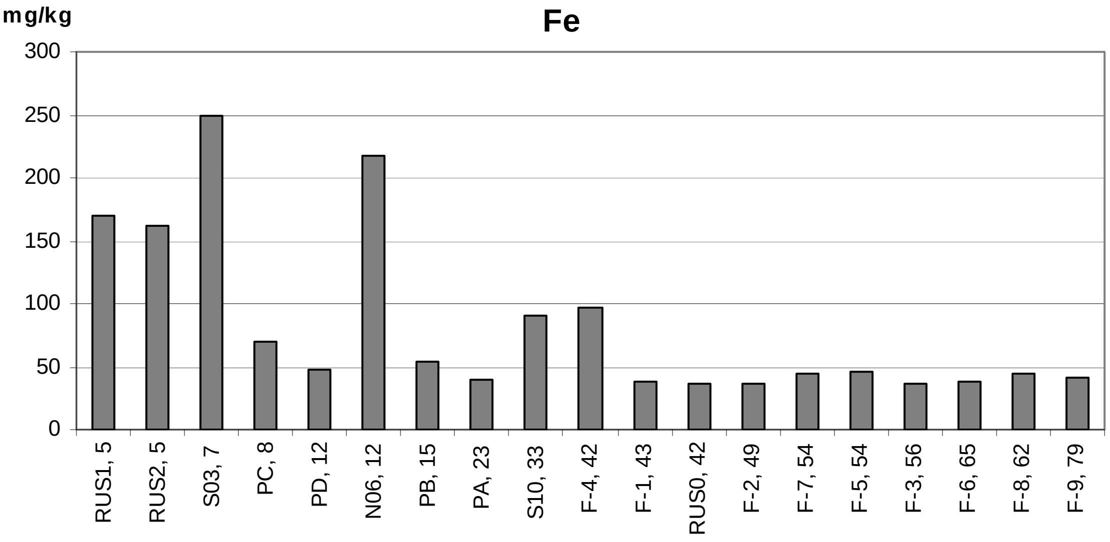


Figure 26. Iron concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

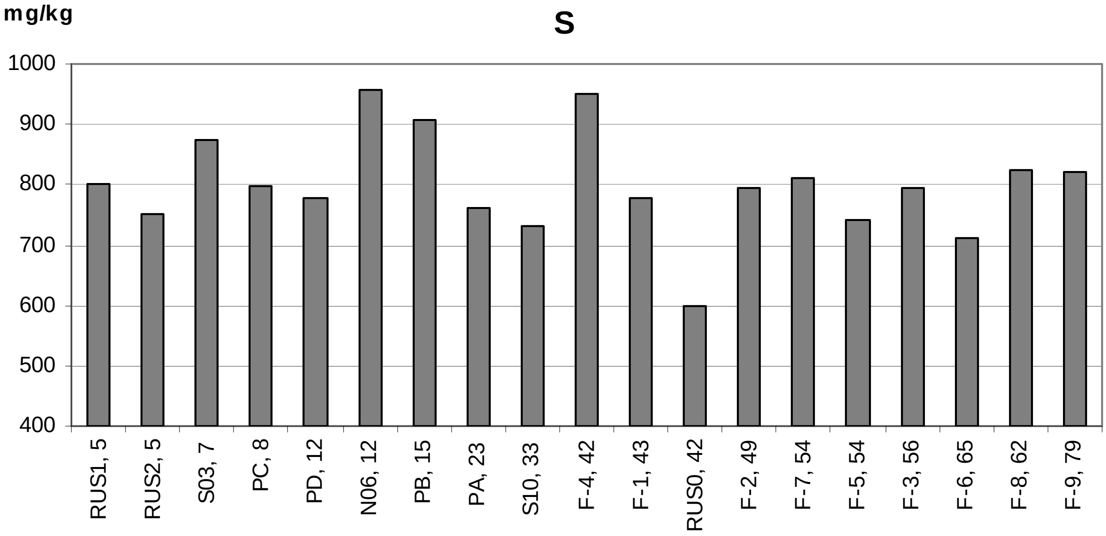


Figure 27. Sulphur concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

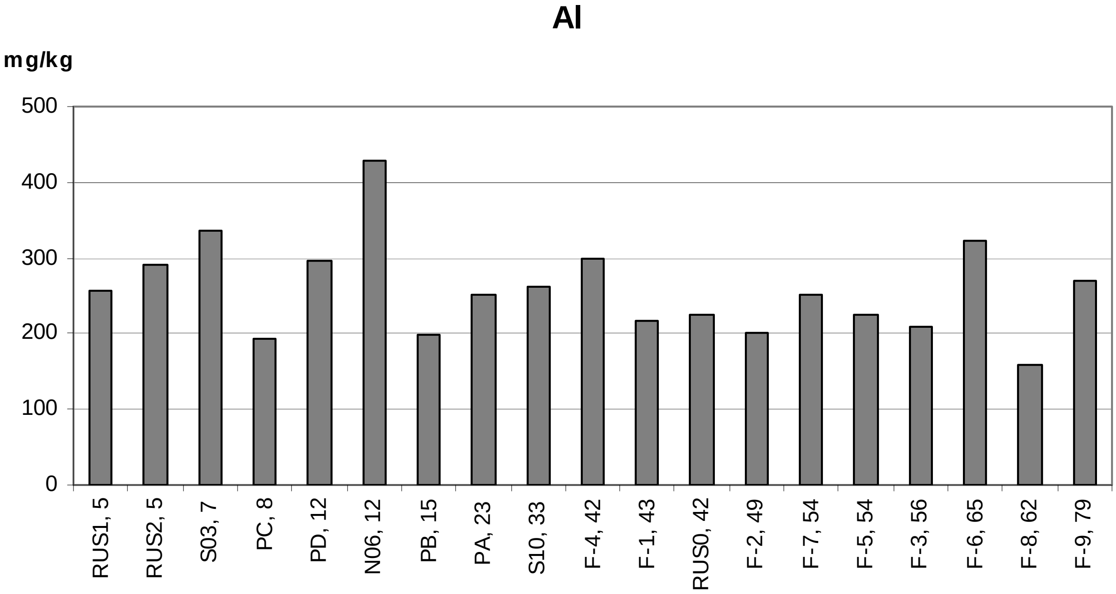


Figure 28. Aluminium concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

Chemical composition of birch leaves

Birch leaves have a relatively high natural concentration of nutrient elements, especially Ca and K, amounting to about 5.2% of the dry weight (Lukina and Nikonov 1998). Birch also accumulates zinc (Gosz et al. 1973) and, in this study, the birch leaves had zinc concentrations in the range of 100-140 mg/kg.

As was the case with pine, the concentrations of heavy metals emitted in large amounts by the smelters (e.g. Ni, Cu, Fe) were much higher in birch leaves in the vicinity of the smelter in comparison to the reference plot. For instance, the Ni concentrations were 7-8 times higher on plots affected by the smelters than on the reference plot (RUS0) (Fig. 29). The sulphur concentrations were also clearly higher in the most polluted areas (Fig. 32) and, in general, the Ni and S concentrations in the birch leaves were noticeably higher than in the pine needles. The concentrations of Cu also decreased with increasing distance from the smelter (Fig. 30), whereas the concentrations of important macronutrients such as K, Ca and Mn (Table 22) showed an increase along the same gradient.

Comparison of the Ni, Cu and S concentrations in birch leaves sampled in 2000 and in 2004 indicated only small differences (data not shown), as was the case for macronutrient concentrations (Ca, Mg, Mn, K and P). However, there was a marked decrease in the Fe and Al concentrations. Due to the short time interval between the sampling rounds and the inter-year variation in deposition levels caused by varying weather conditions, it was not possible to draw any reliable conclusion concerning these trends.

Conclusions

The concentrations of Cu, Ni and some other metals were strongly elevated in both birch leaves and pine needles close to the Nikel smelter, but showed a gradual decrease to approximately background levels at a distance of 70-80 km from the smelters. The Cu and S concentrations in birch were markedly higher than in pine, and in birch the distribution pattern of S concentrations more closely reflected the distance to the pollution source. In pine relatively high levels of aluminium coincided with low concentrations of Ca and Mn, suggesting that aluminium antagonises the uptake of these two elements.

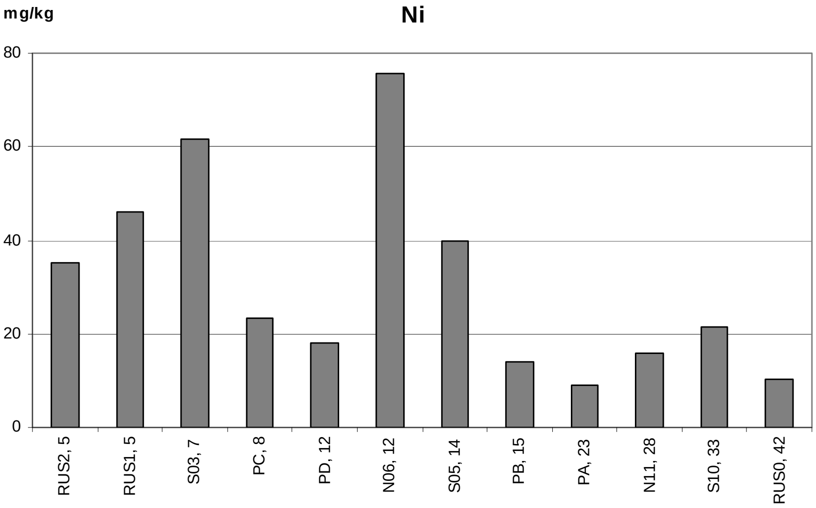


Figure 29. Nickel concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See1 for the location of the plots. The distance in km is given after the plot code.

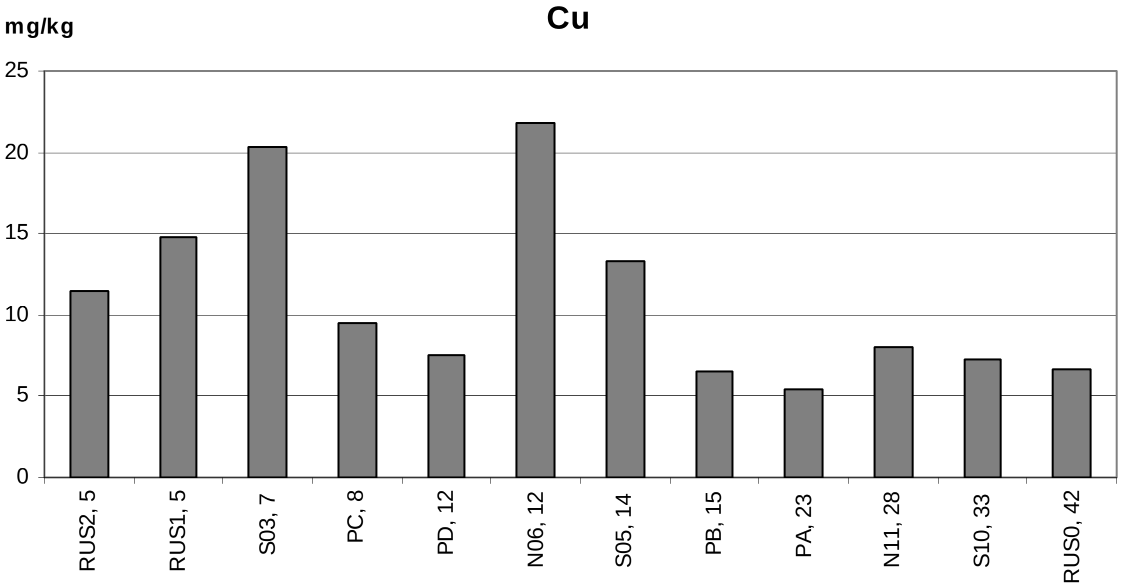


Figure 30. Copper concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

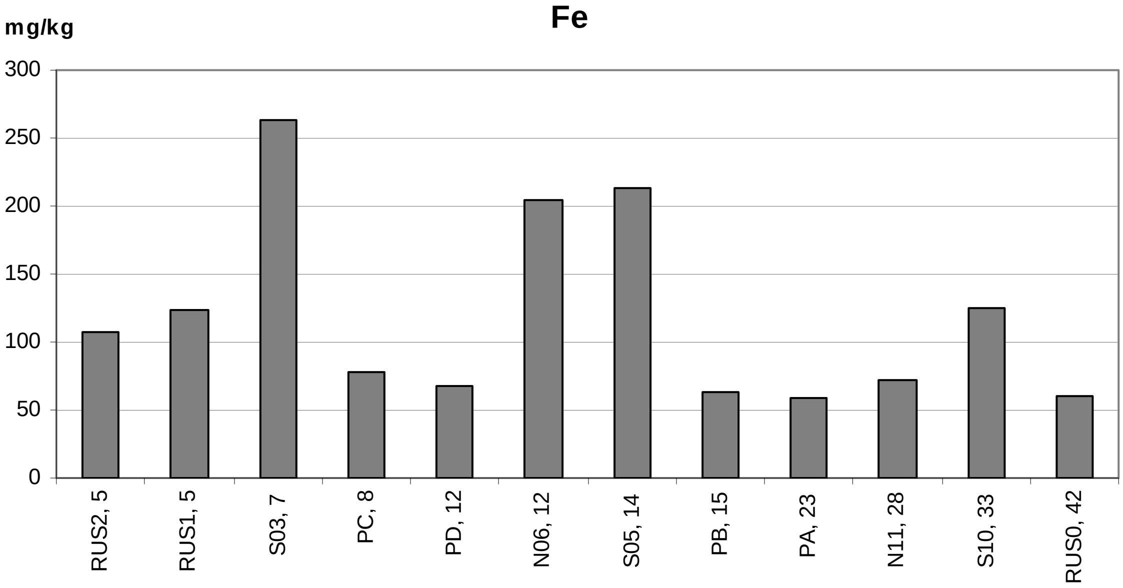


Figure 31. Iron concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

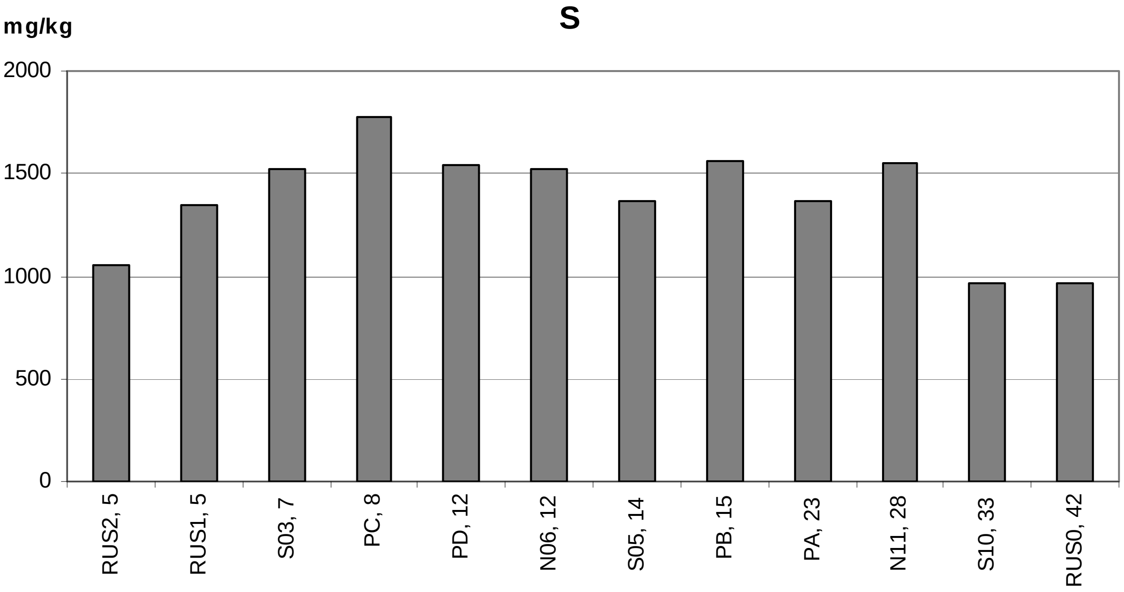


Figure 32. Sulphur concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

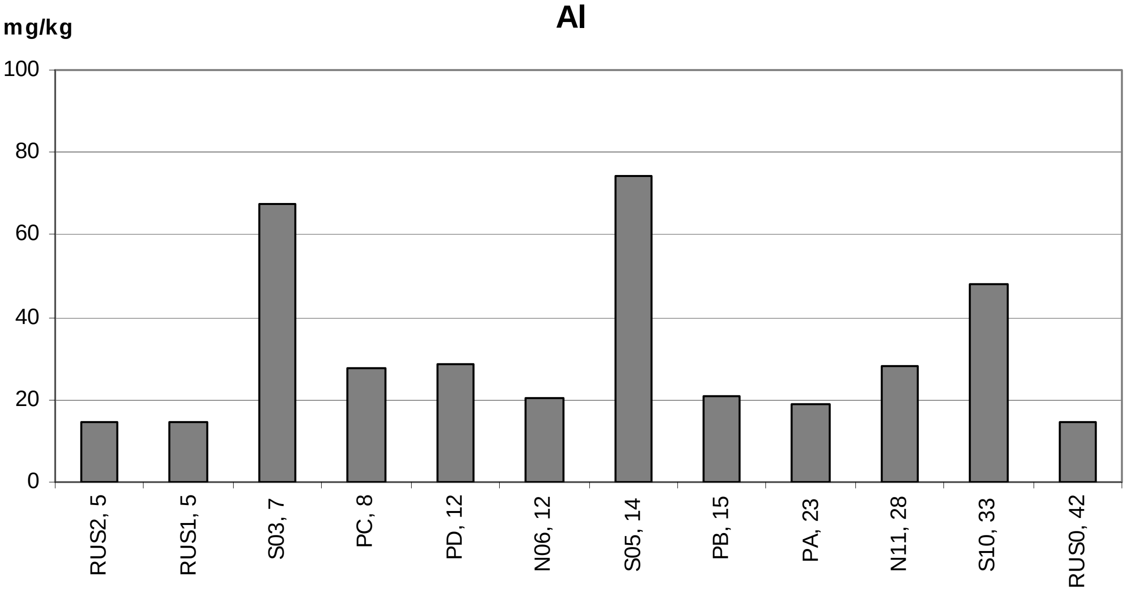


Figure 33. Aluminium concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots. The distance in km is given after the plot code.

Table 21. Element concentrations in current-year Scots pine needles on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots.

Plot code	Distance km	Ca mg/kg dw	Mg mg/kg dw	K mg/kg dw	Al mg/kg dw	Fe mg/kg dw	Mn mg/kg dw	Zn mg/kg dw	Ni mg/kg dw	Cu mg/kg dw	P mg/kg dw	S mg/kg dw
RUS2	5.1	3256	880	4420	292	161	608	20.1	36.9	15.7	1127	753
RUS1	5.2	3445	778	4569	257	171	655	20.8	34.9	19.5	1116	800
S03	7.0	2585	1028	3097	337	249	389	24.1	43.0	21.8	1002	873
PC	8.1	2721	805	3945	193	69.3	469	30.3	16.3	9.66	932	799
PD	11.9	2649	1145	3382	297	46.9	558	27.3	9.28	6.74	1078	777
N06	12.3	2722	709	4501	429	217	516	21.3	55.5	23.6	1359	955
PB	15.3	3571	1401	3492	199	54.2	685	32.6	10.9	6.61	1189	908
PA	23.3	3070	832	3785	253	40.2	952	38.5	5.93	4.45	951	761
S10	32.8	3123	1053	3996	261	90.4	883	53.3	17.5	3.48	1207	731
RUS0	42.2	1696	877	3907	224	36.1	588	27.9	6.07	4.25	1259	599
F-4	42.3	2710	993	3511	298	96.7	500	38.8	15.5	11.6	1200	949
F-1	42.7	2222	924	3349	218	38.7	394	41.4	3.81	4.33	1022	777
F-2	49.4	2539	882	3763	200	36.7	568	41.5	2.32	3.36	1074	795
F-7	53.7	2386	1185	3611	251	44.7	357	35.2	5.15	5.40	1157	812
F-5	54.0	2287	892	3480	224	46.0	302	37.1	5.25	5.52	1000	741
F-3	55.8	3024	953	4013	210	36.6	674	38.8	2.00	2.89	1081	795
F-8	61.7	3475	1130	4502	322	44.2	361	50.7	2.51	3.55	1187	826
F-6	65.0	2578	927	3497	158	38.2	515	44.2	3.33	4.05	1023	712
F-9	79.3	2822	1253	4146	269	41.0	717	43.6	3.65	3.62	1283	820

Table 22. Element concentrations in birch leaves on the individual sample plots. The plots are arranged in order of increasing distance from the Nikel smelter. See Fig. 1 for the location of the plots.

Plot code	Distance km	Ca mg/kg dw	Mg mg/kg dw	K mg/kg dw	Al mg/kg dw	Fe mg/kg dw	Mn mg/kg dw	Zn mg/kg dw	Ni mg/kg dw	Cu mg/kg dw	P mg/kg dw	S mg/kg dw	C % dw	N % dw
RUS 2	5.1	5479	2567	7355	14.7	108	912	109	35.3	11.5	2314	1054	53.5	0.11
RUS 1	5.2	5001	2737	8517	14.5	123	930	121	46.2	14.8	2085	1349	58.2	0.13
S03	7.0	4770	2378	6950	67.6	264	385	120	61.7	20.3	2210	1527	56.3	0.15
PC	8.1	5503	2862	7820	27.8	77.6	1640	86.2	23.2	9.53	1933	1777	50.0	2.38
PD	11.9	6649	3514	5251	28.6	67.0	1391	82.4	18.1	7.56	2171	1546	48.4	2.14
N 06	12.3	5106	2308	9695	20.4	204	1026	129	75.7	21.8	2606	1525	60.2	0.15
S 05	14.1	5182	2424	7186	74.1	213	1123	143	39.8	13.4	2411	1363	50.3	0.14
PB	15.3	5840	2984	5713	21.0	62.6	930	105	14.1	6.48	2004	1561	50.0	2.39
PA	23.3	8036	2381	6366	19.2	58.6	1981	123	8.92	5.40	1954	1362	48.8	2.07
N11	28.4	6004	3305	6006	27.2	77.6	971	89.6	16.0	8.01	1963	1560	49.5	1.95
S 10	32.8	5506	2173	7225	48.2	125	931	126	21.6	7.21	2297	962	50.4	0.10
RUS 0	42.2	5695	2374	7738	14.8	59.6	946	133	10.2	6.65	2790	964	64.5	0.10

4.9 Birds

Kjell Einar Erikstad[2], Paul Aspholm[6] and Niels Felstedt Thorsen[2]

The species composition of hole nesting passerines and information about the reproductive success of the pied flycatcher (*Ficedula hypoleuca*) were recorded in nesting boxes along the pollution gradient running to the west of the Nikel smelters. Each plot had about 40 bird boxes located along a double line, 50 m apart with a distance of 30 meters between the boxes in the line. The tail feathers of both young and adults were sampled for chemical analysis.

Concentrations of metals in feathers

In general, the concentrations of heavy metals in the feathers of young pied flycatchers are much lower than those in adults. The concentrations in adults showed a clear decreasing trend with increasing distance from the smelters. The trend was significantly lower only for the adults (Fig. 34, Table 23).

Effects of metal concentration on breeding birds

The pied flycather accounted for more than 85% of the total number of birds breeding in the nest boxes on all the plots. Other species occupying the boxes were the great tit (*Parus major*), the Siberian tit (*Parus cinctus*) (not on the reference plot) and the red start (*Phoenicurus phoenicurus*). There was little variation in the breeding density between the plots (except for the plots on the Russian side, which had a much lower density). Furthermore, parameters such as egg laying date and clutch size were relatively similar between the plots. However, the body mass of nestlings was lower on plots where the parents had the highest metal concentrations (Fig. 35). A low body mass at fledgling may severely reduce their chances of survival and becoming recruited in the earlier documented flycatcher population.

Adult females showed increased fluctuating asymmetry (FA) in tarsus length in the most polluted areas (Fig. 36). This suggests that the birds may be subjected to stress in the area. An increase in FA is a biologically early warning sign of developmental instability expressed by many animals under various types of environmental stress.

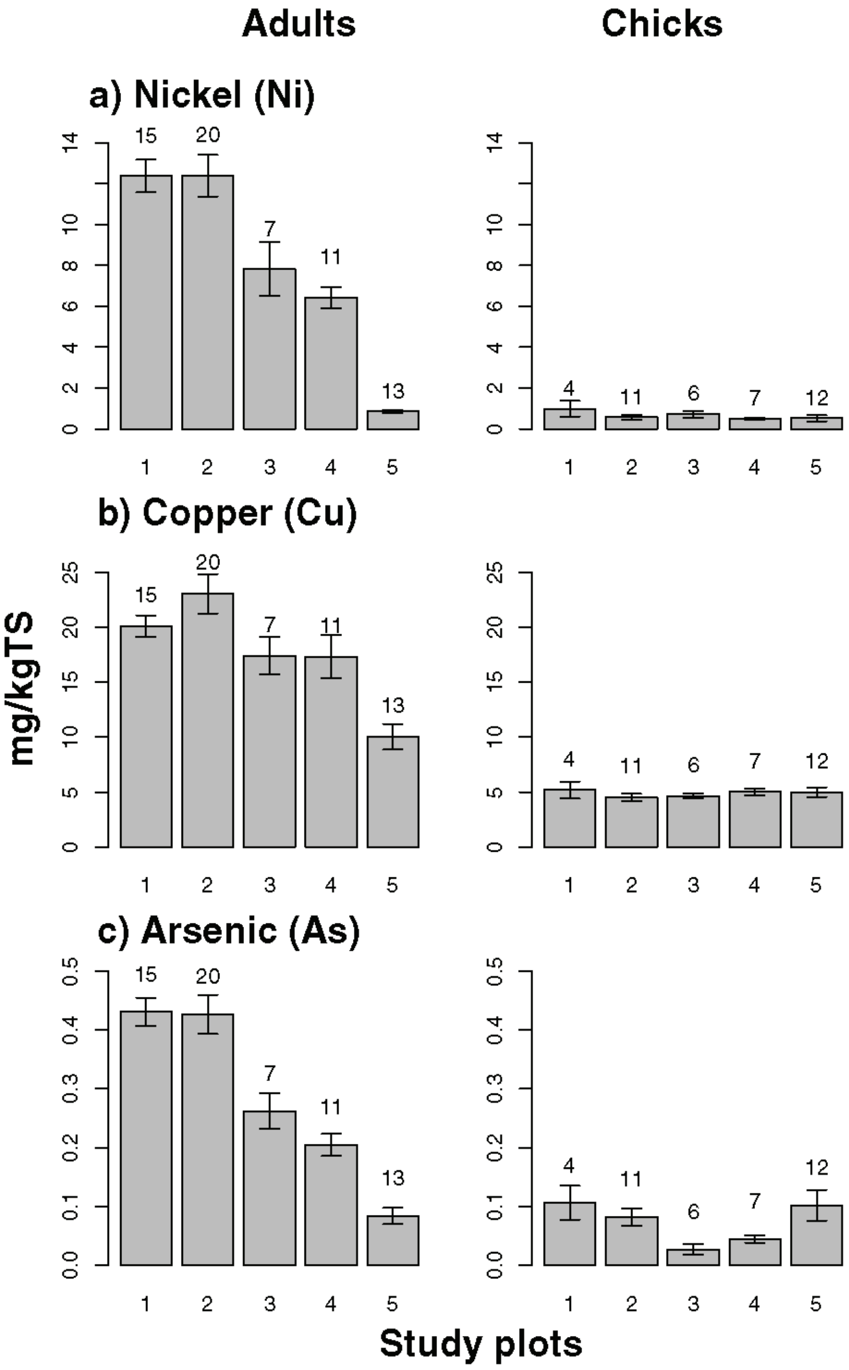


Figure 34. The concentration of nickel, copper and arsenic in the tail feathers of the Pied Flycather at various distances from the Nikel smelters. Sample plots 1 to 4 are at distances of 5, 8, 13 and 22 km, respectively, while plot 5 is a reference area in Lakselvdalen outside the city of Tromsø more than 700 km from the Nikel smelters. (Note difference scale on the vertical axes). Study plots 1 to 4 refer to the monitoring plots PC, PD, PB and PA, respectively.

Table 23. Concentrations of heavy metals in tail feathers (µg/g dry weight) of the Pied Flycatcher at different distances from the Nikel smelters. Sampling sites N1 to N4 are located at distances of 5, 8, 13 and 22 km, respectively, while Lakselvdalen is a reference area close to the city of Tromsø more than 700 km to the west of the Nikel smelters. Juv = juvenile, Ad = adult.

Site	N1				N2				N3				N4				Lakselvdalen			
Metal	Juv (n = 4)		Ad (n = 15)		Juv (n = 11)		Ad (n = 20)		Juv (n = 6)		Ad (n = 7)		Juv (n = 7)		Ad (n = 11)		Juv (n = 12)		Ad (n = 13)	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Cd	0.009	0.006	0.092	0.008	0.007	0.003	0.517	0.387	0.008	0.002	0.104	0.013	0.010	0.002	0.133	0.023	0.013	0.005	0.104	0.008
Hg	0.585	0.117	0.860	0.117	0.597	0.066	1.70	0.182	0.691	0.040	1.63	0.520	0.513	0.099	1.40	0.194	0.346	0.017	0.889	0.100
Pb	0.242	0.143	2.06	0.279	0.056	0.014	2.46	0.324	0.158	0.042	2.12	0.242	0.107	0.025	1.86	0.259	0.174	0.025	2.05	0.203
Al	13.8	6.71	92.0	11.3	5.50	1.20	131	11.6	18.3	5.53	126	25.7	17.9	5.22	128	21.5	26.0	7.51	157	37.5
Ca	617	42.4	791	153	789	36.3	1238	107	748	28.4	734	86.6	698	30.1	659	64.9	749	78.0	1398	110
Cr	0.115	0.023	0.649	0.109	0.179	0.039	0.786	0.076	0.212	0.033	0.549	0.055	0.122	0.010	0.572	0.077	0.265	0.061	0.643	0.062
Fe	44.3	13.3	146	13.9	28.6	1.49	192	42.0	51.2	10.3	141	24.5	33.1	3.48	152	24.1	57.1	13.8	145	25.0
Co	0.040	0.014	0.631	0.098	0.028	0.005	0.712	0.062	0.044	0.008	0.566	0.105	0.027	0.003	0.495	0.059	0.074	0.023	0.323	0.036
Ni	0.988	0.381	12.4	0.799	0.568	0.106	12.4	1.02	0.724	0.170	7.82	1.31	0.499	0.055	6.43	0.512	0.521	0.146	0.850	0.070
Cu	5.18	0.771	20.1	0.976	4.52	0.332	23.0	1.79	4.65	0.209	17.4	1.69	5.02	0.302	17.3	1.98	4.97	0.441	10.0	1.16
Zn	162	6.90	79.6	6.12	138	4.49	84.9	8.23	159	5.46	83.1	11.5	164	4.20	89.5	7.71	167	7.95	83.0	7.51
As	0.106	0.029	0.431	0.024	0.082	0.015	0.427	0.033	0.027	0.009	0.262	0.030	0.045	0.006	0.205	0.019	0.102	0.026	0.084	0.014
Se	2.02	0.338	1.65	0.162	1.30	0.120	1.99	0.132	1.78	0.106	2.28	0.136	2.16	0.289	2.13	0.162	1.29	0.087	1.38	0.126

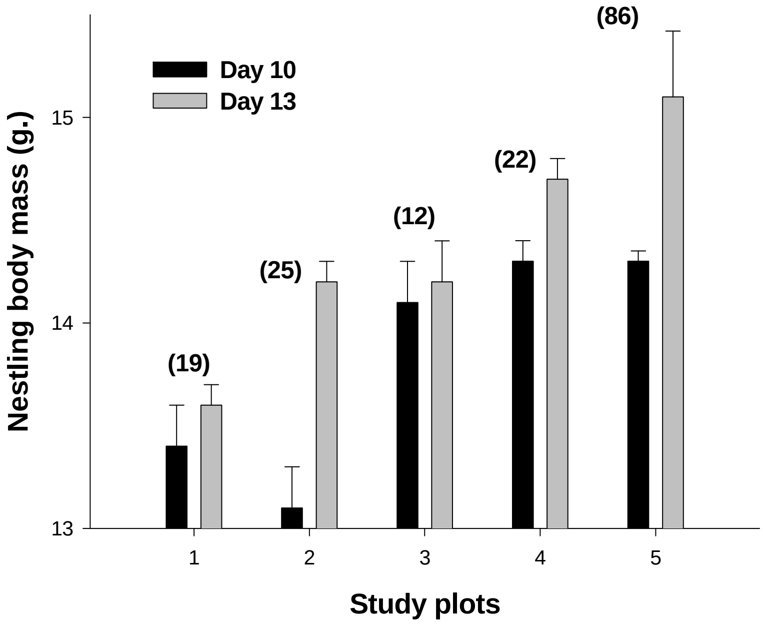


Figure 35. The body mass of pied flycatcher nestlings at different distances from the Nikel smelters. The data refer to chicks 10 day after hatching and at about fledging age (day 13). See Fig. 34 for explanation of plot number.

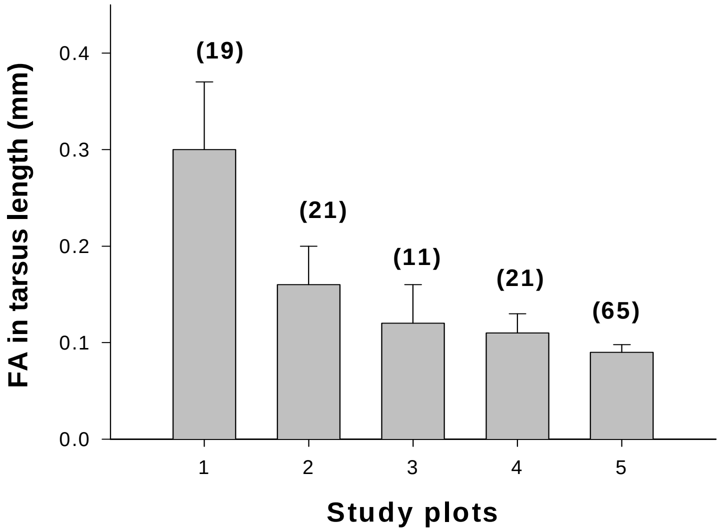


Figure 36. Fluctuating asymmetry (FA) in tarsus length of adult female pied flycatchers at different distances from the Nikel smelter. See Fig. 34 for explanation of plot number.

4.10 Small mammals

Paul Aspholm[6] *and Kjell Einar Erikstad*[2]

During the period 1985-2005, Wikan monitored rodent *Microtidae*, and shrew *Soricidae* populations using line transects of traps. One transect was located close to Svanvik, about 7 km west of Nikel, and the other close to Roavvevarri, about 13 km west of Nikel. Trapping data by Kataev from the Roavvevarri transect has only been collected since 1994. The two transects consisted of about 100 traps placed 20 m apart in identical positions each year. The traps were active for two to three days during early summer and autumn of each year.

Four species of vole were captured at both sites: the ruddy vole (*Clethrionomys rutilus*), the grey-sided vole (*Clethrionomys rufocanus*), the short-tailed vole (*Microtus agrestis*), and the root vole (*Microtus oeconomus*). Three species of shrew were also captured: the common shrew (*Sorex araneus*), the pygmy shrew (*Sorex minutus*) and the masked shrew (*Sorex caecutiens*). The grey-sided vole and the ruddy vole were the dominant voles, and the common shrew the most frequently occurring shrew (Table 24).

Rodents are known to have relatively large population fluctuations. In our region we observed a consistent population cycle of about 5 years in voles, with a somewhat less consistent cycle for shrews (Fig. 37). This may be the result of several biological factors, such as an alternating shift in the dominant species, climatic factors or predatory pressure. However, the population oscillation of shrews and of voles correspond relatively well with each other when analyzed over a longer time series. We observed a high degree of correlation between the fluctuations of the total abundance of small mammals at both Svanvik and Roavvevarri (Figs. 38 and 39).

The composition of the species of voles at Svanvik and Roavvevarri are illustrated in Fig. 40, which shows that the grey-sided vole accounted for approximately the same proportion of captures at both Svanvik and Roavvevarri. As regards the dynamics of the composition of voles over the years, it appears that there is more synchrony in the vole population at Svanvik than at Roavvevarri (Figs. 41 and 42). It has been reported that the ruddy vole occurs more frequently and at higher densities than the grey-sided vole at other sites on the Kola Peninsula.

Although the total number of small mammals captured at Svanvik and Roavvevarri during 1994- 2005 shows that there were some differences in the catch-effort, there were substantially more captures of all species at Roavvevarri. There are a number of potential reasons for these large differences (nearly twice as many at Roavvevarri), but the exact causes of this are currently unclear.

Table 24. Captures and proportions (%) of voles and shrews (all species combined) trapped over the 11-year period along line transects in Svanvik and Roavvevarri (note that the catch effort is not equal at the two sites).

	Svanvik	Roavvevarri	Svanvik, %	Roavvevarri, %
Ruddy vole	31	61	33.7	6.3
Grey-sided vole	272	462	37.1	62.9
Short-tailed vole	16	11	59.3	40.7
Root vole	2	8	20.0	80.0
Shrews	120	203	37.2	62.9
Total/Proportion	441	745	37.2	62.8

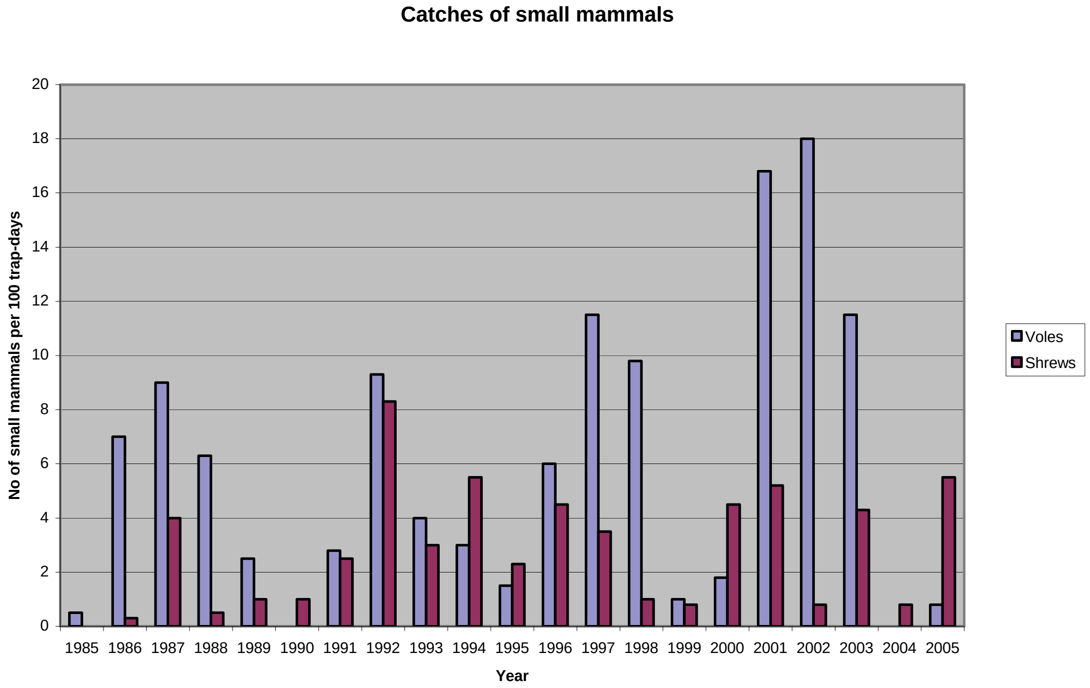


Figure 37. Variation in the capture of voles and shrews (catches per 100 trap-days) along the Svanvik transect during 1985-2004. Data from Wikan.

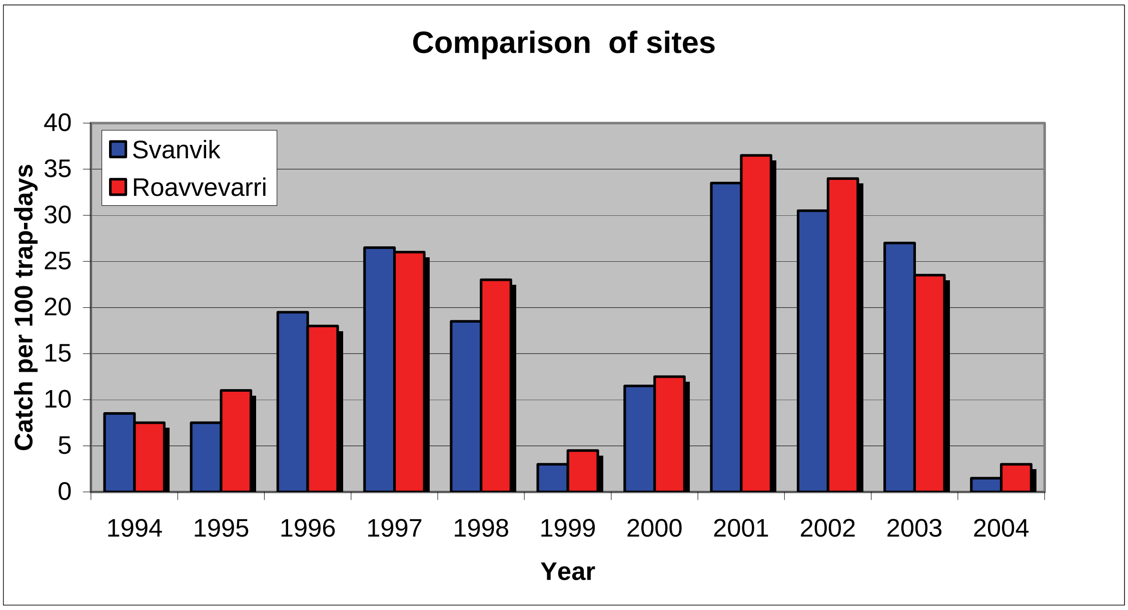


Figure 38. Comparison of autumn catches of small mammals (both voles and shrews) per 100 trap-days at Svanvik and Roavvevarri, 1994-2004. Data from Wikan and Kataev.

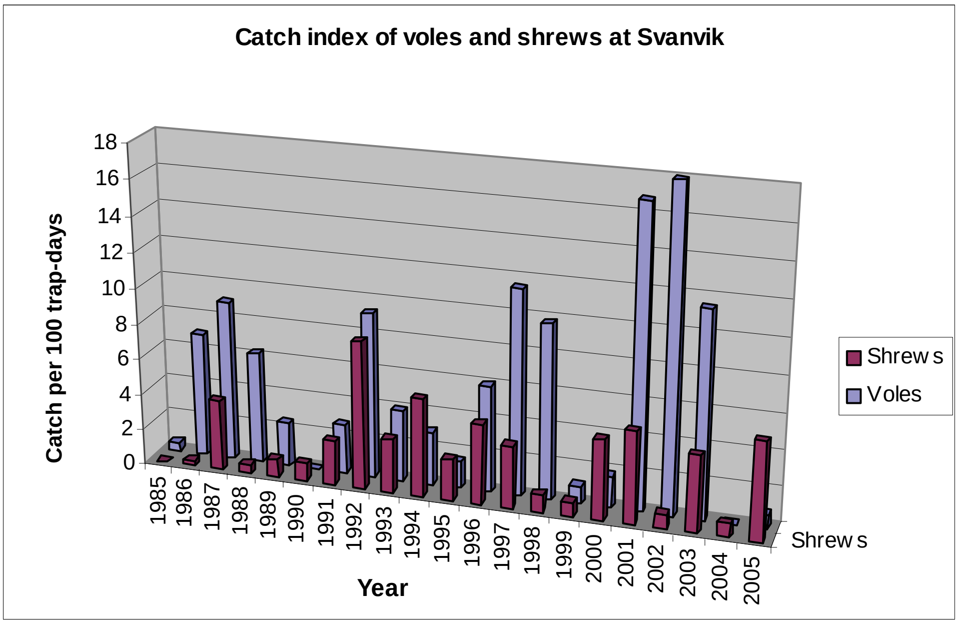
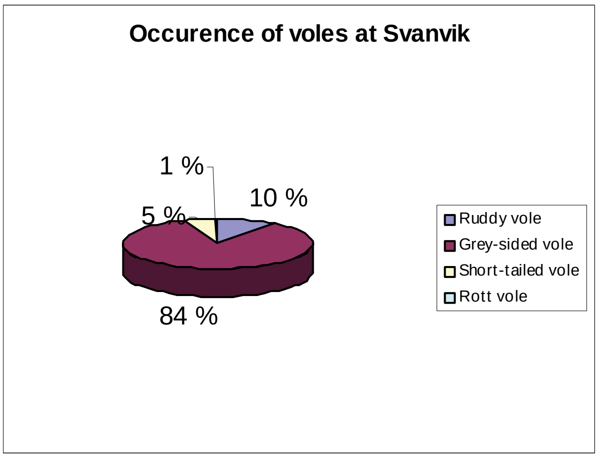


Figure 39. Annual occurrence of voles and shrews at Svanvik indicated by the catch index, i.e. the number of individuals per 100 trap-days.



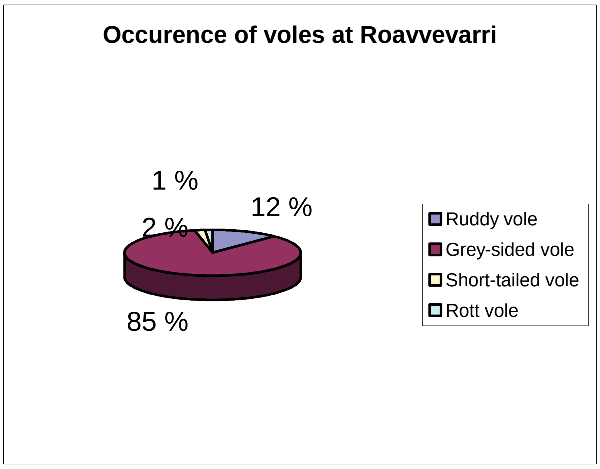


Figure 40. Distribution of vole species at Svanvik and Roavvevarri, based on the total number of voles caught along the two transect lines.

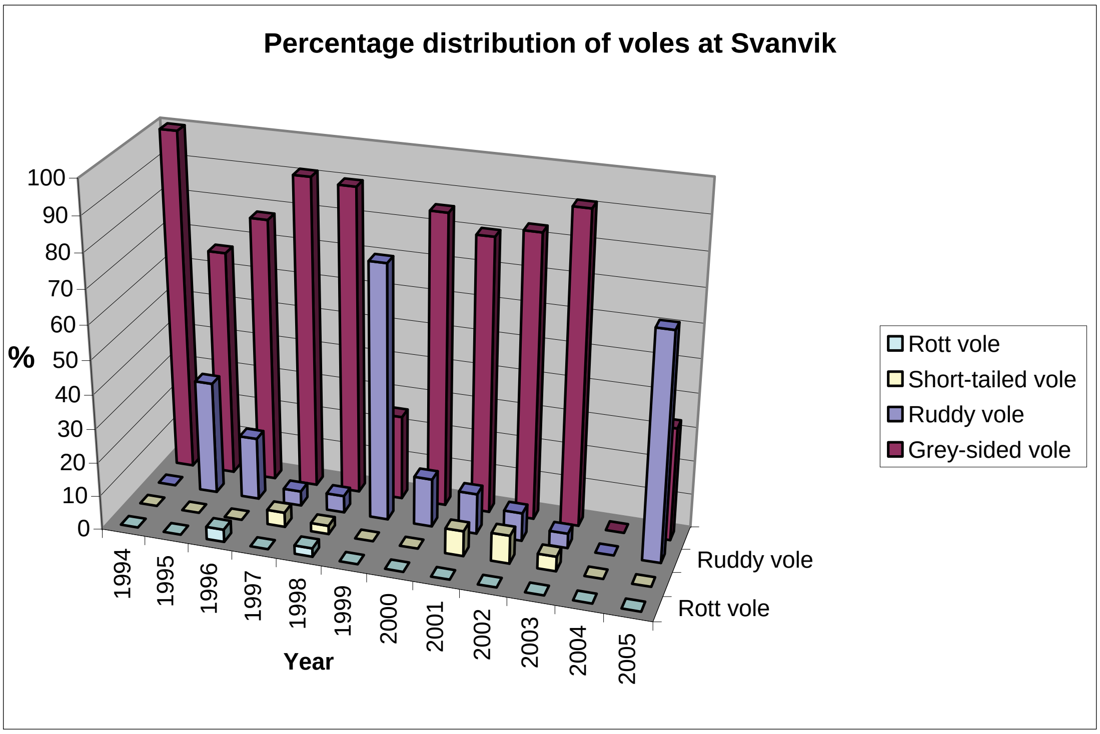


Figure 41. The annual distribution of vole species at Svanvik during the trapping period.

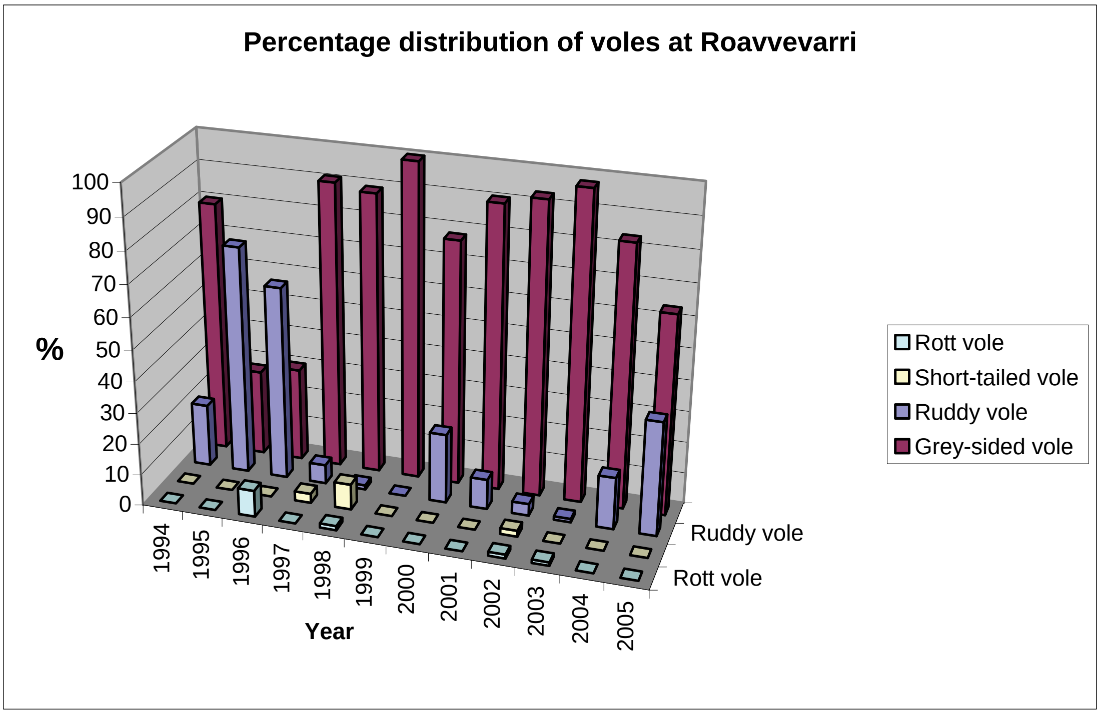


Figure 42. The annual distribution of vole species at Roavvevarri during the trapping period.

4.11 Soil

John Derome[1]

Soil sampling was carried out on 9 plots in Finland (F-1.....F-9), 5 plots in Norway (PA, PB, PC, PD, N11) and 8 plots in Russia (RUS0, RUS1, RUS2. RUS3, N06, S03, S05, S10) in August, 2004. 20 sub-samples were collected of the litter layer (L layer) and of the organic layer (F + H layers) in a 3 m × 4 m grid on each plot, and then pooled per layer. Sampling took place close to the quadrates used for the vegetation analysis. The samples were taken to the laboratory where they were air dried. The air-dried samples were milled to pass through a 2 mm sieve. The moisture content of the milled samples was determined by drying a sub- sample for 24 h at $105^{o}C$. pH was measured in an aqueous slurry. Total carbon and nitrogen were determined on a CHN analyser. Total Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S and Zn concentrations in the L and F+H samples were determined by wet digestion of the samples in a microwave oven, followed by analysis by ICP/AES. The digestion mixture used in Norway was HNO_3 + $HClO_4$, in Finland HNO_3 + H_2O_2, and in Russia HNO_3 + HCl. Exchangeable Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb and Zn concentrations were determined by extraction with NH_4NO_3 (Norway), $BaCl_2$ (Finland) or NH_4CH_3COO and $BaCl_2$ (Russia), followed by analysis by ICP/AES. Exchangeable acidity (EA) was determined by titrating the NH_4NO_3 or $BaCl_2$ extract to pH 7.0. As relatively high concentrations of exchangeable heavy metals (Cu, Ni, Zn) were present in many of the samples, especially those taken near the smelter, cation exchange capacity (CEC) was determined using the equivalent sum of exchangeable Ca, Mg, K, Na, Cu, Ni, Zn and EA (see Derome & Lindroos 1998). Base saturation (BS) was determined as the proportion of cation exchange sites occupied by base cations.

Heavy metal and macronutrient concentrations in the litter (L) layer

Heavy metal and mineral nutrient concentrations in the litter layer in the region are primarily determined by three factors: 1) the elemental composition of the plant material from which the litter originates, 2) the dry and wet deposition of metals and other elements emitted by the smelters directly onto the litter layer, and 3) the rate of leaching of metals and nutrients from the litter as a result of decomposition processes. The elemental composition of the original plant material is, in turn, affected by the concentrations of metals and nutrients in the soil (chemical composition of the soil and bedrock, and the accumulation of metals originating from earlier pollutant deposition), as well as the varying ability of individual plant species to take up specific metals.

There was a highly significant positive relationship between the total concentrations of Cu, Ni, Fe, Cr and Pb, which are the main metal pollutants emitted by the smelters, and the distance to the emission source (Table 25, Fig. 43). There was also a positive significant relationship for Mg, Ca, Mn and pH (Table 25). However, the pollutant gradients were extremely short and, at distances greater than 40 km from the smelters, the concentrations were approximately equivalent to so-called natural, background levels. As the relationship between pH and distance was positive, this clearly indicates that SO_2 emissions have not had an acidifying effect on the litter layer. This is further supported by the fact that there was no relationship between the total S concentrations and the distance to the smelters (Fig. 43). Particulate emissions from the smelters include alkaline material, such as Ca and Mg oxides, and this has a neutralizing effect on acidifying SO_2 deposition. The S concentrations in the litter are also affected by the

Table 25. Relationship between total element concentrations, pH and the C/N ratio in the litter layer (L) on the plots and the distance between the plots and the emission source at Nikel. *** = significant at the 0.1% risk level, ** = at the 1% risk level, and * = at the 5% risk level.

Element/parameter	L layer Total R^2	F + H layer Total R^2	F + H layer Exch. R^2	n
Ni	0.844***	0.839***	0.578***	22
Cu	0.834***	0.807***	0.815***	22
Fe	0.729***	0.752***	0.163	22
Cr	0.599***	0.580***	0.657***	22
Pb	0.465***	0.183	0.190	22
Zn	0.284	0.359*	0.152	
Mn	0.274*	0.262*	0.009	22
S	0.039	0.145	-	22
N	0.058	0.008	-	22
C/N	0.119	0.337*	-	22
pH	0.420**	0.455**		22
CEC	-	-	0.016	22
BS	-	-	0.184	22
Ca	0.420**	0.359*	0.059	22
Mg	0.492***	0.635***	0.017	22
K	0.048	0.103	0.148	22
Na	0.102	0.659***	0.158	22

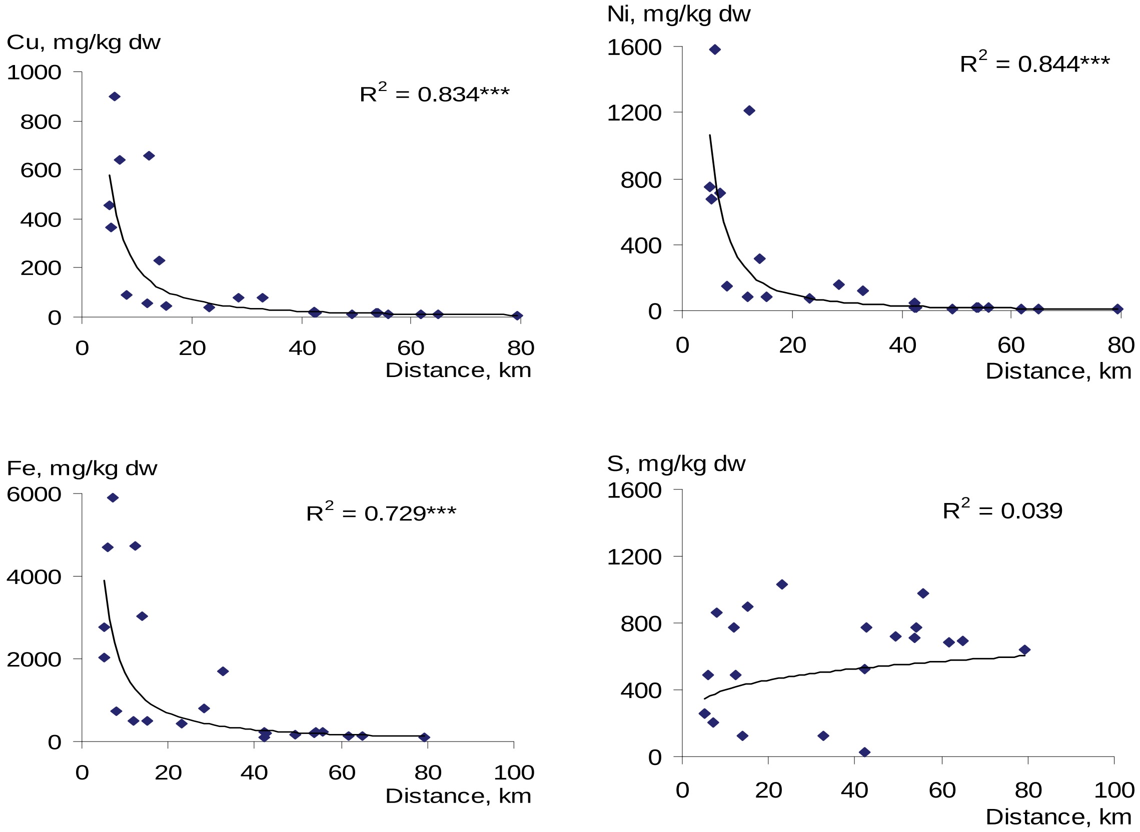


Figure 43. Total Cu, Ni, Fe and total S concentrations in the litter (L) layer on the plots at different distances from the emission source at Nikel.

somewhat conflicting effects of emissions from the smelters and the input of marine-derived sulphate: the gradients run in different directions.

The total metal (Al, As, Cd, Cr, Cu, Fe, Ni, Pb and Zn) and sulphur concentrations in the litter (L) layer on the plots located at different distances from the emission source at Nikel are given in Table 26, and the pH, C/N ratio and total concentrations for other elements (Ca, K, Mg, Na, P and Mn) correspondingly in Table 27. There were clearly elevated levels of As and Zn in plant litter within a distance of ca. 30 km from the smelter, but the relationship with the distance was not significant: there was considerable variation between the plots located in different directions from the smelter. This was undoubtedly due to topographic factors and differences in prevailing wind direction in the area.

Heavy metal and macronutrient concentrations in the organic (F+H) layer

There was a highly significant positive relationship between the total concentrations of Cu, Ni, Fe and Cr, and the exchangeable concentrations of Cu, Ni and Cr, and the distance to the emission source (Table 25, Fig. 44). This clearly shows that, at distances of less than ca. 20km for Cu, 50 km for Cr and less than ca. 70 km for Ni, the uppermost layer of the forest soil is seriously contaminated with these metals (Table 28). Furthermore, a relatively high proportion of these toxic metals are present in a form (exchangeable) that is readily taken up by plants growing in the area (Table 30). This long-term accumulation of metals in the organic layer is a serious problem because, even though emissions are substantially reduced, there will be no corresponding reduction in metal accumulation.

Emissions of metals and SO_2 do not, however, appear to have had a detrimental effect on the fertility of the forest soils. The cation exchange capacity (CEC), which is a measure used to depict the capacity of the soil to retain important macro- and micronutrients, has not been reduced as a result of the emissions (Fig. 44, Table 31). The base saturation (BS), which is a measure of the soil's capacity to counteract the adverse effects of acidifying deposition (e.g. SO_2), appears in fact to be slightly higher close to the smelters (Fig. 44). The pH close to the smelter is also significantly higher than at greater distances from the emission source, clearly suggesting that alkaline fly ash from the power station is deposited in the immediate vicinity of the industrial complex (Table 29).

Table 26. Total metal and sulphur concentrations in the litter (L) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis. < LOQ = concentration below the limit of quantitation of the analytical equipment. nd = not determined.

Plot code	Distance km	Al mg/kg	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg	Pb mg/kg	S mg/kg	Zn mg/kg
RUS2	5.2	397	5.81	0.72	10.4	455	2764	746	17.2	259	115
RUS1	5.1	326	4.36	0.60	8.74	365	2039	672	14.1	260	123
RUS3	6.0	517	11.0	1.36	18.0	901	4698	1584	23.6	485	146
S03	7.0	1679	9.98	0.85	24.7	643	5901	715	26.6	202	115
PC	8.1	429	1.27	< LOQ	1.30	90.3	720	147	3.11	865	43.2
PD	11.9	434	0.75	< LOQ	1.25	54.0	504	86.5	2.28	775	40.2
N06	12.3	564	8.89	1.20	16.5	657	4729	1207	23.2	486	250
S05	14.1	1197	3.54	0.51	12.7	233	3045	315	16.4	125	97.2
PB	15.3	336	0.75	< LOQ	1.25	45.2	509	79.1	2.28	896	68.6
PA	23.3	359	0.75	< LOQ	1.25	40.0	448	69.4	2.49	1030	128
N11	28.4	318	0.75	0.34	1.61	78.0	792	155	4.14	1669	221
S10	32.8	934	0.74	0.32	7.32	79.4	1698	121	7.80	124	151
RUS0	42.2	230	0.30	0.16	0.78	24.4	242	45.5	2.90	27.9	74.4
F-4	42.3	267	nd	< LOQ	0.85	16.9	110	20.9	< LOQ	521	26.3
F-1	42.7	412	nd	< LOQ	0.84	16.5	214	17.8	3.54	777	28.5
F-2	49.4	272	nd	< LOQ	0.52	12.6	178	13.6	3.59	717	63.1
F-7	53.7	324	nd	< LOQ	0.83	14.8	192	14.1	2.36	713	23.6
F-5	54.0	463	nd	0.04	1.39	14.9	245	16.7	3.24	773	37.1
F-3	55.8	327	nd	< LOQ	0.88	13.3	232	13.9	2.81	976	72.0
F-8	61.7	350	nd	0.21	0.98	10.3	123	8.94	1.60	689	23.1
F-6	65.0	261	nd	0.05	0.57	10.9	136	10.7	3.43	689	59.8
F-9	79.3	277	nd	< LOQ	0.61	7.6	84.5	6.08	< LOQ	640	56.5

Table 27. pH, the C/N ratio and total element concentrations in the litter (L) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis.

Plot code	Distance km	pH	N %	C/N	Ca mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	P mg/kg	Mn mg/kg
RUS2	5.2	4.34	0.90	58.3	6607	751	1578	72.1	771	689
RUS1	5.1	4.21	1.03	48.2	8395	1188	1517	85.2	922	896
RUS3	6.0	4.65	0.58	86.5	11529	747	2451	71.1	888	492
S03	7.0	4.43	0.89	55.0	4867	542	1596	84.1	705	260
PC	8.1	4.08	0.62	87.5	5719	907	654	89.7	567	677
PD	11.9	4.10	0.63	84.4	5836	751	790	68.1	567	719
N06	12.3	4.61	1.35	39.3	8282	658	1844	65.2	1026	1235
S05	14.1	4.26	0.93	53.9	4726	552	1239	91.3	759	649
PB	15.3	4.19	0.81	65.1	5467	1071	970	71.7	833	684
PA	23.3	4.28	1.05	49.8	8701	1157	1058	84.4	997	1551
N11	28.4	4.82	1.68	31.2	10369	1505	2544	103	1499	1419
S10	32.8	4.38	1.34	35.6	6304	849	1475	84.3	1026	92.0
RUS0	42.2	3.99	0.76	67.4	4097	606	565	59.2	618	501
F-4	42.3	3.88	0.57	107	2427	796	368	113	328	148
F-1	42.7	3.82	0.72	79.5	1903	591	369	94.9	459	127
F-2	49.4	3.88	0.73	77.7	3763	583	519	60.0	436	243
F-7	53.7	3.60	0.61	92.0	2824	495	237	115	342	176
F-5	54.0	3.87	0.78	72.9	2857	719	339	111	422	138
F-3	55.8	4.11	1.17	51.4	4634	1010	720	87.7	806	379
F-8	61.7	3.58	0.61	91.0	2223	585	247	129	356	155
F-6	65.0	3.83	0.70	78.0	3707	731	483	61.1	495	239
F-9	79.3	3.89	0.69	78.6	4570	779	672	98.6	459	516

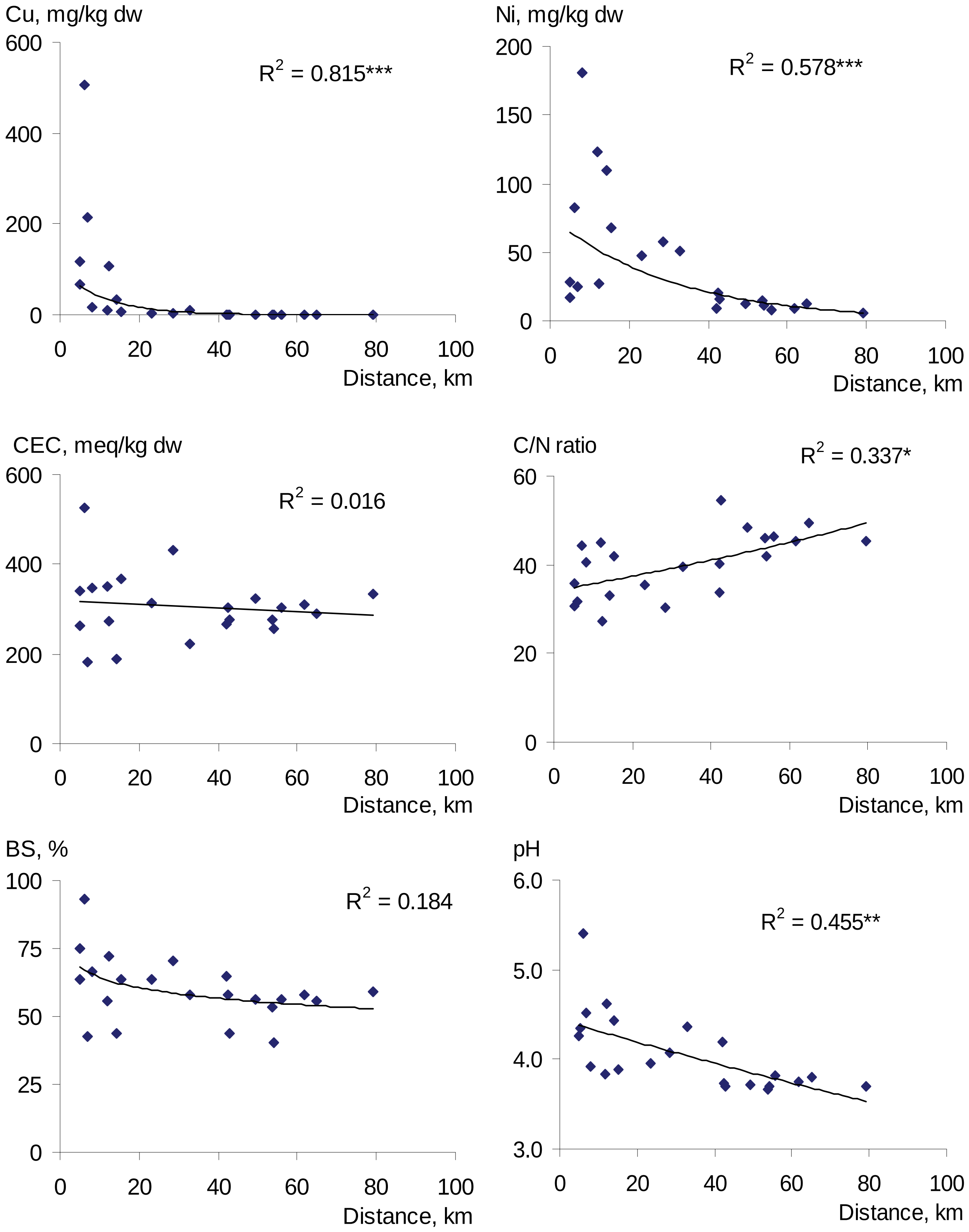


Figure 44. Exchangeable Cu and Ni concentrations and cation exchange capacity (CEC), C/N ratio, base saturation (BS) and pH (H_2O) in the organic (F+H) layer on the plots at different distances from the emission source at Nikel.

Table 28. Total metal and sulphur concentrations in the organic (F + H) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis. < LOQ = concentration below the limit of quantitation of the analytical equipment. nd = not determined.

Plot code	Distance km	Al mg/kg	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg	Pb mg/kg	S mg/kg	Zn mg/kg
RUS2	5.2	3099	10.2	0.60	31.8	453	10976	532	16.4	242	65.0
RUS1	5.1	1991	13.9	0.89	39.0	881	9444	1015	21.9	367	92.6
RUS3	6.0	3356	51.3	2.01	114	2282	26053	2706	37.2	1529	162
S03	7.0	9838	28.3	0.50	127	822	17938	776	22.3	391	90.6
PC	8.1	2903	6.14	< LOQ	9.83	246	5172	317	13.5	1533	52.4
PD	11.9	2422	4.35	< LOQ	6.03	127	3810	177	13.7	1314	37.3
N06	12.3	3801	15.9	1.89	55.0	771	16393	994	49.5	404	275
S05	14.1	5401	7.23	0.36	47.1	245	11330	307	18.5	211	53.4
PB	15.3	1579	3.90	< LOQ	3.07	92.1	2411	128	12.8	1529	60.7
PA	23.3	2736	2.85	< LOQ	6.97	91.5	4679	113	13.5	1395	84.9
N11	28.4	2485	2.62	0.45	5.77	96.1	4849	129	57.8	1963	91.0
S10	32.8	3721	2.49	0.21	27.3	132	7572	124	17.5	205	55.4
RUS0	42.2	937	1.54	0.27	2.74	56.9	1289	76.8	16.1	180	60.7
F-4	42.3	1023	nd	0.32	3.67	31.1	1051	41.0	15.3	1543	53.5
F-1	42.7	1658	nd	0.16	3.34	21.2	1784	29.0	11.3	1220	38.3
F-2	49.4	1105	nd	0.20	2.53	23.2	1074	27.4	15.8	1431	40.5
F-7	53.7	996	nd	0.23	3.52	29.1	995	36.4	14.7	1470	43.3
F-5	54.0	2442	nd	0.28	5.11	20.5	1820	26.5	24.7	1071	40.8
F-3	55.8	1609	nd	0.19	5.26	17.3	1618	20.7	13.8	1417	36.0
F-8	61.7	807	nd	0.17	2.19	17.6	710	20.1	11.7	1509	45.4
F-6	65.0	873	nd	0.25	2.19	24.2	891	27.4	13.3	1431	40.6
F-9	79.3	1255	nd	0.17	2.13	14.4	936	14.4	9.91	1490	42.6

Table 29. pH, the C/N ratio and total element concentrations in the litter (L) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis.

Plot code	Distance km	pH	N %	C/N	Ca mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	P mg/kg	Mn mg/kg
RUS2	5.2	4.26	1.12	35.9	4025	871	2026	206	928	350
RUS1	5.1	4.34	1.61	30.8	5273	693	1885	150	1058	667
RUS3	6.0	5.40	1.45	31.6	10633	606	4791	186	1438	1642
S03	7.0	4.52	0.62	44.3	2959	528	6893	342	902	269
PC	8.1	3.92	1.17	40.6	4192	1208	1172	262	948	297
PD	11.9	3.83	1.07	45.1	3423	774	1063	257	768	210
N06	12.3	4.62	1.49	27.3	4317	568	2958	173	1170	1194
S05	14.1	4.44	1.11	33.1	2116	448	2606	255	702	210
PB	15.3	3.89	1.18	42.1	3860	735	897	236	876	258
PA	23.3	3.96	1.26	35.6	3836	1122	1155	254	1016	508
N11	28.4	4.08	1.65	30.3	4782	1114	1493	277	1180	430
S10	32.8	4.36	0.94	39.6	2499	473	1846	201	759	280
RUS0	42.2	4.20	1.51	33.6	3325	375	659	99	688	533
F-4	42.3	3.73	1.26	40.3	2565	946	573	88	736	133
F-1	42.7	3.70	0.89	54.5	1844	647	519	141	629	81.8
F-2	49.4	3.72	1.09	48.4	2790	900	559	102	732	134
F-7	53.7	3.67	1.19	45.9	2500	1056	472	82	744	176
F-5	54.0	3.69	0.90	41.8	1829	689	367	101	547	57
F-3	55.8	3.81	1.07	46.4	2767	885	700	100	786	163
F-8	61.7	3.76	1.21	45.2	2520	1028	511	63	798	316
F-6	65.0	3.80	1.10	49.3	2453	975	490	85	776	170
F-9	79.3	3.69	1.18	45.3	2819	1084	588	107	837	285

Table 30. Exchangeable metal concentrations in the organic (F + H) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis. < LOQ = concentration below the limit of quantitation of the analytical equipment. nd = not determined because $BaCl_2$ was used as the extractant for the Finnish samples.

Plot code	Distance km	Cu mg/kg	Ni mg/kg	Cd mg/kg	Cr mg/kg	Pb mg/kg	Zn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	S mg/kg
RUS2	5.2	67.2	16.6	0.45	0.94	12.1	36.6	412	116	230	155
RUS1	5.1	116	27.9	0.60	1.07	13.4	50.3	337	79.8	382	93.0
RUS3	6.0	506	82.6	1.27	4.57	14.6	80.4	20.7	16.4	297	129
S03	7.0	213	25.2	0.32	8.33	13.0	27.2	302	423	38.1	115
PC	8.1	16.8	180	0.13	0.49	1.14	43.2	192	162	314	164
PD	11.9	10.7	124	< LOQ	0.36	2.03	30.3	246	154	192	137
N06	12.3	108	27.3	1.27	2.77	24.6	166	94.7	331	429	123
S05	14.1	35.0	110	0.23	5.85	12.5	19.3	305	426	65.5	66.6
PB	15.3	5.47	68.3	< LOQ	0.39	0.99	52.5	100	51.9	265	122
PA	23.3	4.45	47.5	< LOQ	0.46	1.18	73.1	128	65.7	448	132
N11	28.4	3.75	57.2	0.69	0.66	4.45	80.2	215	71.0	390	117
S10	32.8	9.00	51.0	0.16	1.10	12.7	29.4	235	175	185	75.7
RUS0	42.2	1.21	9.31	0.22	0.06	16.6	29.2	35.4	74.3	324	63.8
F-4	42.3	0.91	20.8	0.27	0.09	2.21	41.2	130	67.0	132	nd
F-1	42.7	1.30	16.0	0.14	0.09	2.59	31.3	302	105	77.1	nd
F-2	49.4	0.94	13.0	0.21	0.09	3.02	32.2	157	62.2	134	nd
F-7	53.7	0.49	14.6	0.17	0.09	2.19	29.7	113	56.7	179	nd
F-5	54.0	0.92	10.9	0.24	0.12	3.92	26.6	409	109	44.4	nd
F-3	55.8	0.61	8.46	0.19	0.09	2.33	28.3	157	70.0	172	nd
F-8	61.7	0.31	9.33	0.19	0.09	1.94	35.6	109	40.6	333	nd
F-6	65.0	0.91	12.4	0.22	0.09	2.74	31.5	120	47.9	180	nd
F-9	79.3	0.31	6.16	0.17	0.09	1.35	30.7	178	54.6	309	nd

Table 31. Exchangeable base cation (Ca, Mg, K, Na) and exchangeable acidity (EH) concentrations, cation exchange capacity (CEC) and base saturation in the organic (F + H) layer on the plots located at different distances from the emission source at Nikel. The results are expressed on a dry weight basis.

Plot code	Distance km	Ca mg/kg	Mg mg/kg	K mg/kg	Na mg/kg	EA meq/kg	CEC meq/kg	BS %
RUS2	5.2	2152	465	689	43.0	95.2	260	63.4
RUS1	5.1	3576	653	631	42.1	84.2	334	74.8
RUS3	6.0	7229	1173	557	39.5	34.2	507	93.3
S03	7.0	961	192	348	20.5	100	173	42.5
PC	8.1	3105	578	983	115	107	340	66.3
PD	11.9	2631	536	638	122	151	348	55.6
N06	12.3	2806	440	604	33.2	75.1	268	72.0
S05	14.1	1021	218	414	32.6	104	185	43.8
PB	15.3	3260	668	642	108	126	365	63.8
PA	23.3	2893	477	829	96.6	102	311	63.9
N11	28.4	3894	1066	920	161	118	431	70.2
S10	32.8	1678	365	540	25.3	92.8	221	58.1
RUS0	42.2	2545	397	397	36.3	94.4	266	64.5
F-4	42.3	2188	496	873	91.3	127	304	58.0
F-1	42.7	1359	413	536	131	154	275	44.0
F-2	49.4	2270	521	818	106	140	321	56.4
F-7	53.7	1922	347	840	70.8	126	275	53.4
F-5	54.0	1375	230	481	79.4	152	255	40.2
F-3	55.8	2058	550	699	74.8	133	302	56.0
F-8	61.7	2270	466	963	76.8	129	309	58.2
F-6	65.0	1987	440	843	92.2	129	290	55.5
F-9	79.3	2430	536	1024	115	136	332	59.1

4.12 Sensitivity of the soil in the region to acidification

Raija Pietilä[8], Vesa Perttunen[8], Matti Kontio[8], Jouni Pihlaja[8] and Riitta Pohjola[8]

Introduction

An overview of the sensitivity of the soil in the region to acidification was carried out by the Northern Finland Office of the Finnish Geological Survey (GTK). It is based on GTK's existing research and mapping data and joint projects carried out with other surveys. The rectangular-shaped area in the northern part of Finland, Norway and NW Russia has a surface area of 243 x 186 km^2, and covers the whole of the Paz river catchment area and its surroundings.

Geological bedrock map material

A simplified bedrock map that includes the primary rock types in the area is given in Fig. 45 The map is based on bedrock survey material from several projects carried out by GTK and other surveys at different scales. GTK's 1:1.000.000 bedrock map provides an overall picture of the bedrock occurring in Finland. The map shows the types of rock and the stratigraphic and structural properties of the bedrock. The most recent map was published in 1997. Survey data have been collected in northern Finland during two separate bedrock survey projects. The 1:1.000.000 bedrock map from the Nordkalott Project (1987) covers both northern Finland and northern Norway. The bedrock material (digital bedrock data for Northern Finland) from the Lapland Vulcanite Project, which is at a scale of 1:400.000, covers the whole of the Näätämö area. The 1:1.000.000 bedrock map of the Fennoscandian Shield, which was produced as a joint project between Finland, Norway, Sweden and Russia, has been used in identifying the major types of bedrock and rock types in the part of the region located in Norway and Russia. The most accurate bedrock survey from Finland is from 1994, at a scale of 1:100.000 and covers map sheet areas 3934, 4912 and 4914.

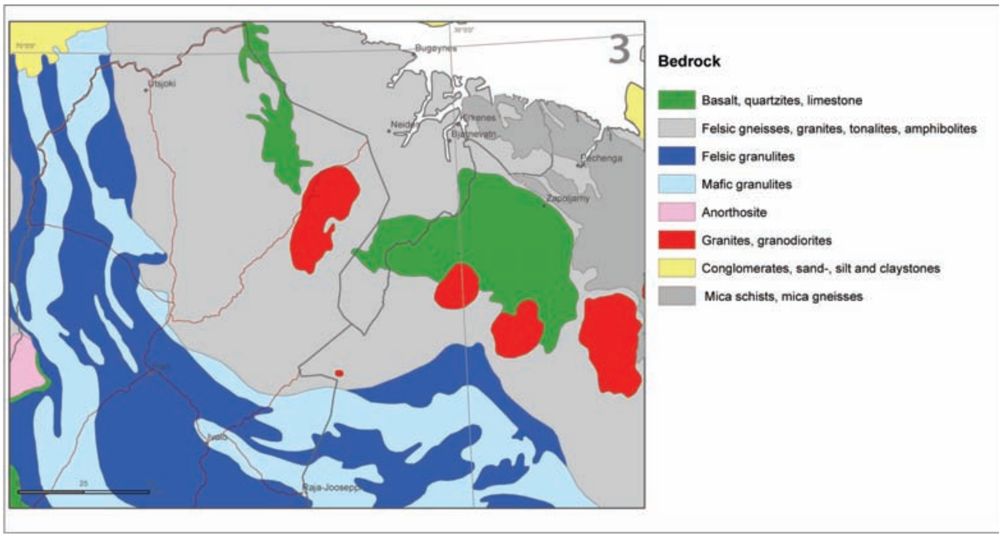
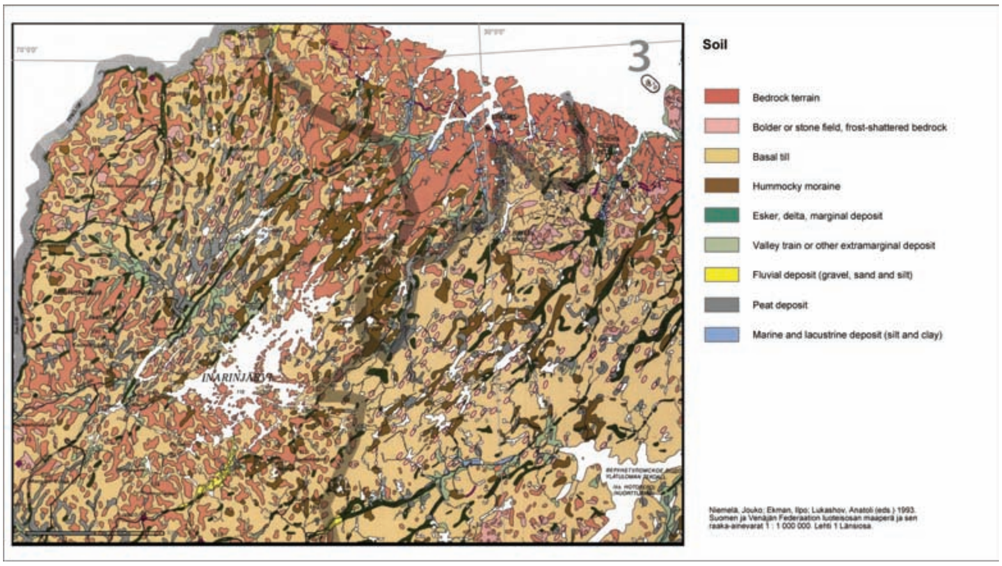


Figure 45. Simplified bedrock map showing the primary rock types in the region.

Geological soil mapping material

The most comprehensive soil map covering Finland, the northern part of Norway and the north-western part of Russia is from 1993 and is at a scale of 1:1.000.000. The soil map of the catchment area is a part of this map (Fig. 46). The map provides a general picture of the geological formations and the proportions of different soil types in the region. The most accurate soil data for the part of Finland in the region is at a scale of 1:400.000. The data provide a good overall picture of the distribution of different soil types, the soil structure and different types of soil formation such as hummocky moraine areas, peat and clay deposits and eskers.



Niemelä, Jouko; Ekman, Ilpo; Lukashov, Anatoli (eds.) 1993.
Suomen ja Venäjän Federaation luoteisosan maaperä ja sen raaka-ainevarat 1 : 1 000 000. Lehti 1 Länsiosa.

Figure 46. Soil map of the region.

Other geochemical material

The geochemical soil research material for the Paz river catchment area consists of data from 176 points sampled in connection with the Barents Eco-geochemical project, the Lapland Forest Damage Project, and a joint project carried out together with the Lapland Environmental Centre (Fig. 47). The results of the Barents Eco-geochemical Project are from subsoil (C horizon) samples taken from below the podzol profile. *Aqua regia* extraction was used in analyzing the samples, and the results are of indicative use when assessing the sensitivity to acidification. In addition, geochemical mapping data from 51 points in different parts of northern Finland sampled in 1995 in connection with the Lapland Forest Damage Project, and 45 points sampled in 1990-1992 in connection with the joint project carried out together with the Lapland Environmental Centre, were also used. Three separate extraction methods were used in the Lapland Forest Damage Project: *aqua regia* extraction, ammonium acetate extraction and ammonium nitrate extraction. However, only the results of *aqua regia* and ammonium nitrate extraction are presented here. The samples from the Lapland Forest Damage Project are primarily from five depths in till soil. For the sake of consistency, the results presented here are for the C horizon. In the joint project with the Lapland Environmental Centre, samples were taken from the organic layer and from four depths in the underlying till. The results of *aqua regia* extraction on C horizon samples are presented here.

In the Barents Eco-geochemical Project, the analyses were carried out on mineral soil material with a particle size of less than 2 mm, while in the Lapland Forest Damage Project and the joint project together with the Lapland Environmental Centre the analyses were performed on material with a particle size of less than 0.5 mm. As mafic minerals have a greater effect on the results when they occur in the sand and silt fractions, the results for the < 2 mm samples give a more reliable picture of the occurrence of easily weatherable minerals and the cation exchange capacity. The Ca concentrations are higher in the silt and sand fractions than in the clay fractions, especially in samples from the A and B horizons.

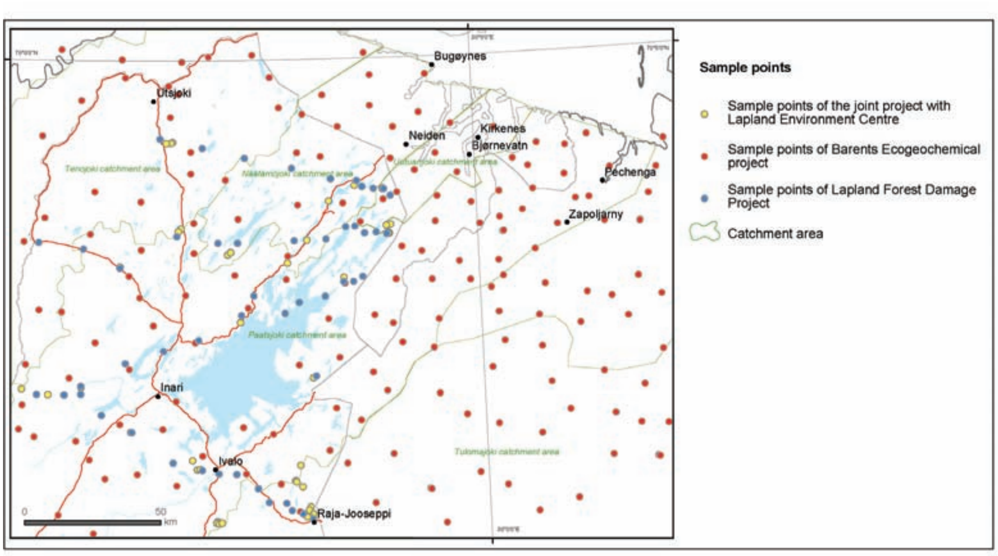


Figure 47. Location of the sampling plots employed in the Barents Eco-geochemical Project, the Lapland Forest Damage Project and in a joint project carried out together with the Lapland Evironment Centre.

Bedrock

A large granite-gneiss complex extends from the Kola Peninsula through the northern Inari and eastern Utsjoki area, and continues into Norway. The complex consists of granites and granodiorites of Archean age, as well as amphibolites and gneisses of varying composition, and a greenstone belt of volcanic origin. The greenstone belts consist of basaltic and komatitic vulcanites, which include ore deposits such as the nickel deposit at Zapoljarny, Russia, and iron deposit in Björnevann, Norway. A zone of Proterozoic mafic and felsic gneisses, called granulites, stretches from the western part of the Kola Peninsula, through Finland into Norway. In the west the granulite belt plunges under younger, late Proterozoic and early Paleozoic sedimentary rocks, such as sandstones and conglomerates. The Vaskojoki area in the southwestern corner of the map-area consists of anorthosite, a rock rich in calcic feldspar.

The geochemical and mineralogical composition of the bedrock affects the chemical properties of the soil. There is considerable variation in the composition of the bedrock at the local level. The occurrence of even small areas of special rock types can affect the composition of the till and, consequently, its sensitivity to acidification and the chemical composition of the ground water in the area.

Soil

The dominant mineral soil type in the area is till. Only 10% of the area consists of sorted sediment deposits such as eskers, shore deposits or dunes. The mineralogical composition of till mainly reflects the local bedrock, and the particle size of the material ranges from boulder to clay fractions. The material in the moraine formations is primarily gravel and sand till. The types of moraine formation in the area also include hummocky moraines and drumlins, in which lenses of sorted material are more common than in areas with ground moraines. The average thickness of the till soil in the valleys, on the lower slopes of hills and in flat areas is a few metres. There is no soil at all on the hill and fell tops.

A relatively high proportion of the soil material in Lapland has been weathered before the last Ice Age, and this may be reflected in the geochemical properties of the till in certain areas. Weathered material contains large amounts of easily soluble elements which, however, have been leached out of the surface layers of the soil. Sorted sediment deposits, such as eskers and shore deposits, have low proportions of fine material and easily soluble elements. Approximately 10% of the surface area is peatland. The mires in northern areas are usually aapa, palsa and bare fell mires.

Geochemical effects of the bedrock

Basic rock types contain relatively small amounts of silica, SiO_2. The most typical basic rock types are gabbros and basalts, which consist of dark, iron and magnesium-bearing minerals (amphibole and pyroxenes) and calcic feldspar. The calcium in these minerals is in an easily soluble form. Komatic vulcanites are especially rich in magnesium and low in silica. The amount of heavy metals, such as chromium and nickel, in basic rocks is relatively high, and their effect is further enhanced in the soil because these rock types readily disintegrate into fine particles.

Acidic rock types contain more silica, mostly in the form of quartz. The most typical acidic rock type is granite. The primary minerals in granite, quartz and feldspars do not decompose easily and they therefore have a reducing effect on the amount of soluble elements in the soil. However, if these rock types contain relatively large proportions of mica, then they release potassium, iron and aluminium into the soil. Till formed from acidic rock types usually contains a low proportion of fine material.

Gneisses are medium- or coarse-grained, structurally foliated metamorphic rocks. The catchment area contains several types of gneiss of different composition. Granite usually gneisses have the same mineralogical and chemical composition as granites and mica gneisses. Mica gneiss can also be found in the northern part of the Paz river catchment areas that extends from Russia into Norway. Soluble elements in the soil in gneiss areas are, depending on the chemical composition of the gneiss, primarily aluminium and potassium.

Granulites differ from gneiss in that the mica is either partially or wholly replaced by red garnet. The composition of the rocks in granulite areas varies between dark (mafic) and light granulites (felsic). Depending on the mineral composition, soluble aluminium, iron, base cations (Ca, Mg, K, Na), heavy metals and sulphur, may occur in the soil. The rocks in the Lapland granulite area are coarse and easily disintegrate.

In addition to mafic vulcanites, black schists and mica schists also occur in the greenstone zone. Mica schists with a high aluminium concentration also occur in the northern part of the zone in Russia that extends into Norway. The composition of the schists varies, but they mainly release aluminium, potassium and magnesium into the soil. Of the schist rocks, quartzite usually has a reducing effect on the amount of soluble elements in the soil.

Young sedimentary rocks, such as sandstones, conglomerates and graywackes, occur in the coastal area in the northern parts of the Kola Peninsula and Norway. These rock types primarily consist of quartz. Calcium occurs as carbonate in the matrix of these rock types. The claystones in some parts of the Varange area have relatively high concentrations of phosphorus.

Sensitivity of the soil to acidification

The geochemical properties of the soil are affected by the chemical and mineralogical composition of the bedrock. The geochemical properties can be used to estimate the sensitivity of the soil to acidification and the quality of the groundwater and runoff. Due to chemical decomposition and leaching, the till may contain considerably lower amounts of soluble cations than their parent material. The minerals in the upper part of the podzol profile are more weathered and their composition is strongly dependent on the degree of weathering and on climatic and vegetation factors, as well as on the parent material. The material in the lower part of the soil profile may, in some areas, have been affected by pre-glacial weathering.

Soil acidification is a process in which the hydrogen ion concentration of the soil solution increases as the base cation reserves in the soil are gradually depleted through cation exchange and the weathering of minerals. The development of a podzol profile acts as a natural buffering mechanism that prevents excessive acidification. The decomposition of organic substance, and subsequent release of weak organic acids, lowers the pH of the surface layer of the soil. Coarse-grained soil material is more sensitive to acidification than fine-grained material, because the surface area of coarse particles is smaller and they contain relatively small amounts of exchangeable cations. As acidification increases, the dissolution of Al^{3+} as well as of base cations, is accelerated. The dissolution of aluminium start at a pH of ca. 4.4.

The acid neutralization capacity (ANC) is a measure of how large an acid load the soil can withstand while the neutralization reactions continue to function in the soil. The regional acidification sensitivity of the soil is expressed as the sum of the equivalent concentrations of exchangeable base cations (Ca^{2+} + Mg^{2+} + K^+, expressed as meq/kg) in the mineral fraction of the soil. The risk of acidification in the mineral soil can be assessed on the basis of the dissolution of aluminium, and it is expressed as the ratio of the equivalent aluminium concentration to the sum of the equivalent base cation concentration ($Al^{3+}/Ca^{2+} + Mg^{2+} + K^+$ meq/kg, Al/BC). The higher the value of the ratio, the greater is the risk of acidification.

Conclusions

According to the results for *Aqua regia* extraction (HNO_3 + HCl), there are more base cations (Ca + Mg + K) in the greenstone zones and the Vaskojoki anorthosite area than in areas with granites and felsic gneisses, which are acidic rock types (Fig. 46). In the area extending from Paatsjoki to Kirkkoniemi, the occurrence of mica schists, mica gneisses, hornblende gneisses, and in some areas gabbros, increase the amounts of base cations in till. The areas with felsic gneisses also include outcrops of amfibolites and hornblende gneisses, which are reflected in the higher amounts of base cations.

The risk of acidification was estimated on the basis of the Al/BC ratio (Fig. 48). In the granite area of northern Lapland, which is a rock type that disintegrates easily, the bedrock has a reducing effect on the proportion of fine material in the till, and therefore on the amounts of base cations. As the Al/BC ratio is higher than that in the surrounding areas, the risk of acidification is higher in the granite area. No corresponding higher acidification risk was found in north-western Russia, presumably due to the too sparse sample plot network.

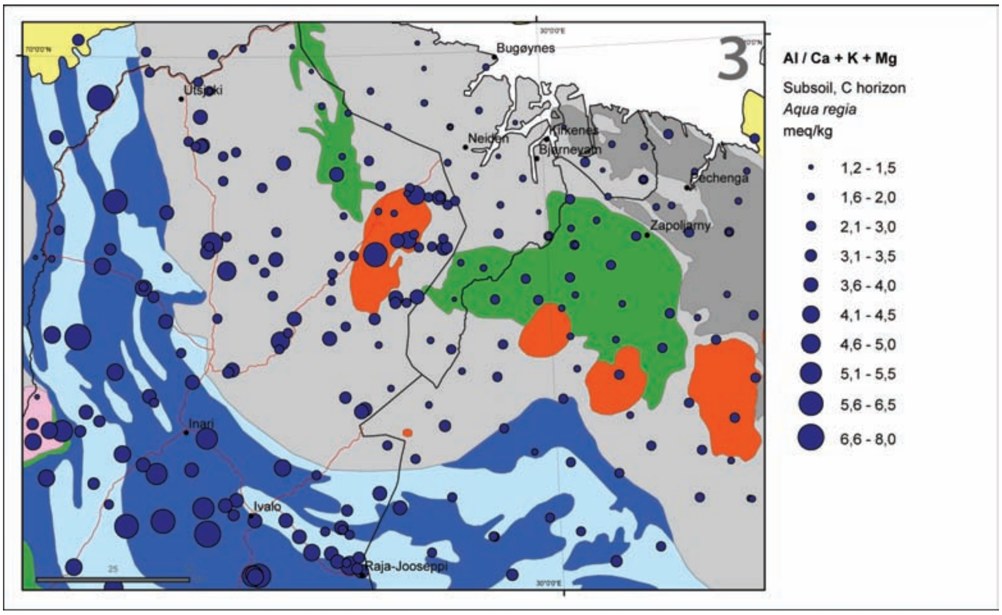


Figure 48. Map of the aluminium/base cation ratio (Al /(Ca + K + Mg)) (Aqua regia digestion) in the subsoil (C horizon) in the region.

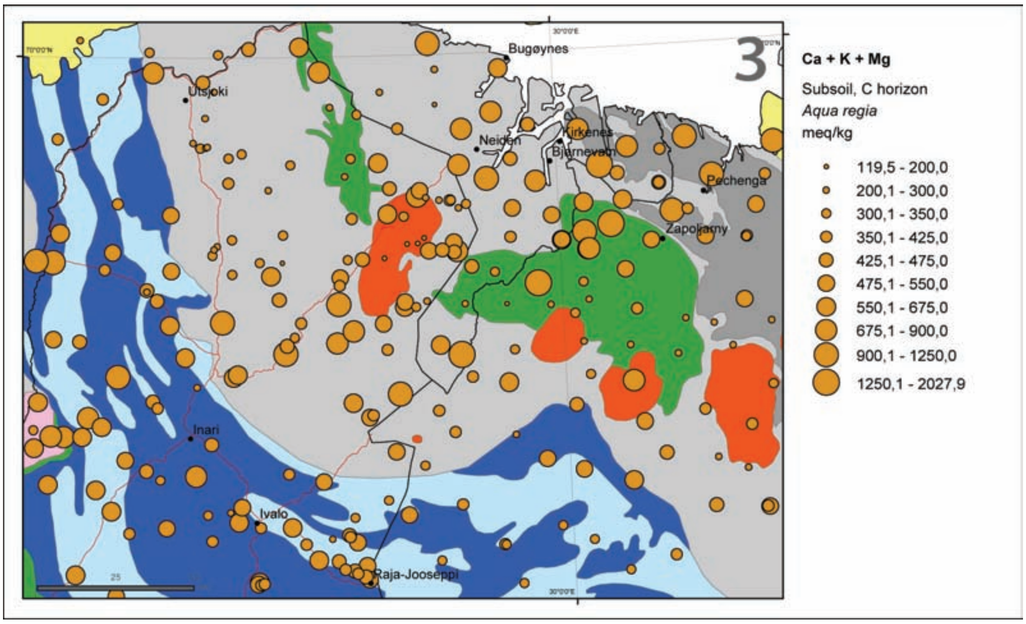


Figure 49. Map of base cation (Ca + K + Mg) concentrations (Aqua regia digestion) in the subsoil (C horizon) in the region.

The higher Al/BC ratio values observed in the granulite area may also indicate a higher risk of acidification. The tills in the granulite areas have higher aluminium concentrations than in the surrounding areas because granulite contains relatively high proportions of aluminium-rich minerals such as micas. The Al/BC ratio for the Vaskojoki calcium and aluminium-rich anorthosite area mainly indicates the natural effects of the local bedrock on the geochemistry of the area, because the anorthosite area also contains large amounts of easily soluble base cations. The Al/BC ratio along the Paatsjoki-Kirkkoniemi axis is low and therefore there is little risk of acidification. This is also the case in the surroundings of Zapoljarny and in the greenstone areas.

Of the results for weak acid extractions, only the results for ammonium nitrate extraction (NH_4NO_3) are reported here (Figs. 50 and 51). Ammonium nitrate extraction has been carried out only on part of the samples from Finland. The results for base cations are similar to those obtained with *Aqua regia*, although the concentrations are much lower. In the Vaskojoki anorthosite area, the Al/BC ratio values obtained with ammonium nitrate extraction are very different compared to those with *Aqua regia*, presumably due to the fact that the aluminium in anorthosite is not as easily soluble as e.g. in mica. The extraction of aluminium with ammonium nitrate in the mica granulite area also gave somewhat different results from those obtained with *Aqua regia*, which suggests a higher capacity of the soil to buffer acidification.

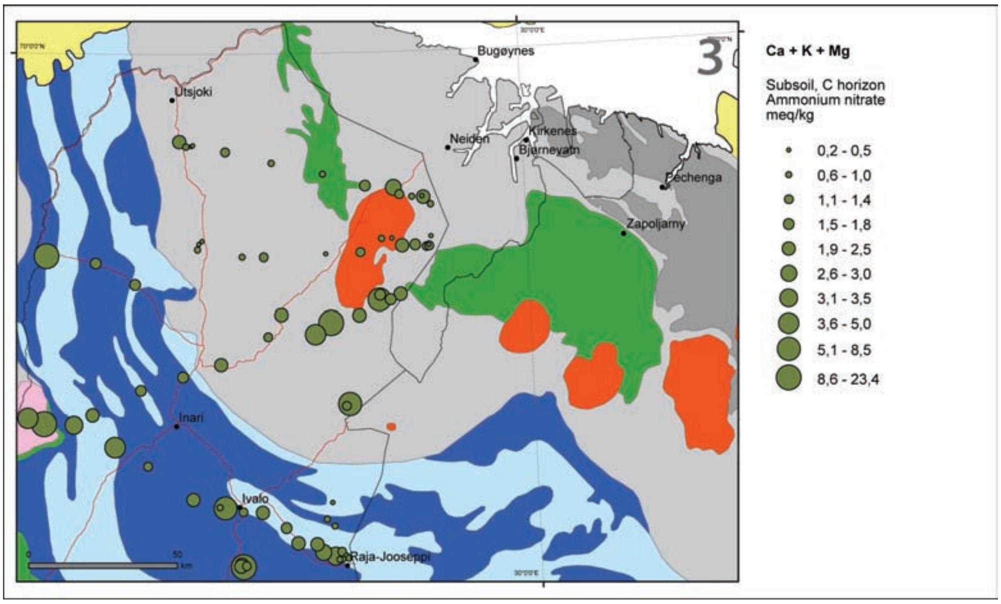


Figure 50. Map of base cation (Ca + K + Mg) concentrations (ammonium nitrate extraction) in the subsoil (C horizon) in the region.

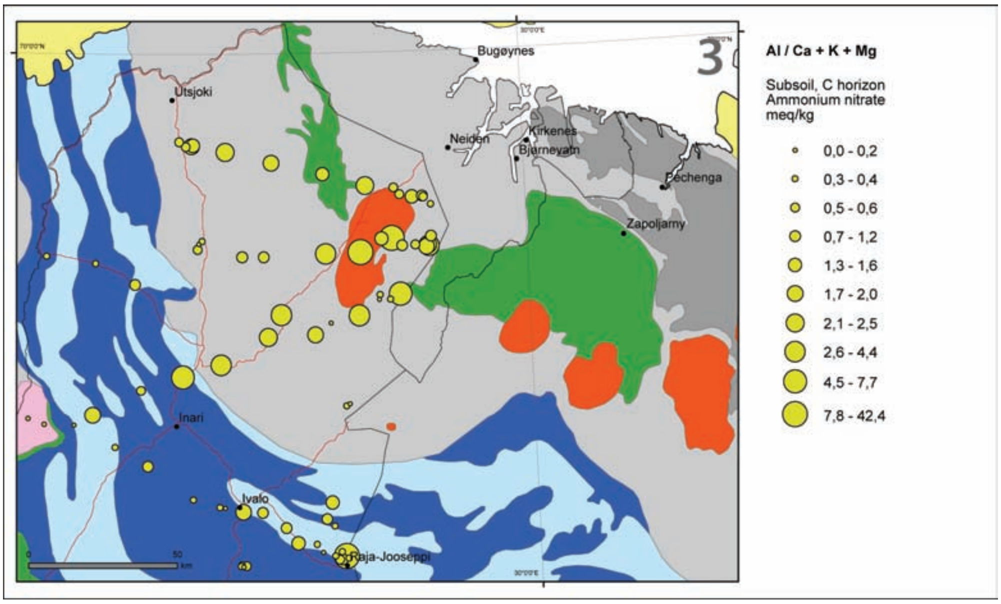


Figure 51. Map of the aluminium/base cation ratio (Al /(Ca + K + Mg)) (ammonium nitrate extraction) in the subsoil (C horizon) in the region.

4.13 Satellite imagery

Hans Tømmervik[2]

Monitoring the vegetation in the study area using satellite imagery in 7 separate years during the period 1973 – 1999 (Fig. 52) clearly indicated that major changes have occurred, especially in the lichen (epigeic) dominated vegetation cover, since 1973 when these vegetation formations were dominating (Tømmervik et al. 2003). The satellite data were analyzed and correlated with chlorophyll fluorescence measurements (photosynthetic efficiency), and significant positive relationships were found between the photosynthetic efficiency in species common in the mixed forest vegetation and the NDVI (Odasz-Albrigtsen et al. 2000). We found a significant negative relationship (r = - 0.94. p = 0.001) between the extent of the area of mixed forests with a lichen cover and SO_2 emissions during the period. The area of the category “industrial barrens” had a significant negative relationship (r = - 0.95. p = 0.001) with SO_2 emissions during the same period (Tømmervik et al. 2003). The overall accuracy of the different maps produced in the period 1973- 199 was 75–83%.

Satellite monitoring of the study area continued with an assessment of a Landsat scene from 26th July 2004. The data from 2004 were compared with previous satellite images taken during the period 1973 – 1999 (Tømmervik et al. 2003) in order to reveal changes in the vegetation at the landscape and regional levels. The coverage of lichen was at its lowest (due to air pollution) in 1992, with a subsequently increase from 1994 to 2004.

Using the low resolution satellites like NOAA-AVHRR and MODIS on the TERRA satellite, the biomass (Fig. 53) can be monitored on a daily and an annual basis using the Normalized Difference Vegetation Index – NDVI (Tømmervik et al. 2005), as well as phenological events and the length of the growing season (Fig. 54), (Høgda et al. 2006 in print, Karlsen et al. 2006). The length of the growing season clearly increased during the period 1982 - 2002 in the immediate surroundings of the Nikel smelters. The NOAA-AVHRR and the MODIS data are available free of charge for the scientific community, and are assessed through phenological monitoring projects (Phenoclim and NorSEN) led by NORUT with co-partners in Norway (NINA and Svanhovd Environmental Center), Russia (Kirovsk Botanical Garden, Pasvik Zapnovednik) and Finland (FMI and METLA).

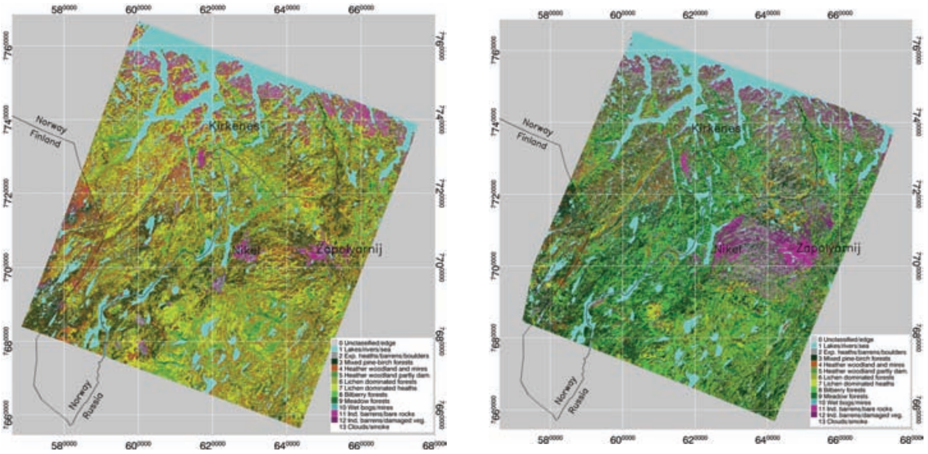


Figure 52. Land cover maps based on Landsat imagery of the study area. Damaged areas are shown in red to violet colour, abd lichen-dominated forests and alpine heaths are yellow to green. The map shows the situations in 1973 and in 1999.

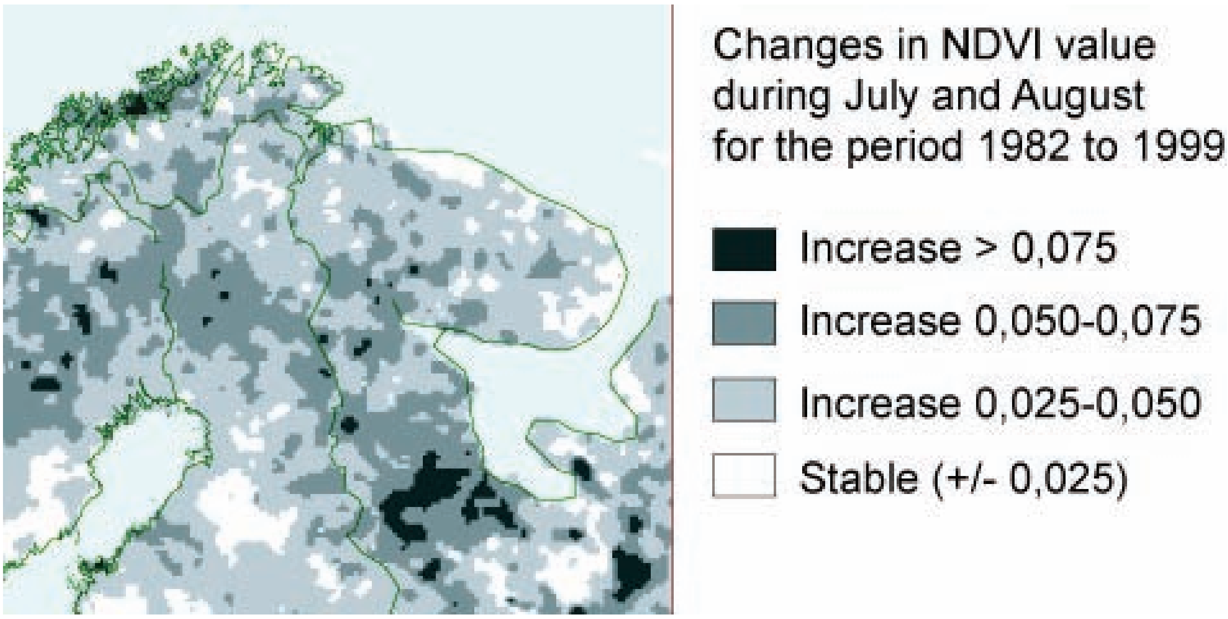


Figure 53. Changes in the NDVI values in July and August during the period 1982 - 1999 in Fennoscandia monitored by the NOAA-AVHRR satellites (NASA GIMMS data set). The NDVI value express the status of the vegetation (vitality) as well as the biomass. Source: Tømmervik et al. 2005.

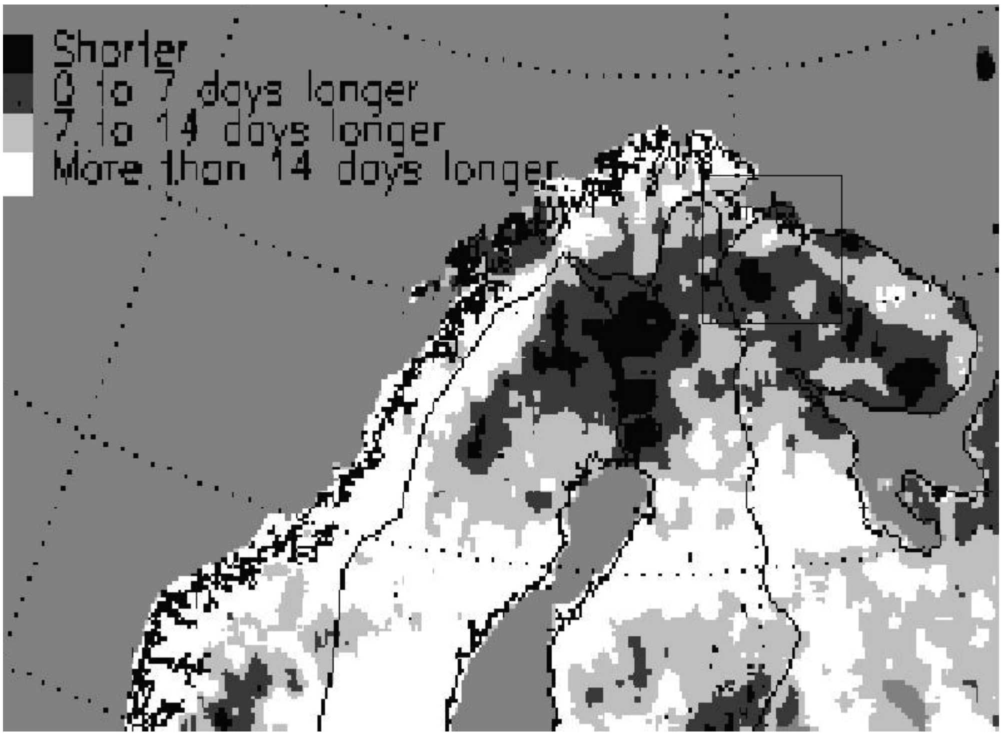


Figure 54. The spatial variation in the length of the growing season (1982 -2002) in Fennoscandia monitored by the NOAA-AVHRR satellites (NASA GIMMS data set).

5 Overall assessment of the state of the environment

There are signs of a slight recovery in the condition of terrestrial ecosystems in the area around the emission source, e.g. the reappearance of pioneer species of bryophytes and lichens on a number of the Russian plots, and the marked recolonization of epiphytic lichens on the least polluted plots along the transect running to the west of the smelter. Satellite imagery indicates that there has been an increase in lichen coverage in the area from 1994 to 2004, which is related to the reduction in emissions during the past 10 years. Lichens are sensitive indicators of pollution, especially SO_2. Furthermore, there has been an increase in the vitality of birch and bilberry (measured as photosynthetic efficiency) along the transect running to the south of the smelter, as well as a smaller increase along the transect running to the north. In contrast, the accumulation of heavy metals (especially Ni) in mosses has increased during the past 15 years. The continuing emission of heavy metals is clearly reflected in the metal concentrations in mosses up to a distance of ca. 30 km from the smelters. The soil (litter and humus layers) close to the smelter contains extremely high concentrations of a wide range of heavy metals, representing accumulation over the lifetime of the smelters. Elevated heavy metal concentrations also extend up to a distance of 30-40 km from the smelters. Although a relatively high proportion of the metals are in an immobilized form, the concentrations of plant-available metals are still excessively high. Accumulation of metals in the litter and organic layer is reflected in heavy metal concentrations in plants, such as grasses and dwarf shrubs, as well as in the needles and leaves of trees: in addition to the direct deposition of metals on the surfaces of plants, these concentrations are affected by metal uptake from the soil. The soil in the immediate vicinity of the smelter is not suffering from soil acidification, despite the continued relatively high level of SO_2 emissions. This is due to the abundant occurrence of basic types of bedrock in the area, as well as to the relatively low rate of conversion of SO_2 to sulphuric acid in the relatively dry, cold Arctic climate. Overall, the results support the official reports by the smelter company that there has been a decrease in the emissions of SO_2 in recent years, but the decrease in heavy metal emissions is perhaps not as strong (especially in the case of nickel) as has been assumed.

References

Aamlid, D. 1993. Symptoms of sulphur dioxide injury to some boreal plants. In: Jalkanen, R., Aalto, T. and Lahti, M. (eds.). Forest pathological research in northern forests with special emphasis to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3-7 August 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 93-102.

— 2002. Air pollution effects in the Norwegian-Russian border area. A status report. Norwegian Pollution Control Authority (SFT). 34 p. ISBN 82-7655-446-6.

— and Skogheim, I. 2001. The occurrence of Hypogymnia physodes and Melanlia olovacea lichens on birch stems in northern boreal forests influenced by local air pollution. Norwegian Journal of Geography 55: 94-98.

— , Vassilieva, N., Aarrestad, P., Gytarsky, M., Lindmo, S., Karaban, V., Rindal, T., Kuzmichema, V. & Venn, K. 2000. The ecological state of the ecosystems in the border areas between Norway and Russia. Boreal Environment Research 5: 257–278.

Aber, J.D., Nadelhoffer, K.J., Steudler, P. & Melillo, J.M. 1989. Nitrogen saturation in northen forest ecosystems. Bioscinesce Vol. 39: 378–386.

Bekkestad, T., Knudsen, S., Johnsrud, M. & Larsen, M. 1995. Modellberegninger av SO_2 og metallavsetninger i grenseområdet Norge-Russland (Model estimates of SO_2 and metal deposition in the border area Norway-Russia). NILU Rapport 605/95. The Norwegian Air Research Institute. Kjeller.

Bliss, L.C. l962. Adaptation of arctic and alpine plants to environmental conditions. Arctic 15: 117–144.

Bruteig, I. 1984. Epifyttisk lav som indikator på luftforurensning i Aust-Finnmark. Master thesis. University of Trondheim, Trondheim.

Brække, F.H. 1996. Needle analyses and graphic vector analyses of Norway spruce and Scots pine stands. Trees Vol. 11: 23–33.

Buse, A., Norris, D., Harmens, H., Büker, P., Ashenden, T. & Mills, G. (eds.). 2003. Heavy Metals in European Mosses: 2000/2001 Survey. UNECE ICP Vegetation. Centre for Ecology & Hydrology. Bangor. UK. 45 p.

Darral, N. M. 1989. The effect of air pollutants on physiological processes in plants. Plant Cell & Environment Vol. 12: 30.

Derome, J. & Lindroos, A-J. 1998. Effects of heavy metal contamination on macronutrient availability and acidification parameters in forest soil in the vicinity of the Harjavalta Cu-Ni smelter, SW Finland. Environmental Pollution 99:225-232.

— , Lindroos, A-J. and Niska, K. 1998. Effects of SO2 and heavy metal emissions from the Kola Peninsula, NW Russia, on soil acidity parameters in NW Russia and Finnish Lapland. Scandinavian Journal of Forestry Research, 13:421-428.

Demmig-Adams, B. & Adams III, W.W. 1996. The role of xanthophyll cycle carotenoids in the protection of photosynthesis. Trends in Plant Science 1: 21–26

— , Moeller, D.L., Logan, B.A. & Adams III, W.W. 1998. Positive correlation between levels of retained xeaxanthin + antheraxanthin and degree of photoinhibition in shade leaves of Schefflera arboricola (Hayata) Merrill. Planta 205: 367–374.

Evers, F.-H. & Huettl, R.F. 1991. A new fertilization strategy in declining forests // Management of nutrition in forest under stress. Zoettl, H.W. and Huettl, R.F. (eds.). - Kluwer Academic Publishers. p. 495–508.

Ewald, J. 2005. Ecological background of crown condition. growth and nutritional status of *Picea abies* (L.) Karst. in the Bavarian Alps. European Journal of Forest Research 124: 9–18.

Gosz, J.R., Likens, G.E., & Bormann, F.N. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook Forest. New Hampshira. Ecological Monographs 43:173–191.

Gytarsky, M., Karaban, R., Nazarov, I., Sysygina, T. & Chemeris, M. 1994. Monitoring of forest ecosystems in the Russian Subarctic: effects of industrial pollution. The Science of the Total Environment 164: 57–68.

Hagen, L.O., Sivertsen, B. & Arnesen, K. 2006. Grenseområdene i Norge og Russland. Luft- og nedbørskvalitet. april 2005–mars 2006 (Border areas in Norway and Russia. Air- and precipitation quality. April 2005–March 2006). Rapport 966/2006. NILU Rapport OR 69/2006. (In Norwegian with English summary).

Hatakka, J., Aalto, T., Aaltonen, V., Aurela, M., Hakola, H., Komppula, M., Laurila, T., Lihavainen, H., Paatero, J., Salminen, K. & Viisanen,Y. 2003, Overview of the atmospheric research activities and results at Pallas GAW station. Boreal Environment Research 8: 365–383.

Helmisaari, H.-S. 1992. Spatial and age-related variation in nutrient concentrations of *Pinus sylvestris* needles. Silva Fennica 26 (3): 145–153.

Henttonen, H., Hirvi, J.-P., Gower, C.N. and Yoccoz, N.G. 2002. Contaminants in the common shrew (/Sorex araneus) in northern Fennoscandia in relation to humus deposits. – 2nd AMAP Int. Symp. Environ. Poll. Arctic, extended abstracts: P-M39.

Hill, M.O. 1979b. DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging. - Cornell Univ., Ithaca, New York.

— & Gauch, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. - Vegetatio 42: 47-58.

Huettl, R.F., 1993. Mg—deficiency—a “new” phenomenon in declining forests. Symptoms and effects, causes, recuperation. In: Hütl, R.F., Müller-Dombois, D. (eds.), Forest Decline in the Atlantic and Pacific Regions. Springer-Verlag. Berlin, Heidelberg, p. 97–144.

— & Fink, S. 1991. Pollution, nutrition and plant function. In: Porter, J.R. & Lawlor, D.W. (eds). Plant growth: interaction with nutrition and environment. Society for experimental biology, Seminar series 43. Cambridge University Press, Great Britain, p. 207–222.

Huttunen, S., Laine K. & Torvela, H. 1985. Seasonal sulphur contents of pine needles as indices of air pollution. Annales Botanici Fennici. Vol. 22: 343–359.

Høgda, K.A., Karlsen, S.R. & Tømmervik, H. 2006. Changes in growing season in Fennoscandia 1982–1999. In: Orbaek, J.B., Tombre, I.M., Kallenborn, R., Heggseth, E.N., Falk-Petersen, S. & Hoel, A.H. (eds). Arctic-Alpine Ecosystems and People in a Changing Environment. Environmental Challenges in Arctic-Alpine Regions. Springer Verlag. Berlin (in print).

ICP Forests. 2005. Manual. Part VI. Measurement of deposition (http://www.icp-forests.org/Manual.htm).

Il’in, B.V. 1991. Heavy metals in the system “soil-plants”. Novosibirsk. 151 p. In Russian.

Innes, J.L. 1995. Influence of air pollution on the foliar nutrition of conifers in Great Britain. Environmental Pollution. Vol. 88: 183–192.

Kandler, O. & Innes, J.L. 1995. Air pollution and forest decline in central Europe. Environmental pollution 90: 171–180.

Karlsen, S.R., Elvebakk, A., Høgda, K.A. & Johansen, B. 2006. Satellite-based mapping of the growing season and bioclimatic zones in Fennoscandia. Global Ecology and Biogeography. doi: 10.1111/j.1466-822x.2006.00234.x

Kashulina, G., Reimann, C. & Banks, D. 2003. Sulphur in the Arctic environment (3): environmental impact. Environmental Pollution 124: 151–171.

Kauhanen, H. & Varmola, M. (toim.) 1992. Itä-Lapin Metsävaurioprojektin väliraportti. Metsäntutkimuslaitoksen tiedonantoja 413. 266 p.

Kesola, R. 1994. Näätämö. Geological Map of Finland. 1: 100 000. Pre-Quaternary rocks. Sheet 3934+4912+4914. Geological Survey of Finland.

— 1995. Näätämön kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Näätämö map-sheet area. Kallioperäkartan selitys 1: 100 000. 3934+4912+4914. Geological Survey of Finland.

Kitajima, M. & Butler, W.L. l975. Quenching of chlorophyll fluorescence and primary photochemistry in chloroplasts by dibromothymoqinone. Biochimica et Biophysica Acta 376: 105–115.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds.) 1997. Suomen kallioperäkartta - Berggrundskarta över Finland - Bedrock map of Finland 1:1 000 000. Espoo: Geological Survey of Finland.

Kozlov, M.V. 1992. pollution-induced changes in the birch population structure in Kola Peninsula, Northern Russia. In: Disturbance Related Dynamics of Birch and Birch Dominated Ecosystems. p. 51–53. Nordic Symposium. Illugastathir. Fnjóskadalur. Iceland 18–22 september 1992. Iceland Forest Research Station.

Krause, G.H. 1994. Photoinhibition induced by low temperatures. In: Baker, N.R. & Bowyer, J.R. (eds.). Photoinhibition of photosynthesis from molecular mechanisms to the field. Bios Scientific Publishers. Oxford. England. p. 331–348.

Kålås, J. F., Ringsby, T. H. and Lierhagen, S. 1993. Metals and radiocesium in wild animals from the South Varanger area, North Norway. – NINA oppdragsmelding 212: 1-26.

Kähkönen, A.-M. 1996. The geochemistry of Podzol soils and its relation to lake water chemistry. Finnish Lapland. Bulletin. Geological Survey of Finland 385.

Lindroos, A-J., Derome, J. & Derome, K. 2007. Open area bulk deposition and stand throughfall in Finland during 2001–2004. In: Merilä, P., Kilponen, T. & Derome, J. (eds.). Forect condition monitoring in Finland – National report 2002–005. Working Papers of the Finnish Forest Research Institute 45. p. 81–92. http://www.metla.fi/julkaisut/workingpapers/2007/mwp045.htm

Løbersli, E.N. & Steinnes, E. 1988. Metal uptake in plants from a birch forest area near a copper smelter in Norway. Water, Air and Soil Pollution Vol. 37: 25–39.

Lukina, N.V. & Nikonov, V.V. 1996. Biogeochemical cycles in the forests of the North under conditions of air borne industrial pollution. Two parts. – Apatity. KSC RAS. – Part1 – 213 p.; Part2 – 192 p. In Russian.

— and Nikonov, V. V. 1997. Pollution-induced changes in nutritional status of pine forests on the northern tree line (Kola peninsula). In: R.M.M Crawford (Ed), Disturbance and Recovery in Arctic Lands, Kluwer Academic Publishers, p. 303-319.

— & Nikonov, V.V. 1998. Nutrient status of the northern taiga forests: natural and technogenic aspects. Apatity: KSC RAS. 316 p. In Russian.

Merilä, P., Lindgren, M., Raitio, H. & Salemaa, M. 1998. Relationships between crown condition, tree nutrition and soil properties in coastal *Picea abies* forests (western Finland). Scandinavian Journal of Forest Research 13: 413–420.

Mitrofanov, D.P. 1977. Chemical composition of forest plants of Siberia. Novosibirsk. 120 p. Russian

Mäkinen, A. 1994. Biomonitoring of atmospheric deposition in the Kola Peninsula (Russia) and Finnish Lapland. Based on the chemical analysis of mosses. Ministry of the Environment. Rapport 4: 1–83.

Neuvonen, S. 2001. Pollution-induced changes in mountain birch forests. In: Wielgolaski, F.E. (ed.). Nordic Mountain Birch Ecosystems. 390 p. Man and Biosphere series. Vol. 27: 331–342

Nordkalott Project 1987. Geological Map. Pre-Quaternary Rocks. Northern Fennoscandia. 1: 1 000 000. Geological Surveys of Finland, Norway and Sweden.

Odasz-Albrigtsen, A.M., Tømmervik, H. & Murphy, P. 2000. Decreased photosynthetic efficiency in plant species exposed to multiple airborne pollutants along the Russian-Norwegian Border. Canadian Journal of Botany 78: 1021–1033.

Osmond, C.B. 1994. What is photoinhibition? Some insights from comparisons of shade and sun plants. In: Baker, N.R. & Bowyer, J.R. (eds.). Photoinhibition of photosynthesis from molecular mechanisms to the field. Bios Scientific Publishers. Oxford. England. p. 1–24.

Poikolainen, J., Kubin, E.,.Piispanen, J. & Karhu, J. 2004. Atmospheric heavy metal deposition in Finland during 1985–2000 using mosses as bioindicators. The Science of the Total Environment 318: 171–185.

Reimann, C., Niskavaara, H., Kashulina, G., Filzmoser, P., Boyd, R., Volden, T., Tomilina, O. & Bogatyrev, I. 2001. Critical remarks on the use of terrestrial moss (*Hylocomium splendens* and *Pleurozium schreberi*) for monitoring of airborne pollution. Environmental Pollution 113: 41–57.

— , Äyräs, M., Chekushin, V., Bogatyrev, I., Boyd, R., Caritat, P. de, Dutter, R., Finne, T.E., Halleraker, J.H., Jaeger, O., Kashulina, G., Lehto, O., Niskavaara, H., Pavlov, V., Räisänen, M-L., Strand, T. and Volden, T. 1998. Environmental Geochemical Atlas of the Central Barents Region. NGU-GTK-CKE Special Publication, Geological Survey of Norway, Trondheim, Norway.: 745 p.

Räisänen, M.–L. & Lahermo, P. 1985. Maaperän happamoitumistutkimuksiin soveltuvista osittaisuuttomenetelmistä. Geologian tutkimuskeskus. Ympäristö-geokemiallisia tutkimuksia no. 2.

SFT, 2002. Air Pollution Effects in the Norwegian - Russian Border Area. Norwegian Pollution Control Authority. TA 1860/2002

Solberg, S. 1999. Crown condition and growth relationships within stands of *Picea abies*. Scandinavian Journal of Forest Research 14: 320-327.

Steinnes, E., Berg, T. & Sjøbakk, T.E. 2001. Atmosfærisk nedfall av tungmetaller i Norge. Landsomfattande undersøkelse i 2000. Statens foruensningstilsyn (SFT). Rapport 838/01.

— , Lukina, N., Nikonov, V., Aamlid, D. and Røyset, O. 2000. A gradient study of 34 elements in the vicinity of a copper-nickel smelter in the Kola Peninsula. Environmental Monitoring and Assessment 60: 71-88.

Tikkanen, E. (toim.). 1995. Kuolan saastepäästöt Lapin metsien rasitteena: Itä-Lapin metsävaurioprojektin loppuraportti. 232 p.

— & Niemelä, I. (eds.). 1995. Kola Peninsula pollutants and forest ecosystems in Lapland. Final report of The Lapland Forest Damage project. Finland's Ministry of Agriculture and Forestry. The Finnish Forest Research Institute 83 p.

— & Raitio, H. 1990. Nutrient stress in young Scots pines suffering from needle loss in a dry heath forest. Water, Air, and Soil Pollution. Vol. 54: 281–293.

Traaen, T.S., Moiseenko, T., Dauvalter, V., Rognerud, S., Henrikesen, A. & Kudravseva, L. 1991: Acidification of Surface Waters, Nickel and Copper in Water and Lake Sediments in the Russian-Norwegian Border Areas. Progress Report for 1989-1990. Working Group for Water and Environmental Problems under the Norwegian-Soviet Environmental Protection Commission. Oslo and Apatity.

Tømmervik, H., Høgda, K.A. & 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.

— , Johansen, M.E., Pedersen, J.P., and Guneriussen, T. 1998. Integration of remote sensed and in-situ data in an analysis of the air pollution effects on terrestrial ecosystems in border areas between Norway and Russia (Russia). Environmental Monitoring and Assessment, 49: 51-85.

— , Wielgolaski, F.E., Neuvonen, S., Solberg, B., & Høgda, K.A. 2005. Biomass and Production on a Landscape Level in the Northern Mountain Birch Forests. In: Wielgolaski, F.E. (ed.). Plant Ecology. Herbivory. and Human Impact in Nordic Mountain Birch Forests. Berlin: Springer-Verlag. Ecological studies 180: 53–70.

Vassilieva, N.P. 1992. Cartographic assessment of state and sensitivity of forest to air pollution from the Pechenganikel metallurgical works for critical load definition. In: Kismul, V., Jerre, J. and Løbersli, E. (eds.) 1992. Effects of air pollutants on terrestrial ecosystems in the border area between Russia and Norway. Proceedings from the first symposium, Svanvik, Norway 18-20. March 1992, SFT, p. 134-144.

— 1993. Response of forest ecosystems to aerial emissions of “Pechenganikel” smelters complex. In: Kozlov, M.V., Haukioja, E. and Yarmishko, V.T. (Eds.). Aerial pollution in Kola Peninsula: Proceedings of the international workshop , April 14-16, 1992, St. Petersburg, Apatity, Kola Scientific Centre, p. 403-405.

De Vries, W., Klap, J.M. & Erisman, J.W. 2000. Effects of environmental stress on forest crown condition in Europe. Part I: Hypotheses and approach to the study. Water, Air, and Soil Pollution 119: 317–333.

Yoccoz, N.G., Tømmervik, H., Bakkestuen, V., Nikonov, V., Lukina, N., Jensen, H., Finne, T.R. & Henttonen, H. 2001. Environmental and pollution impact research and competence build-up in northern Norway through integrated ecological, geological and remote sensing studies. A multidisciplinary project between NINA, NGU, INEP and METLA. Final Project Report. Norwegian Institute for Nature Research. Tromsø.

Zoettl, H.W. & Huettl, R.F. (eds.) 1991. Management of nutrition in forest under stress. Kluwer Academic Publishers. 668 p.

Äyräs, M., Niskavaara, H., Bogatyrev, I., Chekushin, V., Pavlov, V., de Caritat, P., Halleraker, J.H., Finne. T.E., Kashulina, G. & Reimann, C. 1997. Regional patterns of heavy metals (Co, Cr, Cu, Fe, Ni, Pb, V and Zn) and sulphur in terrestrial moss samples as indication of airborne pollution in a 188.000 km^2 area in northern Finland. Norway and Russia. Journal of Geochemical Exploration 58: 269–281.

WWW-sites:

Phenoclim: http://projects.itek.norut.no/phenology/no/
NorSEN: http://norsen.fmi.fi