International cooperation on environmental issues and environmental protection in the polar areas

Air Pollution Effects in the Norwegian – Russian Border Area

1860
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A Status Report

Preface

Air pollution in the Norwegian-Russian border region has been of major concern for decades, particularly the emissions from the Petchenganikel smelter. In 1988 the Joint Norwegian-Soviet Commission on Environmental Co-Operation was established, which later was renegotiated with Russia in 1992. Its overall goal was to jointly solve the environmental problems in the border region. As a result, much research have been undertaken through different projects to establish a knowledge base to understand the effects air pollution have upon the terrestrial and aquatic environment in the area.

The Norwegian Government and the Nordic Investments Bank (NIB) are supporting a modernisation project to reduce emissions from Pechenganikel. The goal is to reduce emissions by 90 per cent and thereby reduce the environmental consequences in the region. To follow up this modernisation project, the Norwegian Ministry of Environment (MD) has asked the Norwegian Pollution Control Authority (SFT) to co-ordinate and prepare this report. It summarises the environmental status in the border area based upon the most important findings from Norwegian and Russian research. The report will be handed to NIB in line with the grant facility agreement between Norilsk Nickel and NIB of 17 December 2001.

SFT hired Dan Aamlid from Skogforsk to be the main editor of this report. He has extensive experience from environmental research in the border region.

Many institutions from both Russia and Norway have been involved in preparing the report. This status report is based upon different sources where both published scientific papers have been investigated and several experts have given their contributions.

The following persons have contributed to the report:
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Oslo, March 2002

Joakim Lystad
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Extended summary and conclusions

The Pechenganikel combine in the Nikel-Zapolyarny area was established in 1933. During the first 30 years of production, 100 000 tons of sulphur dioxide (SO_2) were emitted annually. Since 1971, nickel from the Norilsk ores in Siberia have been processed in the smelters. The Norilsk ore contains more sulphur than the Nikel ore. As a result of the processing of this sulphur-rich ore, emissions of SO_2 increased rapidly, reaching 400 000 tons in 1979. Current annual emissions are much lower, about 150 000 tons. However, the present emission is still above the critical level for sensitive biota in the Nikel-Pasvik area.

Investigations of soils show that the soil layers are contaminated by heavy metals (nickel and copper). The results also indicate an influence on soil fertility expressed as changes in base saturation (BS), cation exchange capacity (CEC) and soil acidity. According to the calculations (critical loads) future sulphur deposition has to be reduced to very low levels in order to stop the ongoing soil acidification.

Air pollution influence has had severe effects on forest vegetation in the Nikel-Pasvik area. Trees, vascular plants, mosses and lichens are all affected. In the close vicinity of the smelters forests are dead or severely damaged. Visible injuries to vegetation caused by SO_2 have some years been frequent. Symptoms are recognised on Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*), which are the dominant tree species in the region, and on other plants, e.g. dwarf birch (*Betula nana*) and bilberry (*Vaccinium myrtillus*). The species composition of the ground vegetation in the forest has been influenced, and epiphytic lichen vegetation has been severely influenced over large areas. Critical levels are exceeded on more than 3200 square kilometres of Russian and Norwegian territory.

Air pollution has reduced invertebrate and animal diversity due to lack of forest vegetation and contamination of surface soils in the vicinity of the nickel smelters. Small vertebrates are impacted by an increased heavy metal content in the liver. However, no negative health effects to reindeer are foreseen.

Long-term monitoring of water chemistry in lakes and rivers has revealed that extensive surface water acidification has taken place, particularly on the Norwegian side of the border. Critical loads are exceeded in large areas of Sør-Varanger municipality, especially in the Jarfjord area, and in areas situated around Nikel and Zapolyarny. However, on the Russian side, the contamination of lakes by the heavy metals (nickel and copper) is more severe than acidification, especially in the vicinity of the smelters, where damage to fish populations as well as phytoplankton and invertebrate communities are observed.

Studies of human health in the Nikel-Pasvik area revealed no major health effects that can be ascribed to the air pollution by nickel and sulphur dioxide in the Nikel-Zapolyarny area or in the Pasvik valley.

The most severe effects of air pollution in the border areas between Norway and Russia, caused by sulphur dioxide emission from Nikel and Zapolyarny, on the terrestrial and aquatic ecosystems seem to be on vegetation, surface water and soils, and thus also on other compartments of the ecosystem.

1. Introduction

The Norwegian-Russian border area and the western part of the Kola Peninsula have during several decades received high loads of sulphur caused by sulphur dioxide (SO_2) emissions from the nickel smelter in Nikel and the roasting plant in Zapolyarny, also named Pechenga-Nikel Smelters or Pechenganikel Smelters. The smelter in Nikel is one of the largest sulphur emitters in Europe. The maximum emission so far occurred around 1980, reaching approximately 400 000 tons of SO_2.

Effects of the air pollution in the Norwegian-Russian border region have been studied in several investigations and monitoring projects in the last two decades as part of the Joint Norwegian-Russian Commission on Environmental Co-operation. Three expert groups have been working, namely the Expert Group on Studies of Local Air Pollution Problems (Sivertsen et al. 1994), the Expert Group on Water Pollution Problems (Kalabin and Svelle 1994) and the Expert Group on Studies of Air Pollution Effects on Terrestrial Ecosystems (Kismul et al. 1992; Løbersli and Venn 1995).

In addition to all investigations performed as part of the activities of the expert groups, several national programmes and projects have been executed over several years. These include the so-called Baseline Study of Air Pollution in Sør-Varanger 1988-1991 (Hagen et al. 1991), part of the national monitoring programmes (SFT 2001) and research papers (see reference list). A comprehensive Environmental Geochemical Atlas of the Central Barents Region has also been developed and published recently (Reimann et al. 1998).

Air quality was measured at both Norwegian and Russian sites as part of the bilateral co-operation during 1990 - 1997. However, detailed investigations started at Norwegian sites in 1988, and simple air quality measurements have been made at Svanhovd since 1974 (Sivertsen et al. 1994). Measurements of air quality have therefore been executed for a long period in the area, and data on air quality is comprehensive and very valuable for evaluation of the state of the ecosystems in the area.

Surface waters in parts of the area are known to be very sensitive to acid deposition (Kalabin and Svelle 1994). The emissions may therefore cause acidification, which may be harmful to living organisms. Accumulation of heavy metals in water may also affect living organisms in the area.

The boreal forests in the border region are among the northernmost coniferous forests of the world. Under the prevailing extreme growth conditions due to a climate in which trees and vegetation are under strong natural stress, it can be presumed that even minor loads of air pollutants may have severe effects upon forest vitality. The capacity of ecosystems to withstand or buffer the effects of acid deposition varies widely according to their physical, chemical and biological properties.

The main aim of this report is thus to summarise the most important findings based on available data. These findings are a basis for future evaluations of the ecosystems, as well as serving as a basis for monitoring the ecosystems in relation to future air quality in the area.

2. The area

The report covers areas located in the eastern part of Finnmark county, Norway, and the western parts of Murmansk county (oblast), Russia (69-70°N, 29-32°E), defined by the catchment areas of the Pasvik and Pechenga rivers. The term Nikel-Pasvik used in this report refers to this area (Fig. 1).

Arctic and north boreal ecosystems are dominant. Areas without forest trees can be characterised as low arctic and sub-arctic, while areas with tree growth belong to the north boreal forest type, characterised by Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*). However, because of the high northern latitude the polar tree lines of both pine and birch are met in the area and alpine plants are common even at low altitudes.

The macro-topography of the area is rather flat, dominated by smooth hills up to about 450 meters above sea level. Approaching the coast, in the north-east, the area is rockier, and can be characterised as hilly highlands. Precambrian bedrock covered with moraine dominates the area. The central part of the area includes the so-called Petsamo formation, consisting of eruptive and sedimentary rocks, which are easily weathered, and richer in nutrients than the much harder and infertile gneissic and granitic bedrock that dominates to the south and north. Calcium-rich bedrock covers large areas south-east of Nikel and along the east and south sides of the Kuetsyarvi, and crosses the Pasvik River at Langevatn. Small areas with lime bedrock, which are rich in nutrients, can also be found in the uppermost part of the Pasvik River valley. The Shuoniyoki River valley south of Nikel includes large fluvioglacial deposits with gravel and sand. A further description of topography and geology is given by Reimann et al. (1998).

Due to the Gulf Stream current, the Barents Sea is a major factor in the climate of the western part of the Murmansk region. However, there are clear climatic gradients occurring in the area. The climate in the coastal areas of the north is oceanic, while the climate towards the south is more continental. The annual mean temperature in the northern areas (Kirkenes) is -0.2° C, while it is -1.1° C in the southern part of the Pasvik Valley (Aune 1993). The annual precipitation varies from 340 – 640 mm/yr. Snow cover normally sets in mid-December and lasts to May.

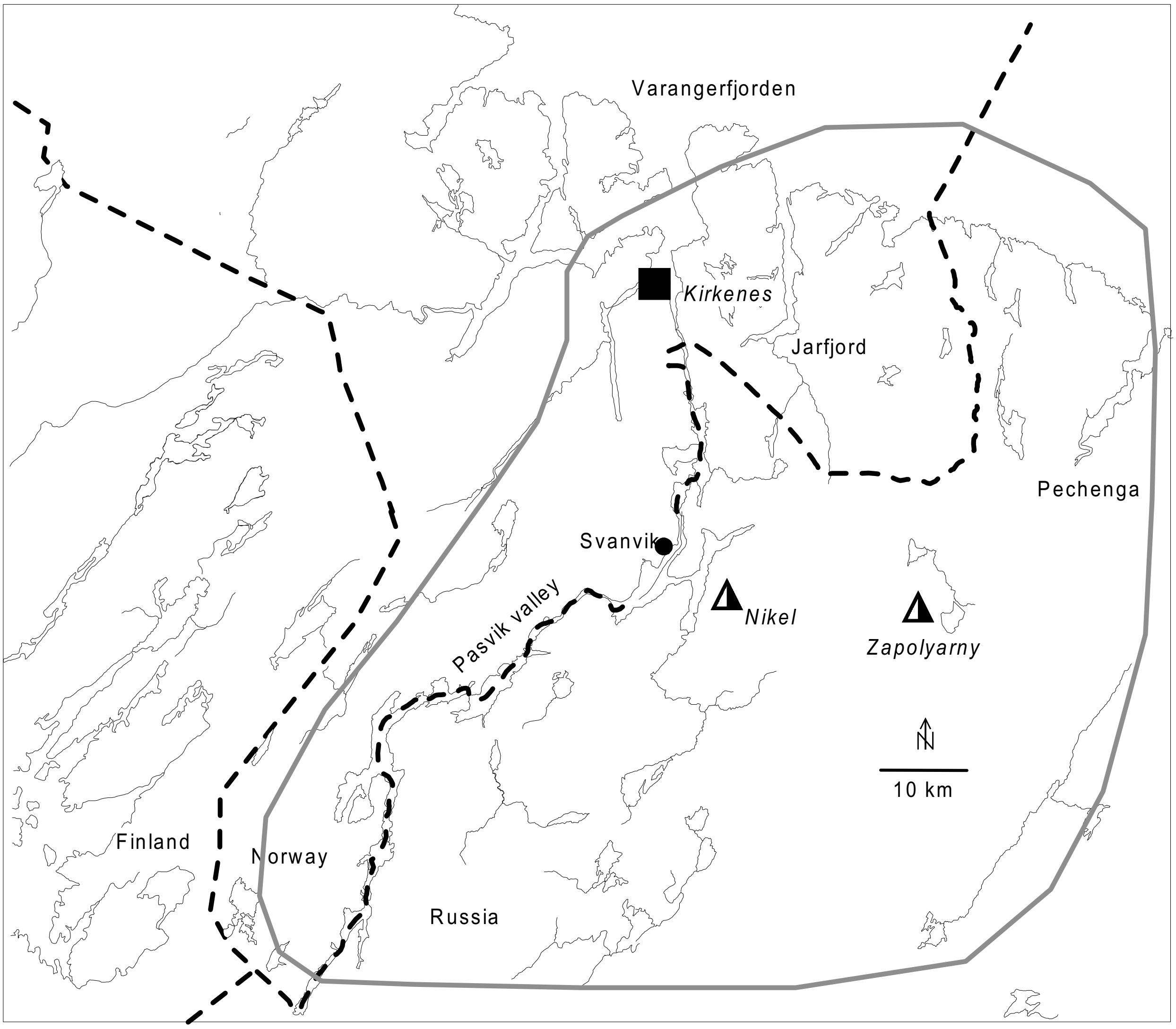

Fig. 1. Map of area of interest (outlined) in the border region between Norway and Russia.

3. Air pollution

The Pechenganikel combine in the Nikel-Zapolyarny area was established in 1933. During the first 30 years of production, 100 000 tons of SO_2 were emitted annually. Since 1971, nickel from the Norilsk ores in Siberia have been processed in the smelters. The Norilsk ore contains more sulphur than the Nikel ore. As a result of the processing of this sulphur-rich ore, emissions of SO_2 increased rapidly, reaching 400 000 tons in 1979. Current annual emissions are about 150 000 tons. However, the present emission is still above the critical level for sensitive biota in the Nikel-Pasvik area.

The main air pollution sources in the border areas are the nickel smelters of Pechenganikel established by the Finns in 1933. The smelters are located in Nikel and roasting takes place in Zapolyarny. From 1971, Norilsk high-sulphur copper-nickel ore has been frequently used. The sharp increase of sulphur emissions in 1974 was caused by increased use of this sulphur-rich ore. The highest level of SO_2 emissions took place in the fifteen-year period from 1974 to 1988 (Fig. 2). In this period, annual emissions also accounted for 512 tons of nickel and 308 tons of copper (Kola Science Center, pers. comm.). In addition to Ni and Cu, other elements are emitted (see 4.1.2.1).

Air quality and meteorology have been measured at Norwegian and Russian sites (Fig. 3) as part of the bilateral co-operation during 1990 - 1997. However, detailed investigations started at Norwegian sites in 1988 and simple air quality measurements at Svanhovd in 1974 (Sivertsen et al. 1994). Measurements of air quality have therefore been executed for a long period in the area.

The measurements have shown that the air pollution in the border areas is dominated by episodes linked to adverse meteorological conditions. During these episodes the concentrations of SO_2 have exceeded national and international guideline values by a factor of ten at distances up to 30 km from the smelters. The deposition of the heavy metals Ni and Cu also exceeds guideline values by a similar factor within 10-30 km from the smelters (Sivertsen et al. 1994). Due to topography and weather conditions the dispersal of the emissions is uneven, as shown in Fig. 3. Analyses of mosses and soils (Reimann et al. 1998, pp. 485-487) revealed a similar pattern as for modelled SO_2 (Fig. 3), indicating that the deposition of sulphur follows a similar distribution as does that of SO_2. As expected, the highest concentrations of SO_2 measured in Svanvik were observed when winds were from the east and in the Jarfjord area when winds were from the south. In the city of Nikel, the highest concentrations were measured when winds were from the north-east.

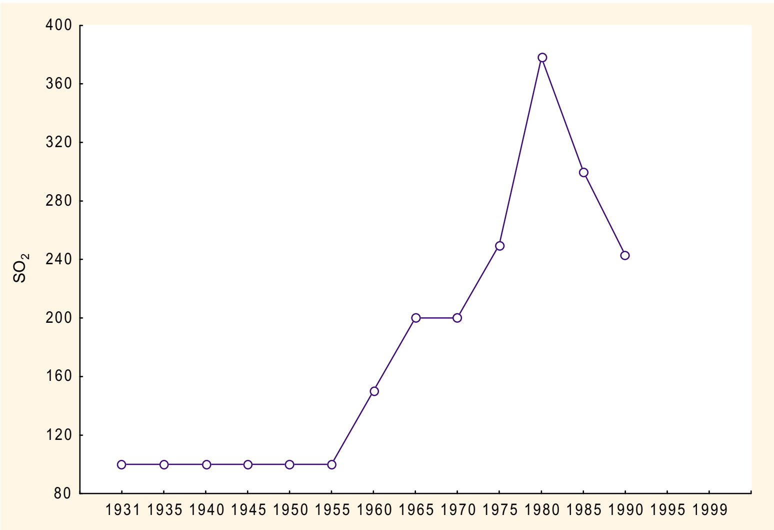

Fig. 2. Estimated emissions from the Pechenga-Nikel smelters, 1931-1990 (Wright and Traaen 1992). Largest emissions of SO_2 were in the early 1980s. Today, emissions are about 150 000 tons.

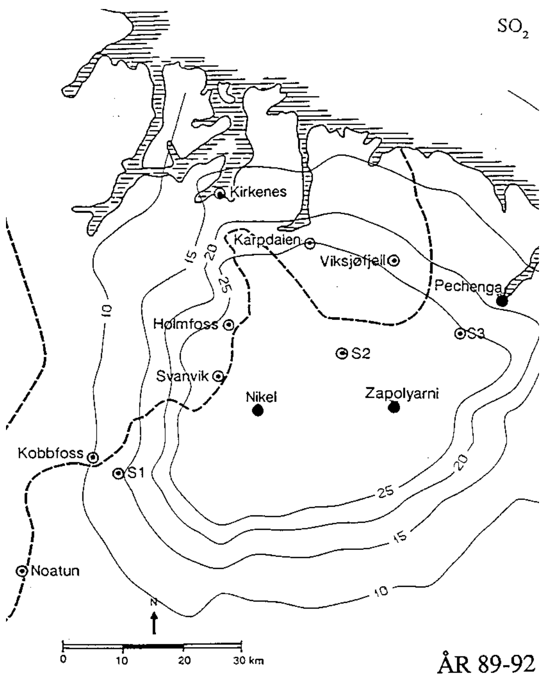

Fig. 3. Concentrations of sulphur dioxide in air, average 1989-1992 (model estimations based on measurements by NILU), µg/m³. Locations of air monitoring stations are marked with open circles. Map provided by Norwegian Institute for Air Research (NILU).

In the beginning of the 1990s the SO_2 emissions declined (Figs. 2, 4, 5 and 6), mainly because of economic depression in Russia. The emissions in 1999-2000 were approximately 62% of those in 1980 (Kola Science Center, pers. comm.).

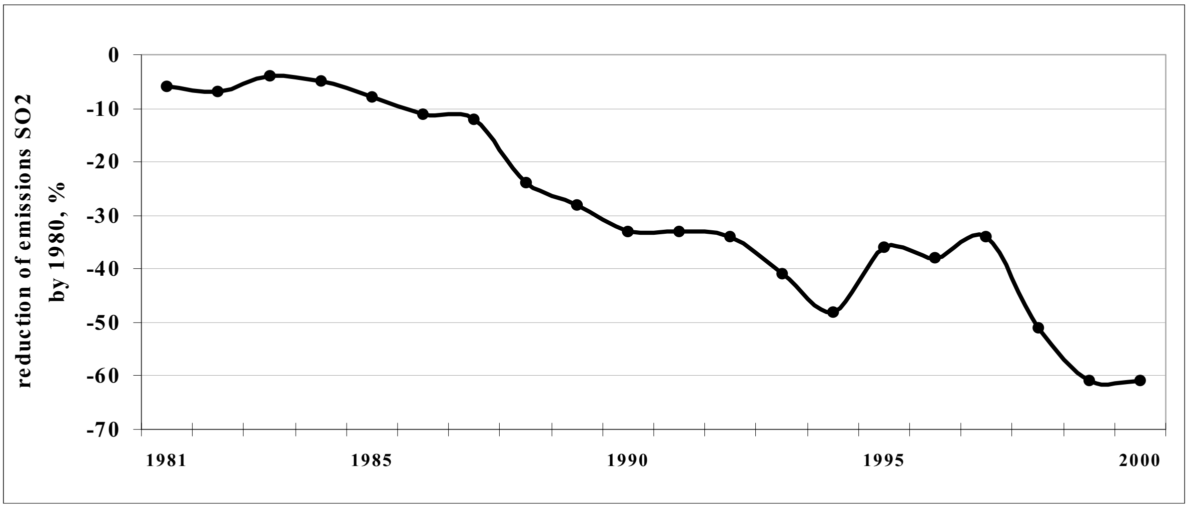

Fig. 4. Dynamics of sulphur dioxide emissions into the atmosphere by the Pechenganickel smelters between 1980 and 2001 (Figure from Kola Science Center).

However, increased levels of SO_2 in the Nikel area are observed when winds are from the north and north-east. In the city of Zapolyarny, increased levels are observed when winds are from the south and south-west.

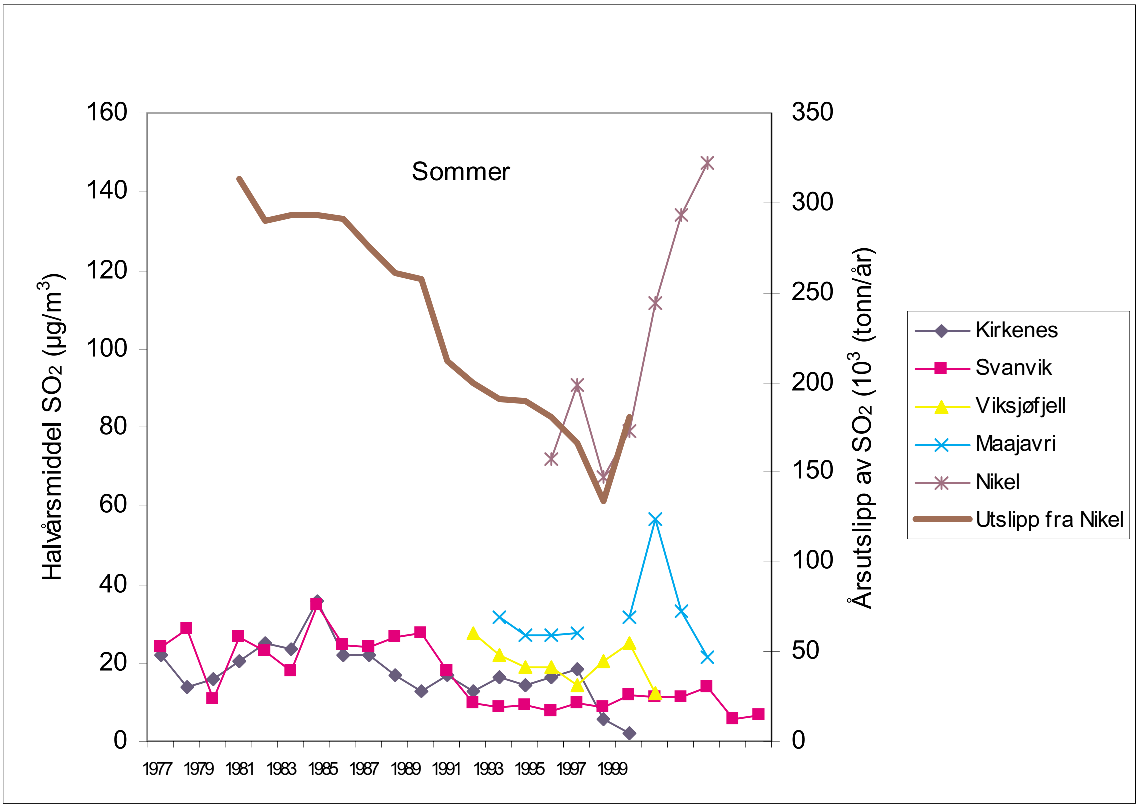

Fig. 5. Average concentrations of sulphur dioxide during summer periods (April-September) 1977 - 2000 at measuring stations in the Nikel-Pasvik area (Hagen et al. 2001). (Halvårsmiddel = Half year mean, Årsutslipp = Yearly emissions, Sommer = Summer, Utslipp = Emissions)

Damaged birch forest north of Nikel.

Average monthly concentrations of atmospheric sulphur dioxide in the surroundings of the nickel smelters depend on the wind conditions. The pollution level is also influenced by meteorological conditions unfavourable for dispersion of pollutants: calm weather, stagnation of air, fogs, periods of stable anticyclone circulation.

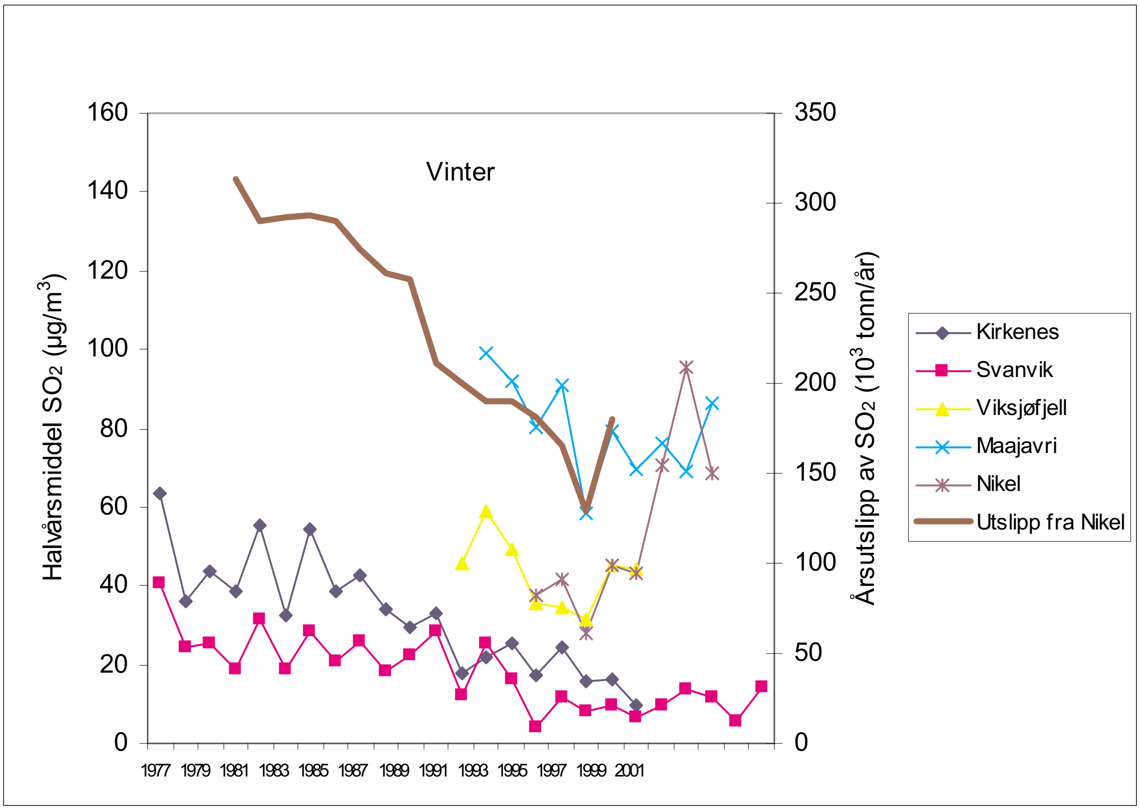

Fig. 6 Average concentrations of sulphur dioxide during winter periods (October-March) 1977 - 2001 at measuring stations in the Nikel-Pasvik area (Hagen et al. 2001). (Halvårsmiddel = Half year mean, Årsutslipp = Yearly emissions, Vinter = Winter, Utslipp = Emissions)

In Svanvik, about 10 km west of Nikel, average hourly concentrations have been at approximately 10 µg/m^3 for several years. The background value for the area is about 1 µg/m^3. The guideline and limit values for protection of human health are 40 µg/m^3 (half year, Norway), 90 µg/m^3 (daily, Norway), 125 µg/m^3 (daily, EU), 350 µg/m^3 (hourly, EU) and 500 µg/m^3 (10 minutes, WHO). However, episodes of high levels of SO_2 have occurred, leading to toxic and harmful levels to sensitive vegetation (Aamlid 1993). During the last two years such episodes have hardly been observed at Svanvik (Fig. 7) (Hagen et al. 2001). Much higher levels have been observed at the Russian stations in Nikel and Maajavri (north of Nikel). However, data has not been compiled since spring 1999.

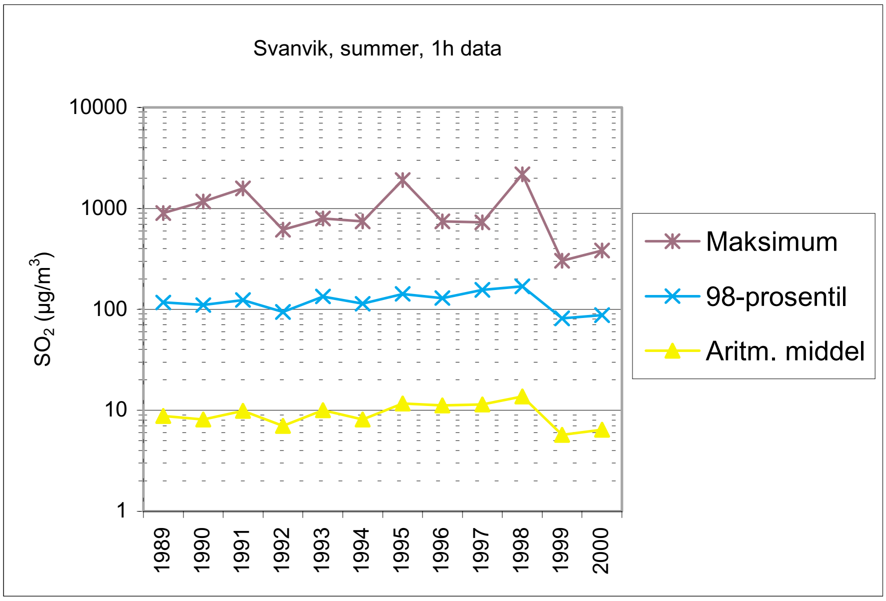

Fig. 7. Hourly concentrations of SO_2 measured at Svanvik 1989-2000, maximum, 98 percentile and average (Hagen et al. 2001).

The areas in the vicinity of Nikel and Zapolyarny have the highest depositions of pollutants. The annual nickel deposition ranges from 30 to 160 mg/m^2 and anthropogenic sulphur deposition from 600 to 1700 mg/m^2 (Fig. 8). In the more remote areas, the annual nickel deposition was less than 100 mg/m^2 and anthropogenic sulphur deposition was from 300 to 700 mg/m^2. Deposition of anthropogenic sulphur in south Norway varies from 700 to 1000 mg/m^2.

During episodes of high levels of sulphur dioxide in the atmosphere of the Nikel settlement, the pH in the precipitation varied from 3.7 to 4.5. In comparison, the pH in precipitation at Svanvik varied from 4.3 to 5.1, which is within normal pH levels in precipitation in Norway (pH in natural, unpolluted precipitation is approximately 5.6).

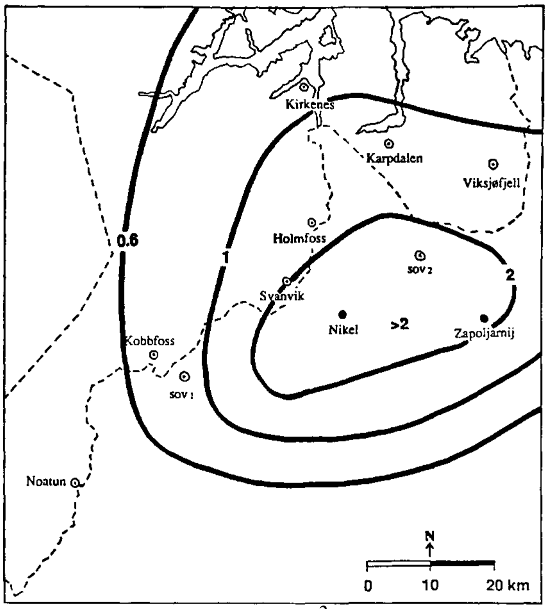

Fig. 8. Total deposition of sulphur (wet + dry, g/m^2 per year) in the border areas in the beginning of the 1990s (Sivertsen et al. 1992).

Measurements of Ni, Cu and other heavy metals in snow cover were executed in 1999-2001 in the vicinity of Zapolyarny, Nikel and Pechenga (Figs. 9 and 10). The main pollutants in snow were copper and nickel. In March 2001, the concentrations of copper and nickel in snow were 137 µg/l and 64.3 µg/l, respectively (Figs. 9 and 10). Zones of maximum accumulation were located in the surroundings of Zapolyarny and Nikel.

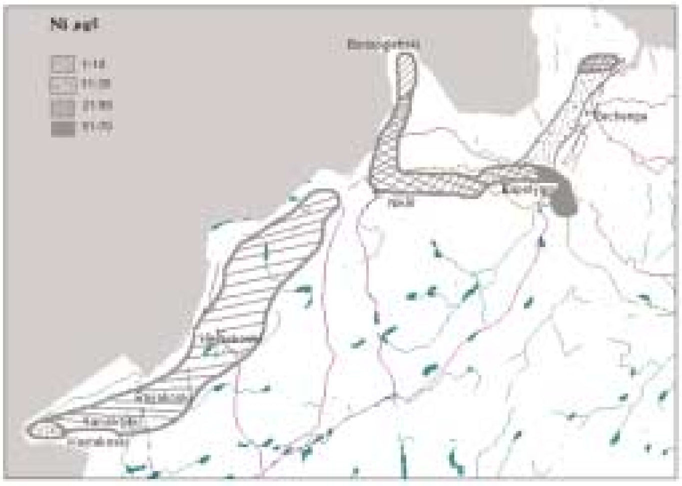

Fig. 9. Concentration of nickel in the snow cover in 2001 (areas where sampling was done are marked; map from Hydromet, Murmansk)

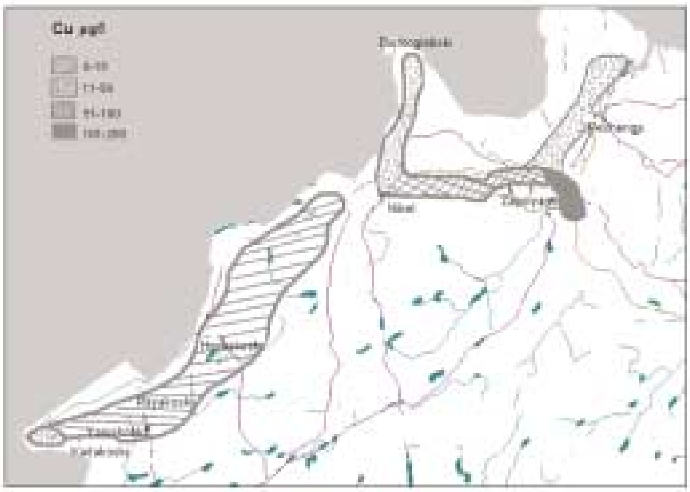

Fig. 10. Concentrations of copper in the snow cover in 2001 (areas where sampling was done are marked; map from Hydromet, Murmansk)

4. Air pollution impact

4.1 Terrestrial ecosystems

There are two major pathways for air pollutants to enter a terrestrial ecosystem. Direct damage may occur due to direct exposure to SO_2, entering via leaf stomata, breathing or the plant/animal surface. Indirect damage may occur by deposition of air pollutants via soil-mediated processes leading to toxic effects of heavy metals on roots and mycorrhiza, nutrient imbalances and soil acidification, or via contamination of forage.

4.1.1 Effects of air pollution on soil

Investigations of soils have shown that the soil layers are contaminated by heavy metals (nickel and copper in particular). The results also indicate an influence on soil fertility expressed as changes in base saturation (BS), cation exchange capacity (CEC) and soil acidity. According to critical load calculations, future sulphur deposition has to be reduced to very low levels in order to stop the ongoing soil acidification.

Air pollution from the nickel smelter has resulted in pronounced changes in soil properties and element uptake by plants in forests of the Norwegian /Russian border areas (Reiman et al. 1997, Steinnes et al. 2000). Pollution-induced changes in the organic matter have caused variation in the cation exchange capacity and acidity of the soil (Lukina and Nikonov 1997). The reason for decreased cation exchange capacity, total and active acidity in the organic horizon close to the smelter is a significant loss of organic matter due to the intense leaching of hydrolysable humus compounds and small amounts of litterfall. A decrease in base saturation is related to displacement of base cations from the cation exchange sites by protons and heavy metal cations derived from the atmospheric deposition and to a decrease in litterfall amounts. The increase in soil acidity and cation exchange capacity at a distance from the smelter is related to an enhanced content of organic matter due to higher annual inputs of litterfall resulting from intense needle loss and death of lichen and mosses (Lukina and Nikonov 1997). The explanations for a decrease in extractable Mg, Ca, Mn and K concentrations close to the smelter are: a) a decrease in cation exchange sites due to a decrease in the organic matter concentration and b) displacement of these cations from cation exchange sites by protons and heavy metal cations derived from the atmosphere. Increased concentrations of nutrients in the soil at a distance of 10-15 km from the smelter could be explained by higher annual inputs of litterfall (Lukina and Nikonov, 1997).

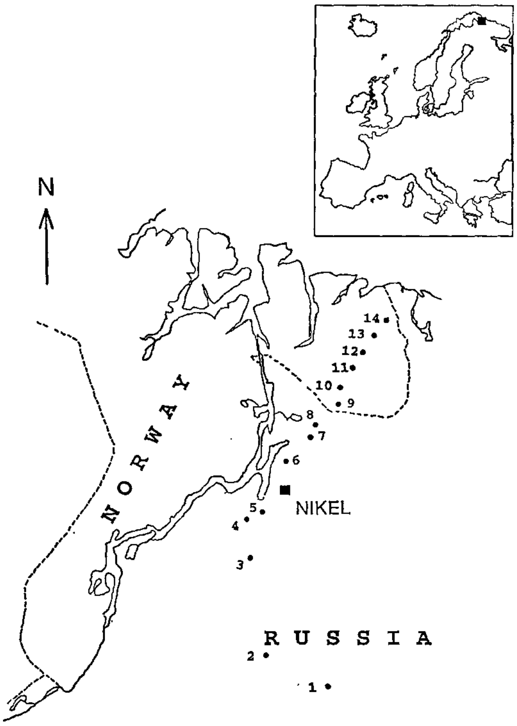

Fig. 11. Locations of Norwegian and Russian permanent sampling sites where multi-element chemical analyses of soil and plants were conducted (Steinnes et al. 2000)

The critical load concept is widely used to assess the sustainability of ecosystems, to compare critical loads with the present pollutant deposition and to connect them with emission reduction strategy in the framework of the Convention on Long-Range Transmission of Air Pollution (CLRTAP). A critical acid load is defined as the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on an ecosystem structure and function according to present knowledge (Nilsson and Grennfelt, 1988). Koptsik et al. (1999) calculated critical loads for some sample plots in the areas in the surroundings of the Pechenganikel smelters with the PROFILE model (6 plots in Russia and 3 plots in Norway). The release rate of base cations due to weathering ranges from 0.05 to 0.28 $kmol_c$/ha/yr in the 0 - 50 cm soil layer, thus demonstrating the high sensitivity of the coarse and thin podzols studied. Calculated steady-state BC/Al values were significantly lower than the presumed critical value of 1, which indicates a possible negative effect on vegetation through soil acidification. According to the model calculations future sulphur deposition has to be very low in order to stop the ongoing acidification and prevent vegetation damage. However, Koptsik et al. (1999) pointed out that due to modelling assumptions, uncertainty in input data and the critical chemical values applied, modelling results have to be interpreted carefully.

4.1.2 Effects of air pollution on vegetation

Air pollution influence has had severe effects on forest vegetation in the Nikel-Pasvik area. Trees, vascular plants, mosses and lichens are all affected. In the close vicinity of the smelters forests are dead or severely damaged. Visible injuries to vegetation caused by SO_2 have some years been frequent. Symptoms are recognised on Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*) which are the dominant tree species in the region, and on other plants, e.g. dwarf birch (*Betula nana)* and bilberry (*Vaccinium myrtillus)*. The species composition of the ground vegetation in the forest has been influenced, and epiphytic lichen vegetation has been severely influenced over large areas. Critical levels are exceeded on more than 3200 square kilometres of Russian and Norwegian territory.

4.1.2.1 The state of forest vegetation

Air pollution may influence vegetation by causing changes on several different levels. Plants accumulate atmospheric pollutants via direct exposure to foliage, and damage (chloroses and necroses) occurs when toxic levels are reached. Different species have different tolerance of air pollution, e.g. pine is generally more susceptible to air pollution than birch due to its long-lived needles. Plants may also be affected indirectly via the roots, as toxic substances are taken up by roots, causing local injury in the roots or transported to other parts of the plant, and causing injury there, e.g. chlorosis and necrosis in the foliage. In severe cases this may lead to reduced production or vitality, or even plant death. Forest health assessments have been carried out in several investigations executed in the area during the last fifteen years. The methods used were in accordance with national and international methods (ICP Forests 1998, Sanitary Regulations 1992; Instructions 1983; Aamlid and Venn 1993). In the investigations by Vassilieva (1992, 1993) the results showed that air pollution had an impact on tree foliage. With increasing air pollution, defoliation of trees increased from no defoliation in background areas (about 40 km south of Nikel) to moderate (25 to 60%) and severe defoliation (more than 60%). These findings are comparable to the findings of Chernenkova, who studied similar forest types along the southern gradient from Nikel (Chernenkova 1992; Chernenkova et al. 1995). In a joint Norwegian/Russian investigation based on intensively monitored plots along a western gradient from Nikel (Fig. 12), several effects of air pollution on the forest ecosystem were detected (Aamlid et al. 2000). The number of species in ground vegetation cover was reduced along the gradient, mainly caused by disappearance of lichens and moss species (Table 1) (Vassilieva et al. 1995; Aarrestad and Aamlid 1999; Aamlid et al. 2000).

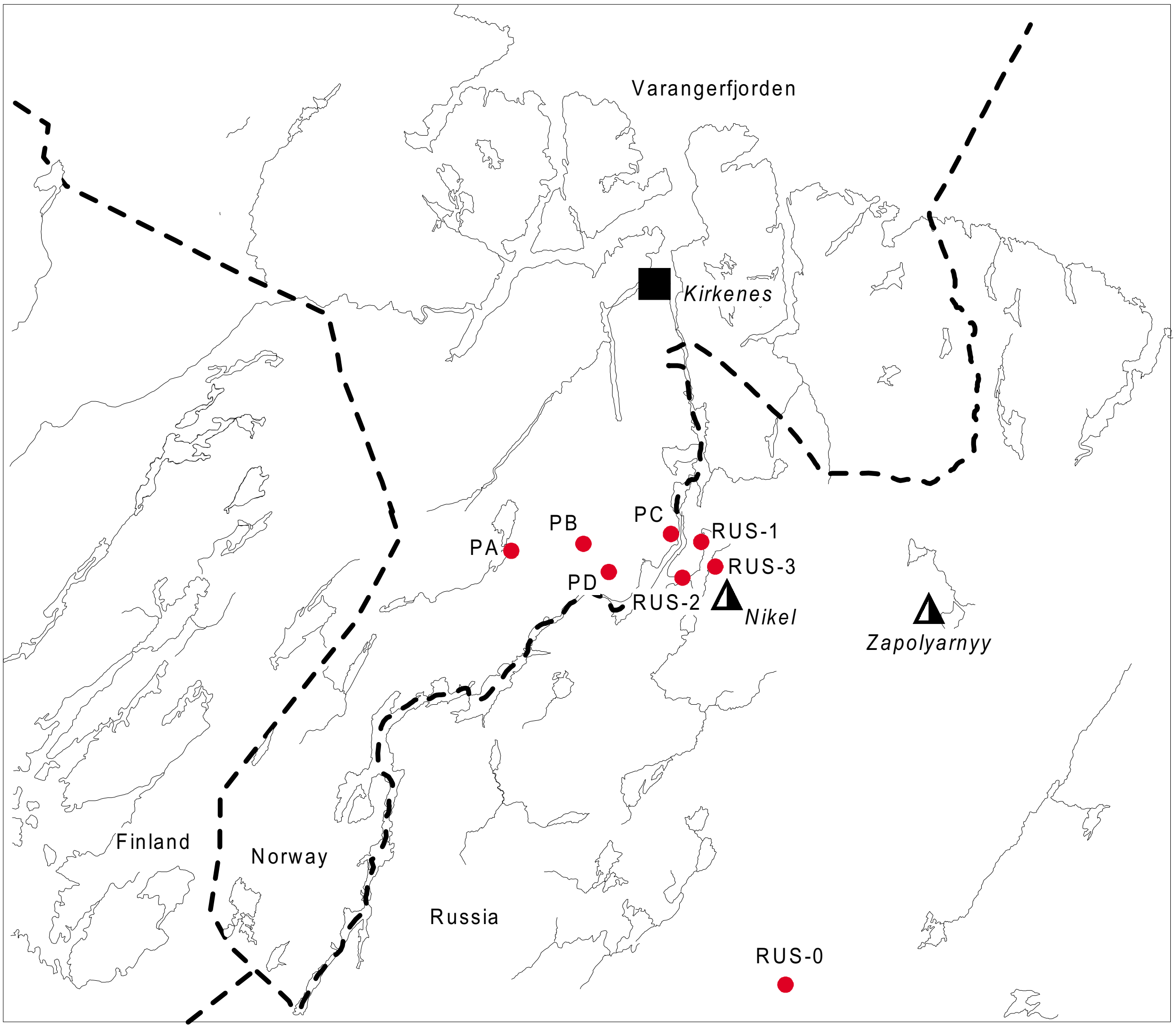

Fig. 12. Location of joint Norwegian/Russian sites (with site codes) for intensive terrestrial monitoring.

The air pollution may also cause changes in species composition in forest floor vegetation, resulting in dominance of air pollution resistant species such as wavy hair-grass (*Deschampsia flexuosa*) and crowberry (*Empetrum hermaphroditum*). Estimates made by the use of the Shannon index indicated a decrease in species diversity and an increase in mono-dominant communities (Vassilieva et al. 1995), as did use of Hill's N2 diversity number (Aamlid et al. 2000). In the area where moderate damage occurred, disappearance of mosses and lichens caused a decrease in ground biomass (Chernenkova 1992). Investigations by Lukina and Nikonov (1993) showed that high pollution levels corresponded to more reduced biomass in pine forests with lichen cover than in those with dwarf shrubs.

Table 1. Number of species in pine forests decreases with decreasing distance to the nickel smelter in Nikel (by species group, average and maximum number (in brackets) of species within 1 m² plots along a western gradient from Nikel, data from Aamlid et al. 2000 and additional unpublished data)

Species group	Sample plots (Fig. 12) and their distance from Nikel						
	RUS-0 45 km south	PA 25 km west	PB 16 km west	PD 12 km west	PC 9 km north-west	RUS-1 6 km north	RUS-2 6 km west
Small shrubs	3.5 (5)	2.9 (4)	3.1 (4)	3.1 (4)	3.4 (4)	4.2 (5)	4 (5)
Herbs	1.9 (4)	1.9 (3)	1.7 (4)	0.8 (2)	1.9 (3)	2 (3)	1.1 (3)
Mosses	5.1 (7)	4.6 (9)	4.7 (8)	4.7 (6)	4.6 (7)	1.2 (3)	2.1 (4)
Liverworts	1.3 (3)	1.5 (3)	2 (3)	1.5 (3)	1.6 (2)	0.7 (2)	1.2 (3)
Lichens	3.7 (9)	4.1 (9)	7.5 (12)	8.2 (14)	3.9 (9)	2.3 (7)	3.1 (7)
All species	15.4 (24)	14.9 (30)	19.2 (32)	18.7 (31)	15.6 (26)	10.9 (23)	11.5 (17)

(Sample plot names refer to the joint Norwegian/Russian gradient of intensively monitored plots, Fig. 12)

Epiphytic lichens (lichens that grow on other plants, mostly tree stems and branches) are known as sensitive indicators of air pollution, SO_2 in particular. The coverage of common epiphytic lichens (*Hypogymnia physodes*, *Parmeliopsis ambiqua*, *Parmelia olivacea* and *Bryoria* sp.) on birch stems along a western gradient at distances of 23, 12, and 6.5 km from the emission source was 12, 3, and 1.9% respectively (Aamlid et al. 2000). The decrease in coverage of stem surface correlated with the direction to emission source (Fig. 13). The lichen *Parmeliopsis ambiqua* proved to be relatively resistant to air pollution. Similar results were obtained by Aamlid and Skogheim (2001) in an investigation on 51 permanent sample plots on Norwegian territory (Fig. 14), and by Vassilieva et al. (1995) who investigated the epiphytic lichens along northern and southern gradients from Nikel.

Investigations of vegetation cover, Sør-Varanger.

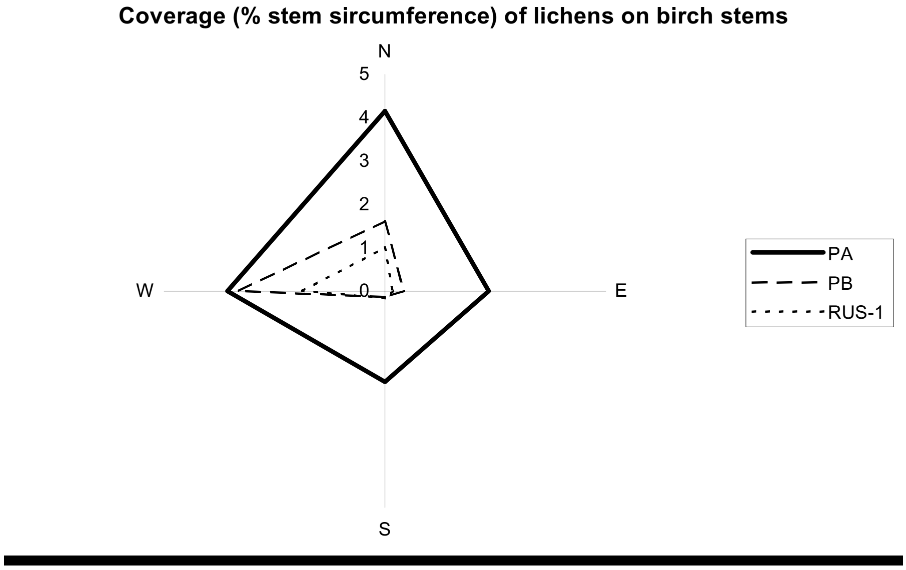

Fig. 13. Lichen cover on birch stems, % of stem circumference. More lichens were found on the stem side facing away from the Nikel smelter (Aamlid et. al., 2000).

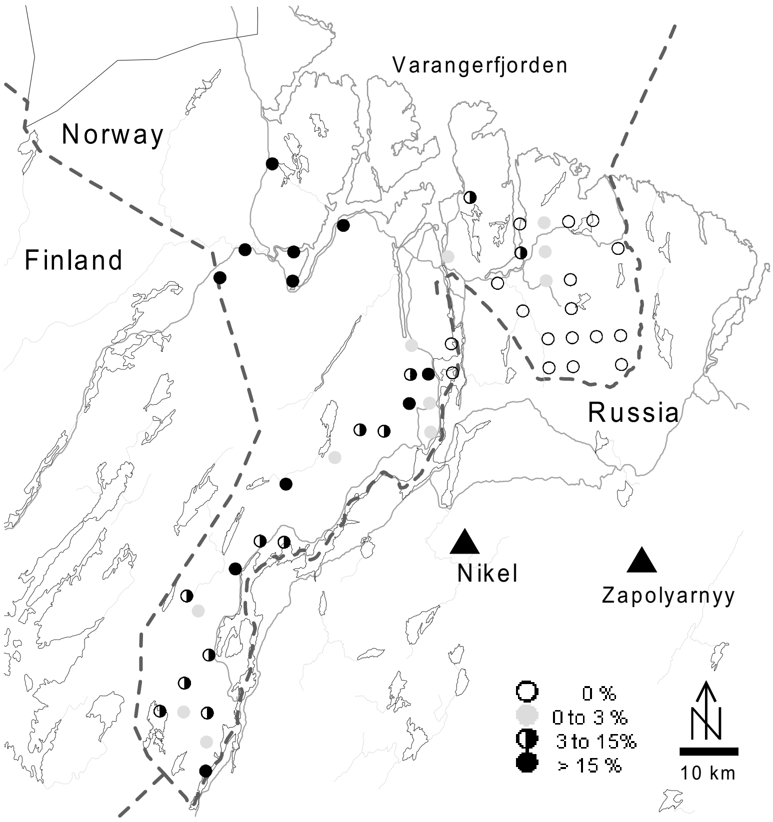

Fig. 14. Coverage of the lichen Melanelia olivacea *on birch stems (% of stem circumference) on the Norwegian network of sample plots in Sør-Varanger. The epiphytic lichen vegetation on birch stems is more or less lacking in the areas north of Nikel and Zapolyarnyy (Aamlid and Skogheim 2001).*

Environmental pollutants accumulate in almost all plants (Aamlid et al. 2000; Lukina and Nikonov, 1993; Steinnes et al. 2000). The concentrations of sulphur, nickel and copper in pine needles collected in polluted areas is several times higher than the background levels.

Concentrations of 34 elements (including heavy metals) were studied in the humus horizon and forest plants along a north-south gradient (Fig. 11) through the Pechenganickel smelter complex by Steinnes et al. (2000). Several possible sources and uptake paths were found. Strong influence from the smelter was evident for Fe, Co, Ni and Cu, mainly associated with dry deposition of large particles. Se, Te, As, Mo, Sb, Bi, Pb showed strongly enhanced concentration levels in the vegetation near the smelter and appeared to be derived from anthropogenic (i.e. man-made) sources in the Nikel area, from the smelter itself, from coal burning and in the case of Pb probably also from the use of leaded gasoline. These elements are predominantly released in volatile form in connection with high-temperature processes, and therefore often occur together in the small-particle fraction of pollution aerosols. V, P, S, Cr, Zn and Tl in either vegetation or humus indicated a certain contribution from air pollution sources in the Nikel area. P and S, being essential nutrients in plants, did not show significantly higher levels in vegetation near the source, although they appeared to be enhanced in the corresponding surface soil. Steinnes et al. (2000) also concluded that there were no indications or evidence of contributions from local air pollution to soils and plants along the transect for typical crustal elements such as Li, Be, B, Mg, Al, Ca, Y, Cd, La, Th and U. Cadmium is an element often observed as a typical air pollutant, but apparently none of the anthropogenic activities in Nikel result in significant air pollution with Cd. Reduced concentrations of Mn, Rb, Sr, Cs and Ba in vegetation near the source may be explained by cation exchange with protons and heavy metal cations in the soil and subsequent leaching from the root zone.

Plants may be used as indicators of certain air pollutants. Epiphytic lichens are known to be useful indicators for SO_2 as different species have different sensitivities to SO_2. Lichens and other plants may also be useful for monitoring the heavy metal load, as they adsorb heavy metal particles on their surface. In the context of bio-indicators for metal accumulation capacity, Steinnes et al. (2000) summarised on the basis of a gradient study that the most acceptable vascular plant bio-indicators are downy Birch (*Betula pubescens*) and bilberry (*Vaccinium myrtillus*). The arguments in favour of this contention were a) photosynthetic organs of these plants are characterized by a high accumulation of metals owing to efficient trapping of particles on the leaf surfaces, b) these plants are widely distributed in forests at the Norwegian/Russian border and c) there is no need to rank these plants according to age classes because they have leaves of the current year only.

Scots pine needles injured by SO_2, Svanvik, Sør-Varanger.

4.1.2.2 Critical levels/loads - Areas of damaged forest ecosystems.

A critical load or a critical level is the exposure of an ecosystem to a pollutant, below which no harmful effects occur. The term "load" is related to deposition and thus affects biota indirectly via the soil, while the term "level" is related to direct effects to plants via stomata. Thus the term "level" is mostly related to concentrations of harmful gasses such as SO_2. Several investigations show that critical levels (of SO_2) were exceeded over large areas (Aamlid et al. 1995; Gytarsky et al. 1995; Tømmervik et al. 1995, Vassilieva 1992, 1993). For sensitive ecosystems the critical levels were exceeded on more than 3200 square kilometres of Russian and Norwegian territory (Fig. 15), of which approximately 2400 square kilometres were on Russian territory (Aamlid et al. 1995; Tømmervik 1998). The Jarfjord Mountain area, which is located north of Nikel, has been assessed as being the most influenced part of the study area, together with a narrow zone west of Nikel (Sivertsen et al. 1994).

Susceptibility to environmental pollution enhances forest decline. The distribution of forest stands by sensitivity classes indicated high sensitivity of pine forests within 10 to 12 km from the smelter, corresponding to severe damage to forest stands (Vassilieva 1992, 1993). The combined negative impact of sulphur and heavy metal pollution resulted in an area of severe forest damage in the vicinity of the smelters (Aamlid et al. 1995; Gytarsky et al. 1995; Tømmervik et al. 1995). The area can be described as an oval that stretches from south to north and influenced by the dominant wind direction and landscape features (Fig. 16, Table 3). Based on forest vitality, 4 classes of forest damage were identified within the industrially impacted territory (Sanitary Regulations 1992; Instructions 1983). The extent of the forest damage decreased with increasing distance from the emission source (Fig. 16).

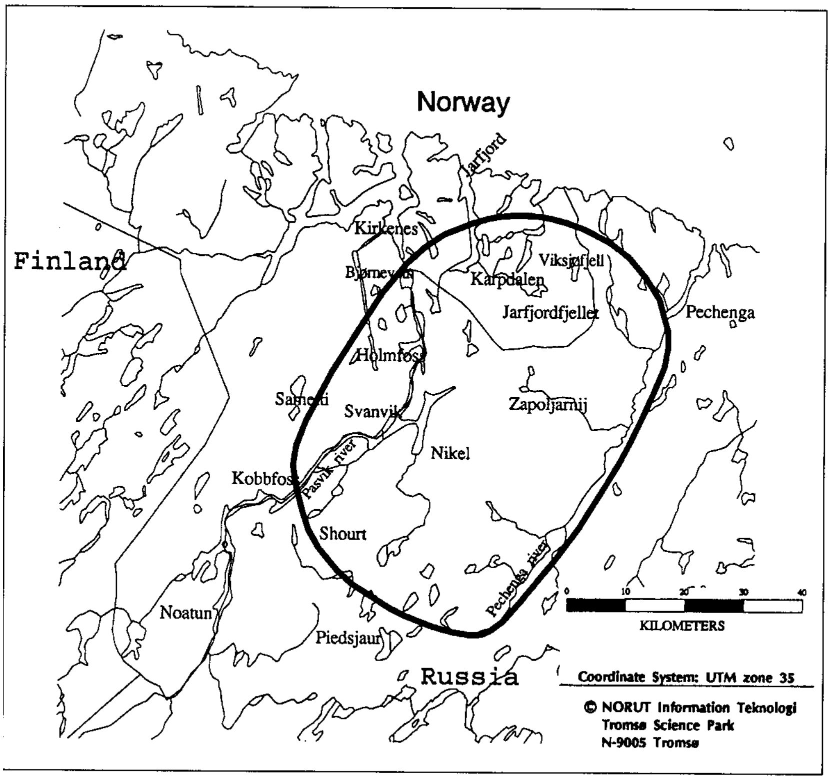

Fig. 15. Outlined area indicating exceeded critical levels for terrestrial vegetation (Aamlid et al. 1995).

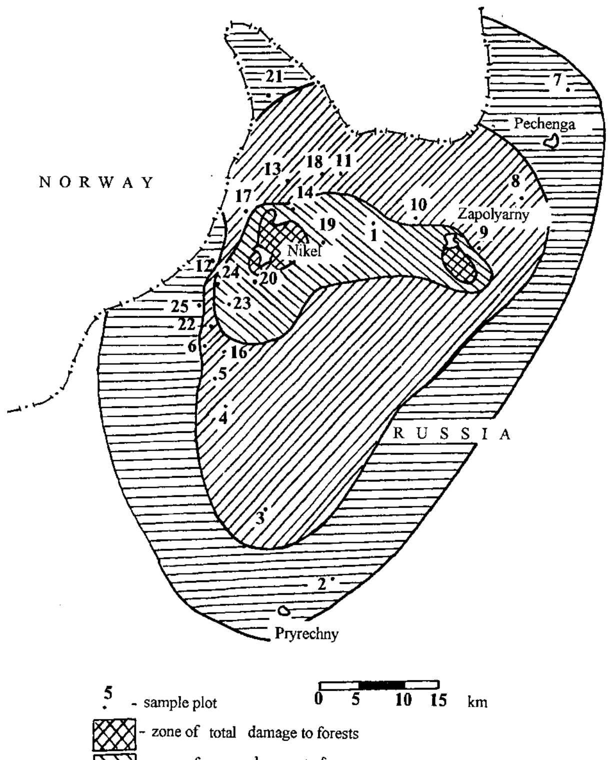

Fig. 16. Classification of forest vitality status within the territory of industrial impact. See text for details (Gytarsky et al. 1997).

Concentrations of sulphur dioxide and sulphur deposition within the area of slight damage in Tables 2 and 3 correspond to critical levels and loads for highly sensitive forest ecosystems. The critical level is 20 μg/m^3 for SO_2 and the critical load corresponds to 0.05 and 1.0 g/m^2/yr of S for coniferous and deciduous species respectively, according to Nilsson et al. (1991) and UN ECE (1993). The area of moderate to total forest damage in the vicinity of the smelter, i.e. on Russian territory, is about 1600 km^2 (Table 2).

Table 2. Estimated area of forest damage in the vicinity of the Pechenganikel smelter in damage categories and estimated mean concentrations of sulphur dioxide during the growing season (from Gytarsky et al. 1997)

Damage category	Concentration of sulphur dioxide, mg/m^3	Areas of zones of damage to forests, km^2
Complete	> 0.15	44.5
Severe	0.08	297.4
Moderate	0.05	1263.2
Slight	0.02	1364.0
Background area	0.013	
Totals for the area		2969.1

Table 3. Estimated annual dry deposition of sulphur (g/m^2/yr) in areas with different damage category and forest type in the vicinity of the Pechenganikel smelter (from Gytarsky et al. 1997)

Damage category	Coniferous forests	Deciduous forests
Severe	3.94	4.70
Moderate	1.13	2.88
Slight	0.46	0.95
Background area	0.32	0.68

4.1.3 Effects of air pollution on terrestrial animals

Air pollution has reduced invertebrate and animal diversity due to lack of forest vegetation and contamination of surface soils in the vicinity of the nickel smelters. Small vertebrates are impacted by an increased heavy metal content in the liver. However, no negative health effects to the reindeer are foreseen.

4.1.3.1 Invertebrate animals

Air pollution has especially affected biodiversity and population density in the most polluted areas due to lack of vegetation and soil contamination. Koneva and Koponen (1993) investigated invertebrates in dwarf shrub pine forests along various gradients from an emission source. The study comprised 14 groups of invertebrates. The results revealed that the diversity of invertebrates was reduced, i.e. 10 groups were found within 3 to 7 km from the emission source, and only 2 groups within 3 km from the emission source. At 1.5 km from the source no fauna was found. The results also revealed that an increase in pollution caused a decrease in quantity (by a factor of 5 to 9) and a decrease in invertebrate biomass (by a factor of 6 to 10) (Koneva and Koponen 1993). In the background areas in a southern gradient (55 km from the emission source), the total biomass of soil fauna in pine forest was 2151 mg/m^2 and the quantity was 385 units per square meter. Approaching the emission source along southern, northern and western gradients (7, 2.5 and 4.7 km long respectively), the biomass was reduced to 157 mg/m^2, with a quantity of about 37 units/m^2, which was very much lower than that observed in the background areas. Beetles from the *Elateridae* family are highly sensitive to pollution, and their biomass was reduced by a factor from 2 to several hundreds. Meanwhile, species from the *Aranea, Diptera* and *Formicidae* families are tolerant, and their biomass may even have increased (Koneva and Koponen 1993).

The trophic structure of soil mesofauna was also influenced by air pollution. In non-polluted territory saprophages dominated the biomass with about 1500 mg/m^2, which is more than 70% of total mesofauna biomass. However, they almost disappeared in the most heavily polluted areas (Koneva 1995), probably due to acidic litter with a high content of heavy metals, resulting in inhibition of soil formation processes in polluted areas. The latter results in accumulation of decomposed elements in litter. Zenkova (1998) obtained similar results for the area impacted by the nickel smelter.

4.1.3.2 Vertebrate animals

Vertebrate animals, like mice and reindeer, normally have high mobility. Migratory species are able to escape from the negative impact of industrial pollution, or at least are not exposed to it through the whole year. Animals that occupy small areas in a polluted territory and do not make distant migrations are therefore susceptible to air pollution. In the Nikel-Pasvik area this concerns only a small number of species. Small mammals (the northern vole *Microtus oeconomus*, the grey-sided vole *Clethrionomys rufocanus* and the common shrew *Sorex araneus*), the willow grouse (*Lagopus lagopus*) and the brown frog *Rana temporaria*) were studied in the Nikel-Pasvik area by Glasov et al. (1992) and Glasov and Leontyeva (1995). Special attention was paid to accumulation of heavy metals. The common shrew was the dominant mammal species on the Russian territory. The northern vole (*Microtus oeconomus*) was less widely distributed. It is mainly associated with agricultural lands, while the grey-sided vole (*Clethrionomys rufocanus*) lives in forests and wetlands. Heavy metals (Ni, Cu, Zn, Fe, Pb, Cd, Co and Cr) were found in all investigated animals. The highest concentrations were found in animals within 10 km to the north and south of Nikel. Heavy metals were found in the liver (Fe, Ni, Cu and Zn), bone and muscular tissues (Cr, Ni Pb), and skin (Cr, Ni, Cu and Cd). The maximum Ni concentration (28-35 ppm) in the skin of the northern vole, the maximum Cu concentration (30-40 ppm) in the skin and liver of the common shrew and the maximum Zn concentration (300 ppm) in the liver of the common shrew were found 5 to 10 km to the south of Nikel.

The accumulation of metals in small mammals depends strongly on their trophic level. The highest content was found in the liver of the common shrew *Sorex araneus*, which stands on the second trophic level as a consumer of invertebrates living in the soil and litter. The investigations on the Norwegian side showed that the common shrew (*Sorex araneus*) accumulated the highest concentrations of Zn, Pb and Ni (Kålås et al. 1993). With an increase in distance from the emission source, accumulation of heavy metals in common shrews was reduced by a factor of 4 to 6. Cd, Co and Pb were found only in the vicinity of the smelter (Table 4).

Table 4. Impact of air pollution on common shrew Sorex araneus illustrated by mean concentration of heavy metals (ppm) in the liver at various distances from the Nikel smelter (from Glasov and Leontyeva 1995).

Direction	Distance from emission source, km	Number of individuals	Cr	Co	Ni	Cu	Zn	Cd	Pb
S	5-6	8	0.6	0.6	2.2	39.0	328.0	0.94	3.7
S	8-10	7	0.3	0.7	1.8	26.0	168.0	1.9	0.9
N	8-10	6	0.3	<0.5	0.6	14.1	93.0	0.4	0.5
S	20-22	5	0.1	<0.5	<0.5	12.2	34.0	0.5	<0.5
S	30	6	0.5	<0.5	<0.5	9.2	64.0	<0.5	<0.5

In willow grouse, no direct relationship between air pollution from the Pechenganikel smelter and the content of Cu, Ni, Cr and Pb was found (Kålås et al. 1995a,b).

Accumulation of heavy metals was found in the bone and muscle tissues and liver of brown frog (*Rana temporaria*), which was the only *Amphibian* species in the region. At a distance of 8 to 10 km from the smelter, the content of Fe, Cu and Zn in the liver of the frog was 2 times higher than in the background area (40 km from the smelter). Thus, high concentrations of heavy metals can be found in tissues of small animals within a 10 km distance from the emission source along northern and southern gradients.

An investigation of Ni, As, Cu and Se in liver of domestic reindeer in Sør-Varanger revealed that somewhat elevated concentrations were found (Løvberg and Sivertsen 1997). However, no negative health effects to the reindeer are foreseen after these findings. There are no domestic or wild reindeer on the Russian territory in the Nikel-Pasvik area.

4.2 Aquatic ecosystems

Long-term monitoring of water chemistry in lakes and rivers has revealed that extensive surface water acidification has taken place, particularly on the Norwegian side of the border. Critical loads are exceeded in large areas of Sør-Varanger municipality (especially in the Jarfjord area), and in areas situated around Nikel and Zapolyarny. However, on the Russian side, the contamination of lakes by heavy metals (nickel and copper) is more severe than acidification, especially in the vicinity of the smelters, where damage to fish populations as well as phytoplankton and invertebrate communities are observed.

4.2.1 Water quality

Lakes and streams in the Norwegian-Russian border area are polluted by large amounts of metals, sulphur and dusts. In addition to this, the Kolosyoki Stream in Nikel town and streams in the surroundings of Zapolyarny are heavily polluted. High concentrations of heavy metals have been recorded from lake sediments in the Pechenga Region (Rognerud 1990, Traaen et al. 1991, Dauvalter 1992, Rognerud et al. 1993).

The area distribution of non-marine sulphate concentrations in surface waters is based on comprehensive investigations of more than 100 lakes in the border area in 1989 - 1990, Fig. 17 (Traaen et al. 1991). The distribution was in good agreement with the prevailing wind directions in the area. Around the industrial centres the sulphate concentrations in the lakes were more than 200 µeq/l. Sulphate values for lakes on the Kola Peninsula varied from 50 to 250 µeq/l. In Sør-Varanger sulphate values ranged from <50 to 125 µeq/l.

In the Pechenga area 81% of the examined lakes had pH values exceeding 6.5. Only 6% of the examined lakes had a pH less than 6.0. Strongly acidified lakes with pH < 5.0 are mainly located southwards from the emission sources in Nikel and Zapolyarny. In contrast to the situation in the Pechenga region, only 17% of the examined lakes in Sør-Varanger had a pH exceeding 6.5. 47% of the lakes had a pH less than 6.0, of which 10% were lower than 5.0. The strongly acidified lakes are mainly found in the Jarfjord mountain area east of Kirkenes.

However, in years with decreased sulphur dioxide emissions it has been shown that the concentrations of sulphate and labile aluminium decreased and pH and ANC increased (Traaen and Rognerud 1996). Annual variation is significant, e.g. there were high concentrations of sulphate in 1999 and low in 2000 (SFT 2001). The concentrations of nickel and copper are quite stable, probably due to accumulation in soils and sediments, and the deposition of nickel and copper is larger than what is being leached (SFT 2001).

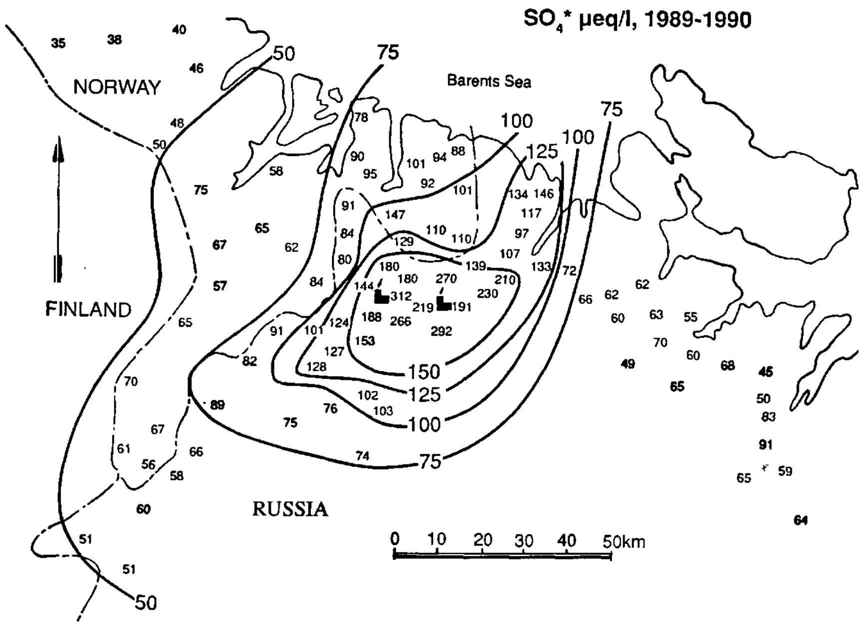

Fig. 17. Distribution of non-marine sulphate concentrations in lakes in the border areas of Norway and Russia. Data from September 1989 and 1990 (Traaen et al. 1991).

In the Pechenga region 26% of the lakes had an alkalinity less than 50 µeq/l. These lakes are sensitive to further acidification. 10 % of the lakes had an alkalinity less than 20 µeq/l, the critical limit used for critical load calculations for surface waters in Fennoscandia (Henriksen et al. 1990). Of the lakes examined in Sør-Varanger, 87% had alkalinity less than 50 µeq/l and 60% less than 20 µeq/l (Traaen et al. 1991). Basic and ultra basic rocks dominate the Pechenga structure. Along the Barents Sea coastal areas (northwards from Pechenga), where the acid rocks of granite-gneiss formations are dominant, the condition of lakes can be characterised as critical.

From the Jarfjord area where small lakes are acidified.

Fig. 18 shows the area distribution of nickel and copper concentrations in lakes. In the Pechenga area the nickel concentration in water is often 20-30 µg/l. In the small and acidified lakes on the Kuorpukas mountain the nickel content is more than 70 µg/l. In Polojarvi lake, which is a source of drinking water for Zapolyarny, the nickel content in the autumn was 21 µg/l and in the spring 35 µg/l. Copper concentrations in the Pechenga district lakes are in the range of 5-10 µg/l. High values of copper were obtained in Kuetsyarvi (max 94 µg/l), Maajavri and in the Nikel lakes (maximum 50 µg/l). Even higher values (125 µg/l) were found in samples from deeper water layers (Langeland 1993). In Store Skardvatn a maximum of 18 µg/l was measured in June 1992. Concentrations of nickel followed the same pattern as for Cu, with the highest values in the Nikel Region (17-443 µg/l). In Sør-Varanger the highest concentrations of nickel are found near the border south of the Jarfjord Mountain, where nickel concentrations up to 20 µg/l have been measured (Traaen et al. 1991, Langeland 1993, Nøst et al. 1997). Most of the lakes in the Jarfjord Mountain area have Ni concentrations from 5 to 10 µg/l. In other parts of Sør-Varanger concentrations of Ni are generally lower than 5 µg/l. Lake water concentrations of copper are generally lower than 5 µg/l throughout Sør-Varanger (Traaen et al. 1991). Ni concentrations in the Jakobs River were usually higher than in Pasvik River (mean value 8 µg/l). The alkalinity was also lower and sulphate concentrations were higher than in the Pasvik River (Traaen et al. 1991).

High values of nitrogen and phosphorus were indicated in streams surrounding Nikel, particularly in Lake Kuetsyarvi and the Pasvik River. (Nøst et al. 1991, Langeland 1993, Moiseenko et al. 1994).

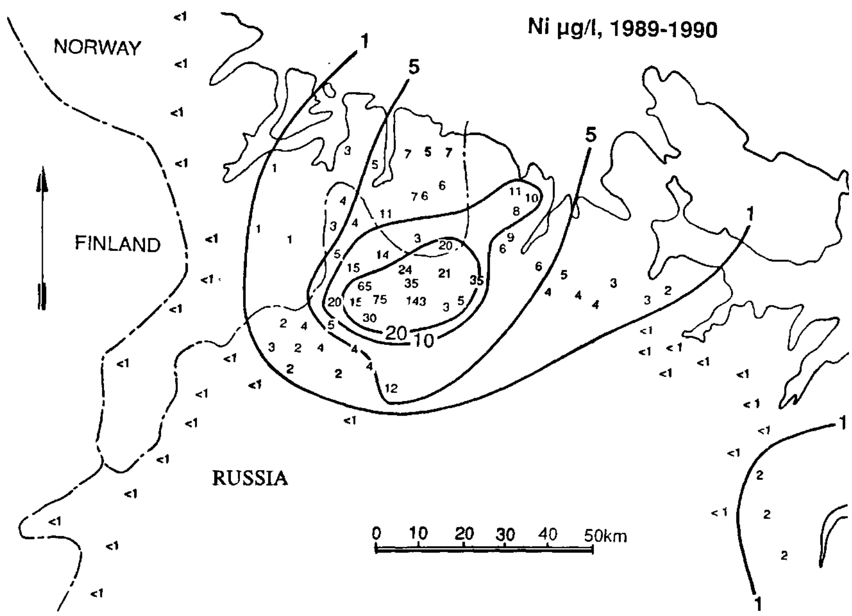

Fig. 18. Concentrations of nickel (Ni) in lakes in the border area of Norway and Russia. Data from September 1989 and 1990 (Traaen et al. 1991).

According to Moiseenko et al. (1993) waste water from the smelter and pits runs into the Kolosyoki Stream, then into Kuetsyarvi and through a channel into the Salmijavri (Svanevatn, Pasvik River). In Fig. 19 transport values of Ni in the lower part of Pasvik River are shown.

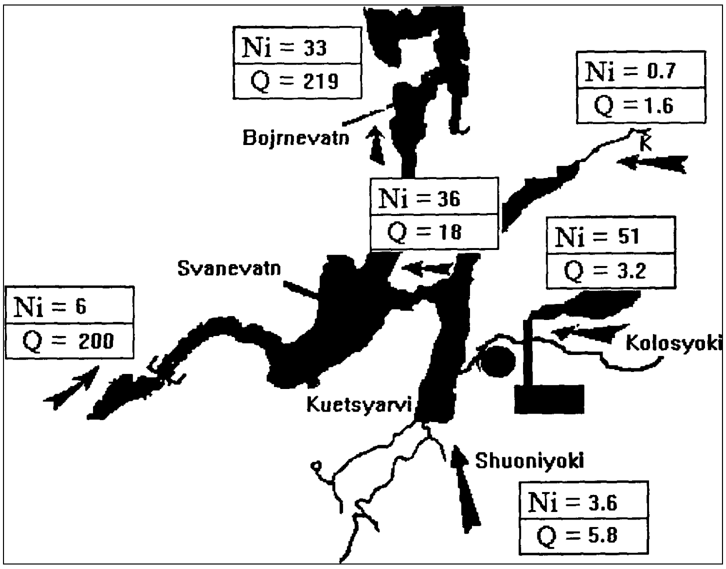

Fig. 19. Transport values of Ni (ton/year) and water flow (Q, m^3/s) in the Pasvik River System in 1993.

Long-term dynamics show high accumulation levels of nickel and copper in rivers and in the whole catchment area. Increased concentrations of pollutants in water reservoirs, which are not subject to the direct impact of emissions, especially during the spring and rain flood-water periods, are evidence of the significant role of atmospheric transfer.

The Jakobs River, forming the most easterly border between Norway and Russia, has greater variations in water chemistry than the Pasvik River. The river catchment lies in an area of very high sulphate deposition. The sulphate concentrations are higher and the alkalinity is lower than in the Pasvik River, and there is a marked depression of alkalinity in the spring. The remaining alkalinity is still sufficient to avoid acid water. The nickel concentrations in the Jakobs River are higher than in the Pasvik River and copper concentrations are lower (Traaen et al. 1991).

4.2.2 Aquatic organisms

Negative effects of acidification on freshwater biota have been documented in the Jarfjord region (Nøst et al. 1991, Langeland 1993, Nøst et al. 1997) where the absence or low numbers of acid-sensitive species of zooplankton, zoobenthos and fish were recorded in the mountain lakes. Bækken and Aanes (1990) found severe acidification effects on benthic invertebrates in several lakes. Acidification of surface waters is usually followed by reductions of relative species richness and abundance of sensitive taxa, such as mayflies, stoneflies, amphipoda and snails, but also by an increase in the relative abundance of tolerant taxa (diptera, water bugs and water beetles).

Severe impacts of pollution on invertebrate communities were recorded near the nickel factories in Nikel and Zapolyarny with a decrease in species richness and high abundance of pollution tolerant taxa (chironomids, water bugs, water beetles, caddis flies (*Polycentropidae*) and worms). An extremely high abundance of chironomids has been recorded in Lake Kuetsyarvi, where simultaneous effects of heavy metals and nutrients on invertebrates occurred. The toxic effects of heavy metals may be neutralised by high organic matter and calcium concentrations, also apparently due to morphological peculiarities of the lake (the prevalence of shallow areas with vegetation) and relatively high water exchange. The eutrophication of Lake Kuetsyarvi has been discussed by Nøst et al. (1991) and Moiseenko et al. (1994).

Levels and distribution of heavy metal (Ni, Cu, Cd and Zn) concentrations in fish tissues and organs varied between organs, species and lakes. Accumulations in muscles were usually considerably lower than the levels found in other organs and tissues (Langeland 1993, 1995). The highest values of most heavy metals were usually found in the kidney and liver. High accumulations of nickel and zinc were also recorded in gills (Langeland 1993)

Pathological and morphological studies have been carried out in several lakes in the Nikel-Pasvik area. Pathological anomalies in fish and low diversities of phytoplankton, zooplankton and zoobenthos were observed in the most polluted localities in the vicinity of the industrial centres in Nikel and Zapolyarny (Kalabin and Svelle 1994, Nøst et al. 1997). The absence of older individuals of brown trout and Arctic char in inlet and outlet streams indicated low survival with age (juvenilisation). In 1996 anomalies were observed in Norwegian lakes too (Dalvatn and Store Skardvatn), indicating an influence of one or several toxins, presumably of organic origin.

4.3 Human health aspects

Studies of human health in the Nikel-Pasvik area revealed no major health effects that can be ascribed to the air pollution by nickel and sulphur dioxide in the Nikel / Zapolyarny area or in the Pasvik valley.

Air pollution from the Pechenganikel smelters has been a matter of great concern during the last decade. Comprehensive research has revealed harmful effects on the environment. On the initiative of the Ministries of the Environment of both countries, a joint Health Group was founded in 1991 (Smith-Sivertsen et al. 1997). The aim of the joint group was to investigate exposure to and possible health effects from the sulphur dioxide and nickel pollution from the Pechenganikel smelters in the border area of Norway and Russia.

The accumulating knowledge about environmental pollution effects over the last decade has caused much public concern about the pollution in the border area. Worry about possible health effects has occupied people to an increasing extent.

The work of the Health Group consists of separate cross-sectional population-based studies with a common protocol conducted on both sides of the Norwegian-Russian border. The population of Sør-Varanger municipality was studied, as well as the cities of Nikel and Zapolyarny. Comparison groups were sampled from Tromsø and Apatity, Kirovsk and Umba. A full screening was undertaken in order to map exposure to and possible health effects from sulphur dioxide and nickel pollution in all study populations. The focus of the work on possible health effects has been on asthma and chronic obstructive lung disease, nickel allergy, other allergic diseases and adverse outcomes of pregnancies (low birth weight and spontaneous abortions).

This study revealed no major health effects that can be ascribed to air pollution by nickel and sulphur dioxide on either side of the border.

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Tittel - engelsk og norsk
Air Pollution Effects in the Norwegian - Russian Border Area
A Status Report

Effekter av luftforurensning i det norsk-russiske grenseområdet
Statusrapport

Sammendrag – summary
Den norske regjering og den nordiske invisteringsbanken (NIB) støtter moderniseringen av nikkelverket i Petsjenga på russisk område. Målet er å redusere utslippene med 90% og dermed også redusere miljøkonsekvensene i området. Miljøverndepartementet (MD) har bedt Statens forurensningstilsyn (SFT) å koordinere og utgi denne rapporten. Rapporten gir en stausbeskrivelse av miljøsituasjonen i grenseområdet basert på forskningsresultater fra både norske og russiske forskere.

The Norwegian Government and the Nordic Investments Bank (NIB) are supporting a modernisation project to reduce emissions from Pechenganikel. The goal is to reduce emissions by 90 per cent and thereby reduce the environmental consequences in the region. To follow up this modernisation project, the Norwegian Ministry of Environment (MD) has asked the Norwegian Pollution Control Authority (SFT) to co-ordinate and prepare this report. It summarises the environmental status in the border area based upon the most important findings from Norwegian and Russian research.

4 emneord	4 subject words
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Our goal is to promote sustainable development. We are working to ensure that pollution, hazardous substances and waste do not cause health problems, affect people´s well-being or harm nature´s own powers of regeneration.

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