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ENVIRONMENTAL PROTECTION

State of the Environment in the Norwegian, Finnish and Russian Border Area

Kerstin Stebel, Guttorm Christensen, John Derome and Ilona Grekelä (editors)

Lapland Regional Environment Centre, Finland
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LAPLAND REGIONAL
ENVIRONMENT CENTRE

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PREFACE

This report describes the results of the monitoring, research, evaluation and development activities carried out within the Interreg IIIA Kolarctic project «Development and implementation of an environmental monitoring and assessment system in the joint Finnish, Norwegian and Russian border area" during the period 2003-2006.

The results of these activities form a basis for the development of a joint environmental monitoring programme in the border area between Norway, Finland and Russia.

The report gives an overall view of the environmental conditions in the Paz River basin and of the changes that have taken place over the last decade as a result of emissions from the mining and metallurgical plant at Pechenganikel (Nikel and Zapoljarnyi), located in the immediate vicinity of the border areas between Russia and Norway and Russia and Finland.

The national monitoring programmes currently carried out in each of the three countries are not sufficient to evaluate the environmental changes taking place under the varying anthropogenic load. Furthermore, the monitoring data collected by the three countries are not integrated into a single monitoring system, and do not give a fully comprehensive picture of the situation throughout the whole catchment area of the Paz River basin. A number of new research and monitoring activities were implemented and tested during the course of the project in order to fill these information gaps, and to determine whether additional parameters and components of the ecosystems, more suited to quantifying the special characteristics of the region, should be monitored. The results from projects carried out earlier in the area were taken into account when assessing the current state of the environment.

An international group of scientists from twenty Norwegian, Finnish and Russian research institutes and conservation authorities participated in the project. This publication is based on the reports of the individual studies carried out during the project. The scientific reports are added to this summary report as CD appendixes. The recommendations for the joint monitoring programme presented in this report were already used for the creation a joint monitoring programme by the three countries. The implementation guidelines of the joint monitoring programme are printed as a separate document.

This project has clearly demonstrated the importance and usefulness of international co-operation between three countries, each with similarities and differences in their monitoring systems. There are still many important challenges ahead. However, this phase of interaction provides a sound basis for further environmental co-operation in the joint border area.

We would like to take this opportunity to offer our warmest thanks to all the experts who have been involved in the project and in the preparation of this report, and especially to the lead editors of the report and the Implementation guidelines document.

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ABSTRACT

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 major threat to the natural environment in the area is posed by the Pechenganikel industrial complex, where copper and nickel ore has been mined and processed for over 70 years.

The results of studies carried out within the project, as well as the results of earlier national monitoring programmes, were used to develop the monitoring programme for the three countries.

During the project air quality and deposition were monitored at three main sites in Nikel, Svanvik and Sevettijärvi. Water quality was investigated in the Inari-Paz watercourse as well as in a number of small lakes and rivers situated at different distances from the pollution sources. During the course of the project, changes in species composition, population structure and pathological status of fish communities were studied both in the Paz watercourse and in separate lakes. The bottom fauna and changes in benthic populations over the last ten to fifteen years were investigated in 15 small lakes. Pollution levels in fish and bottom fauna were also determined. The state of terrestrial ecosystems and recent changes were investigated at 23 monitoring sites established during previous research projects. The monitoring network included activities on a wide range of terrestrial attributes 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 analysis of mosses, lichens and vascular plants, species composition of hole-nesting passerines (birds) and small mammals (rodents and shrew), chemical properties of the organic soil layer, and the chemical composition of bulk deposition and stand throughfall.

One important objective of the project was to harmonize the monitoring methods used by the three countries in the border area. Harmonisation and standardisation of monitoring and assessment methodology have been performed during all stages of the project: field work, chemical and biological analyses, data analysis, and assessment and reporting. The methods used in the different countries are in accordance with national or international standardised methods. Detailed information about the methods is given in the individual scientific reports.

Emissions of sulphur dioxide (SO_2) from the smelters have been considerably reduced during the past two decades, and are currently about 75 % lower than the levels during the 1980s. There are signs of a slight recovery in the condition of terrestrial and aquatic ecosystems in some parts of the area. The results also suggest that there are signs of a reversal in the acidification of some lakes (e.g. in the Vätsäri and Jarfjord lakes) that have earlier been severely affected by the deposition of acidic sulphur deposition, derived from SO_2 emissions from the smelters. There have been improvements in the water quality and fish populations of lakes located at distances of ca. 30 km to the north-west and ca. 50 km to the west of the smelter. There has also been a recovery in the coverage of ground lichens 10 km to the west of the smelter, and signs of an increase in the coverage of epiphytic lichens at a distance of more than 70 km to the west of the smelters. However, the SO_2 concentrations are still excessive in certain parts of the area.

There does not appear to have been a corresponding decrease in heavy metal emissions. The deposition of nickel, copper and other heavy metals in the area has continued at an unacceptably high level and, during the past two years, the deposition of e.g. nickel has increased. The accumulation of heavy metals in mosses and lake sediments has increased during the past 15 years. Water chemistry data indicate that

there has been no decrease in the levels of copper, and nickel in the Paz watercourse during the last 6 years. Increased concentrations of heavy metals in lake water occurred within a 30 km zone around the smelters. There are clear gradients in heavy metal concentrations in many of the plant and aquatic components of the ecosystems in the area, i.e. decreasing concentrations with increasing distance from the smelters. However, the gradients are relatively steep and short, and extend for only a few tens of kilometers e.g. to the west.

The effects of heavy metal emissions from the smelters are clearly evident in the Paz watercourse. The watercourse receives pollutants via atmospheric deposition as well as through the direct discharge of wastewater from the mines and smelter complex. Heavy metal concentrations are highest close to the smelter, and decrease on moving downriver and upstream from the emission sources.

The results of the project clearly show that there is a need for a joint, trilateral monitoring programme to follow up the effects of the modernization process at the Petchenganikel combine and to assess the future state of the environment in the joint Norwegian, Finnish and Russian border area.

Recommendations for a joint environment monitoring programme are presented in this report. It is recommended that the joint monitoring programme should be implemented gradually. Sub-programmes that were harmonized and tested during the project, and which are now ready for implementation, should be started at the beginning of 2007. Additional components should to be developed and included in the trilateral monitoring programme as soon as possible.

1 Description of the area

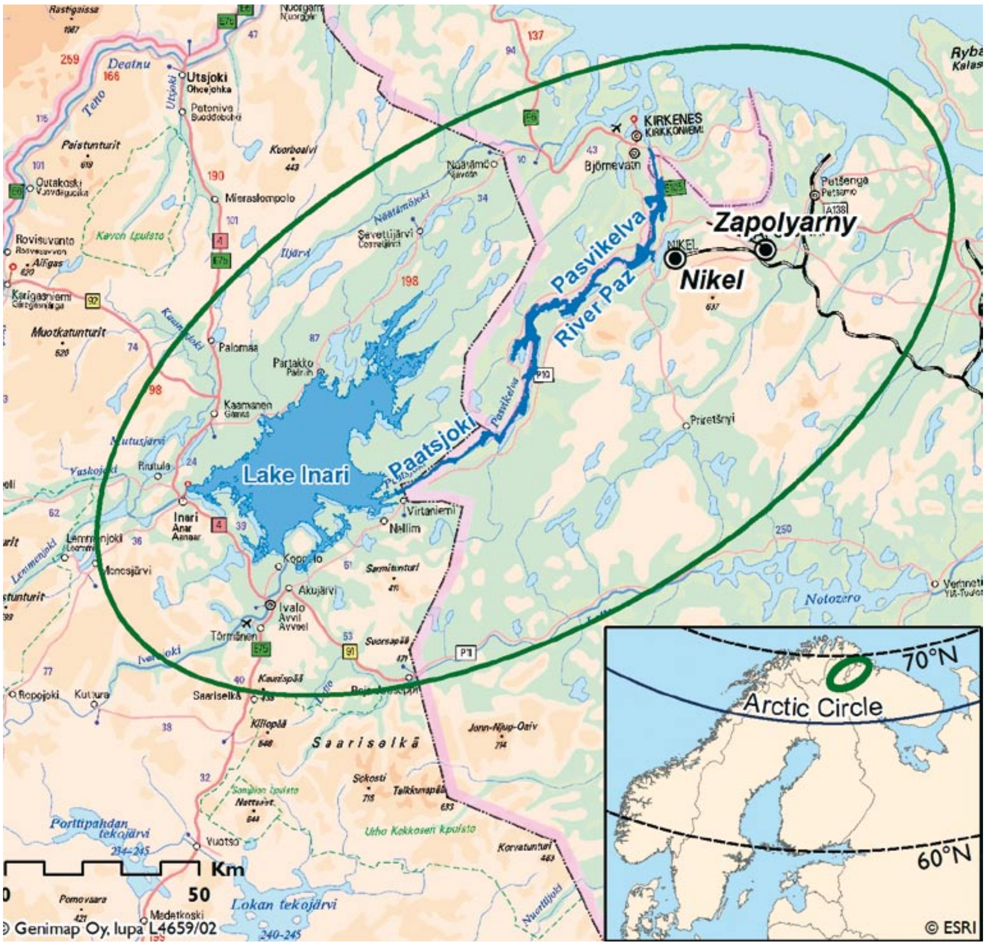

Figure 1.1 The area covered by the project.

The environmental research and monitoring work was carried out in the Paz River basin, which covers areas in Norway, Finland and Russia, as well as in the basins of the Jakobs (Norway), Näätämö (Finland) and Pechenga (Russia) rivers.

Climate

The climate in the area is influenced by the Gulf Stream. It is sub-oceanic/continental along the coast in the northern part, and continental in the southern parts with cool winters and relatively warm summers. The mean annual temperatures in the Kirkenes and the River Paz areas are -2 °C and -1.1 °C, respectively. In the lake Inari are the annual mean temperature is between -1 °C and 0 °C (1971–2000). The mean January and July temperatures are -11.5 °C and 12.6 °C in Kirkenes, and -15.4 °C and 13.7 °C in the River Paz area (1996–1990). The corresponding values for the Lake Inari area are between -14 °C and -12 °C in January, and between 12 °C and 16 °C in July (1971–2000).

The amount of precipitation is relatively low. The long-term annual average varies between 350 and 450 mm. The highest values occur in July and August, with around

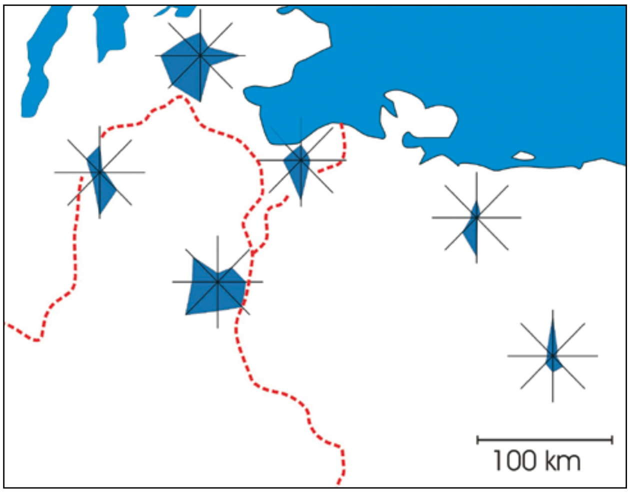

Figure 1.2
Wind roses at a number of meteorological stations in the area.
Author: Minna Hartikainen, according to Mäkinen, A. (1994): Biomonitoring of atmospheric depositions in the Kola Peninsula (Russia) and Finnish Lapland

60 mm per month. During the winter 20–30 mm per month are common. A permanent snow cover usually occurs from mid-November to late May.

The prevailing wind direction during winter is S/SW, while in summer the wind directions are more evenly distributed. However, the wind directions in specific parts of the area are naturally more varied for topographical reasons. It is clear that most of the emissions from the smelter complex in Nikel are carried to the north and north-east of the smelter (1.2). Due to higher solar radiation, unstable stratification and turbulent mixing are more frequent during the summer. At night and during the wintertime stable stratification, caused by outgoing radiation from the ground, as well as cooling of the ground, can inhibit vertical mixing of the air masses.

Vegetation

The area belongs to the north boreal and low-alpine vegetation regions, and is covered by forests, alpine heathlands, bogs and fens. The vegetation is influenced by gradients in climate, soil humidity, soil nutrient status, natural fragmentation and grazing by herbivores.

The forests in the area are composed mainly of downy birch (*Betula pubescens*) and Scots pine (*Pinus sylvestris*). Pine is distributed along the River Paz and adjacent lowland areas in the south and east, whereas birch is the main tree component of the forests in the northern and eastern parts of the area, with a gradual transition to shrubs and heather on approaching the alpine and polar treeline.

The ground vegetation in the pine forests and the dry birch forests reflects the relatively-nutrient poor soil. It is dominated by dwarf shrubs, such as crowberry (*Empetrum nigrum*), cowberry (*Vaccinium myrtillus*), bilberry (*V. vitis-idaea*), wild rosemary (*Ledum palustre*) and twinflower (*Linnaea borealis*). Herbs and grasses have a sparse distribution, except for the wavy hair-grass (*Deschampsia flexuosa*), which is relatively common. The ground has a well-developed cover of lichens and oligotrophic bryophytes, of which *Cladonia* spp., *Pleurozium schreberi, Dicranum fuscescens*, *D. scoparium* and *Barbilophozia* spp. are the most dominant species.

The birch forests on the less dry soils are characterized by low-herb plant communities with slightly more nutrient-demanding species, such as ferns, grasses and herbs. *Vaccinium myrtillus* is the dominating dwarf shrub, and the oak fern (*Gymnocarpium dryopteris*) and Eurasian dwarf cornel (*Cornus suecica*), Lapland lousewort (*Pedicularis lapponica*) and Arctic starflower (*Trientalis europaea*) are very common.

Figure I.3
The mouth of the River Paz.
Photograph: Pekka Räinä

The alpine heathland is characterised by approximately the same species as the dryer forests. However, species reflecting a colder climate are more common, such as dwarf birch (*Betula nana*) and alpine azalea (*Loiseleuria procumbens*). The waterlogged areas are covered by bogs and nutrient-poor fens dominated by peat mosses (*Sphagnum* spp.), dwarf shrubs, graminoids and herbs such as *Betula nana*, sedges (*Carex* spp.), cotton grasses (*Eriophorum* spp.) and cloudberry (*Rubus chameamorus*).

Geology

The bedrock of Northern Finland, the eastern part of Norway and the north-western part of Russia consists of over 1,900 million years old granulite that stretches from the western parts of the Kola Peninsula, through Finland, into Norway. A large granite-gneiss complex extends from the Kola Peninsula through the northern Inari and eastern Utsjoki area, and continues into Norway.

The complex primarily consists of granites, granodiorites, amphibolites, gneisses of varying composition, and a greenstone zone of volcanic origin. The greenstone zones in each country consist of basaltic and komatitic vulcanites, which include multiple ore deposits such as the nickel ore deposit at Zapoljarnyi. Approximately 400 to 1000 million-year-old sedimentary rocks, such as sandstones and conglomerates, occur in the northern parts of Norway and Russia Northern parts.

There is considerably variation in the composition of the bedrock at the local level. The geochemical and mineralogical composition of the bedrock affects the chemical properties of the soil. 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 composition of the ground water in the area.

The dominant type of mineral soil in the area is till, and only 10 % of the surface area consists of sorted soil formation such as eskers, shore deposits or dunes. The mineralogical composition of the 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. Approximately 10 % of the surface area is peatland. The peat bogs in northern areas are usually aapa, palsa and hilltop bogs.

Watercourses

The central lake, Lake Inari, is the deepest and the third largest lake in Finland. Lake Inari is a regulated extensive body of water with a low nutrient content. The River Paz, which runs from Lake Inari into the Barents Sea, acts, throughout almost its entire length, as the border between Norway and Russia. The watercourse of the River Paz is strongly regulated and primarily consists of lakes and reservoirs, linked by short sections of river.

The hydrographic network of the Paz River basin is characterized by a large number of lakes, mires, and numerous rivers with rapids. Lakes and streams occur at altitudes ranging from ca. 100 m to more than 300 m a.s.l., and run through a diverse spectrum of environments ranging from forested areas to vegetation-free mountain areas.

2 Anthropogenic activities in the area

2.1 Settlement and employment structure

The Inari-Paz area encompasses three border municipalities, Pechenga in Russia, Sør-Varanger in Norway and Inari in Finland. The administrative centres of these municipalities are Nikel, Kirkenes and Ivalo, respectively. Pechenga has the largest population, with 45,100 inhabitants (in 2000), followed by Sør-Varanger with 9,500 inhabitants and Inari with 7,120 (in 2004). Both Pechenga and Sør-Varanger are municipalities with an industrial base, primarily centred on mining and metallurgy.

Most of the working population in Pechenga is employed by the Pechenganikel Ni-Cu combine. In Kirkenes and Björbevann in Norway, on the other hand, industrial activities ceased in 1996. The business sector in Sør-Varanger is today much more diversified, and consists primarily of ship repairing, harbour development, agriculture and commerce.

2.2 Industrial activities

The Pechenganikel industrial complex

The main threat to aquatic and terrestrial environments in the joint Finnish, Norwegian and Russian border area is the neighboring Pechenganikel industrial complex, located on the Kola Peninsula in NW Russia. Emissions from the complex comprise high levels of sulphur dioxide (SO_2), dust and a wide range of toxic heavy metals, primarily copper and nickel. The smelter in Nikel and roasting plants in Zapolyarny were originally established in 1933. There has been a gradual accumulation of pollutants in the soil and bottom sediments of the watercourses in the area for over 70 years.

Nowdays the Pechenganikel Mining and Metallurgical Combine, located in the Russian border towns of Nikel and Zapolyarny, is a part of the Kola GMK Company, a subsidiary of the MMC Norilsk Nickel Group. The enterprise comprises three mines, a concentrating plant, a roasting plant, a smelting plant, a sulphuric acid plant, and 15 departments supporting the main production processes. Copper-and-nickel matte is the final product, which is transported to the Severonikel smelter in the town of Monchegorsk for further processing, and sulphuric acid.

Mining

Ore is mined by the open-caste method and underground mining. The open-caste method (the Tsentralny mine, Zapoliarny) produces a large amount of overburden material (not containing non-ferrous metals), which is a by-product of the mining process and dumped on dump sites. In the underground mines (the Kaula-Kotselvaara pit in the Nikel production area, and Severny pit in the Zapoliarny production area), man-made vugs are partly filled with the production waste. Precipitation (rain and snow), surface water runoff and ground water drainage result in the formation of mine water in the mine excavations. The mine water contaminated by heavy metals from the Tsentralny mine is discharged without treatment into the River Bystraya of the Pechenga River basin. Mine water from the Severny pit is discharged, after mechanical treatment, into the same water body. Mine water from the Kaula-Kotselvaara pit passes into the River Kolosjoki, from where it runs through Lake Kuetsjarvi into the River Paz. The watercourses are polluted with suspended material, rock leachates and drilling mud.

The smelting industry

Concentrating plant (Zapolyarny)
Copper and nickel ore from the Pechenga region is processed in the concentrating plant. The end product is copper and nickel bulk concentrate. The discharged water contains toxic substances, including floating reagents (aerofloat, xanthogenate). Mine waste is formed in the production process.

The dumping site for mine waste is located in the Pechenga River basin. In addition to contamination of the surface and ground water, one of the main negative impacts of this dumping site on the environment is the spread of dust over the neighbouring water bodies.

Roasting plant (Zapolyarny)
The raw material used in the roasting plant is bulk flotation copper-and-nickel concentrate from the Pechenganikel processing plant. Hardened copper-and-nickel pellets are the final product. The roasting house in Zapoliarny is the major pollution source.

The roasting and palletizing plant operates round the clock throughout the year. The main pollutants emitted into the atmosphere are SO_2 gas, and nickel, copper and cobalt. The steam power plant located next to the roasting house is the second largest pollution source, emitting SO_2, nitrogen oxides and carbon monoxide.

Smelting plant (Nikel)
Concentrated ore is processed at the smelting plant in Nikel. Burnt pellets and ore from Norilsky Nikel (NE Russia) are also processed there. Copper-and-nickel matte is the final product. Matte blocks weighing about 14 tonnes of weight are transported to the Severonikel plant in the town of Monchegorsk. Emissions from the smelting plant contain large amounts of SO_2, metal compounds, and dust. The granulated slag formed during the production process in the smelting plant is transported to the dumping site on the bank of the River Kolosjoki.

Toxic compounds are leached out of the dumping site by rainfall, snowmelt and surface water. Dust from the dumping site also has a major impact on the environment. Wastewater is discharged directly into the watercourses of the Paz River basin. The discharges into the River Kolosjoki have the highest nickel concentration.

Sulphuric Acid Plant (Nikel)
Exhaust gases from the converter department of the smelting plant contain SO_2 and are the raw material for the sulphuric acid plant located in the Nikel production area of the smelter.

SO_2 emissions from Pechenganikel were at their highest (about 350,000–400,000 tonnes sulphur per year) in the late 1970's to early 1980's. At that time there was a considerable increase in the production capacity, and copper and nickel ore from Norilsk, which has a much higher sulphur content, was also used. The impacts on the environment were also at a maximum at that time.

Figure 2.1 The Paz watercourse is located near mining and metallurgical activities. Photograph: Nikolay Kashulin

Figure 2.2 The open-caste mine at Zapolyarny. Photograph: Nikolay Kashulin

Figure 2.3 Dumping site on the bank of the River Kolosjoki. Photograph: Nikolay Kashulin

Since the mid-1980's, however, emissions have decreased due to increased efficiency of the concentrating and smelter processes and to a reduction in the sulphur content of the ore. More recently, economic problems resulted in a further decrease in production and the use of sulphur-rich ore from Norilsk. Measures are currently being implemented to reduce the level of emissions. According to the Kola GMK Company, sulphur emissions in 2005 amounted to 106,000 tonnes. Although nowadays the emissions are considerably lower than those in the 1980's, the SO_2 concentrations measured in the Nikel area are still above the critical level for sensitive biota. The nickel emissions have decreased 1.5-fold (330 tonnes in 2004) and the copper emissions 2-fold (168 tonnes in 2004) compared to the peak emissions in 1979. During the past decade there has been little change in heavy metal emissions.

Wastewater discharge from the plant has fluctuated considerably, and was at its maximum in 1983 (45.1 million m^3). Discharges stabilized during the period 1989 to 1996. Since 1997 the discharge has mainly decreased due to a reduction in the use of the sulphur-rich ore from Norilsk, and during the past few years it has remained at its current level. In 2005 the Pechenganikel plant discharged 25.9 million m^3 of wastewater into the surface waters. Of this, 17.1 million m^3 was water from the mines and 7.8 million m^3 of this mine water was discharged directly into the River Kolosjoki. Despite the company's efforts to reduce the pollution, the heavy metal concentrations in the wastewater are still very high. For example, the nickel concentration in the wastewater discharged into the River Kolosjoki is 1–3.5 mg/l during summer/autumn.

The total area of dumping sites for mining and processing waste covers at least 10,000 hectares. Almost all of the waste is characterized as "practically" non-hazardous (e.g. nickel concentrations below 0.11–0.16 %), but the negative impacts on the environment are caused by the enormous volume of the waste. Wind and water erosion of the waste storage and waste dumping sites, as well as the leaching of toxic compounds are accompanied by the formation of fine, wind-blown dust containing toxic elements that spread outside the production area, resulting in contamination of the atmosphere and terrestrial and aquatiq ecosystems.

The activities of the Pechenganikel Plant have resulted in the formation of a so-called anthropogenic landscape of extremely low aesthetical value, and have had a negative impact on the environment. Blasting operations and the excavation of vast amounts of rock and ore have considerably damaged the natural landscape, destroyed the mountain tops, and altered the orography.

It is planned that the renovation of the plant will be completed by 2009. As a result, it is expected that there will be a considerable reduction in SO_2 emission (down to 12,000 tonnes/year) and dust (down to 300 tonnes/year). By summer 2006, renovation of the concentration plant was completed and a start made on reconstruction of the roasting plant in Zapolyazrny. Measures are also being taken to increase the utilization of SO_2 in sulphuric acid production.

AS Sydvaranger

The establishment of AS Sydvaranger in 1906 led to the foundation of the town of Kirkenes. The workforce reached its maximum in the 1980's, with 1,200 people. Mining operations and the administration were located in Bjørnevann, while the pelletization plant and shipping took place in Kirkenes. The fall in iron ore prices led to a controlled close down in 1996. The release of dioxins from the pelletization plant in Kirkenes has lead to restrictions on the consumption of fish from the two small lakes, Førstevann and Andrevann, in the immediate vicinity.

2.3

Land use

Historically the region was the dwelling place for the nature-based indigenous Saami people. Nowadays primary industries, including agriculture, fishing, forestry and reindeer herding, play a minor economic role in the area. However, these are important occupations for people living in rural areas in the Norwegian and Finnish part of the area.

Agriculture is most important in Norway, with 903 ha of arable land and 75 man workyears. Finland comes second, the corresponding figures for the Inari municipality being 530 and 25. In Russia, the only agricultural enterprise in the Pechenga region was a pig farm with 5,000 pigs and 600 ha of fodder production that closed down in August 2006.

Reindeer husbandry is an important branch of the primary industry in the Finnish part of the area, with approximately 150–200 persons employed and a total stock of 39,200 reindeer. The Norwegian part of the area is also an important grazing area, with 3,200 reindeer and 35–40 people employed. On the Russian side there is no reindeer farming. Intensive grazing by reindeer has reduced the lichen cover in Norway and Finland, and may slow down recovery of the vegetation after industrial pollution has been reduced, but is not believed to have any influence on the watercourses.

Before the Second World War the area was the site of intensive forestry activities and the River Paz was used to float timber. Floating stopped when the area was divided between the three countries and the watercourse was regulated. In Finland forestry is still important, with 200 persons employed and 7,100 km^2 of productive forest land. Forestry activities in the Norwegian part of the area are much more modest, with approximately 10 persons employed and 46.1 km^2 of productive forest land. In Russia there used to be a department of the Verkhnetulomsk logging company situated in Janiskoski, but it is now closed.

The importance of fisheries has also declined in recent years. Commercial catches of up to 300 tonnes annually in Lake Inari have been reduced to 10 tonnes, and the fish-processing plant in Vaggetem in Norway closed in 1998. There is no commercial fishing in the Pechenga municipality.

It is estimated that a very low proportion of the nutrients discharged into the river is derived from farming and populated areas. In general, the influence of non-industrial activities in the area can be considered negligible compared to the impacts of the extensive mining and metallurgical industries.

Air quality and deposition

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The smelter in Nikel in April 2005. Photograph: Kerstin Stebel.

3 Air quality and deposition

3.1

Monitoring and assessment network

Air quality and environmental impacts have been monitored in the Paz-Inari area for a long time. SO_2 measurements started in the Kirkenes area and in Svanvik already in 1974, and close to the smelter in the town of Nikel in 1980. A joint Norwegian-Russian Commission of Environmental Cooperation was established in 1988, and a comprehensive measurement programme on air quality, precipitation chemistry and meteorology started on the Norwegian and Russian sides of the border in 1988 and 1990, respectively.

The results of these early studies are described in the *Baseline Study of Air Pollution in Sør-Varanger 1988–1991* and the *Summary reports of Air Pollution in the Border Area of Norway and Russia* from 1992 and 1994. Since then, monitoring of air quality has been performed as bi-lateral Norwegian Russian collaboration during 1990–1997, and as a part of the national monitoring activities in Norway, Russia and Finland.

The effects of air pollution on the terrestrial and aquatic ecosystems have been summarized in a SFT status report, published in 2002. In 2003 a tri-lateral Interreg project was initiated on the '*Development and implementation of an environmental monitoring and assessment programme in the joint Finnish, Norwegian and Russian border area*' (for more details see www.pasvikmonitoring.org).

The Norwegian air quality monitoring activity in the border area has decreased throughout the 1990s. Since the breakdown of the monitoring station in Maajavri in summer 2001, there has been no monitoring to the northeast of the smelter, which is

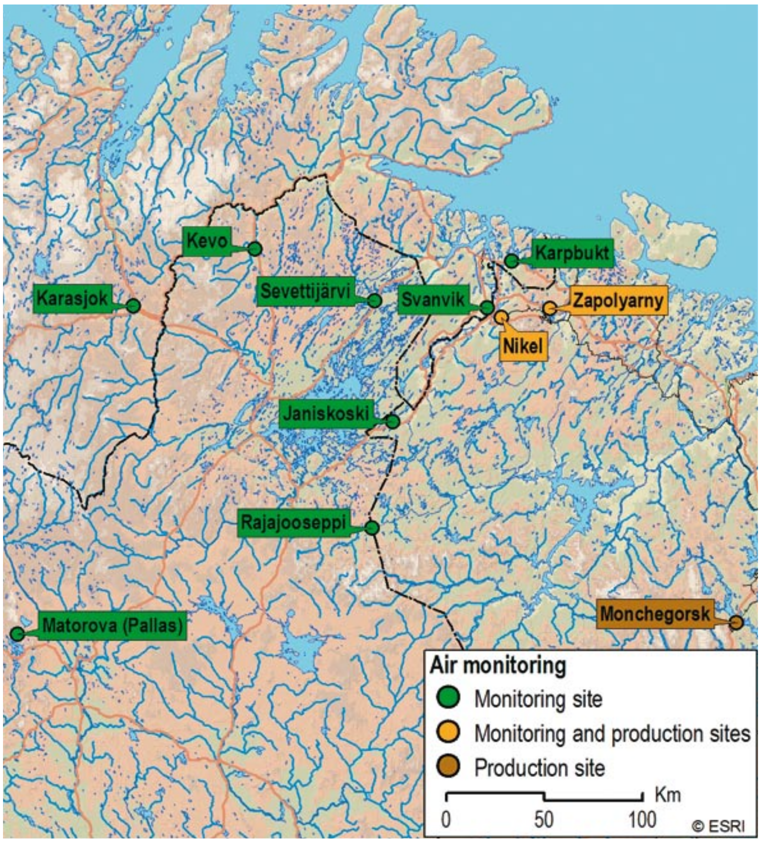

Figure 3.1
Map showing the location of the large, non-ferrous metal production sites (Nikel, Zapolyarny, Monchegorsk) and air monitoring sites in the border area of Finland, Norway and Russia.

Table 3.1 Air quality monitoring programme in 2006.

Station		Air									Precipitation				
		continuous			daily			weekly	monthly		daily	weekly		monthly	
		Meteo	O_3	SO_2	SO_2 CO HCHO	particles	NO_2	heavy metals	heavy metals	Benzapyren(e)	main comp.	main comp.	heavy metals	heavy metals	main comp.
Svanvik	69°27'N, 30°02'E	x		x									x[a]		
Karpbukt	69°40'N, 30°22'E											x			
Karasjok	69°28'N, 25°13'E		x				x				x		x[b]		
Nikel (NILU, P5,P6)	69°24'N, 30°20'E	x P5,P6		x NILU	x P5,P6	x P5,P6	x P5,P6	x[c] P5		x P6					
Jäniskoski	69°00'N, 28°80'E	x													x
Sevettijärvi	69°35'N, 28°50'E	x	x	x					x					x[a]	x
Raja-Jooseppi	68°29'N, 28°18'E	x	x	x											
Kevo	69°45'N, 27°00'E	x		x										x[a]	x
Matorova (Pallas)	68° 00'N, 24°15'E	x			x-SO_2			x[d]				x		x[d]	
Sammaltunturi	67°58'N, 24°07'E	x	x	x											

Heavy metals: a = Cu, Ni, Co, Cd, Pb, Cr, Zn and As
b = Pb, Cd and Zn
c = Fe, Cu, Ni, Co, Cd, Mn, Pb and Cr
d =As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, V, Zn

Table 3.2 Limit and national target values for SO_2 concentration to protect human health and ecosystems in the EU/EOS and Russia.

Type	Effects on	Valid within	Hourly avg. (µg/m³)	Daily avg. (µg/m³)	October-March (µg/m³)	Yearly avg. (µg/m³)	Number of allowed exceedances per calender year
Limit Value	Health	EU / EOS	350				24
Limit value	Health	EU / EOS		125			3
Target value	Health	Norway		90			0
Limit Value	Ecosystems	EU/EOS			20	20	0
WMO guidelines	Health	World	500 (10 min. avg.)				
Maximum permissible concentration	Health	Russia	500 (20 min. avg.)			50 (monthly avg.)	

the area most affected by emissions from the high stacks. In 2004, measurements of the main components in air and precipitation in Svanvik had to be stopped due to the lack of financial support. In contrast, the Finnish monitoring network has been strengthened with the start of additional measurements at Sevettijärvi. These include continuous SO_2 and PM_{10} measurements and the monitoring of sulphate and heavy metal deposition. In 2004, meteorological equipment was installed with FMI funding at Raja-Jooseppi, and continuous measurements of SO_2 were started at Kevo, replacing monthly passive sampling.

The location of air quality monitoring sites operative in 2006, as well as the location of the large non-ferrous metal production sites (in Nikel, Zapolyarny and Monchegorsk), are shown in Figure 3.1. The Russian monitoring stations located in the town of Nikel are the closest to the emission sources. The closest site on the Norwegian side is Svanvik, 9.2 km WNW of Nikel. The main monitoring site in Finland is Sevettijärvi, 57.4 km WNW of Nikel.

General information about the monitoring programme in 2006 is summarized in Table 3.1. Three of the stations listed in Table 3.1 are regional background stations: the stations in Karasjok (before 1997 located at Jergul) in Norway, Janiskoski in Russia, and Matorova/Pallas in Finland, all of which contribute to EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe), which is a scientifically based and policy driven programme under the UN-ECE Convention on Long-range Transboundary Pollution.

3.2

Monitoring methods

Regulations on air quality monitoring and assessment

Monitoring and assessment of air quality in the European Union and associated member states is, to a large extent, harmonized through Regulations. In 1996, the Environment Council adopted Framework Directive 96/62/EC on ambient air quality assessment and management. The list of atmospheric pollutants to be considered includes sulphur dioxide, nitrogen dioxide, particulate matter, lead and ozone (all pollutants governed by already existing ambient air quality objectives) and benzene, carbon monoxide, poly-aromatic hydrocarbons, cadmium, arsenic, nickel and mercury.

The first Daughter Directive (1999/30/EC) relating to limit values for NO_x, SO_2, Pb and PM_{10} came into force in July 1999. The second Daughter Directive (2000/69/EC) relating to limit values for benzene and carbon monoxide came into force in December 2000. The third Daughter Directive relating to ozone (2002/3/EC) was adopted in February 2002. Directive 2004/107/EC from December 2004 relates to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. Regulations on $PM_{2.5}$ are expected to be ratified during the first half of 2007.

In Russia, air quality is assessed according to the standards accepted by the Health Ministry – the maximum permissible concentrations. According to the sanitary and hygiene standards, the maximum permissible single and average monthly concentrations are the main criteria of toxicity of air admixtures. A single admixture concentration is the admixture concentration measured within a period of 20 minutes. An average monthly concentration is the arithmetic mean value of the single concentrations measured within a period of one month. To assess the degree of air pollution, average concentrations are compared to the maximum permissible average monthly

Pollutant	Yearly average (ng/m^3)
Arsenic	6
Cadmium	5
Nickel	20

Table 3.3
EU/EOS target values for arsenic, cadmium, and nickel, in the PM_{10} fraction.

concentration; concentrations measured over 20 minutes are compared to the maximum permissible single concentrations.

In Russia, a complex index of atmosphere pollution is used to assess the total air pollution, which is a regime parameter for air quality, taking into account the hazard degree and the ratio of measured to maximum permissible concentration of the five highest pollutants. A similar approach is, for example, used in Norway to describe local air pollution (see www.luftkvalitet.no), based on the exceedance of predefined values for $PM_{2.5}$, PM_{10}, NO_2 and SO_2.

Table 3.2 summarizes the limit and target values for the SO_2 concentration to protect human health and ecosystems. The EU/EOS and Russian values are comparable. For trace metals, like arsenic, cadmium and nickel, for which there is no identifiable threshold below which these substances do not pose a risk to human health, target values are set (see Table 3.3) to be attained as far as possible with the aim of minimising harmful effects on human health and the environment as a whole.

Sampling, chemical analytical methods and quality control

The participating laboratories, FMI, NILU and MUGMS, perform air quality monitoring for national and international authorities, which assures the quality of the monitoring programme. Measures of quality assurance and quality control are also included. Laboratory ring tests and instrumental inter-comparison exercises are important measures to check the quality of the participating laboratories. The institutions responsible for regional background stations in the Paz River basin (FMI, NILU and the Institute of Global Climate and Ecology, Russia) have taken part in international laboratory comparisons organized via EMEP. Unfortunately, it was not possible within the frame of this project to perform additional field inter-comparisons, which is an important measure to ensure harmonized data quality.

Precipitation samples are collected with polyethylene bulk samplers. pH is determined on the samples by potentiometry, electrical conductivity via a conductivity cell, while anions and cations are determined by ion-chromatography. Trace metals are determined by inductively coupled plasma mass spectrometry (ICP-MS).

The main inorganic components in air, except for SO_2, NO_2, O_3 and heavy metals, are determined by the uptake of gases and particles on a filter pack consisting of a pre-filter for collecting particles, followed by two impregnated filters which collect alkaline and acidic gases. The extracts from the filter are analysed by ion-chromatography. The concentration of SO_2 is measured from a KOH-impregnated filter, and sulphate from the particle filter. Data from the co-located continuous SO_2 monitor are used in cases where the SO_2 concentration exceeds ca. 100 µg S m^{-3}. Total ammonium ($NH_4^+ + NH_3$) is derived from the aerosol filter and the filter impregnated with oxalic acid. Total nitrate ($NO_3^- + HNO_3$) is determined from the aerosol filter extract and the alkaline filter. Na^+, Mg^{++}, K^+, Ca^{++} and Cl^- are determined from the particle filter extract.

Measurements and analysis techniques for SO_2 differ between Russia and Finland/Norway. UV fluorescence is the CEN standard method for continuous measurement of SO_2 within the EU/EOS (i.e. Finland and Norway). The results are stored either as 10- minute or 1-hour averaged concentrations. The method used in Russia is designed

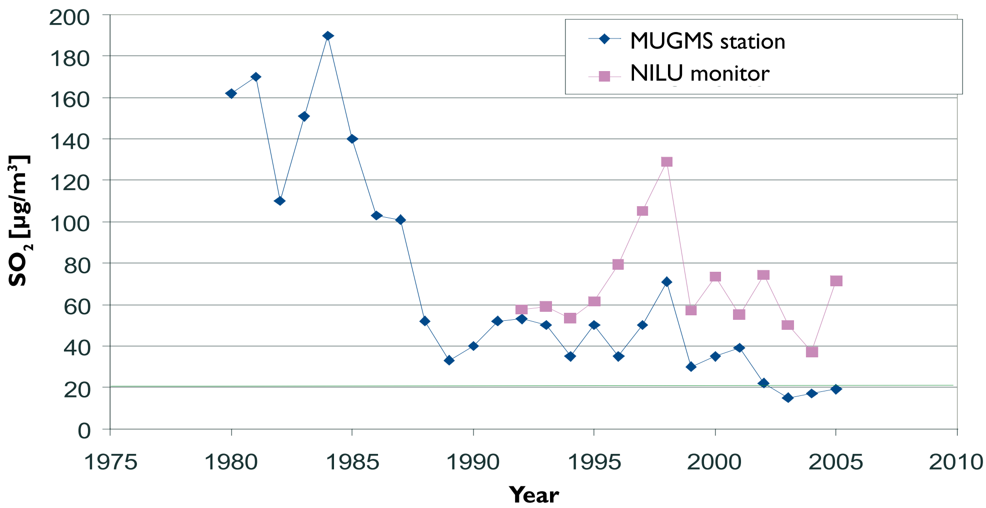

Figure 3.2 Comparison of yearly averaged SO_2 values measured with the one-time monitoring method and an SO_2 monitor at two different sites in Nikel.

for determining the SO_2 concentration within the range 50–1000 µg/m^3 within an air-sampling volume of 10 l. Three times per day, at 07, 13 and 19 LT, air is pumped for 20 minute through a sorptive tube with a flow rate of 2 l/min. The method is based on the interaction of dichlorsulphur-mercurate, formed in the process of SO_2 absorption by sodium tetrachloromercurate (absorbing solution) with formaldehyde and fuchsine. The resultant compound colors the solution violet-red, and the intensity of the color expresses the concentration of SO_2.

3.3

Main findings

Emissions from the Pechenganikel combine

The environment in the border area between Russia, Norway and Finland has been affected during several decades by emissions from non-ferrous metal production at Nickel/Zapolyarny and Monchegorsk on the Kola Peninsula. The main types of air pollution from the Pechenganickel combine, which belongs to the Kola Mining Metallurgical Co. (KMMC), are noxious gases like SO_2 and particles containing heavy metal like nickel, copper and arsenic.

Emission data shown in Figure 3.3 are based on mass balance calculations performed by the Pechenganikel combine. Measured emission data can only be expected after the modernisation of the Pechenganikel combine.

The smelter in Nikel and roasting plants in Zapolyarny were established in 1933. During the first 30 years of production, approximately 100 thousand tonnes of SO_2 were emitted annually. Whereas during the first years local ore was used, from 1971 onward the combine started to import ore from Norilsk in Siberia, which has a sulphur content close to 30 % as opposed to 6.5 % in the local ore. The change in raw material led to a dramatic increase in sulphur emissions. The development culminated in 1979 when emissions were calculated to about 400 thousand tonnes of SO_2. In the beginning of the 1990s SO_2 emissions declined, mainly because of the economic recession in Russia, and from the mid-1990s also due to the enhanced use of local ore.

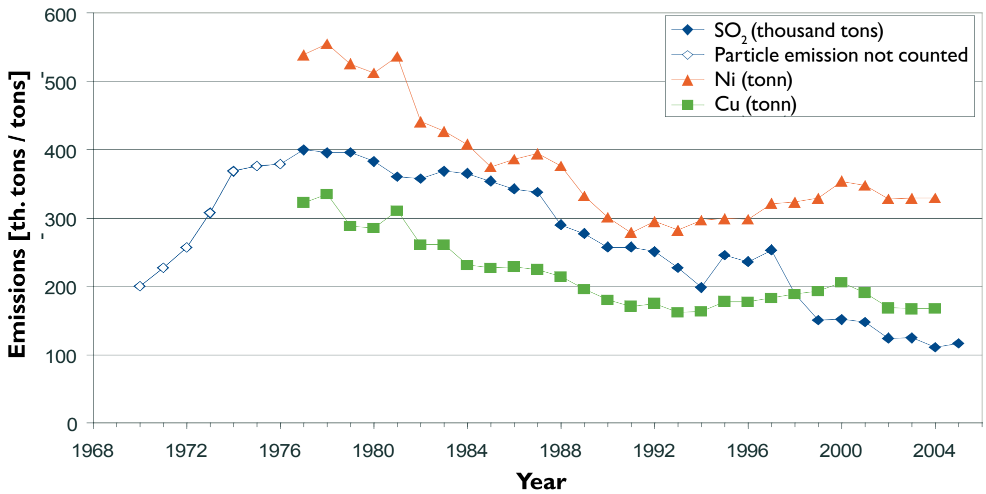

Figure 3.3 Annual emissions of SO_2, Ni, and Cu (calculated values, provided by the Pechenganikel combine). Note that before 1977 particle emissions were not calculated.

Although today SO_2 emissions are about 75 % lower than in the 1980s, the values are still rather high. For example, in 2004 about 110.4 thousand tonnes of SO_2 were emitted from the smelter. This was in the same order of magnitude as the total sulphur emissions in Finland (83.5 thousand tonnes as SO_2 (www.ymparisto.fi)) and about 4.2 times higher than the total Norwegian emissions (25.2 thousand tonnes in 2004, see www.ssb.no).

In addition, a range of heavy metals, like nickel (Ni), copper (Cu), cobalt (Co) and arsenic (As), are released into the environment through the production process. Nickel and copper predominate. In 1977 annual emissions of Ni and Cu were calculated as 539 tonnes and 323 tonnes, respectively. Nickel and copper emissions decreased to 279 and 171 tonnes, respectively, in 1991. From 1991 onward the Cu emissions remained relatively constant, but Ni emissions showed a slight increase. 329 tonnes of nickel and 167 tonnes of copper were emitted in 2004.

Sulphur dioxide

Sporadically high SO_2 concentrations occurring during air pollution episodes still represent an air pollution problem in the border area of Norway, Finland and Russia. A typical feature of the SO_2 concentrations recorded at the monitoring sites are low long-term average concentrations, whereas the peak values are well above the air quality guideline values. Continuous measurements of SO_2 are necessary to register these short-term peak concentrations.

In the town of Nikel, Murmansk Hydromet's permanent air quality monitoring stations are situated in the housing area. In addition, one site with a continuous SO_2 monitor is maintained by NILU. The SO_2 levels in Nikel, close to the smelter, are mainly derived from diffuse emissions. The highest SO_2 concentrations registered by the SO_2 monitor occur when the wind direction is from the northeast (from the smelter). The yearly averaged SO_2 concentration measured with the one-time monitoring method and the SO_2 monitor are shown in Figure 3.2. One-hour averages reported by the one-time monitoring sites are below the critical level of 20 µg/m^3 (yearly average) to protect the ecosystem. Whereas the SO_2 values measured with the SO_2 monitor are around 3 times as high, the Murmansk Hydromet stations report values below the critical level. Further examination is required to determine whether these differences are due to the varying distances to the diffuse emission sources, the

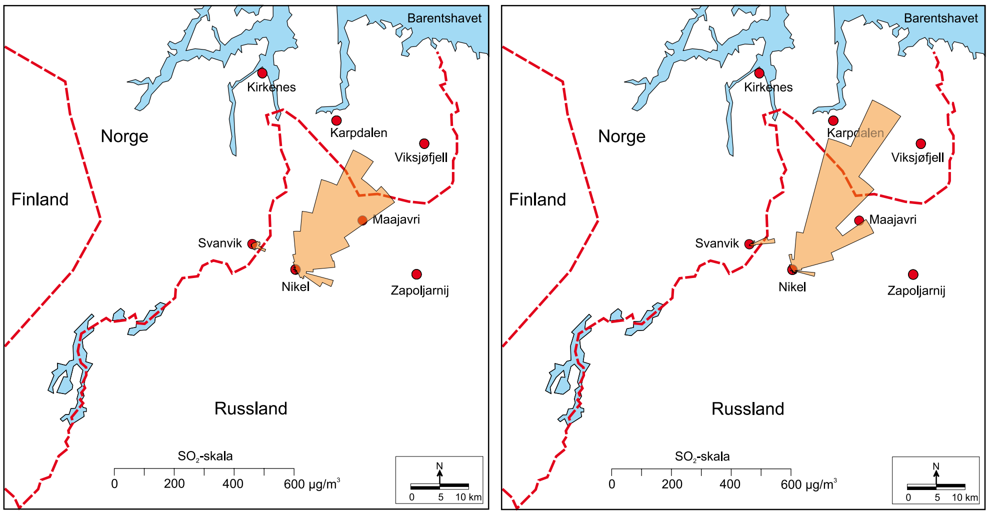

Figure 3.4 Averaged SO_2 concentration in Svanvik and Nikel during summer 2005 (left panel) and winter 2005/06 (right panel), shown for each of the 36 10°-wind sectors.

local/micro-meteorological conditions at the three sites, or differences in the measurement procedures.

Averaged SO_2 concentrations in Svanvik and Nikel for each of the 36 10° wind sectors were calculated on the basis of the hourly-averaged SO_2 values, wind direction, speed and stability in Svanvik (see Figure 3.4). Average concentrations in Svanvik were 7.2 µg/m^3 during summer 2005. Winds blowing eastwards (110°) from the smelter had the highest concentrations (49 µg/m^3). During winter 2005/06 the averaged SO_2 concentrations were 6.4 µg/m^3, and in the most polluted sector values of 84 µg/m^3 were recorded.

The yearly averaged SO_2 concnetrations in Svanvik, at Viksjøfjell, in Maajavri and in Nikel, as well as the SO_2 emissions since the start of measurements in Svanvik in 1974, are shown in Figure 3.5. The red line shows the limit value of 20 µg/m^3 (yearly average) for the protection of ecosystems. This limit value was exceeded in a number of years during the period 1974–1988. Since 1989 no further exceedance has been measured. The mean SO_2 concentration in ambient air seems to follow the general reduction in the yearly total SO_2 emissions. In 2005 the yearly averaged SO_2 concentration in Svanvik was 6 µg/m^3. In Nikel, the SO_2 concentrations are still much higher than the limit level. The Russian measurements show a decline throughout the 1980s. Continuous SO_2 monitoring started in 1992, when the concentrations were around 60 µg/m^3. The high values seen in 1997/1998 can be explained by higher frequencies of north-easterly winds from the smelter. From 1999 onwards the values varied around a level of about 60 µg/m^3. Yearly averaged SO_2 concentrations recorded at a number of Russian, Finnish and Norwegian monitoring sites in 2000, 2004 and 2005 are shown in Figure 3.7. In 2005 the values measured in Nikel (71.4 µg/m^3) were 12 times higher than those in Svanvik. Much lower values of 1.2 µg/m^3 and 0.8 µg/m^3 were recorded in Raja-Jooseppi and in Sammaltunturi, respectively.

The SO_2 concentration in the air during 1992–2004 at Raja-Jooseppi, which is located close to the Finnish-Russian border, is shown in Figure 3.6. The concentrations are normally close to zero, but high peaks are occasionally observed. In 2002, for example, there were 15 episodes when the SO_2 concentration exceeded 10 µg/m^3. These peaks are related to the movement of air masses coming from the NE and SE from the metallurgical plants at Nikel and Monchegorsk. Peak values as high as these are rarely found even in industrial areas, and almost never in uninhabited background areas in other parts of Finland. On the other hand, EU air quality regulations for the protection of human health allow three exceedances of the daily 125 µg/m^3 concentration values per year. The impact of the smelters on the Kola Peninsula can even be seen

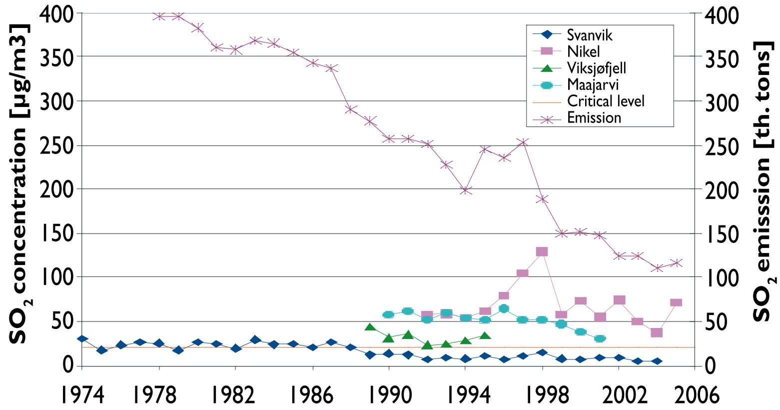

Figure 3.5
Yearly averaged SO_2 concentration in Svanvik (1989–2005), at Viksjøfjell (1989–1995), in Maajarvi (1990–2001) and in Nikel (1992–2005), together with the SO_2 emissions.

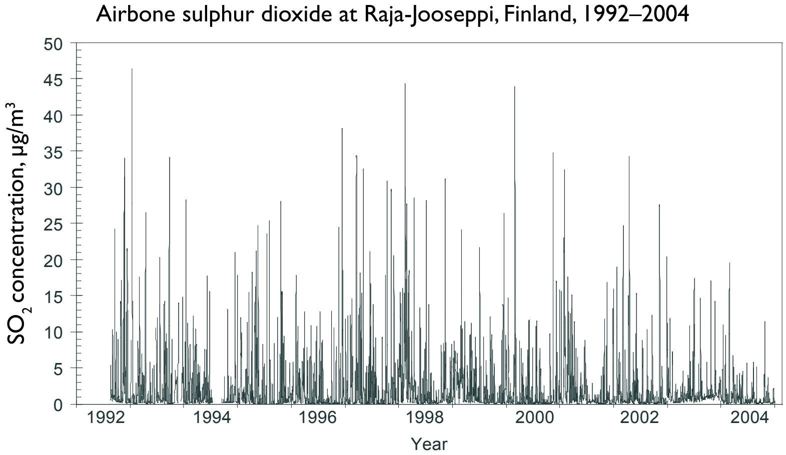

Figure 3.6
Daily averages of the SO_2 concentration in air at Raja-Jooseppi in 1992–2004.

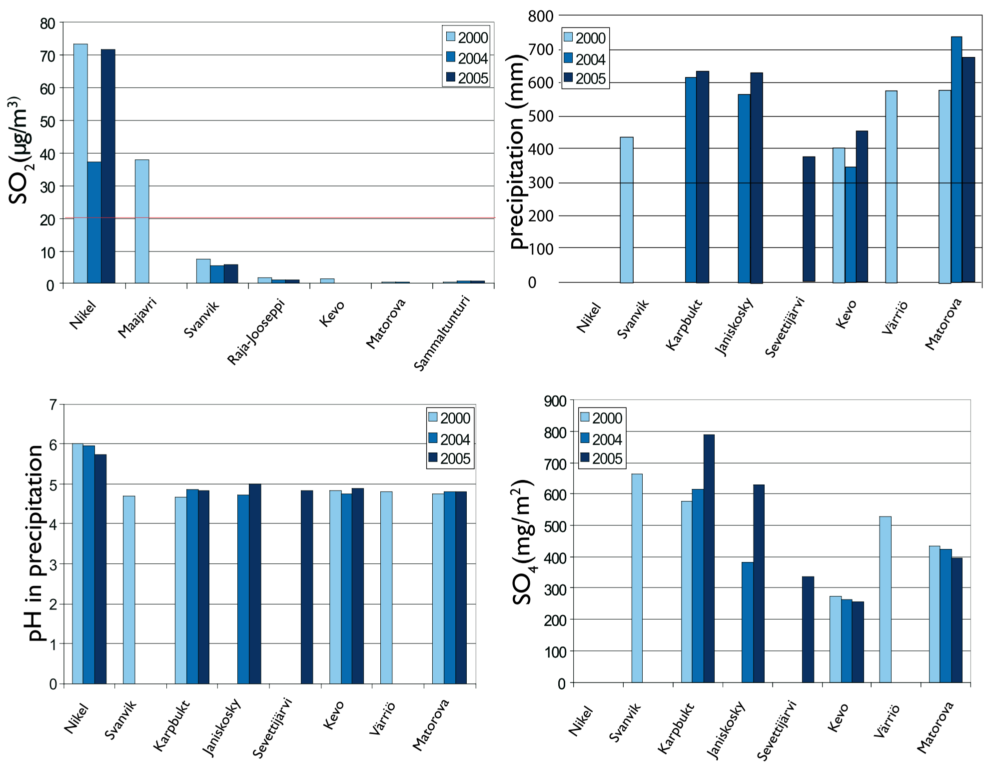

Figure 3.7 Yearly averaged SO_2 concentrations, precipitation amount, pH and SO_4 deposition from Russian, Finish and Norwegian monitoring sites for 2000, 2004 and 2005.

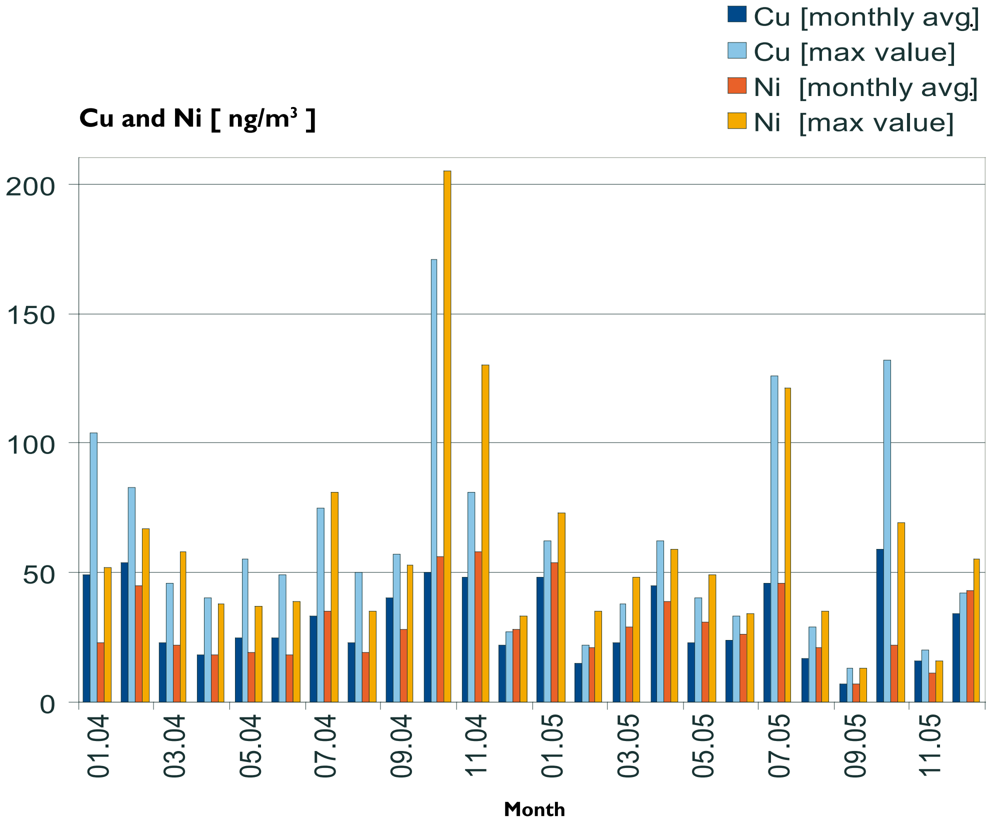

Figure 3.8 Monthly mean and maximum Cu and Ni values measured in the town of Nikel.

Table 3.4 Deposition of trace metals in 2004 and 2005 at Svanvik, Sevettijärvi (only 2005), Kevo and Matorova.

2004	Preci-pitati-on mm	Zn µg/m²	Pb µg/m²	Cu µg/m²	Cd µg/m²	Cr µg/m²	Co µg/m²	Ni µg/m²	As µg/m²
Svanvik	367	2382	485	11372	31	144	350	13535	335
Kevo	301	728	181	401	8	80	7	188	27
Matorova	752	2231	433	573	18	93	7	193	55
Svanvik/ Kevo		3	3	28	4	2	50	72	12

2005	Preci-pitati-on mm	Zn µg/m²	Pb µg/m²	Cu µg/m²	Cd µg/m²	Cr µg/m²	Co µg/m²	Ni µg/m²	As µg/m²
Svanvik	421	2204	774	24373	60	169	667	23244	723
Sevettij.	356	2207	242	1631	37	59	26	969	70
Kevo	408	689	164	574	7	59	6	198	28
Matorova	648	1599	363	649	12	70	6	129	47
Svanvik/ Kevo		3	5	42	8	3	111	117	26
Sevettij./ Kevo		3	1	3	5	1	4	5	3

at the Pallas GAW station in western Lapland 200 km to the west of Raja-Jooseppi. Hatakka et al. reported that the average SO_2 concentration during periods of easterly winds was 1.7 µg/m^3, while it was 0.7 µg/m^3 during southerly winds and 0.3 µg/m^3 during North-Westerly winds.

pH and sulphur deposition (in precipitation)

The amount of precipitation, pH, ambient air concentration of SO_2, and sulphur (SO_4^{2-}) deposition in 2002, 2004 and 2005 are presented in Figure 3.7. In Nickel the pH value of precipitation is clearly higher, close to 6, than at the other stations.

The wet deposition values of sulphate have clearly increased in Karpbukt and Janiskoski, while in Kevo and Matorova the values have slightly decreased. Sulphate deposition at Sevettijärvi and Kevo are relatively similar. The SO_2 emitted by the Petchenganikel smelter has such a short transport time into northern Finland that it does not have enough time to be oxidized to sulphate. During the cold, dark arctic winter there is no sunshine to stimulate the photochemical oxidation processes of SO_2.

The contribution of dry deposition to total deposition is expected to be high in the Finnmark region due to the relatively high air concentrations and low precipitation. At Karasjok the contribution of sulphur dry deposition to total deposition is estimated to be 53 % in winter and 50 % in summer.

Heavy metals and heavy metal deposition (in precipitation)

Heavy metals in precipitation are measured on a weekly basis at Svanvik and Karasjok, and on a monthly basis at Sevettijärvi (start in 2005), Kevo and Matorova (Pallas). Weekly monitoring of heavy metals in air is maintained in the town of Nikel.

An overview of the monthly mean and maximum nickel and copper concentrations in the town of Nikel in 2004 and 2005 is shown in Figure 3.8. The yearly averaged Cu and Ni concentration was 34 ng/m^3 and 30 ng/m^3 in 2004, and 31 ng/m^3 and 31 ng/m^3, respectively, in 2005. These values cannot be directly related to the EU/EOS target value of 20 ng/m^3 for Ni, because the measurements are for the total suspended material, whereas the latter are for the PM_{10} fraction.

The amounts of precipitation and yearly deposition values of Cu, Ni, Co, As, Cr, Zn and Cd, as well the amount of precipitation, during the years 2000–2005 at Svanvik, Sevettijärvi (only for 2005), Kevo, Matorova and Karasjok (only Zn, Pb, and Cd) are shown in Figure 3.9. The amount of heavy metal deposition in 2004 and 2005 at Svanvik, Kevo, Matorova and Sevettijärvi are summarized in Table 3.4.

In 2005, the deposition of Co and Ni was over 100 times higher at Svanvik and 4–5 times higher at Sevettijärvi compared to Kevo. Also the amounts of Cu and As were much higher in Svanvik than at the Finnish sites. The metals Ni, Cu, Co and As are emitted from the smelters in Nikel and Zapolyarny. Deposition values of metals such as Pb and Cr are similar at Kevo and Matorova, and represent long-range transport from more remote industrial and populated regions. Nevertheless, the values for Pb, Cd and Cr measured at Svanvik were also enhanced, which clearly shows the effects of emissions from the metallurgical industry on the Kola Peninsula.

Compared to measurements made at other locations in Norway, Svanvik had the highest level of heavy metals in 2005, with the exception of Zn which was higher at Hurdal. In 2005 the yearly averaged Pb and Cd concentrations measured in Svanvik were 1.84 and 0.14 µg/l, respectively. Compared to southern Norway (Birkenes), the wet deposition of Pb, Zn and Cr was lower, but all the other heavy metals the deposition was highest in Svanvik.

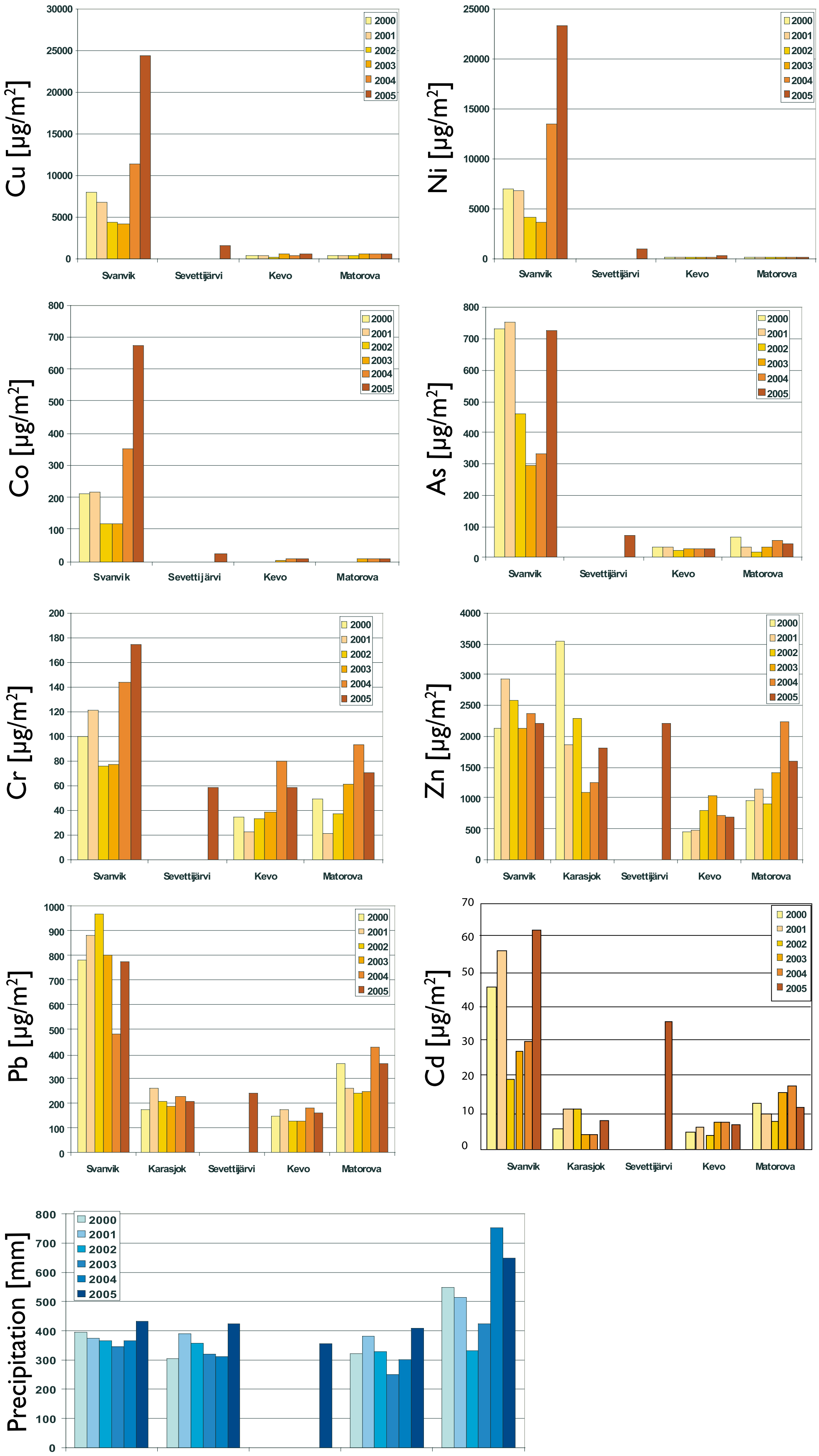

Figure 3.9 Amount of heavy metal deposition and precipitation during the years 2000–2005 at Svanvik, Karasjok, Sevettijärvi, Kevo and Matorova.

The amounts of Cu and Ni deposition have increased at all the stations during the measurement period. In 2005 the amounts of Cu and Ni deposition were over 20 mg/m² in Svanvik, which is about three times higher than in 2000. Whether this is mainly due to meteorological variation or enhanced emissions, cannot be decided on the basis of the existing material and needs to be studied in more detail.

3.4
Data storage

The air quality information system is established through links from the Interreg project web pages (www.pasvikmonitoring.org) to the web-sites of the national organizations, who carry out the measurements for their respective national pollution authorities: NILU (www.nilu.no), FMI (www.fmi.fi) and MUGMS (www.kolgimet.ru)

NILU and FMI have set up Internet sites for the on-line dissemination of SO_2 data. The web pages are an integrated part of the existing national web portals for ambient air quality in Norway (**www.luftkvalitet.info**) and Finland (**www.fmi.fi**). The direct link to SO_2 data from Nikel and Svanvik is **www.luftkvalitet.info/index.cfm?fa=so2.main&cityID=11** (site in the Norwegian language). SO_2 data from Sevettijärvi and the background station at Pallas can be found at **www.fmi.fi/ilmanlaatu/ilatausta_22.html** (site in the Finnish language). Additional data on acidifying and eutrophication compounds and heavy metals from regional background stations in Finnland (Pallas and Matorova (Pallas)), Norway (Karasjok, Svanvik and Karpbukt) and Russia (Janiskoski) are freely accessible to the public through the Chemical Coordinating Centre of the EMEP web-site (**www.nilu.no/projects/ccc**), though with a time delay of about one year.

3.5
Conclusions

Although present SO_2 emissions are about 75 % lower than in the 1980s, the values are still unacceptably high. The mean SO_2 concentration measured in ambient air seems to follow the general reduction in the yearly total SO_2 emissions. Whereas after 1989 SO_2 concentrations in Svanvik were below the critical level of 20 µg/m^3 (annual average) for the protection of the environment, in Nikel the SO_2 concentrations are still three times higher than the limit value.

In Nickel the pH value of the precipitation is clearly higher, close to 6, than at the Norwegian and Finnish sites. The explanation for this is that in Nikel the sulphur dioxide emitted by the Petchenganikel plant does not have enough time to be oxidized to sulphate. Higher SO_2 concentrations might also occur in the main wind direction, towards the NE, from the smelter. Although below the critical level, the influence of the smelters on the Kola Peninsulacan even be seen at the Pallas GAW station, nearly 300 km southwest of the smelter.

Heavy metal deposition in the Inari-Paz region is related to the emissions from the smelters in Nikel and Zapolyarny, with higher values of Ni, Cu, Co and As at Svanvik compared to the Norwegian and Finnish monitoring sites. Metals transported via long-range transport from more remote industrial and populated regions, had higher values close to the smelter: the Pb, Cd and Cr levels measured at Svanvik seem to be related to the operations of the metallurgical industry on the Kola Peninsula.

Whereas the emissions of SO_2 in recent years have been reduced, this has not been accompanied by a corresponding decrease in heavy metal emissions. The Cu and Ni deposition during the last two years has increased at all monitoring stations. Whether this reflects meteorological variations or is linked to increased emissions needs to be studied in more detail.

3.6 Recommendations for a joint monitoring and assessment system

The present study clearly shows the need for a joint, trilateral monitoring programme to follow up the effects of the modernisation process of the Petchenganickel combine and to assess the state of the environment in the Pasvik region. The following remarks only relate to the existing key stations in the area, which are at Nikel in Russia, at Svanvik in Norway and at Sevettijärvi in Finland. Measurements made at regional background stations like Karpbukt/Karasjok (Norway), Jäniskovski (Russia) and Raja-Joseppi/Matorova (Finland) are essential for comparison.

Based on the results of the project, the following measurements are the most important ones. Comparable equipment needs to be used at the sites to perform:

a. Continuous SO_2 and meteorological measurements
b. Measurement of precipitation quality: heavy metals, amount of precipitation, pH, and the main ionic components
c. Measurement of heavy metals in fine and coarse particles in the air

The integration of additional Russian monitoring sites (e.g. at Zapolyarny) is very important for a future joint monitoring system. The establishment of an air quality monitoring site in the main wind direction at the smelter (around NE), where high SO_2 concentrations are expected, is strongly recommended.

For the assessment of the effects of the modernisation process, reliable emission data and results from deposition model runs are essential to estimate the geographical extent of the effects of air pollution and to link air pollution to the effects on the terrestrial and aquatic ecosystems.

This, however, presupposes the establishment of at least one more meteorological station, preferably to the northeast of the smelters.

As very little is known about the presence of organic pollutants (POPs and PAHs) in the air in the area affected by the Pechenganickel smelter, the screening of these pollutants is of high interest.

A future integrated assessment should take into account the effects of the modernisation of the Pechenganikel smelter combined with the expected effects of climate change, long-range transportation of pollutants, as well as changes in land use in the Norwegian, Russian and Finnish border region.

Water quality and aquatic ecosystems

Guttorm N. Christensen. Akvaplan-niva, Tromsø, Norway

Based on the following reports appended to this summary report as a CD appendix:

1. Assessment of water quality and impact of mining and processing plant on the Paz watercourse
Olga Mokrotovarova, Marina Zuyeva & Nikolay Kashulin
2. Water quality of small lakes and streams in the Norwegian, Finnish and Russian border area
Annukka Puro-Tahvanainen & Eira Luokkanen
3. Pollution of the sediments of the Paz River basin
Vladimir Dauvalter & Sergey Sandimirov
4. The analysis of results of heavy metals concentrations in samples of sedimentation
Vladimir Dauvalter, Jaakko Manninen, Kari Kinnunen & Martti Salminen
5. Screening studies of POP levels in bottom sediments from selected lakes in the Paz watercourse. Guttorm N. Christensen, Vladimir Savinov, Tatiana Savinova, Ludmyla Alexeeva, Alexey Kochetkov, Alexander Konoplev, A. Pasynkova, Dimitry Samsonov, Vladimir Dauvalter, Nikolay Kashulin & Sergey Sandimirov
Reference: 2007. Akvaplan-niva report 3665.01
6. Zoobenthic study of biological state of small lakes in the joint Finnish, Norwegian and Russian border area
Valery Yakovlev, Anna Yakovleva & Petri Liljaniemi
7. Ecology and heavy metals contamination of fish in the Paz watercourse
Per-Arne Amundsen, Nikolay Kashulin, Irina Koroleva, Karl Øystein Gjelland, Petr Terentiev, Cecilie Lien, Laina Dalsbø, Sergey Sandimirov, Lubov Kudryavtseva & Rune Knudsen
8. Screening studies of POP levels in fish from the selected lakes in Paz watercourse
Guttorm N. Christensen, Vladimir Savinov, Tatiana Savinova, Ludmyla Alexeeva, Alexey Kochetkov, Alexander Konoplev, E. Pasynkova, Dimitry Samsonov, Nikolay Kashulin, Irina Koroleva, Sergey Sandimirov & Dimitry Morozov
Reference: 2007. Akvaplan-niva report 3665.02
9. State of fish populations in small forest lakes in the Norwegian, Finnish and Russian area
Nikolay Kashulin, Irina Koroleva, Petr Terentjev, Per-Arne Amundsen, Karl Øystein Gjelland, Sergey Sandimirov, Lubov Kudryavtseva, Markku Örn, Cecilie Lien, Laina Dalsbø & Rune Knudsen
10. Recent improvement of fish populations in the Jarfjord Mountains in northern Norway due to reduced surface water acidification
Trygve Hesthagen, Odd Terje Sandlund & Randi Saksgård
11. The effects of airborne emissions from the Pechenganickel smelters on water quality and littoral fish communities of small watercourses in the joint Finnish, Norwegian and Russian border area
Antti Lappalainen, Jouni Tammi & Nikolay Kashulin
12. Groundwater Quality monitoring in the border area between Norway, Finland and Russia
Reference: 2006. NGU Report 2006.042
Liliosa Magombedze & Øystein Jæger

4 Water quality and aquatic ecosystems

4.1 Background

Freshwater systems are focal points for pollution, draining the surrounding land scape and acting as sinks for environmental pollutants. Surface waters in the River Paz border areas are impacted by pollution from the industrial activities in the area. Pollutants reach the lakes and watercourse through the air and as direct discharges into the lake systems.

The watercourses in the Russian, Norwegian and Finnish border area comprise two contrasting types of system: the large Inari-Paz watercourse and the numerous small lakes and streams (Figure 4.1). The Inari-Paz watershed is the main freshwater system in the region, covering an area of approx. 1,250 km^2 and with a catchment area of 18,404 km^2. It originates in Finland, runs for a short distance through Russia, and then forms the border between Norway and Russia over a distance of about 120 km. The watercourse has important environmental qualities and rich natural resources, and constitutes a sub-arctic system with high biodiversity and production of fish and other aquatic organisms. Fish resource utilisation includes commercial, subsistence and recreational fishery, with an annual harvest ranging from 200 to 600 tonnes of fish over the last decades.

The area is, however, subjected to severe anthropogenic influence, particularly from the Pechenganikel smelter industry. The Paz watercourse is impacted by the direct input (discharges) of pollutants from the mining and smelting industry and through the deposition of atmospheric (airborne) pollutants, while the lakes and streams in the catchment area that are not directly linked to the Paz watercourse only receive atmospheric pollutants. The Paz watercourse is impacted both from direct input of pollutants and of atmospheric pollutants while the lakes and streams in the headwater areas of the Paz watercourse only receive atmospheric pollutants. The main pollutants that influence lakes and rivers are sulphur compounds and heavy metals (Ni, Cu, Cd, Cr, Zn, As, Hg etc.), polycyclic aromatic hydrocarbons (PAHs) and persistent organic compounds (POPs). Polluted water from the the Nikel smelters and associated activities are discharged directly into the lower part of the watercourse through Lake Kuetsjarvi (Figure 4.8).

Sulphur dioxide (SO_2) emissions from the smelter could lead to the acidification of surface waters and the contamination of groundwater through the leaching of elements from surface media. For example, data on the contribution of snowmelt to groundwater in this area suggests the possibility of Ni contamination.

The Paz watercourse

Previous investigations in the Paz watercourse revealed high levels of heavy metal contamination in water and sediments in the vicinity of the smelters. Several studies have been carried out on fish and other freshwater biota in the border area during the last decade, including certain aspects of acidification and the impact of heavy metal emissions from the Pechenganikel smelters, ecology and the food web structure in the aquatic communities and fisheries, and environmental management and conservation.

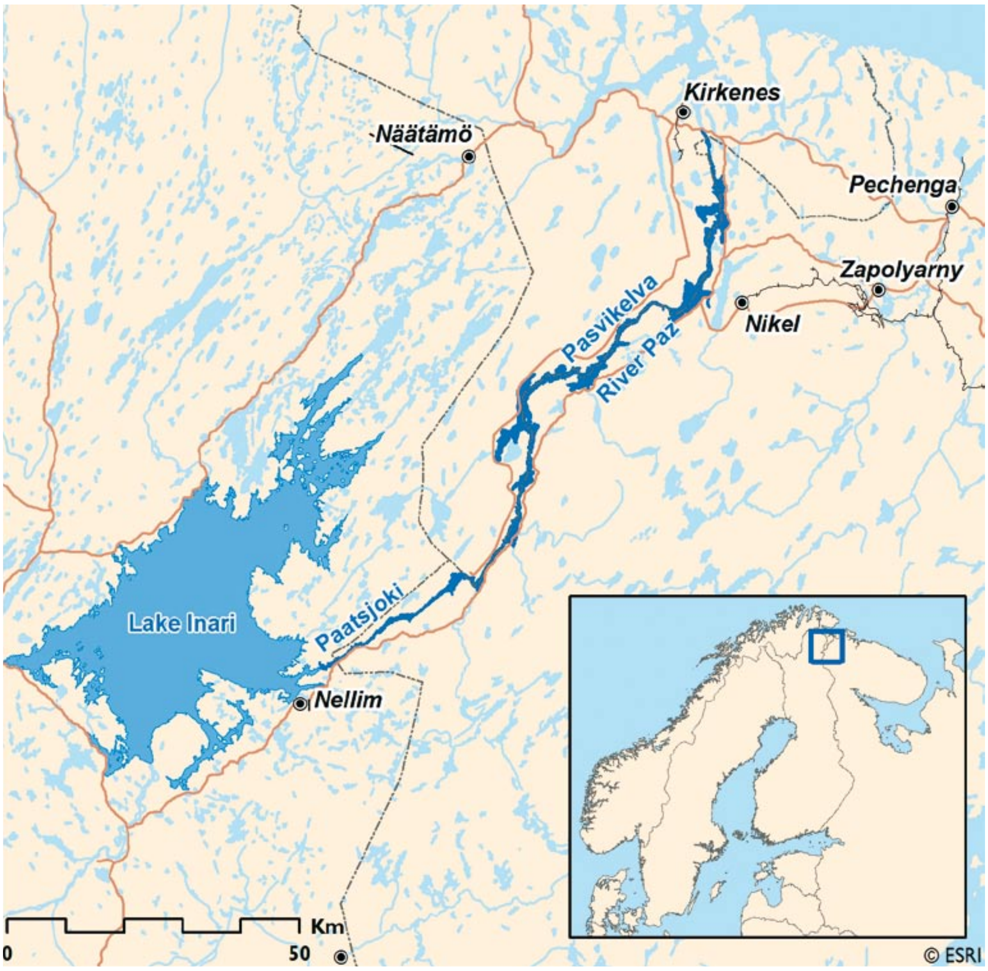

Figure 4.1 Map of the Paz watercourse.

Elevated heavy metal levels have been documented in fish from lakes in the lower part of the Paz watercourse. In this area, and particularly in Lake Kuetsjärvi close to the smelters, a number of pathological modifications have also been found in fish organs and tissue. The prevalence and severity of these problems increase with decreasing distance to the smelters, and the abnormalities have therefore been attributed to heavy metal pollution. Indications of elevated fish mortality or reproduction failure due to episodic pollution events have also been found in the vicinity of the Nikel smelters. Negative effects have also been documented with respect to the biodiversity of both zoobenthos and zooplankton.

Small lakes and rivers

Joint investigations carried out in the early 1990's revealed numerous acidified and heavy metal polluted lakes in the border areas. Negative impacts on acid-sensitive biota especially have been recorded in small lakes and streams. The impact is the greatest at Russian and Norwegian sites in the vicinity of the smelters, but the effects are also seen on the Finnish side of the border. Several studies on contaminant levels in sediments have been conducted over the past decade in the study area, on both a national and an international basis.

Studies on lake sediments in the border area between Norway and Russia in the early 1990s revealed elevated levels of Hg, Ni, Pb and selected POPs in Sør-Varanger.

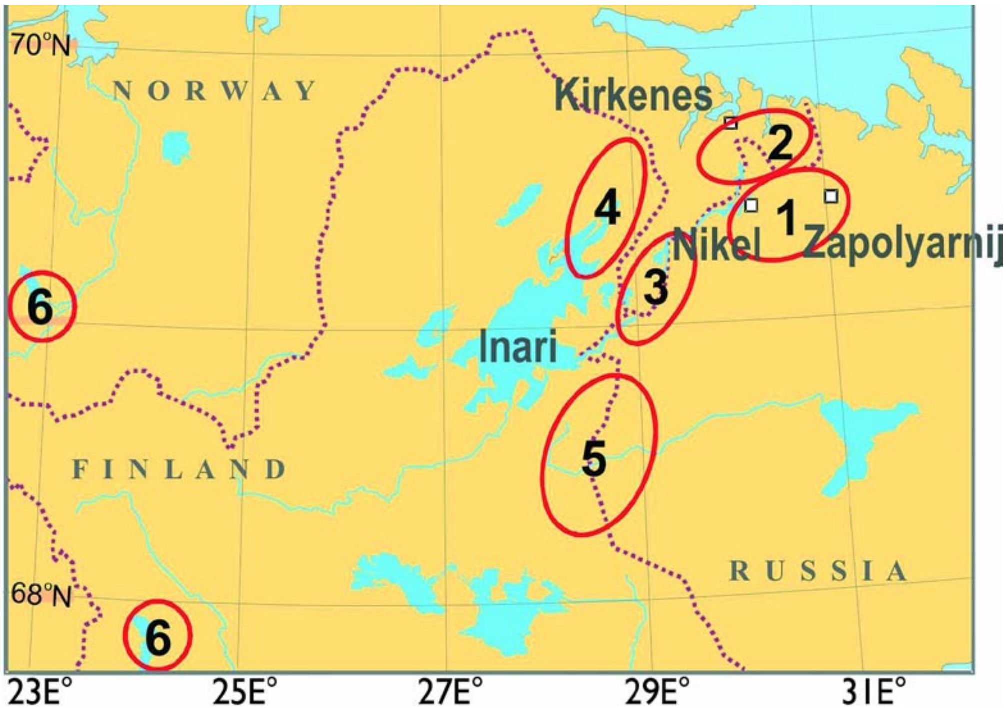

Figure 4.2 Map of the region showing the main areas, where small lakes and rivers have been investigated. 1 = Pechenganikel, 2 = Jarfjord + Sør-Varanger (= area between Jardfjord and Vätsäri), 3 = Paz River valley, 4 = Vätsäri, 5 = Raja-Jooseppi, 6 = reference sites (Pallas in Finland and Stuorajavri in Norway).

The area was classified as being moderately to very severely affected. This contamination is related to local emission sources on the Kola Peninsula, primarily the Ni-Cu smelting industry.

Human health aspects

The majority of towns, villages and other settlements in the Paz catchment area are located in the vicinity of the main river and large lakes. Bio-accumulative pollutants derived from industrial activities pose a potential health hazard to the inhabitants of the Paz watercourse. Heavy metals have been the main subject of pollution studies on freshwater biota in the border area, and there is only limited information available on the levels of POPs and other harmful compounds in biological samples.

Freshwater fish is a resource that is targeted by the human population for recreation and food acquisition, but it is also an important indicator of environment quality. In the Paz-Inari area there are strong traditions of fishery exploitation, including subsistence, recreational and commercial fishing. The fish in the watercourse are therefore a topic of considerable public interest and, in relation to environmental monitoring, studies on fish are highly appropriate with respect to the communication of results and information to the public.

Objectives

The primary objectives of the project were to integrate, standardise and harmonise the monitoring activities currently being carried out by Norway, Russia and Finland on the effects of emissions from the Pechenganikel smelter on freshwater ecosystems in the border area. The information and results from the project were used to develop a monitoring programme that facilitates the elucidation of cause-and-effect relationships with respect to pollutants and damage to freshwater biota. Finally, the project has provided the means necessary for monitoring the rate of recovery of the freshwater ecosystems in the event of the planned reduction in emissions.

4.2
Monitoring and assessment network

The monitoring network in this project is based on the national monitoring systems available in Norway, Russia and Finland, and on the results of previous studies and additional new investigations carried out to increase knowledge of the effects of emissions on freshwater ecosystems in the area. The watercourses in the border area have been investigated more or less intensively since the mid 1980's through either individual national monitoring programmes or specific scientific research. There has been some bilateral cooperation in the past, but most of the investigations have been performed by the individual countries.

The investigated sites can be divided into the following three categories:

- The Paz watercourse
- Small lakes and rivers
- Reference stations

Investigations have been performed in the Paz watercourse both upstream and downstream of Nikel. In addition to the Paz watercourse, small lakes and rivers have also been investigated in 5 areas (Figure 4.2). Assessment of the impact of pollutants in these systems is based on a large number of parameters like distance from the smelter, wind direction and physical and chemical characteristics of the lake or river. The reference areas are located relatively far from the smelters and other industrial activities and are therefore only impacted by long-range atmospheric transport.

Figure 4.3 Water sampling in 2005 on Lake Suovaselkäjärvi, which is located to the east Lake Inari. Photograph: Ilona Grekelä

4.3

Methods

One of the goals in the project is to integrate the monitoring activities carried out in the three countries, and to improve and harmonise the monitoring routines and methodology used in evaluating the effects of emissions on freshwater ecosystems in the border area. Harmonisation and standardisation of monitoring and assessment methodology have been performed during all stages of the project implementation: field work, chemical and biological analyses, analyses of data, assessment and reporting. The methods used in the different countries are all in accordance with national or international standardised methods. Detailed information about the methods is given in the individual scientific reports.

The groundwater quality monitoring part of the project was carried out by Norway (NGU) and Finland (LREC). A comparison of the monitoring stations in terms of the hydrogeological conditions and groundwater sampling procedure, sampling bottle material and analytical methods, was performed at the beginning of the project.

Surface water samples were taken using internationally standardised equipment and methods. Water samples were mainly taken once per year in the autumn during mixing of the water-masses. In some lakes and rivers a more intensive sampling programme has been implemented. The samples were taken either in the major outlet of the lake or from surface water.

Water quality samples have been analyzed in the laboratories of the Lapland Regional Environment Centre (LREC) and the Finnish Environment Institute (SYKE) in Finland, of INEP and Gidromet in Russia, and of NINA and NIVA in Norway. Standardised methods have been used in all the laboratories. The comparability and quality of the analyses of different laboratories have been investigated in separate comparison exercises.

Four laboratory inter-comparison exercises were arranged in 2004. The main purpose of the inter-comparison exercises was to determine the comparability of the results of the environment laboratories in the Kola area, as well as to estimate the overall

Figure 4.4 Comparing sediment sampling methods in the Vätsäri area in April 2005. Photograph: Martti Salminen

Figure 4.5
Gillnet cleaning (Lake Kuetsjarvi, 2004).
Photograph: Per-Arne Amundsen

results of cooperation in the border districts. Both water and biological samples were analysed in these inter-comparison exercises. The results of the inter-comparison of water chemistry analyses indicated satisfactory agreement between the individual laboratories.

Sediment samples were taken by the same technique in all countries, but there were some small differences with respect to which layer in the core was used as the reference layer. Samples were taken from the deepest part of lakes with a gravity corer with a diameter of 5–10 cm. The core was divided into 1.0 or 0.5 cm-thick layers to facilitate the analysis. Sediment samples were placed in polyethylene containers or glass jars and either stored at a temperature of 4 °C or frozen before delivery to the laboratory for analysis.

Investigations on fish populations in small lakes or in the Paz watercourse were performed using the same basic methods. Fish sampling was performed in the littoral, profundal and pelagic habitats using multi-mesh gillnets. However, there were some small differences in the net dimensions, mesh sizes and methods used in the individual studies. The reason for this is mainly because the goal of the studies was slightly different. The fish were identified at the species level. Each fish was measured for fork length and weight, the sex and stage of maturation were recorded, and stomachs samples were collected and preserved in 96 % ethanol for diet analysis. Otoliths were sampled from whitefish, vendace, Arctic char and trout, and opercula from perch for the determination of age. Tissue samples were also collected from muscle, liver, gills, kidney and skeleton for analysis of heavy metals and POPs. Dissection of the fish and tissue sampling were carried out with a knife, scissors and scalpel made of stainless steel. The tissue samples (weight 3–10 g) were put into plastic sachets, aluminium foil or glass jars and frozen.

Analysis of heavy metals in sediments was performed by INEP and SYKE using international standardised methods. However, as the inter-comparison of heavy metal analysis in fish tissue did not give comparable results, analysis of heavy metal in fish was subsequently performed in the same laboratory (INEP). Analysis of POPs in sediments and fish was performed by Scientific and Production Association Typhoon (Russia), which uses international standardised methods and participates in inter-comparison tests with other international laboratories.

The studies on fish populations in small brooks and small lakes were carried out using electro-fishing equipment. The brooks or stony shorelines of the lakes were fished only once and without any closing nets. The actual fishing sites were selected from among the most suitable-looking shores. At each site, the surface area fished (8–300 m^2) was measured in order to obtain semi-quantitative estimates of littoral fish densities. The length of each fish was measured. This is a standardised method in all three countries.

Benthic sampling was conducted using the technique employed in previous studies by Yakovlev (1999) in order to maintain the comparability of the results. The method differs from the widely used national standards, but the results should be relatively comparable with those obtained in other studies when the ecological status is estimated using variables and indices based on relative abundances of different indicator groups.

Sampling was carried out as a qualitative kick net sampling in four habitats (lake littoral and outlet, outflow and inflow streams) in each lake. The total number of samples per lake depended on the number of available habitats. One approximately 3-min composite sample, including all microhabitats, was taken of the stony substrate of each habitat. The aim was to collect 100–200 animals per habitat in order to obtain a reliable estimate of the fauna. Samples were preserved in 70 % alcohol and sorted in the laboratory. Animals were identified mainly to the species level using established taxonomy. Group biomasses were expressed as wet weight. In addition, macroinvertebrate samples were collected for tissue heavy metal analysis from several lakes. The samples were analysed in INEP's laboratory.

4.4
Main findings

The main findings of the individual studies are presented in this chapter. The studies are described in more detail in the scientific reports.

Groundwater

Groundwater monitoring wells were established in the Skjellbekken area during previous studies in the mid-1990s, and were monitored from March 1994 to November 1995. Two new monitoring stations were established, one in the Svanvik area and another in Karpdalen (Figure 4.6). The stations were located in the same geological setting, i.e. Quaternary deposits, and at varying distances and directions from the smelters. Groundwater samples were collected ten times a year from October 2003 to November 2005, and were analysed for pH, alkalinity, conductivity, colour, turbidity, seven anions and fifty elements and cations at low detection limits.

Although the surface media have been affected by the emissions, there are no clear indications of anthropogenic pollution in the groundwater. Metals and other compounds are expected to subsequently leach down from the polluted media into the groundwater. However, there seems to be a dilution of pollutants in the unsaturated zone as water infiltrates down into the groundwater zone. The groundwater is not acidified and still has a high acid neutralising capacity (ANC). However, the ANC level may be decreasing at Skjellbekken. Compared to groundwater quality

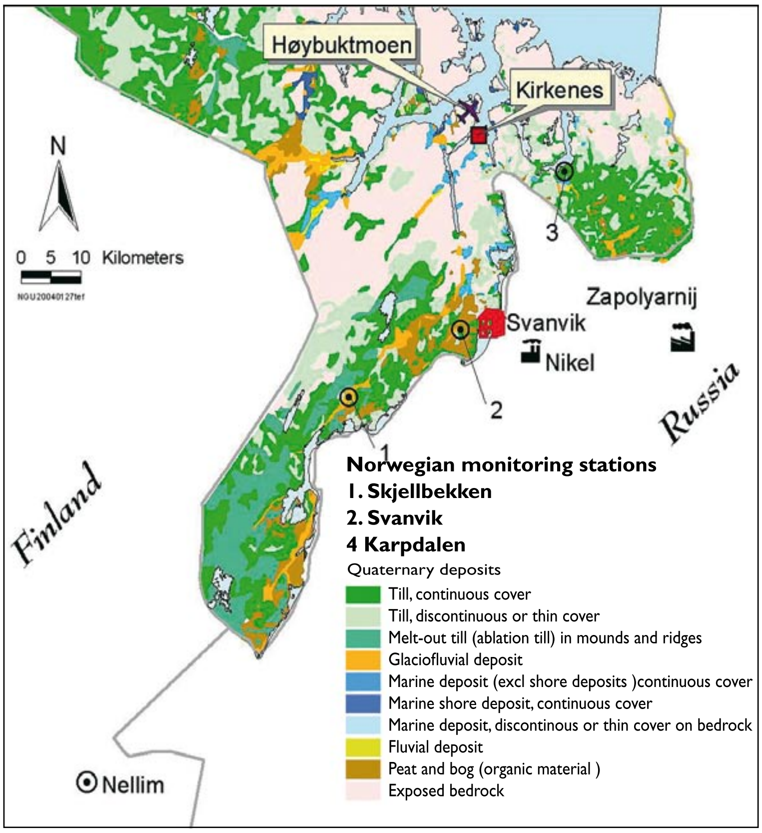

Figure 4.6 Location of the groundwater monitoring wells in Norway and Finland, and the location of the Nikel and Zapolyarny smelters in Russia.

data from 1994/1995, there has been a significant reduction in the concentrations of Ni, Cu and As by 2005.

The results do not show any significant temporal variations in the concentrations of most of the parameters, except for decreasing alkalinity at Skjellbekken and slightly increasing Cu concentrations at Svanvik during 2005. The high element concentrations in groundwater at Karpdalen are mainly due to the contribution from marine sediments and sea spray, and the alkaline environment. However, the relatively high values in snow samples are caused by the high deposition load resulting from Karpdalen's downwind location (S-N) and Svanvik's close proximity to the emission source.

The Paz watercourse

Introduction

The Paz watercourse is located in the vicinity of the Pechenganikel smelters, which release complex mixtures of pollutants into the environment. The pollutants enter the Paz watercourse either directly from the industrial activities associated with the smelters via runoff from the area, or from the air (dry and wet deposition). These pollutants include SO_2, metals (Ni, Cu, Cd, Cr, As, Hg etc.), PAHs and POPs.

The investigations in the watercourse include the measurement of pollutants in water, sediments and fish. There are several monitoring programmes currently in force in the Paz watercourse in Russia, Finland and Norway, and data from these programmes have been included in the present project. The main monitoring stations in the area comprise a gradient of six lakes located at increasing distances from the smelters: Lake Inari in Finland, Rajakoski and Kuetsjarvi in Russia, and Vaggatem and

Figure 4.7 Map showing the locations of the main monitoring stations in the Paz watercourse. Lake Inari in Finland, Rajakoski, Kolosjoki, Lake Kuetsjarvi and Boris Gleb in Russia, and Ruskebukta, Vaggatem, Hestefoss, Bjørnvatn and Skrukkebukta in Norway.

Skrukkebukta in Norway, as well as a reference lake (Stuorajavri) in the Kautokeino-Alta watercourse, Norway (Figure 4.1, Figure 4.2, Figure 4.7).

The existing water quality monitoring programme in the Inari-Paz watercourse includes almost all the chemical parameters required for monitoring the effects of the modernization of the Pechenganikel smelters (Table 4.1). However, the sampling frequencies and number of parameters employed in the monitoring programme vary considerably both between and within the countries. Harmonization of the methods has therefore been required in order to achieve a common water chemistry monitoring programme for the watercourse. The joint programme is mainly based on the existing monitoring programmes in Finland.

Heavy metal pollution in sediments has been studied at several sites in the Paz watercourse during the last few decades. These studies were continued in the project, and two new sites in Lake Inari included. Sampling was carried out once at all the main monitoring sites. In addition to heavy metal studies, a screening survey was carried out on POP concentrations (PAHs, PCBs, PCDD/PCDF) in sediments at a number of selected lakes.

The main emphasis in the biological monitoring in the Inari-Paz watercourse has been on fish, in particular whitefish, vendace, pike, perch and brown trout. The study has also included the biodiversity and community structure of fish, analysis of fish population structure, and pathological and histopathological analyses of fish. Determination of heavy metal concentrations in fish tissue (liver, kidney, muscle and skeleton), as well as a screening of POP concentrations, have also been carried out.

Table 4.1 Water chemistry parameters monitored in the project.

Monitoring attributes	Parameters
Water quality	pH, Conductivity, Alkalinity, Turbidity, Color, O_2, K, Ca, Mg, Na, SO_4, SiO_2, Cl, COD, Mn, TOC
Nutrients	tot-P, tot-N, PO_4-P, NO_2-N, NO_3-N, NH_4-N
Heavy metals	Ni, Cd, Cr, Cu, Pb, Zn, As, Hg, Mn, Al, Fe

Water quality in the Paz watercourse

The water quality monitoring programme in the Paz watercourse includes stations running from Lake Inari in Finland to Boris Gleb close to the outlet of the river (Figure 4.7). There are also sampling stations in a smaller watercourse in the catchment area of the main pollutant source, the Pechenganikel smelters. These sites, on River Kolosjoki and Protoka Stream, are located downstream from the plant and drain into Lake Kuetsjarvi (Figure 4.8). There is also a reference station in River Kolosjoki, 14.7 km upstream from the smelter. The length of the available time series and the sampling frequency vary in the different parts of the watercourse. The first measurements were carried out in 1965.

According to the water quality parameters and nutrient concentrations, the Paz watercourse is a typical oligotrophic system with a generally good water quality. The concentrations of nutrients and organic matter are relatively low, and their spatial and seasonal distribution is close to the natural pattern, which is influenced by morphological and landscape characteristics, by the northern climate, and by the discharge regime of the watercourses. The concentrations of nutrients such as total phosphorus and total nitrogen correspond to levels typical for oligotrophic systems. The pH in the watercourse is close to neutral and varies between 6.2 and 7.2. There is, however, some geographical and seasonal variation.

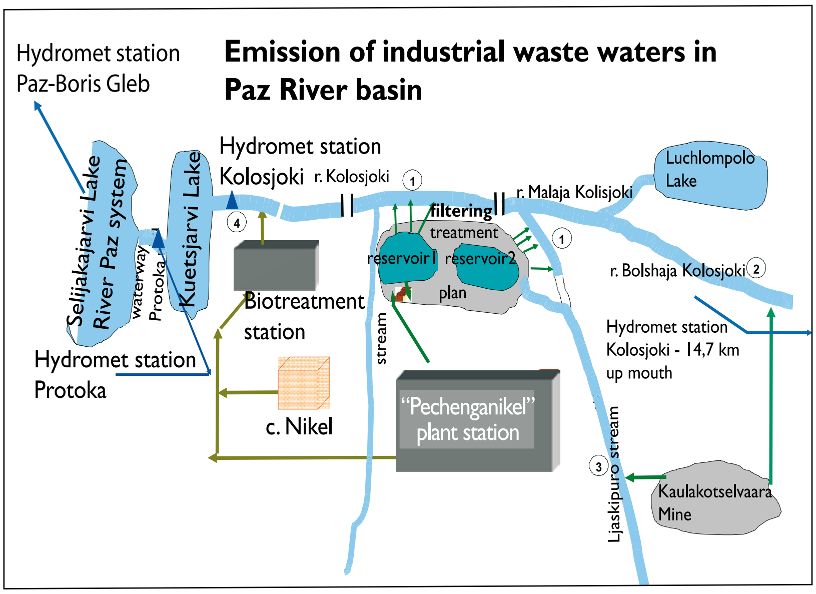

Figure 4.8
Water sampling sites near the pollution sources: Kolosjoki (14.7 km upstream Kuetsjärvi), Kolosjoki (0.6 km upstream Kuetsjärvi), Protoka (waterway running from Kuetsjärvi to the Paz watercourse) and Boris Gleb (lower part of the Paz watercourse).

Contamination of the Paz watercourse with heavy metals (Ni and Cu) was investigated throughout the whole monitoring period, and their distribution clearly demonstrated the impact of the Pechenganikel smelters. Concentrations of the major pollutants (Cu and Ni) were higher downstream from Lake Kuetsjarvi than upstream (Figure 4.9). The highest concentrations occurred in the River Kolosjoki immediately downstream from the smelters (Figure 4.10). The levels in River Kolosjoki upstream from the plant were considerably lower, but still significantly higher than the background levels for natural waters. This is due to atmospheric deposition, as well as to rain and flood runoff from the area heavily polluted by long-term atmospheric deposition.

The differences in the Ni concentrations close to the plant and in the outlet of the Paz watercourse were higher than those for the Cu concentrations. Although the highest Cu concentrations occurred in the mouth of the River Kolosjoki, the difference

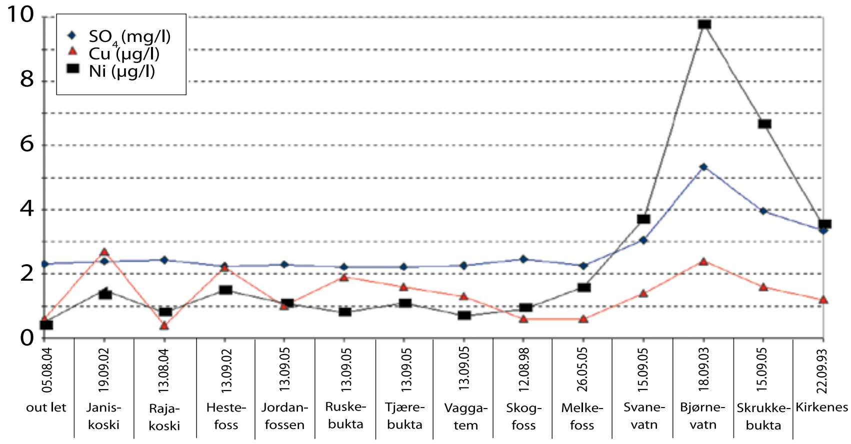

Figure 4.9 Distribution of Cu, Ni (µg/l) and sulphate (mg/l) concentrations in the Paz watercourse.

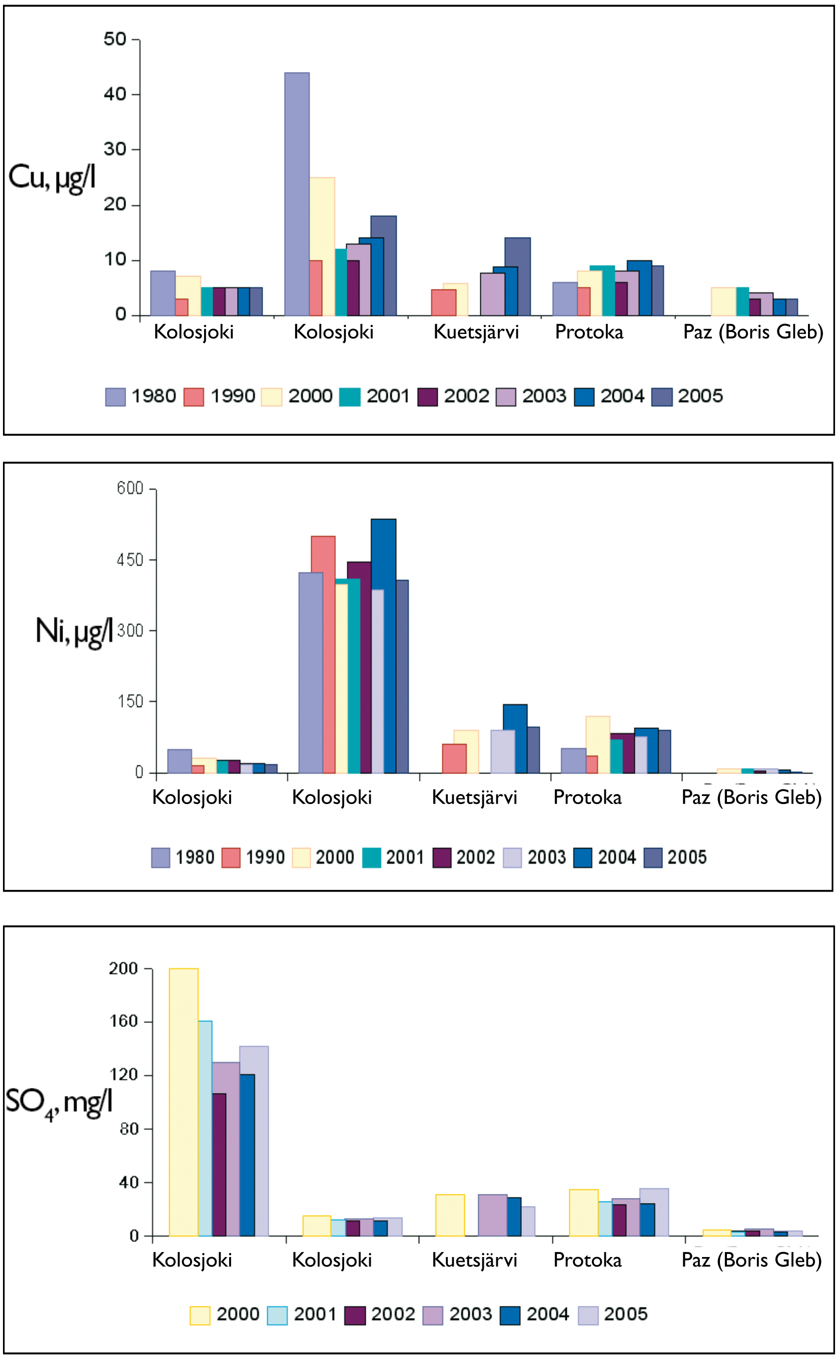

Figure 4.10 Distribution of Cu, Ni (µg/l) and sulphate (mg/l) in the water bodies directly impacted by the Pechenga-nikel smelter complex and in the lower part of the Paz water-course (Boris Gleb).

with respect to the concentrations in the other parts of the watercourse were smaller than those for Ni. This suggests that the routes through which these pollutants pass into the watercourse are different. Nickel primarily (about 80 %) passes into the watercourse directly through discharges from mining and smelter activities, whereas Cu (up to 90 %) is transported to the catchment areas via the atmosphere, resulting in a more uniform pattern of Cu pollution in the area. Furthermore, the presence of Cu in natural, non-polluted waters is a feature characteristic of the water bodies on the Kola Peninsula. This contributes to a more even distribution of Cu in the waterways.

The distribution of sulphate in the Paz watercourse is also influenced by the smelter. Sulphate concentrations reached a maximum value of 5.3–5.6 mg/l at the station in the mouth of the watercourse (Paz-Bjørnevatn), which is a value that is approximately twice that in the upstream and middle stream part of the watercourse (Figure 4.10). Time trends based on results from the mid 1990s and from 2004–2005 indicate that the Ni concentrations are increasing throughout the whole watercourse. The concentrations of sulphate and Cu have not changed significantly during this period.

Sediments in the Paz watercourse

Studies on the chemical composition of the sediment column enable us to construct a historical record of the pollution of lake watersheds, and to estimate the degree of pollution. The determination of undisturbed background concentrations of heavy metals is the basis for all investigations on lake sediments. Sediment samples taken from the deepest core layers (usually deeper than 20 cm) provide information about the background concentrations of elements in the lakes. These layers are several hundred years old, and predate industrial development in Northern Fennoscandia. Information about the vertical distribution of pollutants in lake sediments provides a basis for investigating the effects of anthropogenic factors on the evolution of contamination by heavy metals over time.

The aim of the investigations was to evaluate the accumulation of heavy metals in sediments in the Paz river basin. Four aspects were investigated: 1) background element concentrations, 2) vertical element distributions in lake sediment cores, 3) distribution of the element concentrations in surface sediments, and 4) determination of the contamination factor according to Håkanson (1980).

Sediment samples from the different lakes and stations in the Paz waatercourse were taken from the deepest part of the lakes with a gravity corer, and divided into

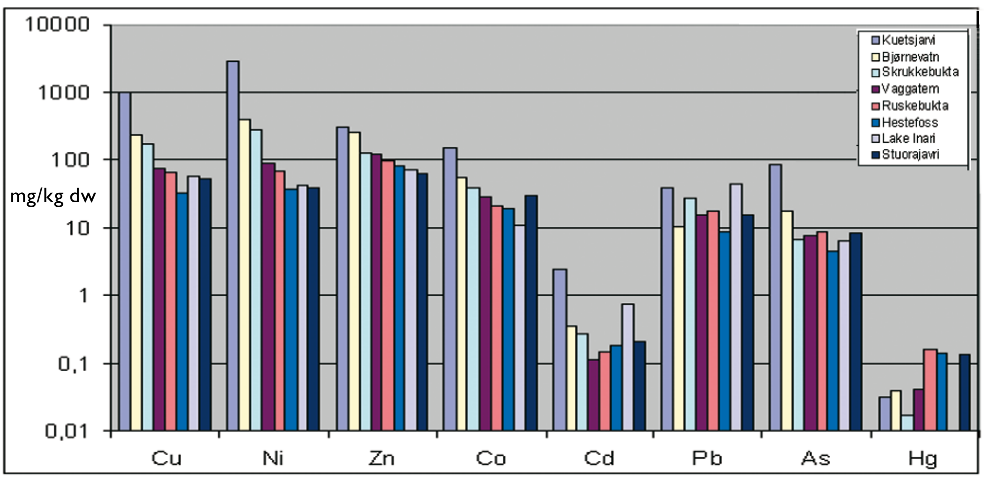

Figure 4.11 Distribution of element concentrations (mg/kg dw) in the upper layer (0–1 cm) of sediment cores in the Paz watercourse. Bjørnevatn and Skrukkebukta are located downstream, while Hestefoss, Ruskebukt and Vaggetem are located upstream from the Pechenganikel industrial complex.

1 cm thick horizontal layers. The samples were analyzed for water content, loss on ignition (LOI) and concentrations of Ni, Cu, Co, Zn, Cd, Pb, Sr, Mn, Fe, Ca, Mg, Na, K, Al, As, Hg and P. In addition, a screening of PAH and POP concentrations was also carried out.

The concentrations of most of the heavy metals, PAHs and POPs in surface sediments were highest downstream (Lake Kuetsjarvi) from the Pechenganikel smelters. There was a sharp, decreasing trend in concentrations on moving downstream. The concentrations upstream from Lake Kuetsjarvi were considerably lower than those downstream (Skrukkebukta and Bjørnevatn) (Figure 4.12). However, this was not the case for Pb and Hg. The Hg concentrations were highest in Ruskebukta and Hestefoss. The reason for this is not clear.

The Ni concentrations in surface sediment in Lake Kuetsjarvi were approximately 100 times higher than the background levels, while the contamination factor at Bjørnevatn and Skrukkebukta was 6.9 and 4.3, respectively. The contamination factor at the upstream stations (Vaggetem, Ruskebukta and Hestefoss) was ca. 1 for Ni, Cu, Co and Zn. Analysis of the accumulation of Ni, Cu, Co, Zn in sediments in the upper part of the Paz watercourse has therefore not demonstrated any influence of emissions from the smelters

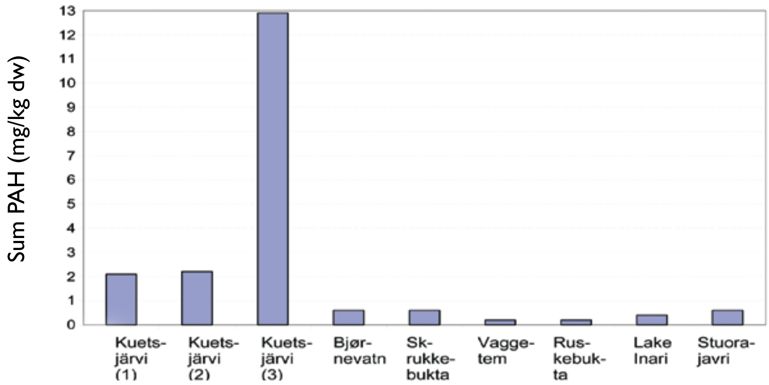

Figure 4.12 Polycyclic aromatic hydrocarbon (PAHs) concentrations (mg/kg dry weight) in the surface layer (0–1 cm) of bottom sediments.

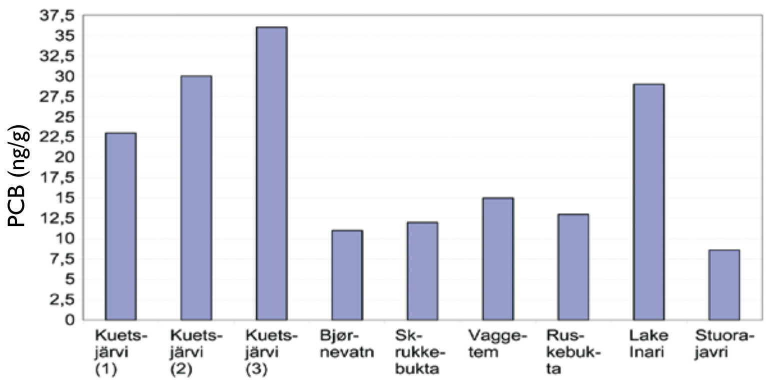

Figure 4.13 Polychlorinated biphenyl (PCB) concentrations (ng/g dry weight) in the surface layer (0–1 cm) of bottom sediments.

The highest ΣPAH-perylene concentrations (2.1–12.9 mg/kg dry weight) were found in sediment samples collected in Lake Kuetsjarvi (3 stations), in the immediate vicinity of the Nikel smelters (Figure 4.12). The PAH concentrations were considerably lower both in Bjørnvatn and Skrukkebukta (downstream from the smelters), and also at the stations upstream from the smelters. The concentrations of total PAH-perylene in these surface sediment samples did not differ markedly from those measured in moderately contaminated sediments in Lake Stuorajavri (0.62 mg/kg d.w.). According to the environmental classification system of the Norwegian Pollution Control Authorities (SFT), the surface sediment at stations upstream from the smelter (Lake Inari and Lake Stuorajavri) is classified as "slightly contaminated"

(< 300 ng/g dw) or "moderately contaminated" (300–2,000 ng/g dw) with PAHs. However, two of the three stations in Lake Kuetsjarvi are classified as "markedly contaminated" (2,000–6,000 ng/g dw), while the third station is classified as "strongly contaminated" (6,000–20,000 ng/g dw).

The concentrations of Σ_{64}PCB in the Paz watercourse varied from 10.5 to 36.4 ng/g dw. The highest PCB concentrations occurred in the bottom sediments from Lake Kuetsjarvi (36.4 ng/g d.w.). There was also a decreasing trend in PCB concentrations with increasing distance from the smelter (Figure 4.13). The PCB concentrations in the Paz watercourse are high compared to those reported for surface sediments in other lakes in Northern Norway. The PCB concentrations in the Paz watercourse can be classified as "moderately contaminated" (5–25 ng/g dw) or "markedly contaminated" (25–100 ng/g dw).

Emissions and runoff from the industrial activities associated with the Nikel smelters (smelting furnaces, slag pits, tailing dumps, and mines) are the main sources of the heavy metals (Ni, Cu, Co, Cd and Zn), PAHs and POPs occurring in the sediments downstream from the smelters. There are no other known local sources that release these pollutants into the watercourse. However, the long-range transport of pollutants from other industrial areas probably makes only a relatively small contribution to the elevated levels in the area.

Biological monitoring in the Paz watercourse

The ecology and pathology of fish, and their heavy metal concentrations, were investigated in the Paz watercourse. A screening study on PAH and POP concentrations in fish was also performed at some of the sites. The study included a gradient of six lakes located at increasing distance from the smelters: Lake Inari in Finland, Rajakoski and Kuetsjarvi in Russia, and Vaggatem and Skrukkebukta in Norway, as well as a reference lake (Stuorajavri) in the Kautokeino-Alta watercourse, Norway (Figure 4.7).

The lakes had a high fish diversity for a sub-arctic region, and consisted of complex, interactive food webs including several piscivorous species (Figure 4.15). Whitefish, perch, pike and brown trout were the most important fish species in the lakes. Vendace, which is a non-native species that has been introduced to the Paz watercourse, was also an important species. Whitefish was represented by two different morphs, referred to as sparsely rakered (SR) and densely rakered (DR) whitefish. The Pechen-

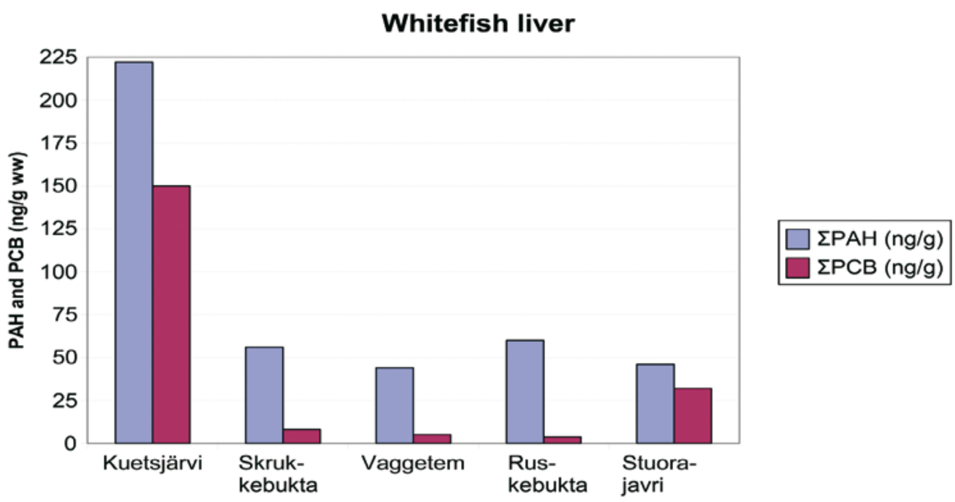

Figure 4.14 ΣPCB and ΣPAH (ng/g ww) concentrations in the liver of SR whitefish from different lakes.

ganikel combine appeared to have a major influence on heavy metal concentrations in freshwater fish in the vicinity of the industrial areas. The highest concentrations of most of the heavy metals, PAHs and POPs occurred in fish from Kuetsjarvi, from where the pollutant levels in fish tissue rapidly decreased with increasing distance to the smelters (Figure 4.14, Figure 4.16). The highest concentrations of most of the heavy metals were in internal organs, including liver, kidney and gills, and the low-

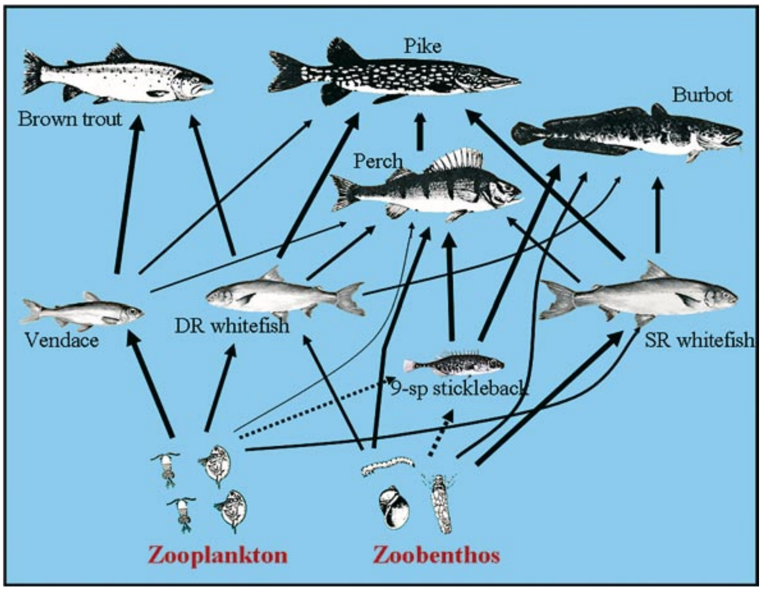

Figure 4.15 Summary of the basic food web structure of the fish communities in lakes in the Inari-Paz watercourse. The line thickness indicates the assumed importance of the different links, and dotted lines unconfirmed links.

est concentrations in muscle tissue. Heavy metal concentrations were of a similar magnitude in the individual fish species. However, the Ni and Cd concentrations were generally the highest in whitefish, and the highest Hg contents in muscle tissue in perch and pike. The concentrations of Ni, Cu and Cd in Lake Kuetsjarvi, as well as to some extent in the stations further downstream, were high compared to the values obtained in other parts of the area. The concentrations of PAHs and POPs in the analysed fish did not exceed the maximum permissible concentration (MPC) for fish (Hygienic norms, 2003).

Fish from Kuetsjarvi had a high prevalence of pathological abnormalities in their internal organs: deformation of the gonads, kidney stones and other changes in kidneys, liver and gills. The incidence of pathological disorders rapidly decreased with increasing distance to the smelters (Figure 4.17). There was a strong correlation between the disorder incidences and the pollutant levels, suggesting a causal relationship between fish pathology and heavy metal pollution. The fish population ecology studies also indicated life-history responses to the impact of pollutants in Kuetsjarvi in terms of early sexual maturation, diminished growth rates and short longevity, especially in whitefish.

Heavy metals, PAHs and POPs are regarded as potential hazards that can endanger both animal and human health, and information about their concentrations in fish is important both with respect to ecosystem monitoring and to the management of freshwater fish populations for human consumption.

It is strongly recommended that the monitoring of water quality (pollutants), sediments (pollutants) and fish (pollutants, population ecology and pathology) should be continued in the Paz watercourse as a part of the planned monitoring programme for the border areas.

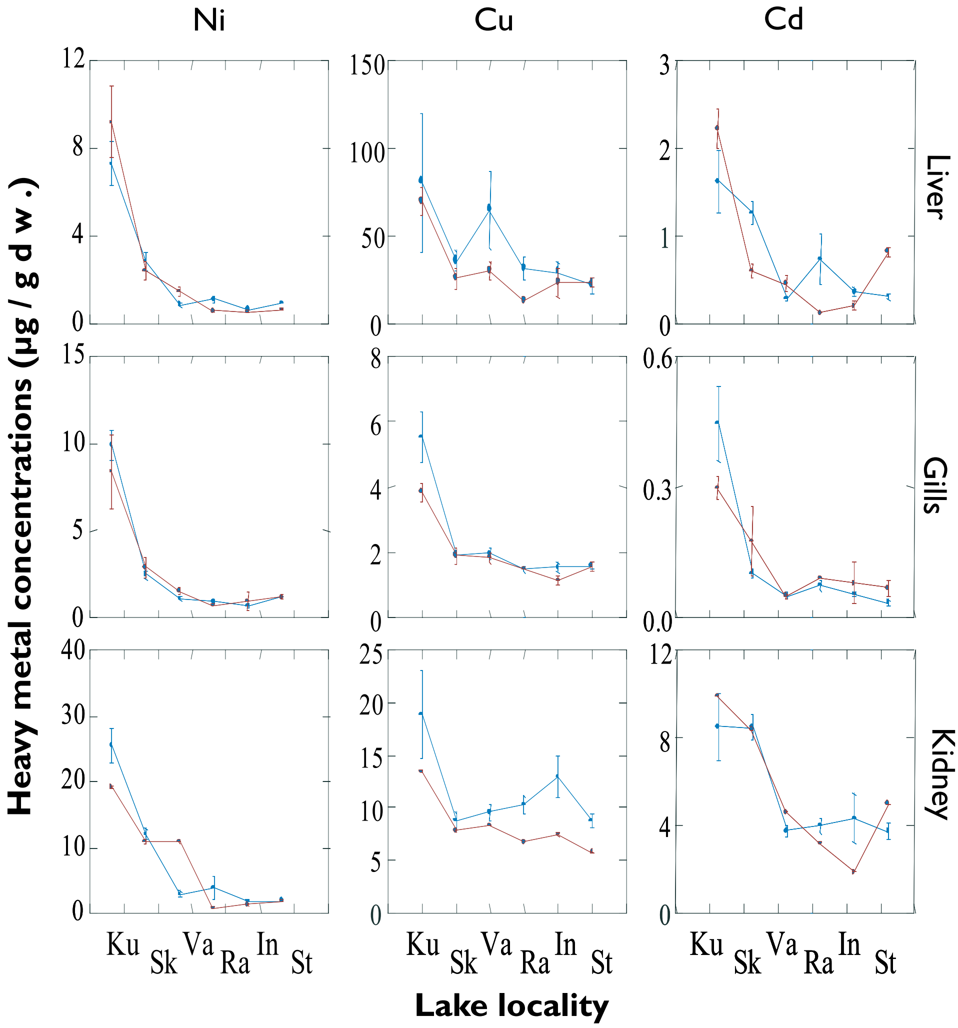

Figure 4.16 Concentrations of Ni, Cu and Cd in different organs of SR and DR whitefish (blue and red lines, respectively) in lakes with increasing distance to the Pechenganickel smelters. Ku = Kuetsjarvi, Sk = Skrukkebukta, Va = Vaggatem, Ra = Rajakoski, In = Lake Inari, and St = Stuorajavri. Vertical bars indicate S.E.

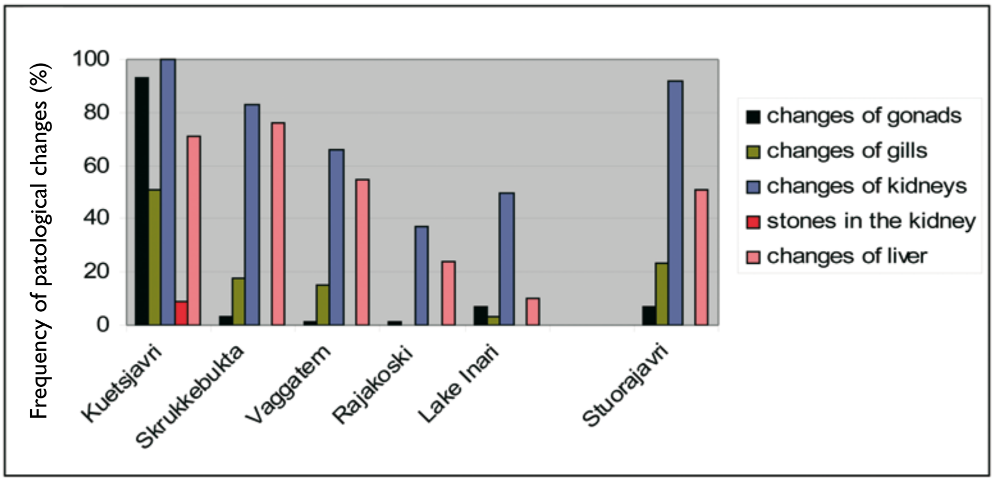

Figure 4.17 Frequency of pathologic changes in the internal organs of whitefish in lakes in the Paz watercourse (2004) and in Stuorajavri (2005).

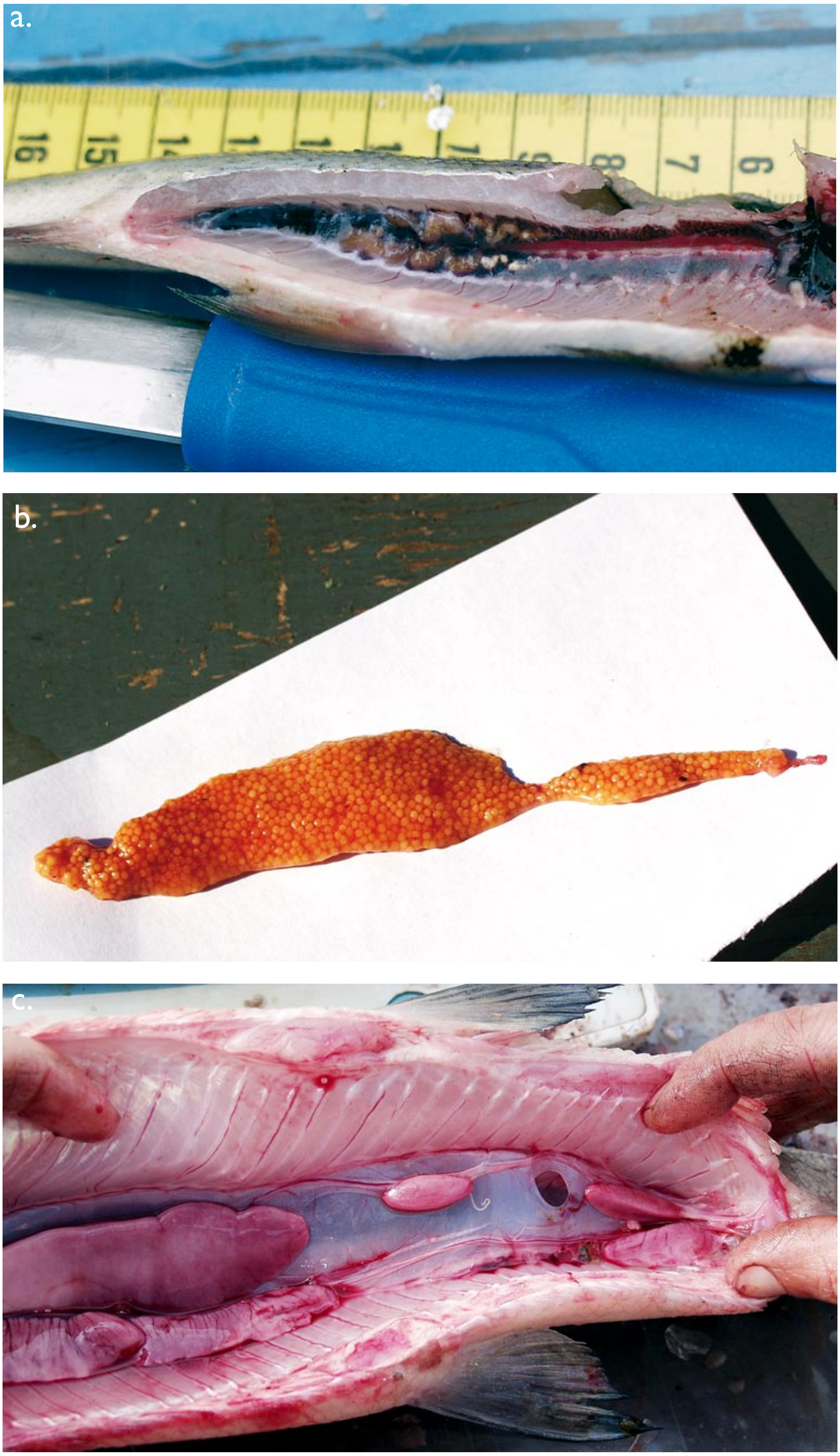

Figure 4.18 Pathological deformations in whitefish from Lake Kuetsjarvi, including the formation of kidney stones (a) and segmentation of the gonads (b and c).
Photograph: Nikolay Kashulin

Small lakes and rivers

Introduction

The emissions from the Pechenganikel smelters mainly contain heavy metals and elements that could lead to excessive acidification. The acidification of surface waters by acid deposition has been considered to be an important ecological problem in northern Finland and Norway. It has also been recognised that north-eastern Finland receives elevated sulphur and acidifying loads compared to other parts of northern Finland. Joint investigations in the early 1990's identified numerous acidified and heavy metal polluted lakes in the border areas.

The impact is the greatest at Russian and Norwegian locations in the vicinity of the Pechenganikel smelter complex located on the Russian side of the border, but the effects are also seen on the Finnish side. Recent studies showed a marked recovery of lakes from acidification in Finland, Norway and Sweden. However, water quality monitoring in eastern Finnmark (Norway) showed that heavy metal concentrations in the lakes remained high during the 1990s. The strongest and most complex effects have been reported in the vicinity of Pechenganikel smelters.

The chemical composition of surface waters is mainly determined by the input of ions from atmospheric deposition and weathering, and by ion exchange reactions in the catchment. There are a number of processes in a catchment that affect the chemistry of the runoff water. these processes are both biological (microbial activity, uptake by plants, decomposition) and chemical (weathering, ion exchange reactions etc.). The concentrations of heavy metals in surface waters are dependent on several factors; the airborne contribution from anthropogenic activities and local point sources, natural leaching from the bedrock and soil, and the natural input from airborne soil dust. In addition, the conditions prevailing in the catchment area have an important influence on the mobility and availability of heavy metals in water.

In order to determine the effects of acidification and heavy metal pollution on the biology of these lakes and rivers, studies were carried out on sediments, zoobenthos and fish in a selected number of lakes and rivers.

Study area

The study area is located in the border area of Finland, Norway and Russia, as well as reference areas in Finland (Pallas) and in Norway (Figure 4.19). There was a total of 85 lakes and 18 streams included in the water quality study, but some of the lakes were excluded from the statistical analysis because they were located outside predefined sub-areas. The lakes and streams included in the statistical analysis were grouped into 6 sub-areas which were mainly defined on the basis of the distance from the smelters and also their geological and topographic features:

1. Pechenganikel
2. Jarfjord - Sør-Varanger (30 km north of Nikel)
3. Paz River valley
4. Vätsäri
5. Raja-Jooseppi
6. Reference areas in Finland (Pallas) and Norway

The altitude of the lakes and streams ranges from ca. 100 m to above 300 m a.s.l., and the surrounding environment from forested areas to open mountain areas. Small headwater lakes are considered to be the most sensitive to acidification. In this study, most of the lakes were small with an area under 0.5 km^2, but there were also larger lakes that were also included mainly in sediment or sedimentation studies. The lakes included both headwater and drainage lakes, as well as closed lakes.

Water quality

Some of the differences and changes in water quality reflected the influence of the Pechenganikel smelters (Figure 4.20). The strongest impacts were the high concentrations of Cu (> 3 µg l^{-1}) and Ni (> 15 µg l^{-1}) in the lakes near the smelters. Areas with high concentrations of Cu and Ni occurred within a 30 km zone around the smelters. The Cu and Ni concentrations decreased with increasing distance from the smelters, although relatively elevated concentrations also occurred on the Finnish side, near the border.

According to the Swedish water quality criteria, harmful biological effects may occur in sensitive waters if the Cu concentration exceeds 3 µg l^{-1} or the Ni concentration exceeds 15 µg l^{-1}. The accumulation of metals in the organs and tissues of fish, together with abnormal fish pathologies, have been reported near the smelters: these were related to high metal deposition, especially of Cu and Ni. Moiseenko et al (1995) presented critical levels for Ni and Cu concentrations in lake waters based on the occurrence of fish diseases. The critical levels in well-buffered waters (ANC > 200 µeq l^{-1}) were 8 µg l^{-1} for Cu, and 20 µg l^{-1} for Ni. In our study, 8 lakes had Cu concentrations exceeding these critical levels, and 12 lakes and 2 small rivers with a Ni concentration exceeding the critical level. In 2004 the Cu and Ni concentrations in the Jarfjord area increased to levels which were the highest recorded since the start of the monitoring in 1990. There was also a weak, increasing trend in the Ni concentration in the lakes at Raja-Jooseppi, and a statistically non-significant increase in the TOC concentration. The catchments of the lakes in the Raja-Jooseppi area have a higher proportion of peatland than the other monitored areas, resulting in higher humic contents. Nickel is known to have a higher mobility than many other metals, and high molecular weight organic compounds such as fulvic and humic acids increase its solubility.

Although SO_2 emissions from Pechenganikel smelters have decreased to approximately one third of the maximum levels in the late 1970s, sulphur deposition still has a clear impact in the region. The sulphate concentrations in lakes and rivers in the vicinity of the Pechenganikel smelters are substantially higher than those in other areas. Despite the high sulphate concentrations, the lakes and rivers in the area are well-buffered and are not suffering from acidification. According to Pietilä et al. (2006), the bedrock in the Pechenganikel area contains relatively large amounts of base cations. Thus, despite the high sulphur deposition, there are enough base cations in the catchment to prevent acidification. This is clearly reflected in water quality: lakes with relatively high sulphate concentrations also have high base cation concentrations of and high alkalinity (Figure 4.20). The emission of dust containing basic material from the smelters and mining activities also undoubtedly contribute to base cation concentrations in the lakes.

The Jarfjord and Vätsäri areas have more weakly buffered lakes. According to the geological survey of the River Paz catchment, the most acid-sensitive soils primarily occur on the Finnish side of the border. The bedrock consists of granite gneiss and, especially in Vätsäri, there is a higher aluminium to base cation ratio than in the other areas. In Jarfjord the soil is not especially acid-sensitive, but it is very thin and stoney. This is also the case in Vätsäri and in Sør-Varanger to the east of Vätsäri. Jarfjord and Sør-Varanger are situated quite close to the smelters and are therefore subjected to relatively high sulphur deposition. Strong signs of acidification have earlier been recorded in the lakes in Jarfjord area but, since 1987, the mean pH has increased from below 5 to 5.4 in 2004. Similar signs of recovery from acidification were observed in the Vätsäri lakes, and this has earlier been documented in a more extensive study on headwater lakes in Finland. However, the lakes in Vätsäri are in the early stage of recovery and the increase in buffering capacity is not yet very clearly reflected in the pH. The low alkalinity and low pH values in some lakes in the Raja-Jooseppi area,

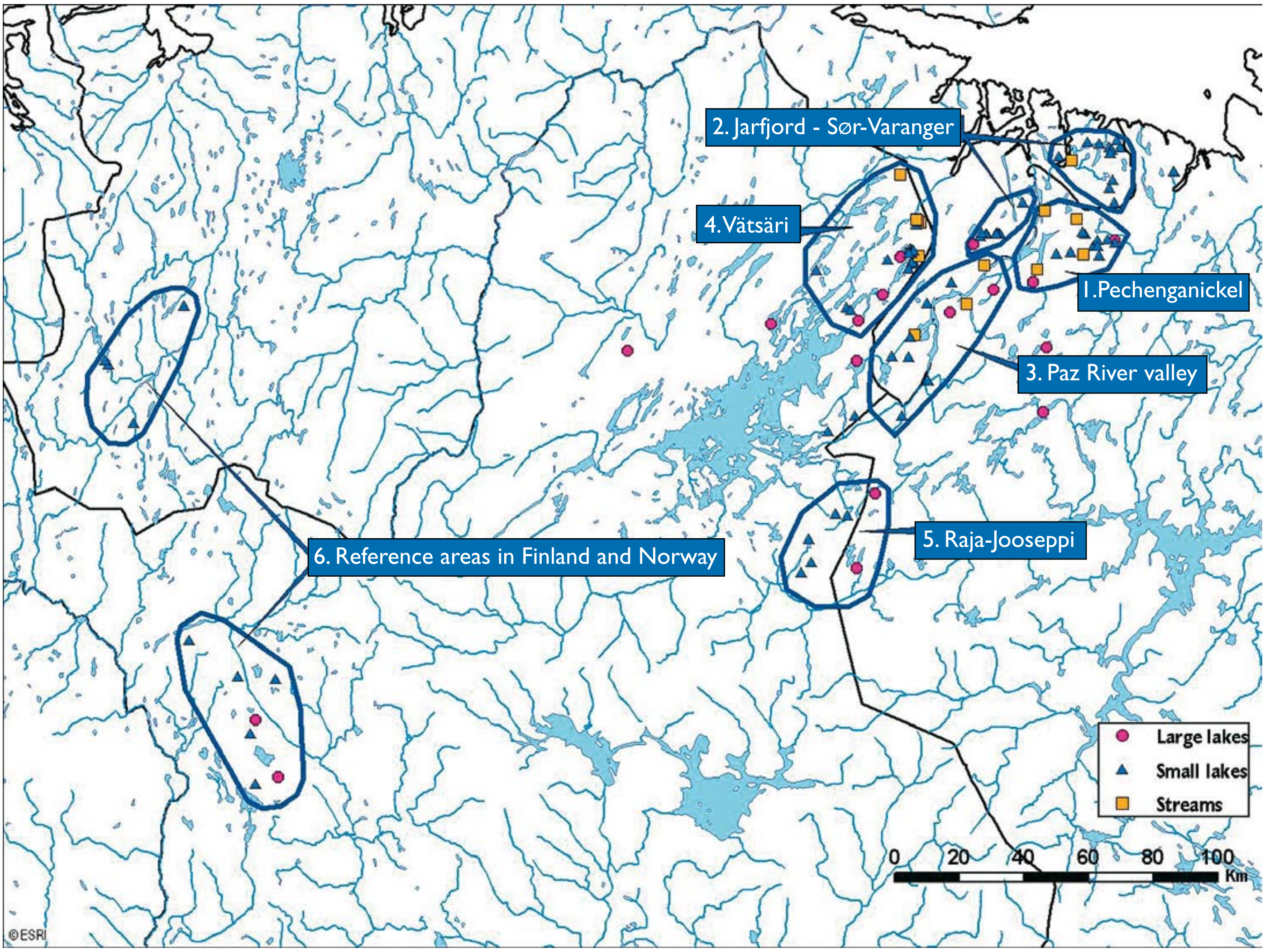

Figure 4.19 Location of the 6 main area in the investigation on small lakes and rives (see legend for explanation).

as well as the reference area in Pallas, are caused by the naturally higher amount of organic acids in the lakes.

Water quality is a basic element in monitoring and assessing the impacts of the Pechenganikel smelters on aquatic ecosystems. It represents the chemical environment in which aquatic organisms live. Water quality more directly reflects changes in the deposition of acidifying compounds than the deposition of metals, because the metal concentrations are more strongly dependent on bedrock geology, pH and the amount of organic material (TOC) in the soil and surface water.

Sediments

Sediment samples from the small (and several larger) lakes provide a good opportunity to determine the dispersal area of emissions from the smelters. The prevailing south-westerly winds carry the emission plume mainly in a north-easterly and southerly direction, and therefore bottom sediments in lakes located 50 km and more to the south of Nikel are only slightly polluted. In the northern parts of Norway and Finland, the deposition of metals and sulphate in precipitation is low, and the concentration of heavy metals in the top layers of lake sediments is correspondingly low. The contamination factor (C_f) value, expressed as the ratio of concentrations in surface sediment to a background value for a given lake, was used to evaluate the degree of pollution by heavy metals. The contamination degree (C_d) was calculated as the sum of all contamination factors for a given lake. To determine the ecological

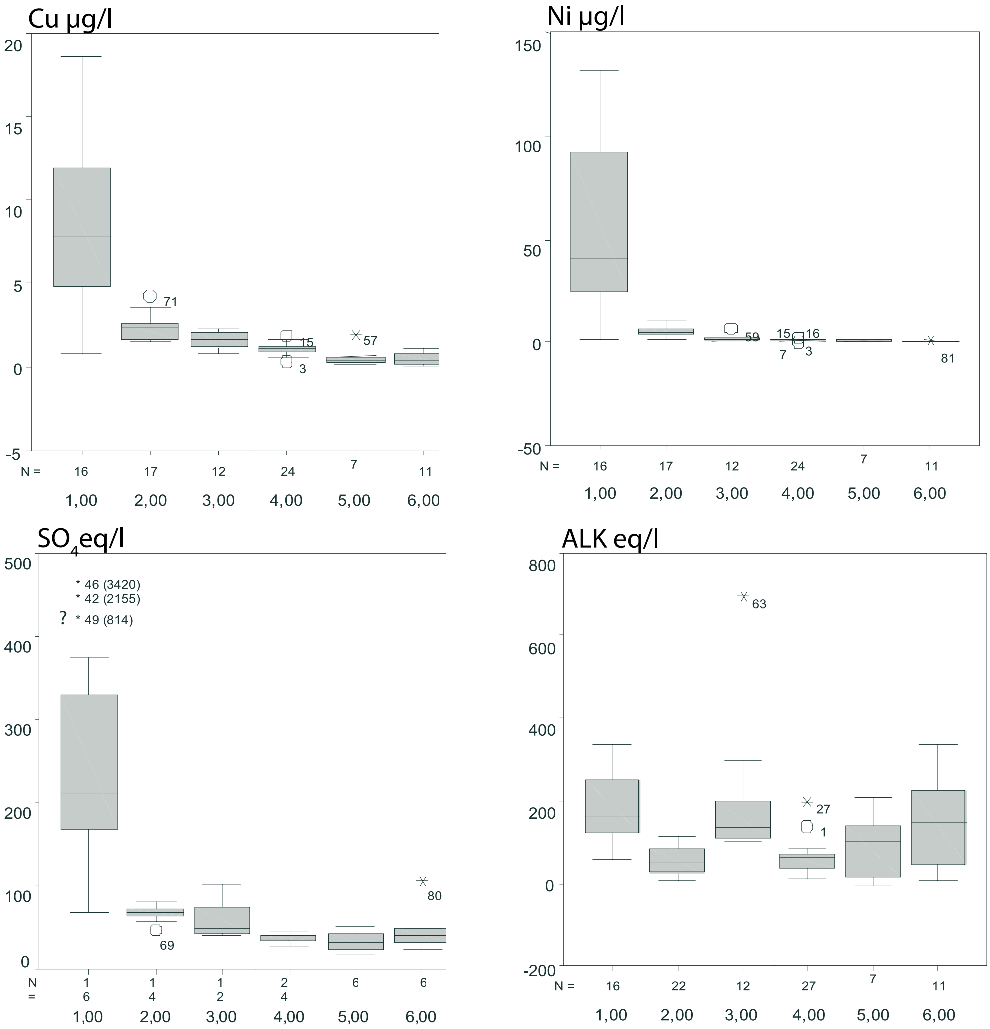

Figure 4.20 The median and quartiles (25 % and 75 %) of the Cu, Ni and SO_4 concentrations and alkalinity in the different sub-areas.

state of the investigated lakes, The C_f value of 8 elements (Cu, Ni, Zn, Co, Cd, Pb, Hg, As), which are the main pollutants in the area, was calculated.

In the lakes close to the main emission source the concentrations of Ni, Cu, Co and Zn in the top 4–7 cm sediment layer were much higher than the background values. The concentrations of Ni, Cu, Co and Zn decreased in younger sediments on moving to the north and south of these lakes. The maximum Ni and Cu concentrations, which exceeded the background values by a factor of 10 to 130, occurred within 10 km of the Pechenganikel smelters. Within 10 to 30 km of the emission source, the corresponding concentrations were only 3–7 times higher than the background values. The Co concentrations were 4–10 times higher than the background value within 15 km of the emission source, and up to three times higher than the values in other lakes at a distance of more than 15 km.

There was a clear trend in the C_f value in the lake sediments and the distance from the smelters. Maximum C_f values for almost all the heavy metals occurred in sediments in lakes LN-2, LN-3, LN-4, Peschanoe, Palojärvi, Zapolyarny, Kirikovanjarvi at a distance of up to 20 km from the smelters. The C_f values of many heavy metals in the upper and lower watercourse of the Paz River were on the borderline between low and moderate pollution, apart from Hg and Cd. Almost all of the lakes in Norway and Finland had low and moderate C_f values for Ni, Cu, Zn and Co.

Figure 4.21 Lake Äälisjärvi. In Finnish Lapland, the soil in the Vätsäri area especially has a very low acid buffering capacity. Photograph: Antti Lappalainen

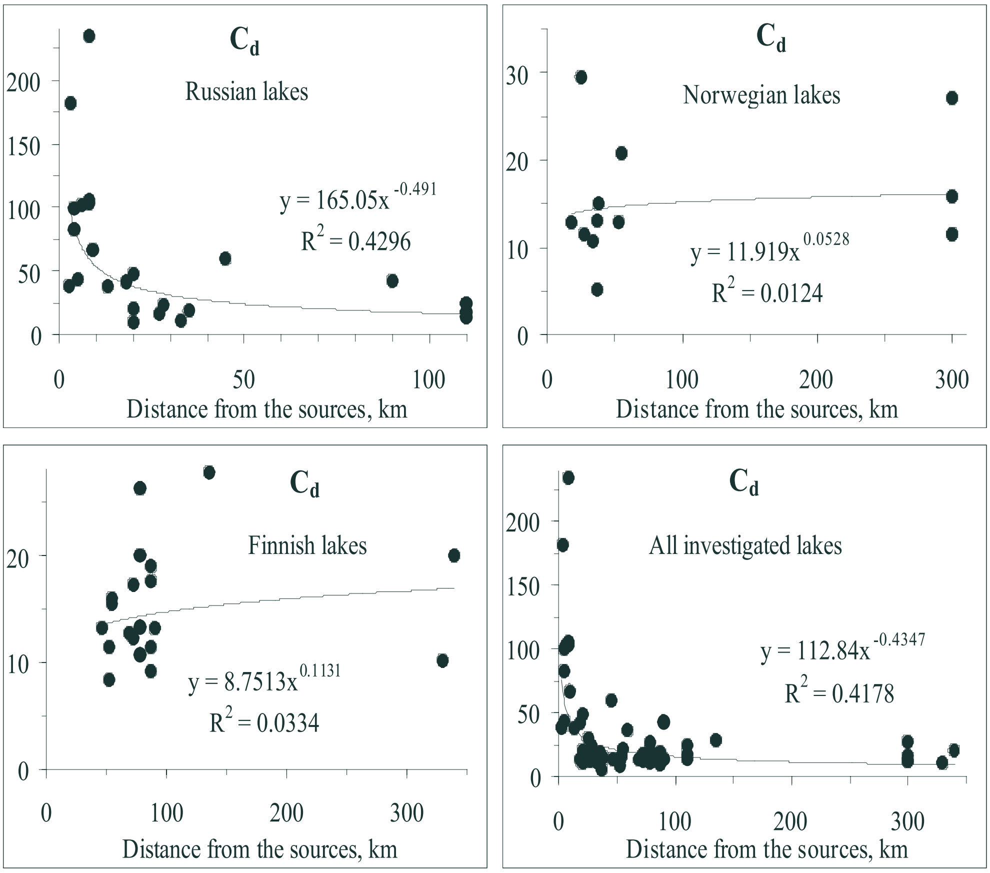

Figure 4.22 Relationship between the C_d (contamination degree) values in lakes in Russia, Norway and Finland lakes and the distance from the Pechenganikel smelters.

A relatively high proportion of the heavy metals deposited in the watershed and carried into the lakes accumulate in the lake sediments. Therefore the metal concentrations in sediments characterize the total load on the watershed, and permit determination of the sources of pollution and the calculation of historical trends. In the majority of the water systems, the element concentrations in the topmost sediment layer (several centimetres thick) were much higher than those in the water column.

The close connection between microelement concentrations (e.g. heavy metals) and the seston and sediments means that the distribution, transportation and availability of these elements cannot be correctly interpreted solely on the basis of water sampling and analysis of the soluble phase. The investigations on the chemical composition of lake sediments have therefore demonstrated their effectiveness in estimating the influence of emissions from the smelters on the water ecosystems, and these studies should be continued.

Biological monitoring

Zoobenthos

In the benthic studies, the wide range of specific characteristics of the individual small lakes made it difficult to make direct comparisons between the different parts of the region (Nikel, Jarfjord, Vätsäri, Raja-Jooseppi and Pallas). The lake characteristics were the most diverse in the Nikel area, where 3 of the 5 lakes (LN 1, LN 2 and LN 3) were severely polluted, but the other 2 lakes (LN 4 and LN 5) were in a moderate and nearly natural condition, respectively. Furthermore, the material from Raja-Jooseppi and Pallas was clearly lacking in suitable stream habitats that are naturally preferred by acid-sensitive species. This lead to misleadingly low results for the total number of species and the total number of sensitive species.

The effects of pollution and acidic deposition were most clearly evident in the biological indices for acid- and pollution-sensitive fauna of the benthic macro-invertebrate assemblages (Figure 4.23). In order to facilitate comparison of the results, the indices represent the fauna of the lake littoral habitat, which was the only habitat available in all the studied lakes. The Kola Biotic Index Score (KolaBIS) clearly expressed the effects of pollution in the Nikel area. Signs of acidification were reported in the Jarfjord area (Norway) in 1993–94, but the situation does not differ significantly from that in the Finnish areas in 2005. In Finland, Vätsäri and Raja-Jooseppi in eastern Lapland did not differ markedly from the western Pallas area, which was regarded as a reference area.

The indices indicate a marked improvement in the ecological status during the last decade in the Nikel, Jarfjord and Vätsäri areas. However, at Raja-Jooseppi and Pallas the ecological status seems to have deteriorated: the reason for this is not clear, and is probably caused by a number of factors.

There was a dramatic decline in the total number of sensitive species in all the areas except for Pallas (Figure 4.24). However, as mentioned above, differences in the availability of suitable habitats tends to distort the results for the total number of species in the individual areas. The lower number of sensitive species may be partly due to differences in precipitation, deposition and other conditions in the individual sampling years. Furthermore, long-term changes in the local and global climate etc. may have contributed to the marked depletion of sensitive fauna. Despite the possible sources of error, the decline in sensitive fauna is alarming and should be studied further.

Polycentropodie larvae (Trichoptera) were collected for determining the bioaccumulation of metals in connection with invertebrate fauna sampling. However, as sampling could only be carried out in 5 lakes with a suitable outlet habitat, the

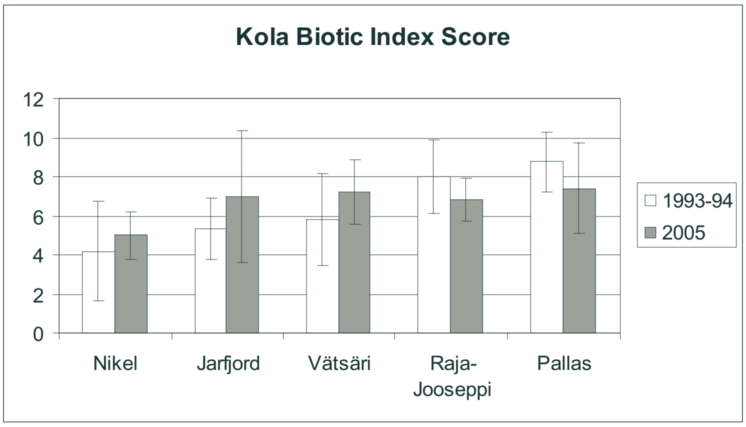

Figure 4.23
Means and standard deviations of the Kola Biotic Index Score in the individual study areas. The distance from the emission source increases from left to right.

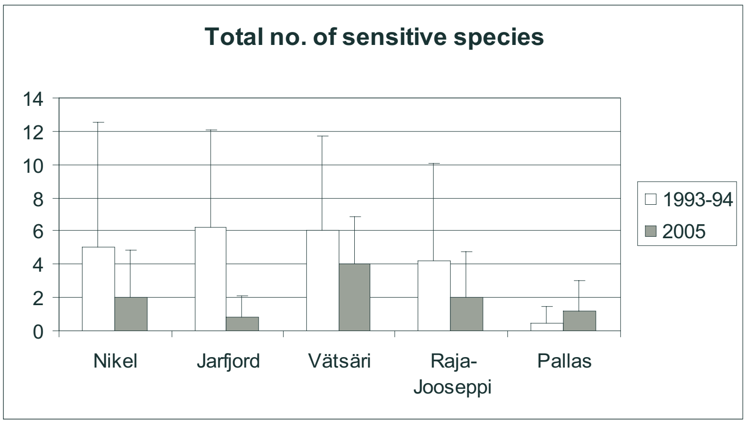

Figure 4.24
Means and standard deviations of the total number of sensitive species in 1993–94 and in 2005. The results are for all the habitat sampled in the areas.
The distance from the emission source increases from left to right.

results should be treated with caution. The Ni and Cu concentrations in larvae tissues were still elevated in lake LN 1 in the Nikel area, although they had declined sharply during the period 1992–2005. In the Vätsäri and Raja-Jooseppi area, the Ni and Cu concentrations in lakes Harrijärvi, Pitkä-Surnujärvi and Takkireuhkajärvi had remained relatively stable. The larvae in Lake Pieni Arttajärvi in the Raja-Jooseppi area had surprisingly high metal concentrations, but this may be due to the chemical characteristics of the local geology. The decreasing Ni and Cu concentrations in Lake LN 1 in the Nikel area are promising and may indicate a decrease in the local pollution load.

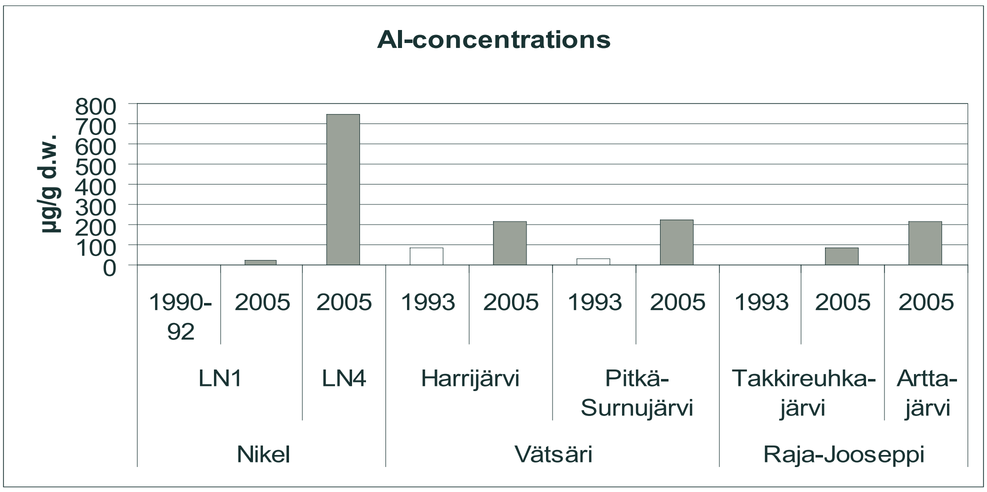

Figure 4.25 Al concentrations (µg/g dw) in Polycentropodidae larvae (Trichoptera) tissues (Al results from 1990–92 missing from lakes LN 1 and Takkireuhkajärvi). The distance from the emission source increases from left to right.

Figure 4.26 Benthic sampling in the outlet of Lake Harrijärvi, Vätsäri.
Photograph: Petri Liljaniemi

Figure 4.27 Net-spinning Polycentropodidae larvae were used in benthic metal concentration analyses. Photograph: Petri Liljaniemi

In contrast, the Al concentrations in Polycentropodidae-larvae tissue are relatively alarming. The Al concentrations had apparently increased in those Vätsäri lakes where a comparison was possible (Figure 4.25). The changes in Al concentrations may be associated with the slight increase in water pH and alkalinity, since bioaccumulation has been found to increase in approximately neutral conditions. Furthermore, the decrease in precipitation caused by changes in the local climate may decrease the load of organic compounds, which complex soluble Al into a biologically inactive form. The increase in the bioaccumulating form of Al may partly explain the decline in the number of sensitive species. However, confirmation of these hypotheses will require further monitoring studies.

Fish

Several types of study have been carried out on fish populations and metal concentrations in small lakes and rivers in the area.

Pollutants and pathology

The fish populations in the small lakes were also investigated with respect to possible effects of the emissions from the smelters. The methods used in fish sampling and analyses, as well as the pathological and heavy metal analyses, were similar to those used in Paz watercourse. The water bodies investigated are mainly located in Finland and Russia (Figure 4.28).

Studies on fish communities during 2002–2005 in Finland, Norway and Russia showed that the ichtyofauna of the water bodies included eight fish species, with whitefish being the dominant species.

The Cu and Ni concentrations in whitefish were comparable with the levels in Vaggatem and Skrukkebukta in the Paz watercourse upstream from the outlet of Lake Kuetsjarvi (Figure 4.15, Figure 4.29). The mean Cu concentrations in whitefish

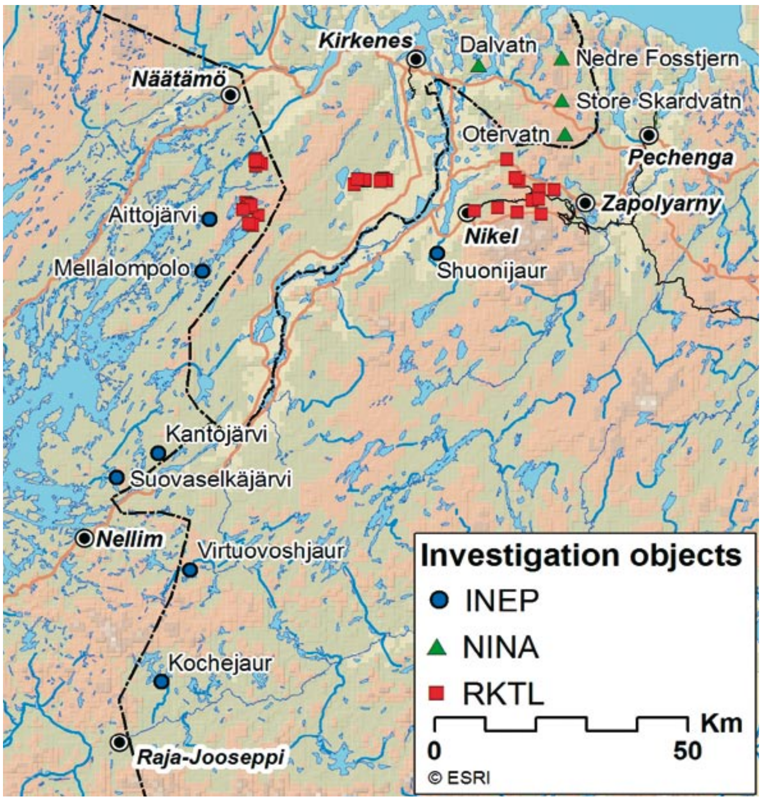

Figure 4.28
The lakes selected for fish studies by INEP, NINA and RKTL.
The fish populations, pathological status of fish communities and pollution levels in fish were investigated in 7 lakes by INEP.
NINA studied the response of fish populations to the improvement in water quality in several Jarfjord lakes.
RKTL sampled 35 extremely small lakes and brooks by electrofishing.

liver were about 30 µg/g dw, which was comparable with the levels found in Lake Kuetsjarvi. The highest Cu concentration occurred in whitefish from Lake Virtuovoshjaur, 100 km from the smelters. The whitefish in this lake and also in Aittojärvi (70 km from the smelters) had high Ni concentrations in their kidneys. There was no correlation between the Cu concentration and the distance to the smelters. On the other hand, there was a decreasing trend in the Ni concentration with increasing distance from the smelters. Metal accumulation in the organs and tissue of fish was apparently irregular. These metals tend to accumulate in so-called target organs. Copper, for example, tends to accumulate in the liver of fish, while the highest Ni concentrations occurred in the kidney and skeleton of whitefish and perch, and in the gills and skeleton of pike.

The Cu concentrations in fish in water bodies located at different distances from the emission sources, especially in the small forest lakes, may be natural background levels. The small size of the water bodies, their dependence on water derived from precipitation, and considerable size of the catchment area, all influence the input of pollutants and their accumulation in the biological systems and lake sediments. The Ni concentrations in kidney clearly reflected the anthropogenic load on the water. This index can be employed in assessing the deposition of pollutants.

Fish from the lakes had a high incidence of pathological abnormalities in their internal organs: deformation of the gonads, kidney stones and other changes in the kidneys, liver and gills. Studies on whitefish populations in Kochejaur carried out in 2002 and 2005 showed an increase in the incidence of pathological changes and increased Ni and Cu concentrations in some organs (Figure 4.30).

Fish populations in small lakes in Jarfjord and small watercourses in the border area

The deposition of acidic sulphur compounds can cause the acidification of lakes and rivers, causing serious damage to the aquatic biota and to fish populations. Two different studies have been carried out to investigate the possible effects of emissions from the smelters.

Fish populations in small lakes on Jarfjord

Several lakes in the Jarfjord Mountains have suffered from serious acidification due to SO_2 emissions from the smelters. This was especially the case in smaller lakes located at a relatively high altitude and with a geology associated with a low resistance to acidic inputs. The results from other studies support the damage to fish populations caused by acidification, which was the most severe in the same lake.

A number of new studies were performed on the response of populations of brown trout and Arctic char to the recent improvement in water quality in four acid-sensitive lakes in the Jarfjord Mountains in eastern Finnmark, northern Norway. The fish populations were sampled with benthic and pelagic gill nets in the autumn, and the catches were expressed as number of fish per 100 m^2 of net area (CPUE). The initial sampling was carried out between 1987 and 1993, and re-sampling was conducted during 2000 to 2005.

Several lakes in the Jarfjord Mountains have previously been found to be suffering from acidification. However, significant chemical recovery has occurred in recent years, as demonstrated by the increasing pH and acid neutralising capacity (ANC). The allopatric population of brown trout in Lake Otervatn has recovered almost completely in recent years. The size of this population was very low in 1987 and 1990, with a CPUE of about 4 fish. During 2004–05 the CPUE had increased about tenfold, to 39–46 fish. Both the pH and ANC values explained a significant proportion of the variation in CPUE of brown trout in this lake. There has also been an increase

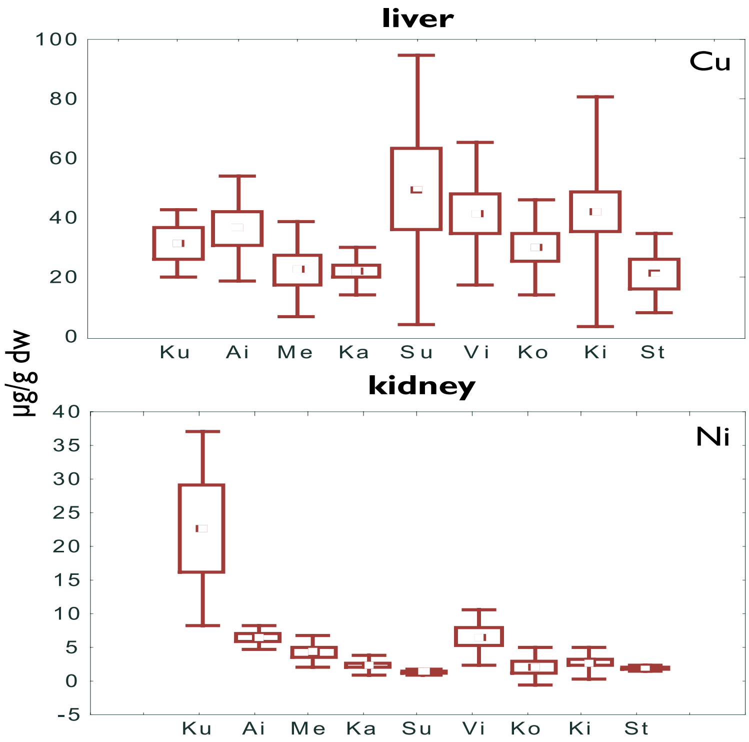

Figure 4.29
Concentrations (µg/g dw) of Cu (liver) and Ni (kidney) in whitefish from small lakes.
Ku = Kuetsjärvi,
Ai = Aittojärvi,
Me = Mellalompola,
Ka = Kantojärvi,
Su = Suovaselkäjärvi,
Vi = Virtuovoshjaur,
Ko = Kochejaur,
Ki = Kivijärvi,
St = Stuorajavri.

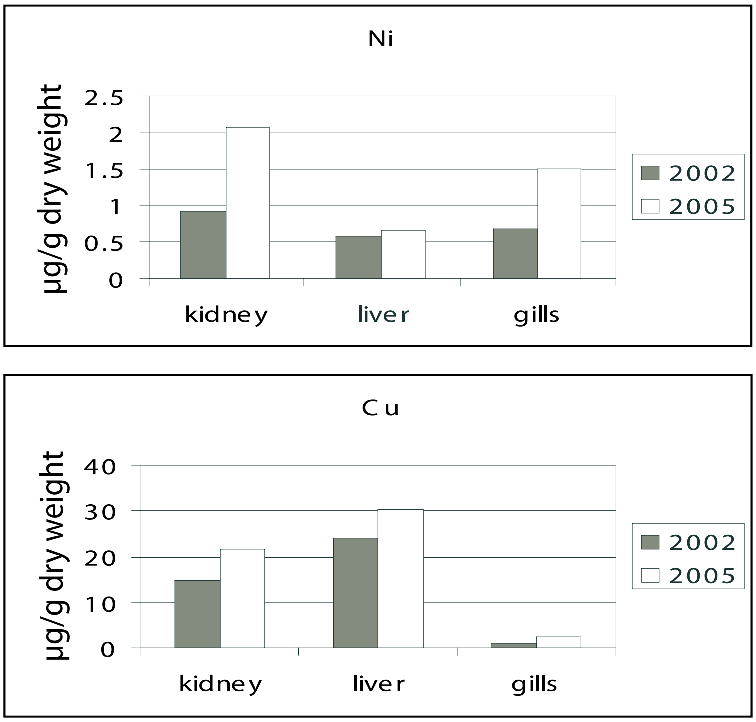

Figure 4.30
Ni ja Cu concentrations (µg/g dw)in kidney, liver and gills in whitefish from Kochejaur lake in 2002 and 2005.

in the catches of brown trout in two other lakes, which also contain Arctic charr. The age-frequency distribution of brown trout in the lakes indicate that a higher number of age groups have been present in recent years, and the recruitment rate has also increased. In contrast, the Arctic charr populations have decreased in abundance in recent years.

There was a significant negative correlation between the catches of sympatric brown trout and Arctic charr in the epibenthic habitat (depths of 0–12 m) of the lakes.

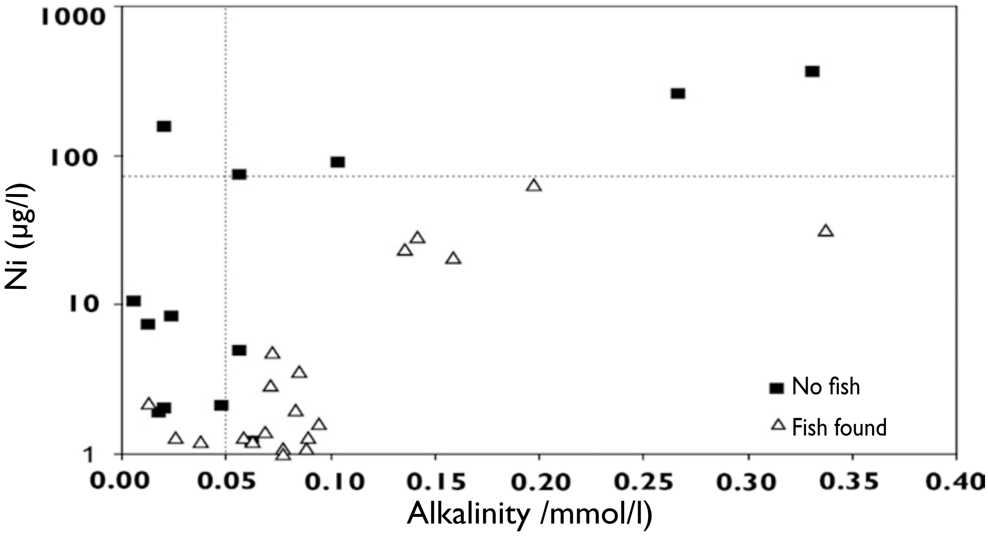

Figure 4.31 Ni concentrations (µg/l) and alkalinity (mmol) in 35 lakes or brooks in the Finnish, Norwegian and Russian border area. Black squares indicate sites without fish, and open triangles indicate sites with fish.

Thus, we suggest that the abundance of Arctic charr in these lakes is regulated by inter-specific competition from brown trout.

Small watercourses in the border area

In order to study the effects of airborne emissions, the water quality of 35 extremely small lakes and brooks at distances of 1–50 km from the smelters were surveyed, and the fish occupying stony shores in these lakes and brooks were sampled by electro-fishing. The results clearly showed that airborne emissions from the smelters have not caused any wide spread damage to the fish populations, even in the most sensitive small waters located in the Finnish, Norwegian and Russian border region.

The small waters close to the smelters (within approx. a 10 km radius) are well buffered against the effects of high sulphate deposition. However, the extremely high concentrations of Ni and Cu are a local threat to the biota in these small waters. The results show that there are apparently lakes that have lost all their fish populations. The Ni concentrations in these lakes exceeded 70 µg/l (Figure 4.31).

In the Russian, Norwegian and Finnish border area, acidification is currently a problem only in a set of extremely small waters located in the local highland areas, 15-50 km from the smelters. The bufferint capacity is low (< 0.05 mmol/l) in some of the lakes and brooks and a number of fish populations, mainly minnows, are most probably lost. The SO_2 emissions from the smelters have decreased to approx. one third of the maximum level in the late 1970s, and this is reflected in the overall recovery of the buffering capacity of small lakes e.g. in the Finnish border area, 40—50 km west of the smelters.

4.5

Data storage

The data from the research studies and monitoring of the Paz watercourse, as well as small lakes and rivers in the area, consist of water quality measurements (nutrients and pollutants), pollutant levels in sediments and in biota (invertebrates and fish), and histopathology and pathology parameters. Ecological data on invertebrates and fish have also been collected at several sites. All the primary data collected during the course of the project have been stored in Excel files and can be used for the creation of an environmental data base for the Norwegian, Finnish and Russian border area. The data will be used for the development of a joint monitoring programme, and they will be supplemented with biological components in the near future.

Data that have been collected in connection with other monitoring programmes and which are relevant for the monitoring of Paz River basin will be used in accordance with an agreement drawn up with the bodies responsible for the individual programmes. Most of these data will be available for the Paz monitoring programme after it has been officially reported in the respective programmes.

The area covered by the project has been identified by the Arctic Monitoring and Assessment Programme (AMAP) as a key area in which pollution emissions and their effects are to be monitored, and all the aggregated data will be submitted to the AMAP database.

A cornerstone of the future programme is co-operation with the international programmes EMEP, ICP Waters, ICP Forest etc. EMEP and ICP Waters will benefit from this co-operation through improvements in the quality and scope of the data available for the Barents region. A serious lack of sites providing data in support of international conventions aimed at reducing the effects of air pollution has been identified for this region (e.g. EMEP 2001).

4.6

Conclusions

The watercourses in the Russian, Norwegian and Finish border area comprise two contrasting types of system: the large-sized Inari-Paz watercourse, and numerous small-sized lakes and streams.

The area is subjected to severe anthropogenic influence from the Pechenganikel mining and metallurgical industry. Production at the smelters is associated with emissions of pollutants into the air (airborne pollutants) and runoff from the mining activities and the Nikel smelter complex (waste water from the mines, smelters, slime pits and tailing dumps). Wastewater is discharged directly into the lower part of the watercourse through Lake Kuetsjärvi. The Paz watercourse is impacted by a direct input of pollutants into the watercourses and by atmospheric pollutants, while the lakes and streams in the headwater areas of the Paz watercourse only receive atmospheric pollutants. The main pollutants affecting the lakes and rivers are sulphur compounds, heavy metals (Ni, Cu, Cd, Cr, Zn, As, Hg etc.), polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs). However, the long-range transport of pollutants (mainly POPs) from other industrial areas contributes to some extent to the elevated levels in the area.

The Paz watercourse

The results of these studies revealed high concentrations of heavy metals in water, sediments and fish in the Paz watercourse. The highest levels were found close to the smelters, and the levels decrease on moving downstream. The concentrations of heavy metals upstream from the smelters were generally lower and comparable with the levels found in other parts of the area. It can be concluded that the effects of emissions of heavy metals from the smelters are most clearly seen in the Paz watercourse.

Water chemistry data indicate that there has been no decrease in the concentrations of Cu and Ni in the Paz watercourse during the last 6 years. Sediment samples from different parts of the watercourse showed that the concentrations of heavy metals in Lake Kuetsjärvi are lower in the surface layer of the sediments compared to deeper layers (2–4 cm). This suggests that there has been a recent decrease in metal deposition. However, the concentrations of heavy metals in sediments further downstream were clearly the highest. At all the sampling points the concentrations of PAHs and POPs were the highest in surface sediments. In Lake Kuetsjärvi the sediments were classified as ″markedly″ to “strongly contaminated″ by heavy metals, POPs and PAHs.

A number of pathological modifications were found in fish organs and tissue. The prevalence and severity of these phenomena increased with decreasing distance to the smelters, and the abnormalities were clearly related to heavy metal pollution.

The Ni, Cu and Cd concentrations in fish from Lake Kuetsjarvi, as well as to some extent also at points further downstream, were high compared to the other study sites in the area. The PAHs and POPs concentrations in the fish did not exceed the maximum permissible concentrations (MPC) for fish for human consumption (Hygienic norms, 2003).

Small lakes

Previous studies performed in the early 1990's identified numerous acidified and heavy metal polluted lakes in the border areas. The studies performed in this project indicated that the smelters are still emitting large amounts of heavy metals and sulphur. Acidification and heavy metals are still the major threat to small lakes and rivers in the study area The prevailing south-westerly winds primarily carry the emission plume in a north-easterly direction and lakes located 50 km and farther to the south of Nikel are therefore only slightly polluted.

Acidification of small lakes

Although SO_2 emissions from the Pechenganikel smelters have decreased to approximately one third of the maximum levels in the late 1970s, there is still a clear impact of sulphur deposition in the region. The study indicaqted that acidification is not a problem in the vicinity of the smelter (< 10 km) even though the deposition in this area is very high. The main reason for this is that the buffering capacity of the small waters in the area is high (probably due to the presence of basic bedrock and emissions of alkaline material from the smelter complex), and they therefore do not show any signs of acidification. The more weakly buffered lakes in the mountain areas of Jarfjord, Sør-Varanger and Vätsäri are especially acid-sensitive- and clear signs of acidification have been observed in lakes in these areas.

There has been some recovery from acidification in the small lakes of the Jarfjord and Vätsäri areas due to decreased emissions of sulphur dioxide. Since the mid 1980s, the mean pH of acidified lakes in Jarfjord increased from below 5 to 5.4 in 2004. A slight improvement in buffering capacity has also been reported in the Vätsäri area. However, negative impacts on acid-sensitive biota were still recorded in small-sized lakes and streams in these areas.

Studies on benthic macro-invertebrates gave contradictory results. Although indices of ecological status, such as the Biotic Index Score (KolaBIS), indicated an improvement in all the investigated areas, the overall number of sensitive species seemed to have declined. The reason for the decrease in the number of sensitive taxa is not clear, and could be caused by a number of factors, both natural and anthropogenic (differences in climate, emission rates and discharge conditions between the sampling times). Several of the studied lakes in Norwegian and Finnish areas were still classified as moderately or strongly acidified. However, in remote western and south-western areas (Pallas and Raja-Jooseppi) the benthic classification reflected the influence of the naturally acidic characteristics of the individual lakes.

In the late 1980s, acidification-induced damage was recorded in fish populations in the Jarfjord area. New studies on the allopatric population of brown trout in Lake Otervatn showed that the brown trout population has almost completely recovered in recent years. The reason for this is a significant increase in the pH and acid neutralising capacity (ANC) of the waters.

Heavy metals in small lakes

Heavy metal concentrations were slightly elevated in the small lakes throughout the border region of the three countries. However, this problem was only acute in the vicinity (< 10 km) of the smelters, where the concentrations of e.g. Ni and Cu were several times higher than in the other areas. The highest concentrations were found in the area between the smelters, and several lakes appeared to have lost their fish populations.

In this study there were altogether 8 lakes exceeding those critical levels for Cu and for Ni in 12 lakes and 2 small rivers. In 2004 the Cu and Ni concentrations in the Jarfjord area increased to the highest levels recorded since the start of monitoring in 1990.

Lake sediments close to the smelters exceeded the background values for Ni and Cu by a factor of 10 to 130. The Co and Zn concentrations in the top sediment layer were also much higher than the background values in this area. Within 10 to 30 km of the emission source, the Ni, Cu and Zn concentrations were 3–7 times higher than the background values. There was a clear relationship in all the investigated lakes between the contamination factor (C_f) and the distance from the Pechenganikel smelters. POPs were not included in this study, but earlier studies on sediments in Sør-Varanger indicated elevated levels of Hg, Ni, Pb and a number of POPs.

Heavy metal analysis of benthic invertebrates (Trichoptera) showed elevated levels of Ni and Cu in larvae tissues in lake LN 1 at Nikel, although there had been a sharp decline during the period 1992–2005. In most of the lakes in the Vätsäri and Raja-Jooseppi areas, the concentrations had remained relatively stable. Larvae in Lake Pieni Arttajärvi in the Raja-Jooseppi area had surprisingly high metal concentrations, but this may be due to the local geology. The aluminium concentrations in larvae tissues were more alarming: Al concentrations appeared to be elevated in Vätsäri lakes. These changes in Al concentrations may be caused by the slight increase in water pH and alkalinity, since the bioaccumulation has been observed to increase in circum-neutral conditions. However, the analyses were carried out on a small number of animals and lakes, and further studies are needed in order to confirm and explain the increase in Al concentrations.

The Ni concentrations in whitefish kidney in some of the small lakes were comparable with levels recorded in the Paz watercourse upstream from the outlet of Lake Kuetsjarvi. The Cu concentrations in whitefish liver in some remote areas were higher than those in Lake Kuetsjarvi. There appeared to be a slight decrease in Ni concentrations with increasing distance to the smelters. Investigations on the whitefish population in Lake Kochejaur (120 km from smelters) indicated that heavy metals in fish organisms have increased slightly during the last three years.

In order to study the effects of airborne emissions on fish communities, the littoral fish species composition of 35 extremely small lakes and brooks at 1–50 km distance from the smelters were surveyed by the electrofishing method. Lakes where the Ni concentrations exceeded 70 µg/l were found to have lost all their fish population.

Human health aspects

In the Pasvik-Inari area there are strong traditions in the exploitation of fish. This includes subsistence, recreational and commercial fishing, with an annual harvest ranging from 200 to 600 tonnes of fish over the last decades. This project revealed high levels of heavy metals in fish in some parts of the area, and elevated levels of POPs in Lake Kuetsjarvi. However, the total body burden of pollutants in the fish (heavy metals and POPs) in the area needs further investigation. This type of study will provide information about the total content of pollutants in the fish species that are utilised for human food consumption. The fish in the watercourse are thus of high public interest, and studies on fish and the overall ecological status of the watercourses are highly appropriate with respect to the communication of results and information to the public.

4.7
Recommendations for a joint monitoring and assessment system

The results from this study reveal that the emissions from the Pechenganikel industrial complex have great impact on nature in the area. The area receives a cocktail of different contaminants both as a result from the emissions from the smelters but also due to long range transport of contaminants from other industrial areas. The Inari-Paz area is a special area and the problems with the negative impacts from the smelters on the watercourses really makes it important to monitor.

There are plans for modernizations of the smelters which would lead to decreased emissions from the smelters. How fast the nature will recover and if it will completely recover are important questions that have to be monitored. Also the global climate change can have an effect on the functioning of aquatic ecosystems and sensitivity of species. Based on the findings from these studies and the above mentioned arguments it is clear that the monitoring programme for the area need to be very specialized so that it will be possible to follow the development of the area.

General

- **The monitoring program must be based as far as possible on the ongoing monitoring and present studies in the area. However it is important that the monitoring continues in the area if other ongoing national monitoring programs in the area end.**
- **It is recommended that also the demands of EU's Water Framework Directive (WFD) are taken in to account.**
- **In a changing situation monitoring should be focused to the most sensitive indicators found in the present studies.**

It is really important that the monitoring program are cost-effective, therefore it should be a limited number of sites. Complete (extensive) sampling and analysis of many parameters from some of the sites will be important for understanding the impact from the smelters.

- **It is recommended to find possibilities of focusing different sub-programmes to the same lakes.**

Paz watercourse

The effects of the mining and metallurgical processes are most clearly seen in the Paz watercourse. This is also the area where freshwater resources (i.e. fish) are most used for human consumption.

• **It is therefore recommended that the Paz watercourse should to be monitored more intensively compared to other parts of the monitoring area.**

• **Monitoring of the water quality should continue on a yearly basis on a selected number of stations throughout the whole watercourse from Lake Inari to the outlet. It is also important to monitor the River Kolosjoki and Stream Protoka, that are recipient and transmitters of sewage discharged by Pechenganikel. Some of the stations should be sampled more frequently.**

• **Sediments are ideal for looking at historical trends in pollutions and must be monitored in selected lakes in the watercourse.**

In the Kuetsjarvi and Paz watercourse high levels of heavy metals and POPs have been found in sediments and fish. Further histopathological changes in fish are relates to the high levels of contaminants.

• **It is strongly recommended subsequent investigations of the link between contaminants and fish pathology. It is known that contaminants have synergetic effects so therefore levels of heavy metals, POPs, biomarkers and pathology should be included for each sampled fish.**

Small lakes

There has been some recovery from acidification in the small lakes of Jarfjord and Vätsäri areas due to decreased emissions of sulphur dioxide. Ongoing modernization of the Pechenganikel smelter would probably lead to further decreasing of emissions.

• **Monitoring of recovery from acidification and it's biological effects is necessary. We recommend using modelling to predict future chemistry as response to changes in the deposition of sulphur dioxide in the small lakes.**

Even during few last years the Cu emissions were nearly constant and Ni emissions showed just a slight increase, the concentrations of heavy metals in water of lakes in the Jarfjord area (about 30 km from the emission source) was increasing in 2004. Accumulation of the pollutants in the lake sediments has continued.

• **We recommend an increased monitoring of heavy metals in the areas close to the smelter.**

Investigations on conditions of the aquatic ecosystems of lakes and their changes showed that due to natural differences between different lakes it is necessary to monitor time trends in the ecosystems.

• **Anyway in order to follow the effect of pollution from Pechenganikel on lakes' ecosystems especially fish studies need further comparison and harmonization of methods as well as assessment of the sensitivity of different indicators.**

Persistent organic pollutants

This study reveals elevated levels of POPs and PAHs concentrations in lake sediments in some part of the area and in fish in Kuetsjarvi. It is known POPs are du to long range transport into the area from other industrialized areas. In order to identify local possible contaminant sources more studies is needed. The fish in the watercourse is associated with large interest in the Inari-Paz area.

- **It is strongly suggest that more extensive screening of POPs, PAHs in freshwater ecosystems of the border area should be carried out in order to map possible sources and to provide a better base for human risk assessment. It is important to include some "new" contaminants like, brominated flame retardants in the analysis since the use and emissions of some of these contaminants still are increasing around the world.**

Quality Control

To achieve comparability of the data generated by the various participants, the methods employed in sampling and analysis must be thoroughly documented. A quality assurance programme must be carried out to demonstrate that results of adequate accuracy are being obtained. Only through such objective control can natural variability or observed human impacts be assigned reliably.

- **The Quality Assurance (QA) and Quality Control (QC) procedures should include all parts of the activities performed at the site and in the laboratory.**

Implementation

- **It is recommended to implement the monitoring programme in it's complete form in the Inari-Paz watercourse.**

- **It is suggested that the joint monitoring of small lakes should be implemented gradually. The components — water quality and sediment contamination — are ready as a joint system for implementation from 2007. Biological monitoring of lakes needs further development and after this the biological sub-programmes should be included into monitoring programme as soon as possible.**

Terrestrial ecosystems

Based on the scientific report: "CURRENT STATE OF THE TERRESTRIAL ENVIRONMENT IN THE JOINT RUSSIAN, NORWEGIAN AND FINNISH BORDER AREA" appended to this summary report as a CD appendix.

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Birch forest with sampling of wet deposition (red funnel) and ground vegetation analysis.
Photograph: Per Arild Aarrestad

5 Terrestrial ecosystems

5.1 Monitoring and assessment network

The primary objectives of this part of the project were 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 (TECM) was established in Norway, Russia and Finland on the basis of existing monitoring networks.

Dormant intensive monitoring plots were activated, and the measurements and assessments required to up-date the baseline information were carried out in 2004 and 2005. The existing monitoring plots were located to the north, west and south of the emission source. The lack of plots situated to the east of the emission source was a serious drawback, but the establishment of suitable new plots to the east was not possible for financial and logistical reasons.

The TECM network consisted of plots selected from three earlier forest monitoring projects:

1. The Finnish Lapland Forest Damage Project monitoring network, established in 1990–1995 (Tikkanen and Niemelä, 1995)
2. The Skogforsk-NINA-VNIIPRIRODA-IGCE monitoring network with eight plots along a transect from the Pechenganikel smelter towards Norway, established in 1994–1998 (Aamlid et al. 2000)
3. 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 into 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 attributes 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, primarily because they were originally designed to monitor different components of the forest ecosystems. As the distribution of the plots overlapped to some extent, especially in Norway and Russia, it was considered unnecessary to include all of the existing plots in the new network.

Figure 5.1 The terrestrial ecosystem monitoring network (TECM) showing the location of the plots in Finland, Russia and Norway. The red triangles indicate plots where bulk deposition (open areas) and stand throughfall (inside tree stands) were also monitored during a period of one year. The two plots furthest to the south in Finland (F-10 and F-11) were used only for deposition monitoring.

The TECM 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 (Figure 5.1). The plots represented a north-south and an east-west gradient related to the emission point sources at the Nikel and the Zapolyarny smelters, and included both heavily affected areas and undisturbed reference plots. The final selection of the number of plots, as well as the parameters to be measured on the plots, was based on a cost-benefit evaluation. 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.

The attributes (Table 5.1) to be assessed or measured on the TECM network were selected on the basis of the results obtained earlier with the different networks, Bulk deposition and stand throughfall were 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 (2004), while studies on photosynthetic efficiency, birds and mammals were carried out on a limited number of the plots.

Plot	Deposition	Crown cond.	Stand growth	Ground veget.	Epiphytic lichens	Photosynth.	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
Rajakoski								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
PC	X	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									

Table 5.1 The plots selected for testing the terrestrial ecosystem monitoring network in Russia, Norway and Finland, and the attributes monitored on the plots during 2004–2005. The assessment of birds and small mammals (*) was carried out in the vicinity of the plots.

5.2
Methods

Harmonization of the monitoring methods 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 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 Rajakoski 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.

The assessment of crown condition, survey of the ground vegetation, determination of stand growth and the sampling and analysis of deposition, plant chemistry and soil were carried out in accordance with the ICP Forests manuals, and the sampling and analysis of forest mosses according to the ICP Vegetation manual. This provided a framework for a considerable part of the monitoring work, and ensured that the assessments and measurements carried out in the individual countries were fully compatible.

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).

The three laboratories participated in Working Ring Test 2005 (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 WRT2005 in May 2005. Five natural deposition samples (bulk deposition and stand throughfall) and 4 synthetic samples were sent to each laboratory for analysis. The total number of individual analyses performed on the samples was over 250. The three laboratories performed satisfactorily in the ring test.

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 litter and humus layers, 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 plant samples, 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 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. The small differences between the results obtained by the individual laboratories were due to the fact that they used different analytical procedures, and not to poor quality of the analytical work. The results for the determination of plant-available (exchangeable) metals and macronutrients showed very poor inter-compatibility, because each laboratory used a different extractant. The standard analytical procedures laid down in the ICP Forests manual should be used for analysing soil samples in future monitoring work.

Figure 5.2 Harmonization of ground vegetation assessment. Photograph: Hans Tømmervik

Figure 5.3 Joint field work. Photograph: Per Arild Aarrestad

One researcher was responsible for collating and checking, in co-operation with the other researchers, the datasets for each of the monitoring attributes. The datasets, as well as information about the sampling, chemical analyses etc., were incorporated in the information system 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 monitoring attributes.

5.3

Main findings

Assessments and measurements of deposition, crown condition, stand growth, ground vegetation, epiphytic lichens, photosynthetic efficiency, plant chemistry, birds, small mammals and soil were carried out on the terrestrial ecosystem monitoring network during 2004 and 2005. Satellite imagery was also used to estimate longer-term changes in the ground vegetation cover in the area.

Deposition

Bulk deposition (open area, wet and dry deposition) and stand throughfall (deposition on the forest floor within pine stands) were collected during a period of one year (summer 2004 – late summer 2005) on two plots in Norway (PC and N11), on three plots in Russia (RUS1, RUS0 and S05), and on three plots in Finland (F-3, F-10 and F-11). Annual deposition of Cu, Ni and sulphate (SO_4-S), and a range of other metals and macronutrients (e.g. Ca, Mg, K, NO_3-N, NH_4-N) were calculated for the plots. Owing to severe vandalism on one of the plots in Russia (S05, 20 km from Nikel), it was not possible to calculate an annual estimate of the deposition load in bulk deposition on this plot.

There was considerable variation in the annual bulk deposition of Cu, Ni and sulphate between the plots (Table 5.2). However, there was a clear decreasing trend in the deposition of Cu and Ni, but not for sulphate, with increasing distance from

Table 5.2 Annual precipitation and annual deposition of Cu, Ni and sulphate as bulk deposition (BD) and stand throughfall (TF) on the plots in Russia (RUS1, S05, RUS0), Norway (PC, N11) and Finland (F-3, F-10, F-11). The plots are listed in order of increasing distance from the emission source. nc = could not be calculated owing to vandalism on the plot, nd = not determined. Values marked with "*" are not true deposition values: almost all of the Cu and Ni concentrations in both bulk deposition and stand throughfall were below the limit of quantitation of the analytical instrument. This probably also applies to the values for the RUS0 plot.

Plot	Annual precip mm	Cu, mg/m²/a BD	Cu, mg/m²/a TF	Ni, mg/m²/a BD	Ni, mg/m²/a TF	SO_4-S, mg/m²/a BD	SO_4-S, mg/m²/a TF
RUS1	461	20.9	20.8	17.3	18.4	306	96.4
PC	722	24.4	27.1	27.3	30.7	355	447
SO5	497	nc	19.2	nc	13.9	nc	145
N11	678	10.0	11.9	7.8	12.1	331	401
RUS0	423	1.5	2.2	0.9	1.5	160	116
F-3	485	1.7*	1.7*	2.7*	2.5*	104	191
F-10	444	1.0*	0.9*	2.2*	2.2*	105	114
F-11	500	1.0*	0.9*	2.5*	2.2*	97	102

the point source. Three factors clearly affected the deposition pattern in the area: the amount of precipitation, the prevailing wind direction at the individual plots, and the proximity to the sea (sulphate). The plots in Norway, for instance, had almost 50 % more precipitation than the Russian plots. The Norwegian plots are also located closer to the sea, so the deposition of sulphate also includes a larger input of sulphate from marine sources. The prevailing wind directions also vary considerably, partly due to the different topography in the area.

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 (Table 5.2), 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 (Figure 5.4).

Deposition in the area is characterised by occasional peaks, with relatively high concentrations of Cu, Ni and sulphate (Fig. 5.4); 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.

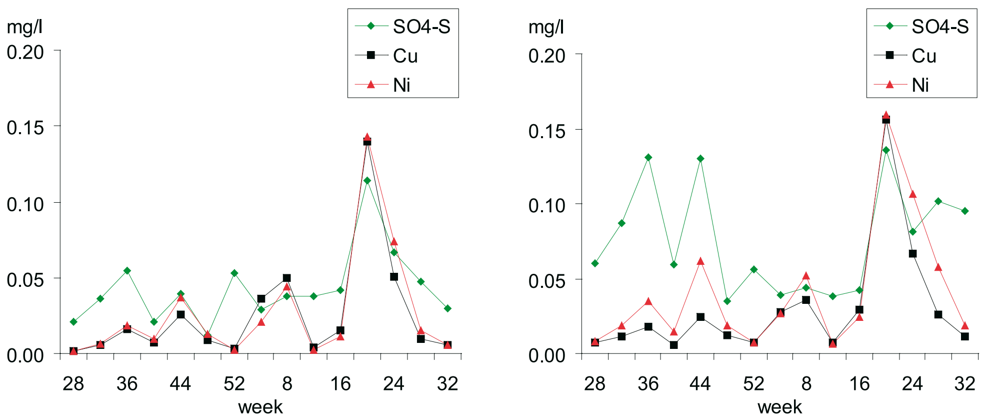

Figure 5.4 Copper, nickel and sulphate concentrations in bulk deposition and stand throughfall at Plot PC in Norway during the period 1.6.2004–8.8.2005. The measured sulphate concentrations have been divided by 10 in order to make comparison of the timing of the peaks easier.

Crown condition

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. Crown density refers to the proportion (in %) of needles or leaves present on a tree with respect to the "theoretical" amount (100 %) on a corresponding "perfectly healthy" tree. The more widely used term "defoliation" is the inverse of crown density, i.e. 100 % crown density = 0 % defoliation.

The crown density of Scots pine 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 background plot in Russia (RUS-0) and in Finland. However, RUS-0 may not be representative of pine stands in the background area because the trees are relatively old and severely damaged by the fungal pathogen, *Peridermium pini*, which has undoubtedly reduced the overall stand vitality and crown density. 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. Thus, there are indications that pollution has reduced the crown density of Scots pine in the border area, but the data are not conclusive.

Crown density in birch was assessed on only a small, varying number of trees on each plot, due to the low presence of birch on many of the plots, especially along the north-south transect. Crown density in birch declined on moving along the western transect towards the emission source. The north-south gradient also included plots located close to the smelter (N06, S03, S05), but these plots had comparably high crown density values. The results for the two transects were therefore somewhat conflicting, and the low crown density on the Russian background plot (RUS-0) cannot be explained in terms of the impact of pollution. Thus the question of whether crown density in birch is negatively influenced by pollution in the area is still open. As it is a deciduous tree, birch is expected to be less sensitive than pine to SO_2 pollution and heavy metal deposition.

Stand growth

The growth of the Scots pine stands was calculated as the relative increase in the increment of basal area, height and volume between 1998 and 2004. The basal area on all the plots increased during 1998–2004 by between 10 and 38 %. The largest increase occurred on plots RUS-1 and RUS-2 in Russia, close to the smelter at Nikel, and the smallest increase on the background plot RUS-0 in Russia. The difference between the plots in Norway was small and not related to the distance from the smelter.

The height increment on all the plots increased by between 7 and 16 %. The highest and lowest increment occurred on PA and RUS-0, respectively. The difference in height increment between the other plots varied by only 4 %, the lowest increment occurring on plot RUS-1 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. Despite the large variation between the plots, there were no indications that pollution from the smelters has had a negative effect on the growth of Scots pine, not even on the plots in the immediate vicinity of the smelters.

Ground vegetation

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 22 plots in the monitoring network in 2004. Several 1 x 1 m quadrats were used to analyse the species abundance on each plot. A total of 212 vegetation quadrats were analysed on 22 plots, and then compared with the results of earlier analyses carried out on the original networks.

The 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 *Empetrum nigrum*, *Vaccinium* spp. and *Ledum palustre*. A number of herbs, such as *Listera cordata, Pedicularis lapponica* and *Trientalis europaea,* and the grass *Deschampsia flexuosa*, were the most common species in the medium dry forests, while lichens dominated in the dryer forests.

Multivariate ordination of the species data on the 212 quadrates surveyed during the project (2004) showed a vegetation gradient running from dry, lichen-dominated plant communities to medium-dry vegetation with more dwarf shrubs and herbs (Figure 5.5). The vegetation on the Norwegian plots (PA-PD, N11) was very similar to that on those Russian plots least affected by air pollution (S10 and RUS0,), and also similar to that on many of the Finnish plots. However, several of the Finnish plots represented a dryer site type more dominated by reindeer lichens and cup lichens. The Norwegian, Finnish and the Russian background plots probably all represent naturally occurring vegetation that is regulated by variation in soil moisture and nutrients and the effects of grazing by semi-domesticated reindeer. The species composition of the ground vegetation on the plots close to the smelter complex (RUS1, RUS2, S3 and S5) was, however, very different from that on the other plots in the monitoring network. The vegetation on these plots was characterized by dwarf shrubs, which are relatively resistant to the effects of heavy metal and other pollutants. The common forest bryophytes (e.g. *Pleurozium schreberi* and liverworts) and reindeer lichens, which are known to be affected adversely by air pollutants, were almost absent on the plots near the smelter.

There have only been minor changes in the species composition on the Norwegian and the Russian plots during the last 4–10 years, and most of the changes can be attributed to year-to-year fluctuations in species abundances. However, the ground

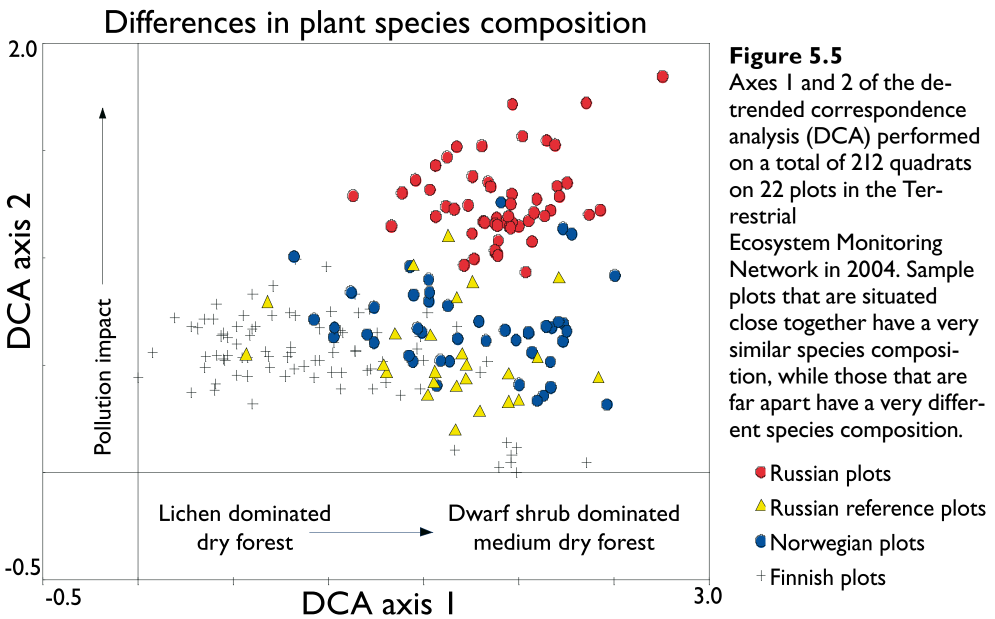

Figure 5.5
Axes I and 2 of the detrended correspondence analysis (DCA) performed on a total of 212 quadrats on 22 plots in the Terrestrial Ecosystem Monitoring Network in 2004. Sample plots that are situated close together have a very similar species composition, while those that are far apart have a very different species composition.

Figure 5.6
Healthy ground vegetation with a cover of dwarf shrubs and bryophytes. Photograph: Per Arild Aarrestad

Figure 5.7
Ground vegetation affected by air pollution lacking a bryophyte cover. Photograph: Per Arild Aarrestad

vegetation in the vicinity of the smelter complex is still adversely affected by emissions. Despite this, there are indications that some species, especially pioneer species of bryophytes and lichens, are recovering on a number of the Russian plots.

Epiphytic lichens

The cover and species composition of epiphytic lichens was surveyed on both birch and pine stems in 1995/1998 and again in 2004 as a part of the project. Epiphytic lichens are sensitive pollution indicators, and the degree of coverage is a reliable measure of the pollution load, especially of SO_2. The most common lichens on birch stems in the area were *Hypogymnia physodes* and *Melanelia olivacea*. The most heavily polluted area around the emission sources was clearly an epiphytic lichen "desert". There was a clear increase, with increasing distance along the western transect, in the lichen cover. The situation along the northern and southern transects was the opposite; only the most remote plots had any lichen cover (N11 and RUS-0, respectively). The southern aspect of the stems had consistently the lowest lichen coverage. Although pollution may have contributed to this pattern, the irradiance level, species composition and 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 (1995–1998) and second (2004) survey of epiphytic lichen cover showed that lichens have recolonised to a substantial extent on the least polluted plots along the western transect (plots PA and PC) within a period of only a few years. The coverage on the background plot in Russia (RUS-0) has decreased slightly, but this is not likely to be affected by pollution owing to its remote position and the prevailing wind directions from south-southwest.

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. The survey strongly indicated that epiphytic lichens are 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. This was further supported by the intra-trunk variation in lichen cover.

Photosynthetic efficiency

A sustained reduction in the efficiency of photosynthesis system II (PSII) has been reported in many species after exposure to stress conditions. The photosynthetic efficiency of birch and bilberry, as well as the concentrations of airborne pollutants in the leaves of the same species, was measured on 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. Photosynthetic efficiency was also measured in lichens (mainly *Cladonia* spp.) and in mosses *(Pleurozium schreberi* and *Hylocomiun splendens*), if present, on the same plots.

Photosynthetic efficiency measurements repeated in 2004 showed that there has been an increase in the vitality of birch and bilberry along the southern transect, as well as a smaller increase along the northern transect, compared to the situation in 2000. The photosynthetic efficiency values were compared to different environmental parameters and concentrations of heavy metals in the soil and leaves of birch and bilberry. A clear negative relationship was found between the Cu and Ni concentrations in birch leaves and photosynthetic efficiency along the northern, southern and western transects. There was also a negative relationship, although weaker, between the Cu and Ni concentrations in the organic layer and the photosynthetic efficiency. Photosynthetic efficiency proved to be a suitable method for determining the vitality of birch and especially bilberry, but not of lichens and mosses.

Plant chemistry (heavy metal and sulphur concentrations)

Samples were taken of mosses, pine needles, birch leaves, lichens, bilberry leaves, and wavy-hair grass on all the plots (except Rajakoski, F-10, F-11) in August 2004. Samples of edible berries (cloudberry, cowberry, crowberry, bilberry) and edible fungi were also taken on the plots in Finland and in Russia in 2004.

The Ni and Cu concentrations in mosses decreased regularly with increasing distance from the smelter complex (Fig. 5.8). The Ni and Cu concentrations in 2004 were clearly higher than those reported in the 1990´s on the plot (RUS1) located nearest to the smelter complex, and also slightly higher on some of the Norwegian plots (PC, PD). The Ni concentration had also increased on the plots between 1985 and 2000, but the Cu concentration had remained relatively constant. The sulphur concentrations near the smelter complex were extremely high. Although the sulphur concentration decreased with increasing distance from the smelter, the decrease was not as clear as that for the Ni and Cu concentrations (Fig. 5.8). However, mosses are not generally considered to be good bioindicators of sulphur deposition and, as is the case for deposition, there is a variable input of marine sulphate on the individual plots.

There was a clear gradient in the Cu and Ni concentrations in lichens, bilberry leaves, and wavy-hair grass, with the highest values occurring on the plots close to

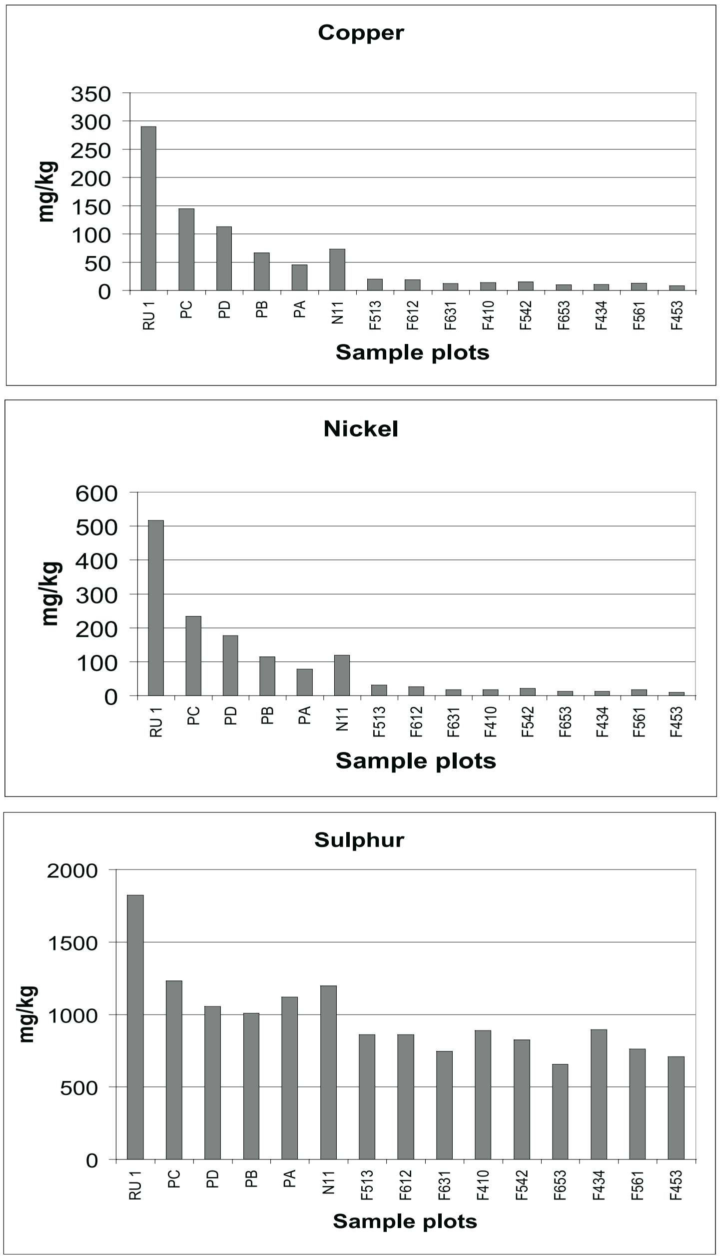

Figure 5.8
Copper, nickel and sulphur concentrations in mosses on the Norwegian, Russian and Finnish plots in 2004. The plots are arranged in order of increasing (left to right) distance from the smelter complex.

the smelters. In bilberry leaves and wavy hair-grass, however, 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. RUS-1). There were also extremely high Ni concentrations in wavy hair-grass on the Russian background plot (RUS-0). The Co, Cr and Pb concentrations in lichens were also strongly elevated on the plots close to the smelters. There was a considerable increase in the Cu and Ni concentrations in reindeer lichen compared to the results obtained on the same plots 8 years earlier.

Copper, Ni and S concentrations in the pine needles and birch leaves showed a similar decreasing trend with increasing distance to the smelter complex as for e.g. mosses, lichens etc. The concentrations of Cu, Ni and S were higher in the previous-year needles than in the current-year needles. The Cu, Ni and S concentrations in the birch leaves were considerably higher than those of the pine needles. The N, P and K concentrations in pine needles on the plots near the smelter complex were close to, or below, the deficiency levels for these elements.

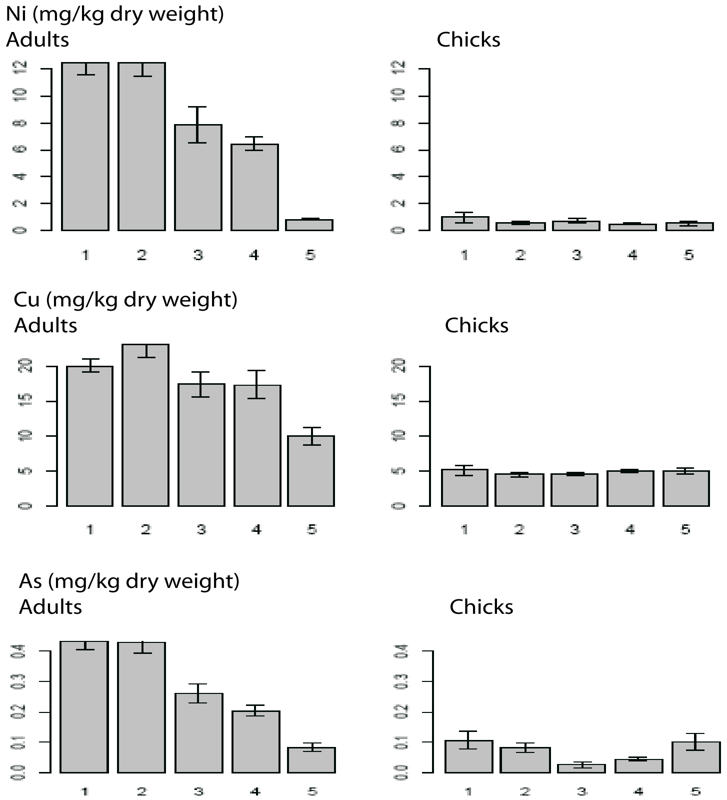

Figure 5.9
Nickel (Ni), copper (Cu) and arsenic (As) concentrations in feathers of the pied flycatcher (Ficedula hypoleuca) at different distances from the smelter complex in 2004.
1 = 5 km (Plot PC),
2 = 8 km (Plot PD),
3 = 13 km (Plot PB),
4 = 22 km (Plot PA)
to the west of the emission source,
5 = reference area in Lakselvdalen outside the city of Tromsø, more than 700 km from the smelter.

Nickel concentrations in edible berries (crowberry, cloudberry, bilberry and cowberry) on the plots in Russia and Finland showed a relatively clear decreasing trend with increasing distance from the smelter complex. The Ni and Cu concentrations in all types of berry on the plots closest to the smelter were above the maximum allowable concentration in foodstuffs for human consumption of 0.5 and 1.0 mg/kg dry weight, respectively. However, the berry samples were not rinsed with water before analysis so we do not know whether the metals are actually present in the berries or are in particulate material on the surface of the berries. This should be investigated in the near future, and appropriate instructions issued for people wanting to collect edible berries in the area.

Birds

Species composition of hole-nesting passerines and the reproductive success of the pied flycatchers *Ficedula hypoleuca* were recorded in nesting boxes located along the western transect running from the Nikel smelter. The tail feathers of both young and adults were sampled for chemical analyses. The tail feathers of adult pied flycatchers showed decreasing concentrations of most heavy metals with increasing distance from the Nikel smelter (Fig. 5.9). In contrast, the chicks appeared to have approximately the same contamination level at all sites. Increasing asymmetry in the tarsus (lower leg bones) of adult female was found with decreasing distance to the smelter. The body mass of pied flycatcher chicks at fledging increased with increasing distance to the smelter. The results suggest that flycatchers in the area nearest to the smelter are subjected to considerable environmental stress.

Small mammals

Rodents are known to follow relatively large population fluctuations. In the study area there was a consistent population cycle of about 5 years in voles with a somewhat less

Figure 5.10 Six, 10–11 days old flycatcher chicks in a nesting box. In a few days time they will leave the nest.

consistent cycle for shrews. This may be the result of several biological factors such as an alternating shift in the dominant species, climatic factors or predatory pressure. Small mammal capture data from two long-term trap series were compared. The sites of the two series, Svanvik and Roavvevarri, are situated about 7 km and 13 km to the west of the Nikel smelter, respectively.

The dominating species trapped were the grey-sided vole (Clethrionomys rufocanus), ruddy vole (Clethrionomys rutilus), and the common shrew (Sorex araneus). The grey-sided vole was the most numerous, approximately 5 times more common than the ruddy vole. In unpolluted areas ruddy vole is usually more common than these two species. At Roavvevarri the populations of the small mammals species are higher than those at Svanvik , which is closer to Nikel. The emissions from the smelters were not found to have any major effect on the small mammal populations.

Soil

Heavy metal, sulphur and macronutrient (Ca, Mg, K, N) concentrations were determined in the litter and humus (F + H) layers on all the plots except Rajaskoski, F-10 and F-11. The soil close to the smelter contained extremely high concentrations of a wide range of heavy metals, representing accumulation over the lifetime of the smelters. Although a relatively high proportion of the metals are in an immobilized form, the concentrations of plant-available (i.e. exchangeable) metals are still excessively high. It was not possible to compare the concentrations of plant-available metals along the transects owing to the fact that different extractants were used in the individual laboratories, and the results were therefore not inter-compatible.

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.

Satellite imagery

Monitoring the vegetation cover in the area using satellite images taken in 7 years during the period 1973–1999 revealed that major changes have taken place, especially in the lichen (epigeic) dominated vegetation cover, since 1973. Significant positive relationships were found between the photosynthetic efficiency of species common in the mixed forest vegetation and the Normalized Difference Vegetation Index (NDVI). There was also a significant negative relationship between the extent of the area of mixed forests with a lichen cover, as well as the area of industrial barrens, and SO_2 emissions during the period.

Satellite monitoring of the area continued with an assessment of a Landsat scene taken in July, 2004. Comparison of the 2004 data with previous satellite images taken during the period 1973–1999 showed that the coverage of lichens was at its lowest (due to air pollution) in 1992, with a subsequently increase from 1994 to 2004. Information provided by low resolution satellites, such as NOAA-AVHRR and MODIS on the TERRA satellite, showed that it is possible to monitor, on a daily and an annual basis, biomass and phenological events and the length of the growing season using NDVI. The length of the growing season was found to have increased during the period 1982–2002 in the immediate vicinity of the Nikel smelter complex.

5.4
Data storage

A terrestrial ecosystem information system was constructed at the Rovaniemi Research Unit of the Finnish Forest Research Institute (Metla) during 2006. The purpose of the system is to collate all the data and metadata on terrestrial ecosystems, produced during the course of the project, into an integrated information system. Access to the information is via Metla's home page, and the information is available at two levels:

1) Primary data and certain types of metadata (documents, reports, maps etc.) accessible only by the researchers who participated in the project.
2) Aggregated data and other documents (scientific/technical report, final report) freely accessible by the public.

Data and related information from early projects (e.g. the Lapland Forest Damage project, 1989–1995) carried out in the area have also been deposited in the information system.

Two-way links have also been established between the web pages of the Pasvik-Pechega Project and the terrestrial ecosystem information system.

5.5
Conclusions

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. These plants 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, and the concentrations of Cu and Ni in edible berries currently still exceed the maximum levels allowed in foodstuffs for human consumption.

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. Although a relatively high proportion of the metals are in an immobilized form, the concentrations of plant-available metals are still excessively high. 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 statement by representatives from the smelter company that there has been a decrease in the emissions of SO_2 in recent years, but that this has not been paralleled by a corresponding decrease in heavy metal emissions.

5.6

Recommendations for a joint monitoring and assessment system

The project has provided invaluable reference data on the condition of terrestrial ecosystems before the reconstruction of the smelter in Nikel. At the same time, this project has represented a combination and a continuation of the main elements of earlier studies in the border area. This means that data have been added to a number of time series and provided a comprehensive, long-term picture of the condition of terrestrial ecosystems in the area, as well as possible changes that have occurred over the past 5 years. However, there is still a need to further harmonise the existing monitoring networks and to increase the number of monitoring plots. We have evaluated, on the basis of the results and experience gained in the project, which attributes should be measured in a future monitoring programme. The presence of elevated concentrations of POPs and PAHs in sediments of certain lakes in the area, strongly suggests that the detection and monitoring of these compounds should also be included in the future terrestrial ecosystems programme. All the relevant assessment and sampling procedures should be carried out in accordance with the ICP Forests and ICP Vegetation manuals (see Implementation Guidelines),

Deposition monitoring provides information about sporadic, elevated deposition values (e.g. when a 4-week or monthly collection cycle is used), as well as about the amount of pollutants deposited over the whole year. However, this presupposes the continuous collection and analysis of samples, which is an expensive and labour-intense undertaking. The collection of deposition samples is therefore not recommended. Estimates of the distribution and level of pollutant deposition can be obtained using the relatively inexpensive method of collecting and analysing moss samples or snowpack samples during the winter. Because the annual deposition load values (e.g. SO4) form a basis for many other studies in the area, this information can be collected as a part of the other monitoring systems, e.g. ICP Forests. However, continuous monitoring of both bulk deposition and stand throughfall should be carried out on two of the new plots, to the east of the Nikel smelters, where catchment studies are to be carried out,

Crown condition assessment of birch and Scots pine is a relatively cheap method and, provided that the training (e.g. inter-calibration and cross-calibration exercises) of the field personnel can be ensured, it should be assessed annually. Norwegian and Finnish field personnel already participate in such exercises under the ICP Forests monitoring programme. It should be assessed on pine and birch (if present) on all the plots in Norway (PA, PB, PC, PD, N11), on six of the plots in Russia (RUS0, RUS1, RUS2, S05, S10, N06) and on nine of the plots in Finland (FI-1–FI-9). The crown condition (including abiotic and biotic damage) assessments should be performed annually during the two first weeks of August.

Stand growth should be monitored at 4-year intervals on all the plots where Scots pine is present (except RUS3 and Rajakoski in Russia, and F-10 and F-11 in Finland). In order to ensure the creation of a time series, the measurements should be performed on the same trees.

Ground vegetation should be monitored every four years during the two first weeks of August on all the plots (except RUS3 and Rajakoski in Russia, and F-10 and F-11 in Finland). For financial reasons, several of the existing 1 x 1 m quadrats on the Norwegian plots were not reanalysed in the project. We recommend that all vegetation quadrats (n = 20) should be monitored on all the selected plots. The abundance of species within the quadrats should be measured by both the frequency abundance method and the percentage cover scale. The percentage cover of less than 1 % should be measured with a similar precision. Additional species, not occurring within the quadrats, but within the plot area, should be recorded for species richness estimates.

Epiphytic lichen cover should be carried out every four years during the two first weeks of August. Measurements should be made on both birch and pine (if present) on all the plots (except RUS3 and Rajakoski in Russia, and F-10 and F-11 in Finland).

Photosynthetic efficiency measurements, based on chlorophyll fluorescence, should be performed on birch and bilberry leaves on the plots located along the north-south transect. In order to better depict the plant vitality conditions along this pollution gradient, the number of plots to be measured should be increased by including more of the stations in the NINA-NGU-INEP-METLA monitoring network (see Yoccoz et al., 2001). The plots are S1, S2, S3, S4, S5, S8, S10, RUS0, N1, N3, N5, N6, N8, N11 and N12. The measurements should be performed every year during the two first weeks of August. Annual measurements are necessary to separate the effects associated with year-to-year fluctuations in climate and timing of the growth season, and the effects of pollution.

Plant chemistry (heavy metal and sulphur concentrations) should be investigated on all the plots (except Rajakoski) every four years during the two first weeks of August. Information about heavy metal concentrations in forest berries and edible mushrooms is extremely important for ensuring that the local population is not exposed to an elevated dietary intake of toxic elements through the consumption of berries and mushrooms. The samples should be taken on a systematic grid in the area, and not only on the monitoring plots. Moss samples should be taken and analysed at 5-year intervals (next sampling in 2010) in order to ensure that the data are compatible with the results of the heavy metal moss survey, carried out by the ICP Vegetation programme at 5-year intervals.

Birds. The pied flycatcher (Ficedula hypoleuca) should be used as the monitoring object. Biological (hatching dates, number of eggs, number of chicks, and recruitment success) and morphometric (length of bones and feathers, and weight) parameters should be monitored using a series of nest boxes on the existing plots/sites. Tail feathers and blood should be sampled from flycatcher parents and chicks for the analysis of heavy metals and organic pollutant. Reference (background) sites should also be employed. The measurement of morphometric parameters and analysis of metals and organic pollutants should be carried out every fourth year. Biological parameters should be measured annually at Rajakoski, N1 N2, N3, N4 and at the reference site at Lakselvdalen (near Tromsø).

Small mammals (rodents and shrews). As the populations of individual mice species fluctuate strongly over periods of four to six years, relatively long time series are needed to determine the dynamics of mice populations in relation to the pollution load. Shrews, which are insectivores, are located one trophic level higher than mice, and represent the same trophic level on the ground as the pied flycatcher. Sampling aimed at monitoring the effects of pollutants on the populations of small mammals should be carried out annually in the spring and autumn populations on the same plots. Analysis of heavy metals and organic pollutants should be carried out on small mammal samples during one bottom and one peak phase of the population cycle of the different species every fourth-fifth year at the N2, N3 plots and at Kalkoupä, as well as at the reference site in Lakselvdalen.

Soil. The spatial variation in soil chemistry within the plots is extremely high, and almost certainly much larger than the changes taking place over time as a result of the deposition of pollutants. Even though there will undoubtedly be a decrease in the deposition of metals and sulphur following the renovation of the smelter complex at Nikel, there will be no appreciable changes in the amount of metals already accumulated in the soil. Thus, frequent analyses of soil condition are not necessary. Soil analyses do, however, provide important information about the fate of the deposited pollutants, i.e. whether the metals are in an immobilized or plant-available form. Soil samples should therefore be collected and analysed every ten years on all the plots (except Rajakoski).

Satellite imagery. Landsat data from 2005 will be analyzed in the near future in connection with another project aimed at strengthening the use of satellite imagery as a tool for monitoring broader changes in the environment. Future monitoring should be carried out on the basis of Landsat satellite imagery (or similar) at a frequency of every 4 years. The satellite data should be analyzed and correlated with chlorophyll fluorescence measurements of birch and bilberry. Using the low resolution instruments like MODIS on the TERRA satellite, the vitality of the vegetation and the length of the growing season can be monitored on a daily and an annual basis. The MODIS data are free of charge for the scientific community, and are assessed every year by NINA together with co-partners in Norway (NORUT) and Finland (FMI and METLA).

Additional monitoring plots. The monitoring network covers the area affected by heavy metal and sulphur to the south, west and north of the Nikel smelter. However, there are no monitoring plots to the east of Nikel. At least four plots, at distances of

2, 5, 20 and 50 km, should be established to the east of Nikel in order to complete the west-east transect. These plots should be established using the same design and assessment methods applied on the plots running along the transect to the west of Nikel (cf. Aamlid et al. 2000). This work should be carried out as soon as possible, and all the attributes listed in Table 5.3 should be assessed and measured at the same time. Two of the new plots (preferably the ones at 20 and 50 km distance) should be established as a part of integrated (terrestrial, aquatic and atmospheric) studies to be carried out in two small catchment areas (e.g. lake and surrounding land area) in order to calculate input-output budgets for heavy metals, organic pollutants and acidifying components. The location of the plots should be decided on between the parties responsible for carrying out the terrestrial, aquatic and atmospheric monitoring sub-programmes.

Table 5.3 Sampling interval for monitoring the individual attributes related to the condition of the terrestrial ecosystems.

Attribute	Species	Annually	2 years	4 years	10 years
Deposition	Snowpack survey (8 x 8 km)		YES		
Deposition	2 new plots for integrated catchment studies	YES			
Crown condition	Scots pine, birch	YES			
Stand growth	Scots pine			YES	
Ground vegetation	All species within quadrats, additional species within plot			YES	
Epiphytic lichens	Birch, Scots pine			YES	
Photosynthetic efficiency	Birch, bilberry	YES			
Plant chemistry	Pine needles, birch leaves, mosses			YES*	
Heavy metal and POP/PAH concentrations in a systematic (8 x 8) survey	Bilberry, crow-berry, cowberry, cloudberry, edible mushrooms		YES		
Birds	Pied fly catcher	Biological parameters		Metals, organic pollut-ants	
Small mammals	Rodent, shrews	Population numbers		Metals, organic pollut-ants	
Soil	Litter, humus				YES
Satellite imagery		MODIS		Landsat (or similar)	
POPs and PAHs	All Components			YES	

* Moss samples should be taken at 5-year intervals (next sampling in 2010 in connection with the pan-European ICP Vegetation heavy metal moss survey)

Additional parameters. A survey of the concentrations of POPs and PAHs in the individual components of the terrestrial ecosystems in the area should be included, as soon as possible, in the programme. Elevated concentrations of these compounds represent a potential health risk to the local population.

6 Overall conclusions

• SO_2 emissions from the smelters have been considerably reduced during the past two decades, and are currently about 75 % lower than the levels during the 1980s. This is supported by the official statistics published by the smelter company, measurements made at a number of air-quality monitoring stations in the area, as well as the recovery of sensitive plant bioindicators (e.g. epiphytic and ground lichens) at varying distances from the smelter. Satellite imagery indicates that there has been an increase in lichen coverage in the area during the period 1994 to 2004. SO_2 concentrations measured in Svanvik have remained below the critical level of 20 µg/m^3 (annual average) for the protection of the environment since 1989.

• However, the SO_2 concentrations are still excessive in certain parts of the areas. The SO_2 concentrations in the town of Nikel are still three times higher than the limit value, and SO_2 concentrations above the limit value are as well expected to occur downwind to the north-east of the smelter.

• There are signs of a reversal in the acidification of some lakes (e.g. in the Vätsäri and Jarfjord lakes) that have earlier been severely affected by the deposition of acidic sulphur deposition (H_2SO_4), derived from SO_2 emissions from the smelters. There have been improvements in the water quality and fish populations of lakes located at distances of ca. 30 km to the north-west and ca. 50 km to the west of the smelter. New studies on the allopatric population of brown trout in Lake Otervatn show that the brown trout population has recovered almost completely in recent years.

• There has also been a recovery in the coverage of ground lichens 10 km to the west of the smelter, and signs of an increase in the coverage of epiphytic lichens at a distanc eof more than 70 km to the west of the smelters.

• There does not appear to have been a corresponding decrease in heavy metal emissions. According to measurements made at a number of air-quality monitoring stations, the deposition of Ni, Cu, Co, As Pb, Cd and Cr in the area has continued at an unacceptably high level and, during the past two years, the deposition of e.g. Ni has increased. The accumulation of heavy metals (especially Ni) in mosses has increased during the past 15 years. Water chemistry data indicate that there has been no decrease in the levels of Cu, and Ni in the Paz watercourse during the last 6 years.

• The area affected by emissions from the smelters is strongly determined by the prevailing wind directions. Elevated heavy metal concentrations in lake and river sediments, soil and plants occur up to a distance of ca. 50 km to the north, south-west and west of the smelter. There are no signs of soil acidification in the area, primarily due to the fact that the bedrock to the south and east of the smelter consists of basic materials.

• There are clear gradients in heavy metal concentrations in many of the plant and aquatic components of the ecosystems in the area, i.e. decreasing concentrations with increasing distance from the smelters. However, the gradients are relatively steep and short, and extend for only a few tens of kilometres e.g. to the west.

• The effects of heavy metal emissions from the smelters are clearly evident in the Paz watercourse. The watercourse receives pollutants via atmospheric deposition as well as through the direct discharge of wastewater from the mines and smelter complex. Heavy metal concentrations are highest close to the smelter, and decrease on moving downriver and upstream from the emission sources.

• There is no information available about the situation to the east of the smelter complex.

• Fish in some parts of the area, especially in Lake Kuetsjarvi (in the Paz watercourse), contain high concentrations of heavy metals, and the concentrations of Cu and Ni in edible berries growing relatively close to the smelter currently exceed the maximum levels allowed in foodstuffs for human consumption. The concentrations of PAH and POPs are generally the highest in surface sediments, which indicates that the levels have increased during the last 10 years . In Lake Kuetsjärvi, the sediments are classified as "markedly" to "strongly contaminated" by heavy metals, POPs and PAHs.

7 Overall recommendations for a joint monitoring and assessment system

The results of the project clearly show that there is a need for a joint, trilateral monitoring programme to follow up the effects of the modernisation process at the Petchenganickel combine and to assess the future state of the environment in the Norwegian, Finnish and Russian border area. The monitoring network will provide the means for carrying out this task. However, there are a number of issues and topics which still need to be addressed.

- **It is recommended to implement the joint monitoring programme gradually. Sub-programmes that have been harmonized and tested during the project, and which are now ready for implementation, should be initiated at the beginning of 2007. Other necessary components should be developed and included in the trilateral monitoring programme as soon as possible.**

In order to be able to assess the effects of the modernisation process on air quality in the area, reliable emission data and results from deposition models are essential to estimate the extent of the area affected by air pollution and to link air pollution to the effects on terrestrial and aquatic ecosystems.

- **It is extremely important to guarantee continuation of the most important measurements (SO_2, meteorology, heavy metals in air and precipitation, main components) using harmonized equipment at the existing key air-quality monitoring stations at Nikel in Russia, Svanvik in Norway and Sevettijärvi in Finland. An additional monitoring site should be established to the north-east or east of the smelter complex.**

There are signs of a slight recovery in the condition of terrestrial and aquatic ecosystems in some parts of the area. The ongoing modernization of the Pechenganikel smelter complex will most probably lead to a further decrease in emissions. Monitoring the recovery and its biological effects are essential. On the other hand, the concentrations of pollutants in many components of the ecosystems are still excessive and will continue to have a considerable effect on the environment in certain parts of the area .

- **It is recommended that monitoring the selected range of attributes and parameters should be continued at predefined intervals on the network of plots employed in the terrestrial sub-project, and at the sampling locations in the aquatic sub-project.**
- **Integrated studies should be carried out in a number of catchment areas (e.g. lake and surrounding land area) in order to calculate input-output budgets for heavy metals and acidifying components.**

Very little is currently known about the sources of organic pollutants (POPs and PAHs) in the air and in terrestrial and aquatic ecosystems in the area affected by the Pechenganickel industrial complex. The limited screening of organic pollutants, performed at a number of locations in the Inari-Paz watercourse during the project, suggests that the input of organic pollutants from local sources, possibly the Pechenganickel smelter complex, could be relatively high.

- **It is strongly suggested that extensive screening of POPs and PAHs in the air and in terrestrial and freshwater ecosystems of the border area should be carried out in order to identify and map possible sources and to determine the levels of organic pollutants and the possible threat of accumulation in the food chains.**

Global climate change will undoubtedly have an effect on the functioning of terrestrial and aquatic ecosystems and the sensitivity of species in the area. A future integrated assessment should take into account the combined effects of the modernization of the Pechenganikel smelter, the interactive effects of climate change, the long-range transportation of pollutants from sources outside the area, as well as changes in land use in the Norwegian, Russian and Finnish border region.

- **It is recommended to establish a international research group (with representatives from governmental authorities) to carry out the monitoring work as co-operation between the three countries, and to develop the monitoring programme in accordance with present and future challenges.**

There is no information currently available about the air quality, deposition and state of terrestrial and water ecosystems to the east of the smelters.

- **This situation should be corrected by establishing one new air-quality monitoring and meteorological station, four new terrestrial ecosystem monitoring plots along a transec-t running to the east of Nikel, and a number of aquatic monitoring locations. The state of the environment should be monitored by assessing all the selected attributes and parameters on these plots as soon as possible.**

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DOCUMENTATION PAGE

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Abstract	The main threat to aquatic and terrestrial environments in the joint Norwegian, Finnish and Russian border area is the neighbouring Pechenganikel industrial complex, located on the Kola Peninsula in NW Russia. Emissions from the complex comprise extremely high levels of sulphur dioxide, and particulate material containing a wide range of toxic heavy metals, primarily copper and nickel. The aim of the report is to give an overall view of the current state of the environment, and on changes that have taken place in recent years, in the border area, primarily in the Paz River basin. This publication includes summarized information about air quality and deposition, water quality and the state of aquatic ecosystems in the Inari-Paz watercourse and a number of small lakes, as well as the state of terrestrial ecosystems. In addition, the report presents specific recommendations for future monitoring activities in the Norwegian, Finnish and Russian border area. The results of the studies carried out in this project, as well as the results of earlier national monitoring and scientific research projects, were used to develop a joint monitoring programme for the three countries. There are signs of a slight recovery in the condition of aquatic and terrestrial ecosystems in some parts of the area due to the reduction of sulphur dioxide emissions from the smelters during the past two decades. However, the sulphur dioxide and heavy metal emissions are still excessive and are continuing to have major effects on the environment. The impact of sulphur deposition was clearly evident up to tens of kilometres from the smelters. Even though heavy metal concentrations in many of the plant and aquatic components of the ecosystems decrease relatively sharply with increasing distance from the smelters, the accumulation of pollutants in the ecosystems is continuing. The effects of emissions from the Pechenganikel are most clearly evident in the Paz watercourse, which receives pollutants through the direct discharge of wastewater from the mines and smelter complex as well as via atmospheric deposition. A future joint trilateral monitoring programme is based on the most sensitive indicators highlighted in the present studies in order to be able to follow future changes in the environment under variable pollution levels.	
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KUVAILULEHTI

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<tr><td>Julkaisun nimi</td><td colspan="4">State of the Environment in the Norwegian, Finnish and Russian Border Area
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http://www.environment.fi/publications</td></tr>
<tr><td>Tiivistelmä</td><td colspan="4">Norjan, Suomen ja Venäjän raja-alueella suurin ympäristön tilaan vaikuttava tekijä on Kuolan niemimaalla sijaitseva Petšenganikel-kombinaatti, jossa tuotetaan kuparia, nikkeliä ja rikkihappoa. Kombinaatin päästöt sisältävät erittäin suuria määriä rikkidioksidia ja raskasmetalleja, pääasiassa nikkeliä ja kuparia.

Tämä raportti on katsaus maiden rajaseudun ympäristön nykytilaan ja siinä viime vuosina tapahtuneisiin muutoksiin. Pääpaino on Paatsjoen vesistöalueella. Julkaisu sisältää tietoa alueen ilmanlaadusta, kuormittavasta laskeumasta, seudun vesistöjen vedenlaadusta sekä vesiekosysteemien ja maaekosysteemien tilasta. Raportissa esitetään myös suosituksia ympäristöseurannan toteuttamiseksi Norjan, Suomen ja Venäjän raja-alueella. Hankkeen tutkimusten ja selvitysten tuloksia käytettiin kolmen maan yhteisen ympäristöseurantaohjelman laatimiseen.

Petšenganikel-kombinaatin rikkidioksidipäästöt ilmaan ovat vähentyneet kahden viime vuosikymmenen aikana. Sen seurauksena sekä vesi- että maaekosysteemeissä on paikoin näkyvissä lieviä rikkilaskeumasta toipumisen merkkejä. Rikkidioksidi- ja raskasmetallipäästöt ovat kuitenkin edelleen suuria ja niiden vaikutus ympäristöön on huomattava. Rikkidioksidilaskeuman vaikutus on havaittavissa jopa kymmenien kilometrien etäisyydellä päästölähteestä. Raskasmetallipitoisuudet kasveissa ja vesistöissä laskevat melko jyrkästi välimatkan sulatoista lisääntyessä, mutta niiden kerääntyminen ekosysteemeihin kuitenkin jatkuu. Petšenganikelin toiminnasta aiheutuvat haitat ovat selvimmin näkyvissä Paatsjoessa, joka saastuu paitsi ilmasta käsin, merkittävästi myös jokeen pääsevien kaivaus- ja metalliteollisuusjätevesien vuoksi.

Kolmen maan yhteinen ympäristöseurantaohjelma perustuu tässä hankkeessa testattuihin herkimpiin indikaattoreihin. Niiden avulla pystytään seuraamaan ympäristössä tapahtuvia muutoksia kuormitustason vaihdellessa.</td></tr>
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Utgivelsesseriens tema	Miljøvern			
Utgivelsesseriens deler/ andre utgivelser fra sammet prosjekt	Raporten finnes på Internet: http://www.environment.fi/publications			
Sammendrag	Hovedtrusselen for det akvatiske og terrestriske naturmiljøet i det felles norske, finske og russiske grenseområdet er det nærtliggende Pechenganikel industrikomplekset, lokalisert på Kolahalvøya i Nordvest-Russland. Utslipp fra komplekset omfatter ekstremt høye nivåer av svoveldioksid, og partikkelmateriale som inneholder en rekke toksiske tungmetaller, primært kobber og nikkel. Målet med rapporten er å gi en oversikt over dagens miljøstatus, og endringer som har skjedd de siste årene i grenseområdet, primært i Pasvikelvas nedbørsfelt. Denne publikasjonen inneholder oppsummert informasjon informasjon om luftkvalitet og deposisjon av forurensende forbindelser, vannkvalitet og tilstanden til akvatiske økosystemer i Pasvik-Enare vassdraget og flere små innsjøer, samt tilstanden til terrestriske økosystemer. I tillegg presenterer rapporten spesifikke anbefalinger for fremtidige overvåkingsaktiviteter i det norske, finske og russiske grenseområdet. Resultatene fra undersøkelsene utført i dette prosjektet har sammen med resultater fra tidligere nasjonal overvåking og vitenskapelige forskningsprosjekter blitt brukt til å utvikle et felles overvåkingsprogram for de tre landene. Det er tegn på en svak bedring i tilstanden til akvatiske og terrestriske økosystemer i deler av området, dette skyldes reduserte utslipp av svoveldioksid fra smelteverket i løpet av de to siste tiårene. Imidlertid er utslippene av svoveldioksid og tungmetaller fortsatt svært høye og har stor effekt på miljøet. Effekten av svovelavsetningen var påtakelig opp til et titalls kilometer fra smelteverket. Selv om tungmetallkonsentrasjonen i mange komponenter av de terrestriske og akvatiske økosystemene avtar relativt brått med økende distanse fra smelteverket, fortsetter akkumuleringen av forurensende stoffer i økosystemene. Effektene av utslipp fra smelteverket er mest merkbart i Pasvikvassdraget, som tilføres forurensende stoffer gjennom det direkte utslippet av avløpsvann fra gruvene og smelteverket i tillegg til utslipp via atmosfæren. Et framtidig felles trilateralt overvåkingsprogram bør baseres på de mest sensitive indikatorene som trekkes fram i disse undersøkelsene for å kunne følge framtidige endringer i miljøet.			
Emneord	Miljø, overvåkning, luftkvalitet, utslipp, vannkvalitet, akvatisk, land, økosystemer			
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Trykkrsted og -år	Kopijyvä Oy, Jyväskylä 2007			

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http://www.environment.fi/publications</td></tr>
<tr><td>Резюме</td><td colspan="4">Горно-металлургический комбинат ”Печенганикель”, расположенный на северо-западе Мурманской области, является одним из самых крупных объектов, влияющих на состояние природной окружающей среды в приграничном районе Норвегии, Финляндии и России. Промышленные выбросы комбината содержат высокие концентрации диоксида серы и тяжёлых металлов, в первую очередь меди и никеля.

Данный отчёт является обзором настоящего состояния окружающей среды и произошедших за последние годы изменений в приграничном районе, прежде всего в бассейне реки Паз. В публикации помещена информация о качестве воздуха и воды, состоянии наземных и водных экосистем как реки Паз, так и ряда малых озёр. В отчёте также приводятся рекомендации по мониторингу в приграничном районе Норвегии, Финляндии и России. Результаты исследований проекта, также как и данные национальных программ мониторинга и предыдущих исследований были использованы для разработки совместного мониторинга.

Выбросы диоксида серы за последние двадцать лет значительно сократились. В следствии этого в определённых районах исследованной территории были замечены некоторые признаки улучшения состояния водных и наземных экосистем. Тем не менее уровень выбросов серы и тяжёлых металлов всё ещё очень высок, и по-прежнему оказывает определяющее воздействие на окружающую среду приграничного района. Влияние загрязняющих выпадений серы прослеживается на расстоянии нескольких десятков километров от источника загрязнения. Хотя содержание тяжёлых металлов в наземной и водной среде довольно резко сокращается по мере удаления от комбината, их накопление в экосистемах продолжается. Наиболее заметно негативное влияние деятельности “Печенганикель” в реке Паз, которая кроме атмосферного загрязнения подвержена также и влиянию сточных вод горно-металлургического производства.

Будущая совместная программа мониторинга трёх стран должна быть основана на чувствительных индикаторах загрязнения, выделенных в данном проекте, для выявления изменений в окружающей среде в условиях изменяющейся антропогенной нагрузки.</td></tr>
<tr><td>Ключевые слова</td><td colspan="4">Окружающая среда, мониторинг, качество воздуха, выбросы, качество воды,
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Almmuheaddji	Lapland birasguovddáš ja Finnmárkku Fylkkamánni	*Dáhton* Njukčamánnu 2007
Čálli(it)	Kerstin Stebel, Guttorm N. Christensen, John Derome, Ilona Grekelä	
Almmuhusa bajilčála	**State of the Environment in the Norwegian, Finnish and Russian Border Area** (Birasdilli norgga, suoma ja ruošša rádjaguovllus)	
Almmuhusa namma ja nummir	The Finnish Environment 6/2007	
Almmuhusráiddu fáddá	Birasgáhtten	
Almmuhusráiddu oasit/eará alømmuhusat fra sammet prosjekt	Raporta lea gávdnamis Interneahtas: http://www.environment.fi/publications	
Čoahkkáigeassu	Váldouhkádus čáhce ja eatnama luonddubirrasii oktasaš Norgga, Suoma ja Ruošša rádjeguovllus lea Pechenganikel industriijarustet mii lea Guoládatnjárggas Oarje-Davve Ruoššas. Luoitimat rustegis sisttisdolllet earenoamáš stuora hivvodagaid riššadioksida (svoveldioksid-SO_2), ja partihkkalávdnasiid mat sisttisdollet máŋga toksalaš lossametállaid, vuosttažettiin veaikki ja nikkela. Ulbmil rapporttain lea govvidit otná birasdili, ja rievdadusaid mat leat dáhpáhuvvan maŋimus jagiid rádjaguovllus, vuosttažettiin Báhčaveaijogas. Dán diehtočállosis leat čoahkkáigesson dieđut áibmokvalitehta ja njuoskkadaga, čáhcekvalitehta ja makkár dilli lea čáhce ekovuogádagain Anar-Báhčaveai čazádagas ja eará smávit jávriin, ja seammas maiddái makkár dilli lea luonddubirrasa ekovuogádagas. Dasa lassin leat raporttas maiddái čielga ja earenoamáš evttohusat makkár vákšundoaimmat berrejit leat Norgga, Suoma ja Ruošša rádjaguovlluin. Dán prošeavtta bohtosat oktan ovdalaš riikkasis vákšundoaimma ja dieđalaš dutkanprošeavtta bohtosat leat geavahuvvon ovdanahttimis oktasaš vákšunprográmma dáin golmma riikkain. Dilli čáhce ja eatnama luonddubirrasis lea veaháš rievdan buoret guvlui go SO_2 luoitimat šolgadanrustegis maŋimus moaddelot jagis lea unnon. Dattetge leat ain hui alla SO_2 ja lossametálla luoitimat ja váikkuhit sakka lundui. Beaktu riššaluoittuin vuhttui gitta logenar kilomehtara eret šolgadanrustegis. Vaikko lossametállahivvodat máŋgga ekovuogádaga šaddo- ja čáhce komponeantain njiedjá oalle jođanit mađii guhkelii eret lea šolgadanrustegis, de čoggojupmi ja nuoskkideaddji ávdnasat ekovuogádagain jotkojuvvo. Beaktu luoitimin šolgadanrustegis sáhttá buoremusat oaidnit Báhčaveaijogas, masa nuoskkideaddji ávdnasat golget sihke ruvke- ja šolgadanrustega duolvačáhceluoitima bakte ja mat áibmo bakte bohtet. Boahttevaš oktasaš golmmabeallásaš (trilaterala) váksunprográmma berre vuođđudit daid olmma hearkkimus beliid nala mat namuhuvvojit dáid guorahallamiin vai galget sáhttit čuovvut boahttevaš rievdadusaid birrasis rievdi nuoskkidan dásiid mielde.	
Fáddásánit	Biras, vákšun, áibmokvalitehta, luoitimat, čáhcekvalitehta, čáhce (akvatalaš, eanan, ekovuogádagat	
Ruhtadeaddji/ bargoaddi	EU / Interreg III A Kolarctic, Suoma Birasministeriia / Lapland birasguovddáš, Norgga Birasgáhttendepartemeanta, Davviriikkaid Ministtarráđđi, Barentsčállingoddi ja Finnmárkku Fylkkamánni og Fylkesmannen i Finnmark	

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Prentenbáiki ja -jahki	Kopijyvä Oy, Jyväskylä 2007

State of the Environment in the Norwegian, Finnish and Russian Border Area

This publication presents information on the current state of the environment and it's changes in recent years in the border area of the three countries: Norway, Finland and Russia. The major threat to the natural environment in the area is posed by the Pechenganikel industrial complex, where copper and nickel ore has been mined and processed for over 70 years.

The environmental authorities and researchers in the three countries have created long-term environmental monitoring programme for getting comprehensive and current information on changes taking place under the varying anthropogenic load.
The programme is based on the outputs of the monitoring, research, evaluation and development activities carried out by an international group of scientists presenting more than twenty organizations.

The research and development work for creation a trilateral monitoring was done within the Interreg IIIA Kolarctic project **"Development and implementation of an environmental monitoring and assessment programme in the joint Finnish, Norwegian and Russian border area"** during the period 2003–2006.

Few reports of the individual studies carried out during the project are summarized in this publication and appended to it as a CD appendix. Recommendations for monitoring activities in the Norwegian, Finnish and Russian border area are given in the individual reports as well as in the publication.

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