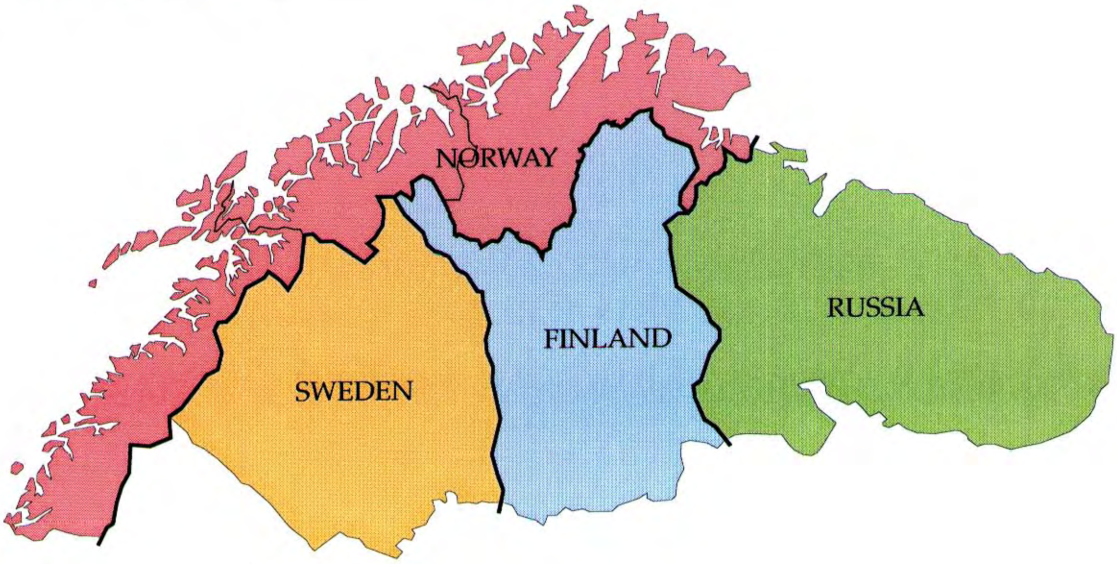
REPORT SNO 3633-97

Regional Lake Surveys in The Barents region of Finland, Norway, Sweden and Russian Kola, 1995

Results

Acid Rain Research

REPORT 45/97



Finnish Environment Institute

Swedish University of Agricultural Sciences

Institute of North Industrial Ecology Problems

Norwegian Institute for Water Research

Norwegian Institute for Water Research

REPORT

Main Office	**Regional Office, Sørlandet**	**Regional Office, Østlandet**	**Regional Office, Vestlandet**	**Akvaplan-NIVA A/S**
P.O. Box 173, Kjelsås	Televeien 1	Sandvikaveien 41	Nordnesboder 5	Søndre Tollbugate 3
N-0411 Oslo	N-4890 Grimstad	N-2312 Ottestad	N-5008 Bergen	N-9000 Tromsø
Norway	Norway	Norway	Norway	Norway
Phone (47) 22 18 51 00	Phone (47) 37 29 50 55	Phone (47) 62 57 64 00	Phone (47) 55 30 22 50	Phone (47) 77 68 52 80
Telefax (47) 22 18 52 00	Telefax (47) 37 04 45 13	Telefax (47) 62 57 66 53	Telefax (47) 55 30 22 51	Telefax (47) 77 68 05 09

Title Regional Lake Surveys in The Barents region of Finland - Norway - Sweden and Russian Kola 1995 - Results.	Serial No. 3633-97	Date
	Report No. Sub-No. O-96163	Pages Price 36
Author(s) *Arne Henriksen* *Jaakko Mannio (FEI)* *Anders Wilander (SLU)* *Tatyana Moiseenko (INEP)* *Tor S. Traaen* *Brit Lisa Skjelkvåle* *Eirik Fjeld* *Jussi Vuorenmaa (FEI)*	Topic group Acid Rain	Distribution
	Geographical area Barents region	Printed NIVA

Client(s) The Barents Secretariat	Client ref. Project 3711

Abstract

The Euro-Arctic Barents Region includes Lapland County (Finland), Nordland, Troms and Finnmark Counties (Norway), the Norrbotten County (Sweden) and Arkhangelsk and Murmansk Counties and the Republic of Karelia (Russia). The three Nordic countries and Russian Kola carried out new national lake surveys in the fall of 1995. Because of the special interest in the local resources in the Barents area, the Barents Secretariat has supported a project which evaluates the chemical properties of the lakes located within the Barents region in Norway, Sweden, Finland and Russian Kola.

In general, the lakes of the Barents region of the Nordic countries are less acid than the lake populations in the countries as a whole. The most acid lakes are found in Russian Kola, where also the organic carbon content is highest. The nitrate concentrations are generally lower in the Barents region than in the countries as a whole. This is in good agreement with the low N depositions in the Barents region. The critical loads of acidity in the Barents region are highest in Norway, while they are largely at similar levels in the other three areas. For Norway, the critical loads in the Barents region are substantially higher than for the whole country, because the most sensitive areas are located in southern Norway. For Finland and Sweden the opposite is the case. The critical loads are exceeded in the Barents region, the highest percentage are found in Russian Kola (14%) and Norway (12%), while Sweden shows the lowest percentage (3%). The data from the lake monitoring programs in the Nordic countries and Russian Kola show that the lakes in the area give a rapid response to reduced sulphur depositions. The planned reconstruction of "Pechenganikel" smelter will give a significant reduction in emissions of sulphur and heavy metals resulting in reduced adverse effects on the ecosystems in the area. It is important to continue environmental research and monitoring in the border areas. Such a programme is needed in order to study the reversibility of acidification and to what extent the actions will be sufficient.

4 keywords, Norwegian		4 keywords, English	
1.	Innsjøer	1.	Lakes
2.	Vannkjemi	2.	Water chemistry
3.	Sur nedbør	3.	Acid deposition
4.	Tålegrenser	4.	Critical loads

Arne Henriksen

Arne Henriksen
Project manager

ISBN 82-577-3191-9

Bjørn Olav Rosseland

Bjørn Olav Rosseland
Head of research department

Regional Lake Surveys in
The Barents region of
Finland - Norway - Sweden and Russian Kola
1995
Results

by

Arne Henriksen
Tor S. Traaen
Brit Lisa Skjelkvåle
Eirik Fjeld
Norwegian Institute for Water Research,
P.O.Box 173 Kjelsås, 0411 Oslo, Norway

Jaakko Mannio
Jussi Vuorenmaa
Finnish Environment Institute
P.O. Box 140, FIN-00251 Helsinki, Finland

Anders Wilander
Department of Environmental Assessment
Swedish University of Agricultural Sciences
P.O. Box 7050, S-750 07 Uppsala, Sweden

Tatiana Moiseenko
Institute of North Industrial Ecology Problems
Kola Centre of the Russian Academy of Sciences
14 Fersman Str. 184200 Apatity, Murmansk region, Russia

Preface

Regional lake surveys were carried out in in the fall of 1995 in the countries Norway, Finland, Sweden, Russian Kola, Russian Karelia, Scotland, Wales and Denmark (1996). The planning and coordination, as well as a common evaluation of the collected data were supported by the Nordic Council of Ministers. The sampling and survey in Sweden was a part of the National lake Survey funded by the Swedish Environmental Protection Agency (SNV). The Norwegian survey was funded by the Norwegian Pollution Control Authority (SFT), and the Finnish lake survey was funded by the Finnish Environment Institute. The lake survey at Kola was supported by Norwegian Department of Environment (MD) and Swedish Environmental Protection Agency.

A special evaluation of the properties of the lakes in the Barents region of Norway, Finland, Sweden and Russian Kola is presented here, supported by the Barents Secretariat under contract no. "Project 3711".

Oslo, 24 March, 1997.

Arne Henriksen

Contents

Summary

The Euro-Arctic Barents Region includes Lapland County (Finland), Nordland, Troms and Finnmark Counties (Norway), Norrbotten County (Sweden), Arkhangelsk and Murmansk Counties and the Republic of Karelia (Russia). The three Nordic countries and Russian Kola carried out new national lake surveys in their respective countries in the fall of 1995. Because of the special interest in the local resources in the Barents area, the Barents Secretariat has supported a project which evaluates the chemical properties of the lakes located within the Barents region in Norway, Sweden, Finland and Russian Kola. We report here subsets of data from the contemporary lake surveys in the Nordic countries and Murmansk county in Russia (Russian Kola).

Most of the investigated area of 462 000 km^2 is situated north of the Polar Circle. Approximately 2 million people inhabit the area. The Barents Region contains some of the largest pristine wilderness areas in Europe, as well as heavily polluted industrial areas. The numerous lakes and rivers are vital resources for settlement pattern, food and energy production, industrial development, transport, recreation and tourism. The water quality is therefore of great importance for the population as well as for the general ecology of the area.

In general, the lakes of the Barents region of the Nordic countries are less acid than the lake populations in the whole countries. The most acid lakes in the Barents region are found in Russian Kola, where also the organic carbon content are highest. There are fewer low alkalinity lakes in the Barents region than in the countries as a whole. The nitrate concentrations are generally lower in the Barents region than in the countries as a whole. This is in good agreement with the low N depositions in the Barents region.

The critical loads of acidity in the Barents region are highest in Norway, while they are largely at similar levels in the other three areas. For Norway, the critical loads in the Barents region are substantially higher than for the whole country, because the most sensitive areas are located in southern Norway. For Finland and Sweden the opposite is the case. The critical loads are exceeded in all countries in the Barents region, the highest percent of exceeded lakes are found in Russian Kola (14%) and Norway (12%), while Sweden shows the lowest percent of exceeded lakes (3%). For Norway and Sweden the percent of exeeded lakes are higher for the whole country than for the Barents region.

The data from the lake monitoring programs in the Nordic countries and Russian Kola show that the lakes in the area give a rapid response to reduced sulphur depositions. The planned rebuilding of "Pechenganikel" smelter will give significant reduction in emissions of sulphur and heavy metals resulting in reduced adverse effects on the ecosystems in the area. Due to accumulated heavy metals in soils and lake sediments, the reduction of heavy metal concentrations will probably be a much slower process. It is important to continue environmental research and monitoring in the border areas. A follow up monitoring programs in this area will give us an unique opportunity to study the reversibility of acidification at several ecosystem levels.

1. Introduction

The Euro-Arctic Barents Region includes Lapland County (Finland), Nordland, Troms and Finnmark Counties (Norway), Norrbotten County (Sweden), Arkhangelsk and Murmansk Counties and the Republic of Karelia (Russia) (Figure 1).

Most of the area of 462 000 km^2 is situated north of the Polar Circle. Approximately 2 million people inhabit the area. The Barents Region contains some of the largest pristine wilderness areas in Europe, as well as heavily polluted industrial areas. Important natural resources include forest, fish and minerals. Oil and gas from the Barents Sea are believed to become of increasing importance in the near future. The numerous lakes and rivers are vital resources for settlement pattern, food and energy production, industrial development, transport, recreation and tourism. The water quality is therefore of great importance for the population as well as for the general ecology of the area.

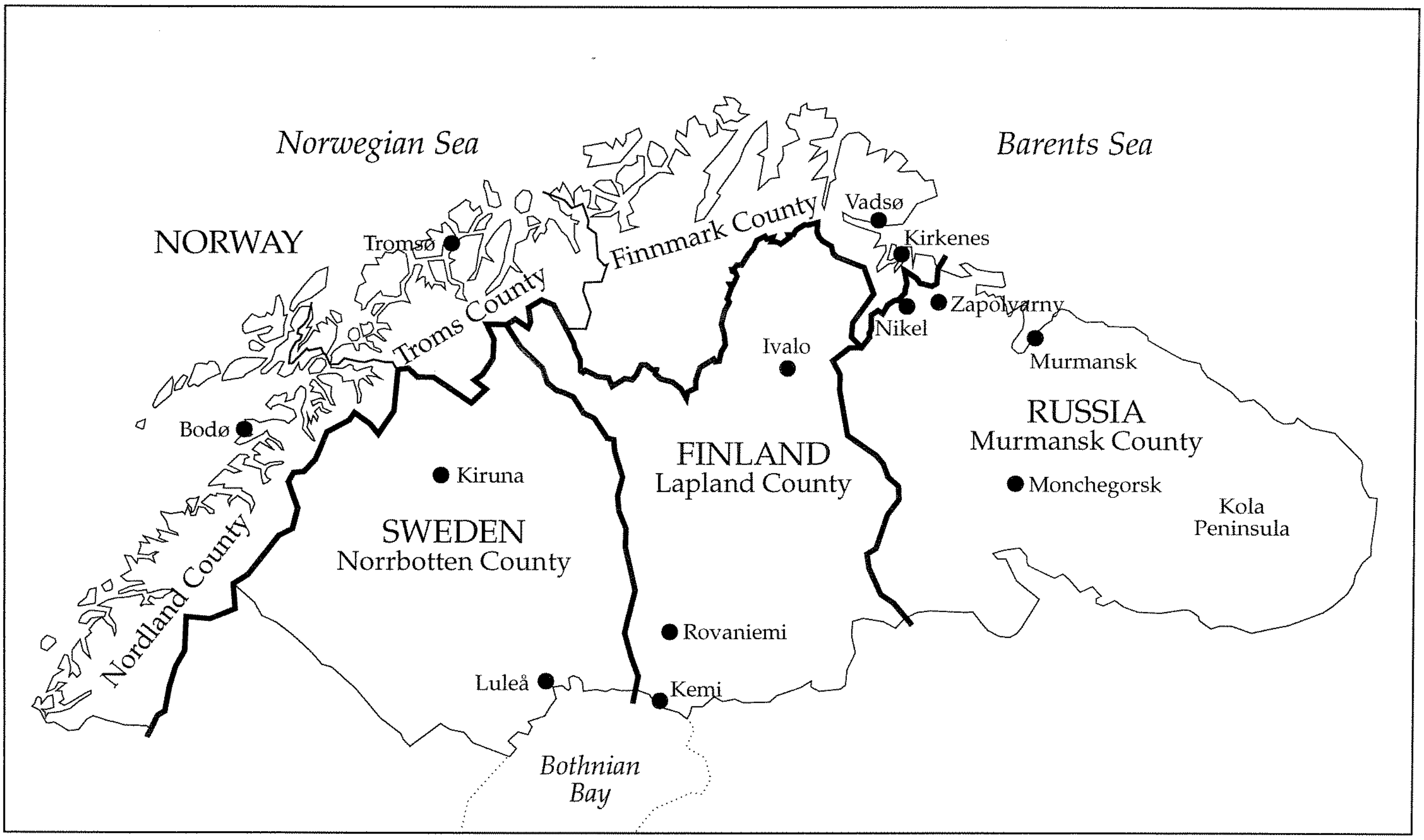


Figure 1. **The studied parts of the Barents region. The Arkhangelsk County and the Republic of Karelia (Russia) are not included in this study.**

The Kola Peninsula (Murmansk Region) experience tremendous adverse ecological effects due to emissions of SO_2 and heavy metals from large nickel smelters. Precipitation falling in this area is severely polluted by strong acids and heavy metals. About 100 km^2 around the industries in the Pechenga and Monchegorsk area are turned into wasteland unsuitable for plants and animals. Adverse effects on nature are observed at least 100 km from the main industrial sites. Rivers and lakes are polluted by heavy metals, waste particles, organic matter and acid rain. Due to economical crisis and decreasing production at the metallurgical enterprises "Pechenganickel" and "Severonickel" emissions of SO_2 were considerably reduced in the early 90's (Figure 2). This trend was however broken in 1995 when there was a marked increase in SO_2 emissions.

Because of the special interest in the local resources in the Barents area, the Barents Secretariat has supported a project which evaluates the chemical properties of the lakes located within the Barents region in Norway, Sweden, Finland and Russian Kola based on lake surveys carried out in 1995 in the four countries (Henriksen et al. 1996).

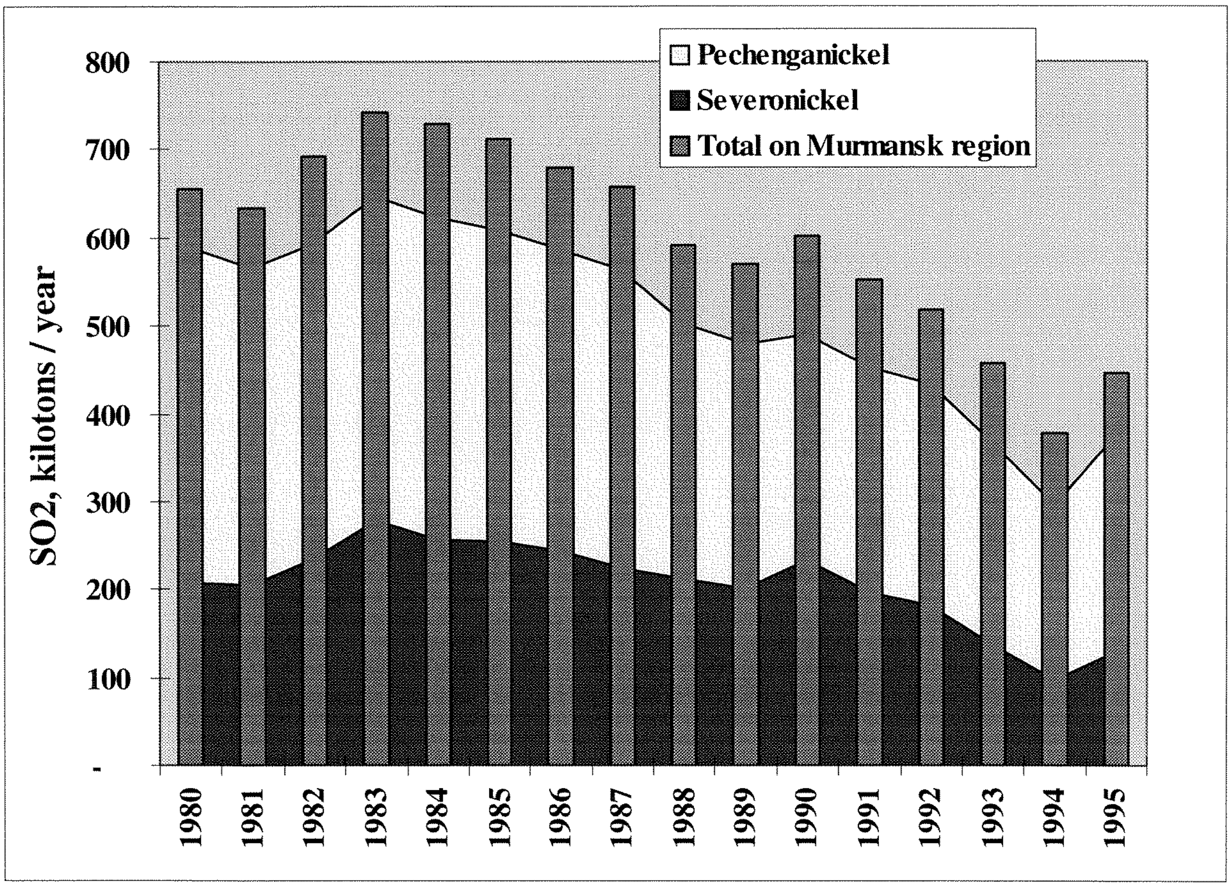


Figure 2. **Emissions of SO_2 from copper-nickel smelters on Russian Kola.**

1.1 Previous lake studies in the Barents region

1.1.1 National lake surveys

Regional lake surveys have previously been carried out in the three Nordic countries, Finland, Norway and Sweden. Finland carried out their first survey in 1987 comprising 987 lakes. Norway started already in the mid 70's, and followed up with an extensive regional survey in 1986 (1005 lakes). Sweden has carried out several lake surveys, the most extensive one in 1990 (4018 lakes). The Finnish and Swedish latest surveys were based on statistical selection of lakes from their national lake registers, while the Norwegian survey was based on subjectively selected lakes within areas with geology giving lakes sensitive to acidification.

The water chemistry data bases for these Nordic surveys were used for the assessment of critical loads and critical load exceedances of surface waters within each of the three nordic countries (Bernes 1986, Forsius et al. 1990, Henriksen et al. 1988, Henriksen et al. 1990, Posch et al. 1997).

During the period 1990-1992 a survey of 370 lakes was conducted in the Russian Kola, based on the sampling and analytical methods used in the Nordic countries (Henriksen et al. 1990).

The three Nordic countries carried out new national lake surveys in their respective countries in the fall of 1995. As a result of Norwegian-Finnish-Swedish-Russian initiatives lake surveys were also carried out concurrently in Russian Kola and the Russian Karelia with financial support from Finland, Norway and Sweden. The working group of the NMR-project also invited the United Kingdom to join the lake survey. As a result of this initiative a lake survey was concurrently carried out in Scotland and Wales, with similar lake selection criterias and sampling methods as in the nordic countries. (Henriksen et al. 1996, 1997).

1.1.2 The “Nordkalott” study

National lake survey data bases from Norway, Sweden and Finland have been used for national critical load calculations and mapping, and for some common assessment of critical load for the three Nordic countries. The concept of critical load has come into wide use in connection with international negotiations on reducing emissions of nitrogen and sulphur compounds. Quantitative estimates of the exceedances over the critical loads provide the means of assessing the present situation as well as the concequences of alternative target loads or deposition patterns resulting from alternative control strategies.

As part of the activities of the "Nordkalott project" an assessment of critical loads and critical load exceedances of the surface waters in Northern Fennoscandia (the Nordkalott area) was conducted (Henriksen et al. 1994a). The sources for this assessment were lake survey data collected in 1986 for Norway, 1988 for Finland and 1990 for Sweden. The Nordkalott area includes areas north of the 64.5^0 latitude.

> The "Nordkalott" committee is a permanent cooperative organization between Finland, Norway and Sweden with the intention of promoting a deeper cooperation in the Nordkalott area on the regional market and political activities and for joint projects that has a bearing on the employment in the area.

The report concluded: "The acidity of the deposition in the Nordkalott area is generally lower than in the southern parts of the Fennoscandian countries. Only in the areas of the smelters on the Kola peninsula the deposition is comparable to those found in the south. Geological and hydrological conditions regulates the critical load value for a given lake or stream, thus both high and low values are found within the area and the levels are very similar to those found for the whole of Fennoscandia. The results demonstrate large spatial variations in critical loads, and sensitive areas are found in scattered areas all over the Nordkalott area, especially in the northeast close to the Russian border. The highest exceedances of the critical load are found in these areas. The exceedances are, however, lower than in the most affected areas in Sweden and Norway. An exceedance of the critical loads occurred in about 11% of the observations in the Nordkalott area. For all three countries as much as 35% of sites are exceeded, and in the most affected areas, in southernmost Norway, almost 100% of the area is exceeded."

Acid precipitation impact on the Russian Kola was considerably higher compared to Northern Finland, Sweden and Norway. The critical loads were exceeded (for $ANC_{limit} = 20$ µeq/l) for 48% of lakes sampled in 1990-1992 in the industrialised areas of western and central Kola (Henriksen et al. 1994b).

1.2 Lake monitoring in the Barents Region

Norway

The border areas between Norway, Finland and Russia are today heavily polluted. Based on extensive chemical analyses of lake water samples collected in the study area, it has been demonstrated that extensive surface water acidification has taken place, particularly on the Norwegian side of the border (Traaen et al. 1991). Numerous small mountain lakes in the area were chronically acid (pH<5). Critical load determinations according to the method of Henriksen et al. (1990) showed that critical loads of sulphur deposition were exceeded in 70% of the area in Sør-Varanger (Traaen et al. 1993). To achieve lasting non-acid conditions in the lakes, the deposition of sulphur would have to be reduced by about 75%.

Lake monitoring in Sør-Varanger show that sulphate concentrations in lakes east of Kirkenes more than doubled in the period 1966 to 1986. From 1986 to 1989 the sulphate concentrations were quite stable. Some reductions in emissions from the smelters have occurred, and the effects of these reduction has already been manifested in lakes in Norway located northwest of the Pechenga Nikel smelter. From 1989 to 1995 the yearly average decrease in sulphate for 9 monitoring lakes (average lake area: 79 ha) was 1.9 µeq/l. and yearly average increase in pH was 0.05 pH units (Figure 3).

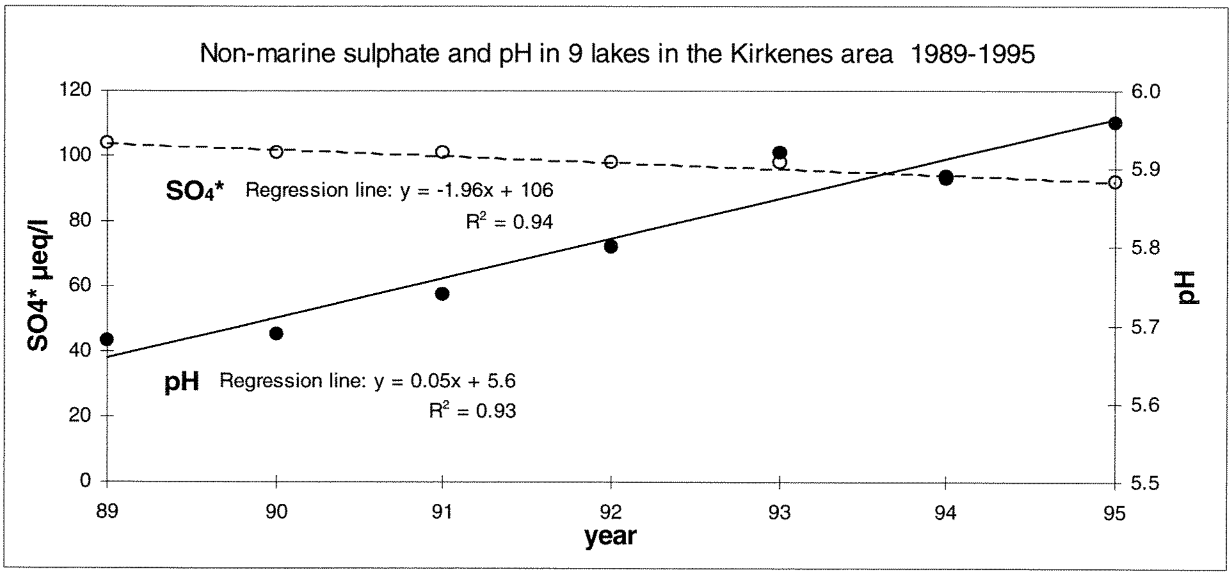


Figure 3. **Trends in average values in non-marine sulphate (o) and pH (•) for 9 monitoring lakes east of Kirkenes from 1989 to 1995.**

A similar, but stronger trend in sulphate was observed for 6 small (average lake area 6 ha), acid mountain lakes at Jarfjordfjellet (Figure 4), showing a yearly decrease of 4.0 µeq/l. From 1989 the corresponding increase in pH was 0.03 pH units/yr.

The reduced sulphate concentrations and the increasing pH in the lakes are in good agreement with the observed reduction in sulphur deposition (wet + dry) in the area the last years. At Svanvik the sulphur deposition was 0.96 gS/m^2 in 1987 and 0.76 gS/m^2 in 1994 (SFT 1988, SFT 1995).

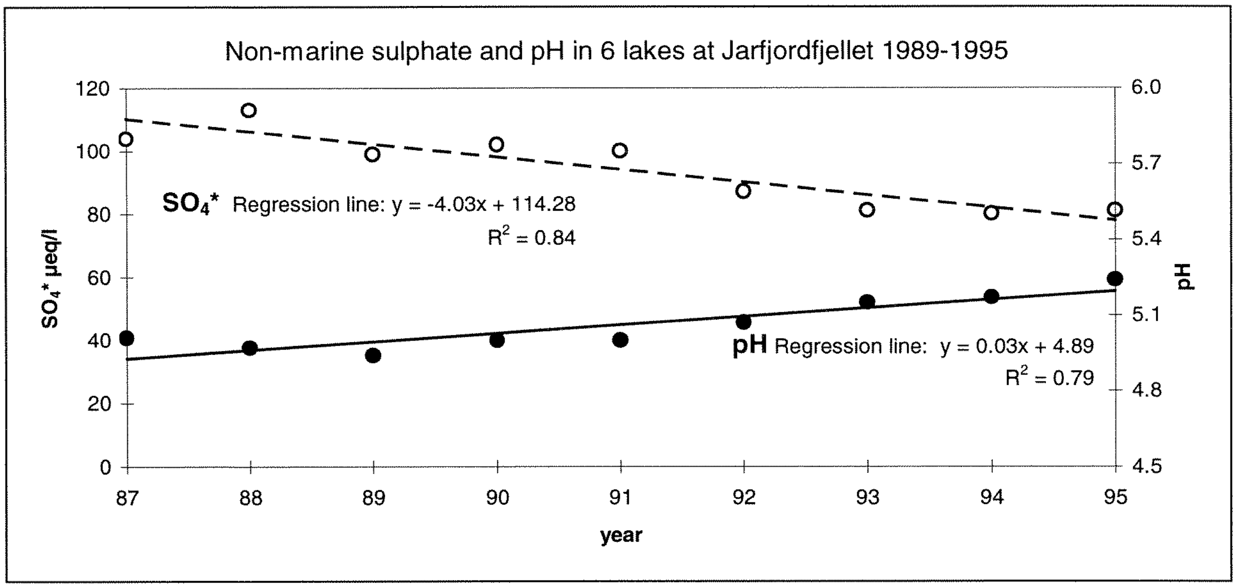


Figure 4. **Average trend in non-marine sulphate (o) and pH (•) in 6 small mountain lakes at Jarfjordfjellet.**

Kola

Studies of lakes located near the "Pechenganickel" smelter also show reduced sulphate concentrations during the early 90's (Figure 5).

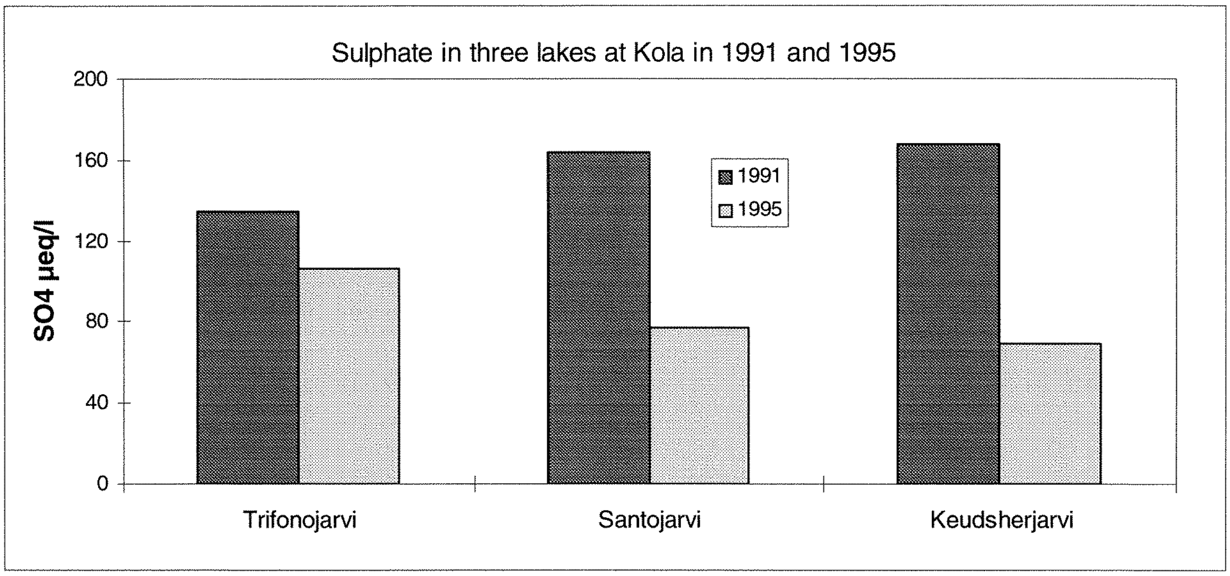


Figure 5. **Sulphate concentrations in the lakes Trifonojarvi, Santojarvi and Keudsherjarvi located**

Finland

Regional monitoring of lake acidification in Finland was extended after completion of the Finnish Lake Survey in 1987 (Forsius et al. 1990). Regular monitoring of surface waters in northern Finland was extended in the years 1990-91 to better cover the whole county of Lapland. Geographically, the monitoring lakes in Finnish Lapland can be divided in western and eastern lake groups based on estimated regional sulphur deposition patterns. The eastern part of Lapland is more exposed to atmospheric sulphur deposition derived from emissions of Cu-Ni smelters in Kola Peninsula than the western part. The eastern lakes (east of 27^{O} E) are small (average lake area: 15 ha), acid sensitive lakes (average BC*: 80 µeq/l) with moderate humic content (average TOC: 5.1 mg/l). These lakes (n=16) response clearly to anthropogenic sulphur deposition (Figure 6), because sulphur contributions from lithological sources, such as sulphide minerals in the soils and bedrock of the catchments, are small. Some monitoring lakes of the western group are located in the ore-rich central Lapland schist area and demonstrate sulphate anomalies (Kähkönen 1996).

Bulk deposition values of sulphate measured at Salla region located in Finnish-Russia border area show response to the reduction of SO_2 emissions in the Kola area during the 1990's. The station Värriö (69^{O} 45' N 29^{O}37' E) was established for measuring deposited air pollutants originating in the Kola region,and the bulk deposition of S was 317 mg S/m^2 in 1991 and 175 mg S/m^2 in 1994 (Leinonen and Juntto 1992, Leinonen 1996). The declining sulphate deposition seems to be reflected generally in eastern Lapland as lowered sulphate concentrations in the lakes. In the period 1990 - 1995 a yearly average decrease of sulphate concentrations in the lakes has been 1.17 µeq/l (Figure 5). However, a yearly variation in pH-value of these lakes has been wide, due to variations in hydrology and organic acidity. Therefore, a consistent and corresponding increase in pH cannot be expected.

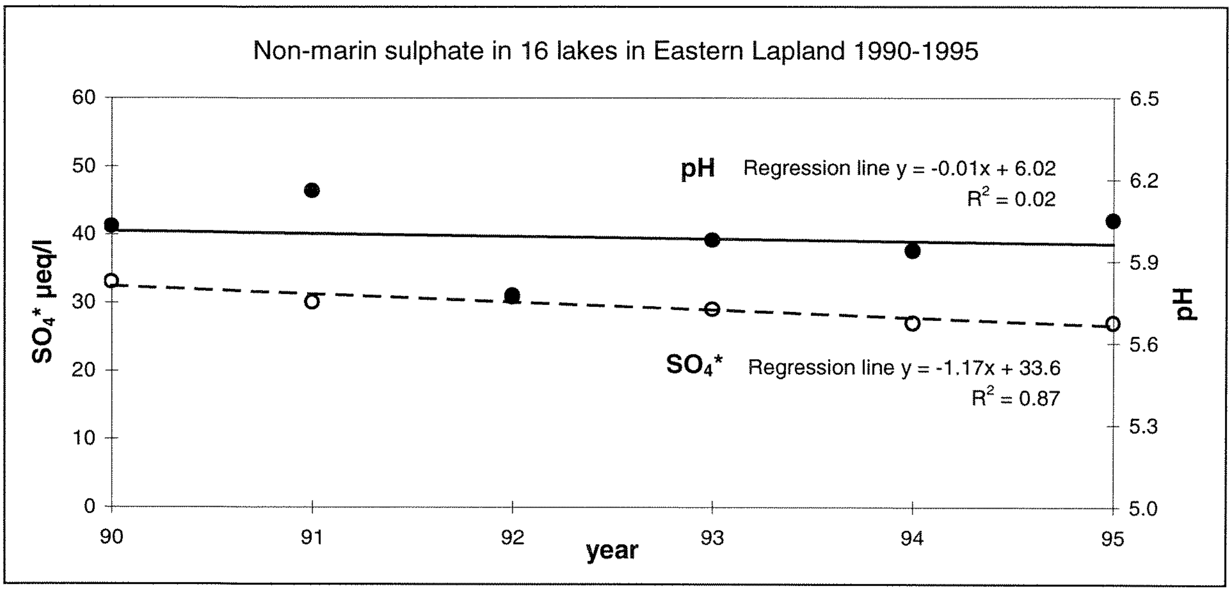


Figure 6. **Trend in non-marine sulphate (o) and pH (•) in 16 lakes in Eastern Lapland (east of 27°E), Finland, 1990 - 1995.**

Sweden

In Norrbotten, 13 lakes have been monitored twice since 1983 (Wilander, 1997). The non-marine sulphate declined in all lakes with an average of -0.8 µeq/l pr. year. There was a rise in alkalinity, although not significant except in 9 of the lakes. In Figure 6 the change in sulphate concentration is illustrated for a lake in northern Sweden, Lake Abiskojaure. The concentration of sulphate is relatively high due to the presence of shales and limestone in the drainage area. However there is a significant decline in non-marine sulphate at 1.26 µeq/l, with time which is likely to be the caused by the lowered deposition of sulphate in the drainage area. A similar trend is also evident on a large scale in River Torne älv located at the border between Finland and Sweden with a drainage area of 34063 km^2 (Figure 6). In this case the rate was -1.5 µeq/l pr. year. The changes observed in Swedish surface waters are thus less pronounced than those in northern Norway, but they add significant evidence of improvement in the Barents region.

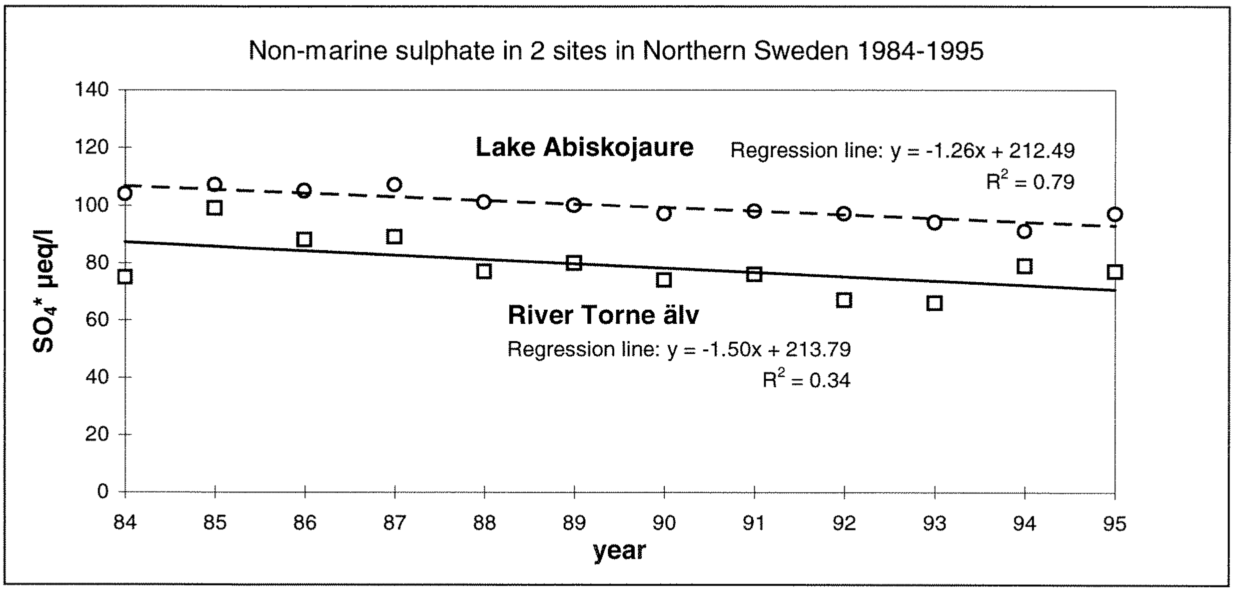


Figure 7. **Trends in non-marine sulphate in Lake Abiskojaure (o) and River Torne älv (□) in Northern Sweden.**

2. Present lake study

2.1 Lake selection

2.1.1 Finland, Norway and Sweden

In the Nordic Lake Survey 1995 (Henriksen et al. 1996) selection strategies and sampling methods were agreed upon. We will here describe how the lakes were selcted for the whole countries and on which criteria lakes were excluded even if this report only deals with lakes in the Barents region.

For Finland, Norway and Sweden the lakes were selected at random from the national registers with the common requirements that:

- a minimum of 1% of the lakes within any county/region shall be included
- the proportion of lakes in size classes 0.04-0.1, 0,1-1, 1-10 and 10-100 km^2 shall be 1-1-4-8; all lakes >100 km^2 shall be included.

The final number of lakes from different counties/regions has been made in slightly different ways, but with a common goal of achieving a larger proportion of lakes in areas with a high degree of acidification or critical load exceedance, few lakes and/or more variable lake chemistry (as estimated from previous surveys). Thus the proportion of lakes in the two smallest size classes was selected as follows:

Norway: 1.2 % in northern Norway, 2.1 % in middle Norway and 3.0 % in southern and eastern Norway.

Finland: 1.5 % in northeastern Lapland, 2 % in inland and remaining parts of northern Finland, 4 % in coastal counties/regions.

Sweden: 2 % in northern and 8 % in southern Sweden; percentage for areas in between depending on the variability in alkalinity as measured in the previous survey and modified so that a similar number of lakes per NILU-grid would be achieved.

The number of lakes in the larger size classes was arrived at by multiplying the basic percentages by the factors 4 or 8 for these size classes on a county or region basis; all lakes >100 km^2 were included. The number of lakes selected in each country is shown in Table 8.

Exclusion criteria:
The following types of lakes were excluded.

1. Hydro-electric power reservoirs with > 5 m regulation
2. Catchment area/lake area > 100/1 (Norway and Sweden only)
3. Maximum lake depth < 1 m
4. Extended rivers
5. Treatment ponds and similar water bodies
6. Limed lakes (Finland and Norway)

If such lakes were drawn they were substituted as follows:

Finland: The selection procedure included ca. 40 percent oversampling. If a lake was excluded the lake was replaced with the first lake from the spare list of the same size category and watershed number. If these types are absent on the list, then the nearest one on the list (within the size category) was selected. The criterium lake/watershed ratio 1:100 was not used because chain-type lakes are common in Finland, but short retention time river extensions were removed.

Norway: The random selection programme selected twice the required number of lakes for each class and region. If a lake was excluded, the first on the "spare" list was selected. If a lake was excluded because of liming a similar lake nearby in the same size class was selected. The latter was done to ensure that areas with many limed lakes (these are the most acidified areas) also were represented in the lake populations.

Sweden: An excluded lake was replaced by the next, randomly chosen lake within the same size class and county.

2.1.2 Russian Kola

The lake selection in the Russian Kola was made by INEP (Institute of North Ecology Problem) based on geographical maps (1:100.000). The lakes were selected randomly from each map according to the selected size classes used in the Nordic survey (see 2.1). More dense sampling was carried out in areas affected by acid deposition and in acidification sensitve areas.

Alltogether 2.4% of the lakes above 0.04 km^2 were sampled in the Barents area (Table 3), which can be considered as a representative sample of the whole lake population in the area. The general properties derived from the chemistry of the sampled lakes thus expresses the general chemical properties of the lake population in the Barents area.

Table 1. Lake size distribution in the participating countries and no. of lakes selected for this study in the Barents region of the Nordic countries and Russian Kola.

Size classes	**1**	**2**	**3**	**4**	**5**	**Total**
km^2	**0.04-0.1**	**0.1-1**	**1-10**	**10-100**	**>100**	**> 0.04**
Norway						
Total no. of lakes	21218	16417	2139	164	7	38845
Barents region	8150	6130	706	38	1	15025
Selected	**96**	**72**	**32**	**4**	**1**	**205**
Percentage	1.2	1.2	4.5	10.5	100	1.4
Sweden						
Total no. of lakes	35802*	20484	3599	379	24	60264*
Barents region	12366*	5080	706	82	7	18241*
Selected	**345**	**176**	**94**	**20**	**6**	**641**
Percentage	2.8	3.5	13.3	24.4	85.7	3.5
Finland						
Total no. of lakes	14717	12311	2164	276	47	29515
Barents region	4866	3357	434	40	4	8701
Selected	**78**	**62**	**34**	**6**	**4**	**184**
Percentage	1.6	1.8	7.8	15.0	100	2.1
Russian Kola						
Total	12129	7283	830	78	5	20325
Selected	**189**	**195**	**62**	**11**	**3**	**460**
Percentage	1.6	2.7	7.5	14.1	60	2.3
Barents region						
Total in study area	37511	21850	2676	238	17	62292
Selected	**708**	**505**	**222**	**41**	**14**	**1490**
Percentage	1.9	2.3	8.3	17.2	82	2.4

*estimated

2.2 Methods

2.2.1 Sampling

The samples in the Barents region were collected shortly after the autumn overturn in all countries, following the procedures given in the Nordic lake Survey manual (Henriksen et al. 1996).

Finland
Thirty percent of the lakes were sampled by helicopter in mid-September all in Northern Lapland. The remaining lakes were all accessable by foot. The samples were transported by car to the Lapland Regional Environment Centre, where short holding time parameters were analysed.

Norway
The samples were collected in September mostly by helicopter (99%) at the outlet of the lake, by filling the bottles directly underneath the surface. At the end of each day of sampling, the water bottles were sent by mail to NIVA's laboratory in Oslo for analyses.

Sweden
The sampling was carried out in the middle of September in the northern parts of Sweden. Most samples were collected from the middle of the lake from a helicopter with a teflon tube submerged into the water and connected through a peristaltic pump to the sampling bottles. Samples were sent daily to the laboratory for analyses.

Russian Kola
The sampling in Russian Kola was carried out by INEP during the period August - October 1995. The sampling requiring helicopter (40%) took place in the period 20 September - 10 October. Fifteen percent of the samples from lakes accessible by car/foot were collected in August, the remaining lakes were collected during September-October. The sampling procedure was as given in the Manual.

2.2.2 Variables and analytical work

All analytical work has been centralized in national laboratories with extensive Quality Assurance/Quality Control routines. No variables have been measured in the field. The laboratories responsible for analyses are:

- Norwegian Institute for Water Research (NIVA), Oslo, Norway.
- Department of Environmental Assessment at the Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden.
- Lapland Regional Environment Centre, Rovaniemi, North Ostrobothnia Regional Environment Centre,Oulu, Finnish Environment Institute, Helsinki, Finland.
- Institute of North Industrial Ecology Problems (INEP), Apatity, Murmansk Region, Russia.

Variables and analytical methods are presentet in table 2.

Table 2. **Variables analysed for the regional lake surveys**

Variable	Finland			Norway	Sweden	Kola
	A	B	C			
pH	x			x	x	x
Conductivity	x			x	x	x
Temperature	x			x	x	x
Alkalinity	x			x	x	x
SO4		x		x	x	x
Cl		x		x	x	x
F		x		x	x	x
Ca, Mg, Na, K		x		x	x	x
NO_3-N	x			x	x	x
NH_4-N	x			x^1	x	x
Tot-N	x			x	x	x
Tot-P	x			x	x	x
TOC		x		x	x	COD_{Mn}
Tot. monom. Al			x^2	x	1/3	x
Non-labile Al			x^2	x	1/3	1/3
SiO2		x		x	x	x
Absorbance				(x)	x	
TIC		x				
Colour	x					x
Turbidity	x					
Phosphate-P	x					x

A = Lapland Regional Environment Centre, Rovaniemi.
B = North Ostrobothnia Regional Environment Centre, Oulu.
C = Finnish Environment Institute, Helsinki.
[1] For eutrophic lakes only
[2] For every second lake in size classes 1+2

2.2.3 Statistics

The lakes from Norway, Sweden and Finland were selected by stratified sampling in order to give a throughout coverage of different regions and lake sizes. Because this sampling strategy favoured acidified regions and large lakes, we had to downweight samples from over-represented strata in order to estimate unbiased descriptive statistics for each nation. The downweighting scheme adjusted the influence of lakes from different strata by giving them weights which were inversely proportional to their sampling frequency. The weights for the different strata were calculated as

$$w_j = \frac{p_{\min}}{p_i}$$

where $p_{\min}$ is the sampling frequency for the stratum with lowest sampling frequency and p_i is the sampling frequency for the other strata, respectively.

The data for the Barents region were downweighted on size distribution. All cumulative curves and percentile values presented here were calculated according to the downweighted values.

3. Water chemistry in the Barents region in 1995

3.1 Factors affecting the water chemistry

The chemical composition of surface waters is mainly determined by contribution from ions through atmospheric deposition and from weathering and ion exchange reactions in the catchment. The atmospheric deposition is influenced by contributions from sea salts and long-range transported air pollutants. In northern Europe and the Barents region contributions of base cations from soil dust and volcanic emissions are very small.

The chemical composition of precipitation is a function of distance from sea, anthropogenic pollution sources and amount of soil dust. The composition of precipitation is modified by a number of processes when passing through a catchment. Such processes are both biological (microbial activity, uptake by growing plants, release of ions through decomposition etc.) and chemical (weathering, ion exchange, adsorption/desorption, redox processes, precipitation/dissolution). The biological processes usually lead to recirculation or removal of ions, while weathering processes gives a net contribution of ions. The total sum of contributions of ions from deposition and weathering together with all the various biological processes occurring in a catchment determine the chemistry of the runoff water.

The different processes in the soil are related to characteristics in the catchments like:

- geology
- hydrology
- precipitation chemistry
- soil thickness and type of soil
- vegetation - forested / non forested areas

3.1.1 Geology

The Barents region consists of two major geological provinces; the northern part of the Precambrian Baltic shield and the Caledonian fold belt towards north and west. The Precambrian province can further be divided into three main provinces: (1) the Archean Kola Karelian province in the northeast comprising gneisses and supracrustal belts intruded by Proterozoic gabbro, anorthosites and granite, (2) the central Archean Karelian province dominated by greenstone and schist belts divided by Proteozoic gneiss and granite, and (3) the southwestern proterozoic Svecofennian province of supracrustal rocks intruded by felsic and mafic plutons. The Caledonian fold belt, includes Precambrian and Palaeozoic sediments and. Within the framework of European geology, the Norwegian, Swedish, Finnish and Kola Precambrian is a part of the Fennoscandian or Baltic shield.

The Precambrian rocks are dominated by gneisses and granitic gneisses with low weathering rates, and low content of base cations (Ca, Mg, Na and K) and high content of SiO_2 ("Acidic rocks"). The Caledonian and the Archean Karealian province also include rocks of more basic characters, such as gabbro, greenstone and schist etc. whith higher weathering rates. Bedrock with low weathering rates releases much less base cations and bicarbonate than bedrock with high weathering rates.

3.1.2 Hydrology

There is a wide range of precipitation in the investigated area as reflected in the mean, minimum and maximum runoff values for the lakes in the different countries (Table 3).

The precipitation amount is very important for the fluxes of the ions; i.e. the amount of an ion transported through the catchment. With high precipitation the dilution effect is large. Some of the patterns seen in water chemistry can clearly be related to hydrology, e.g. some of the very dilute waters in the coastal parts of northern Norway.

Table 3. **Mean, maximum and minimum values for runoff (mm/yr) for the Barents region.**

Runoff mm/yr	Norway	Sweden	Russian Kola	Finland
Mean	**1052**	**454**	**394**	**350**
Minimum	252	198	284	318
Maximum	3623	1292	662	454

3.1.3 Precipitation chemistry

The chemistry of the precipitation is largely determined by sea salt inputs, long range transported air pollutants and local air pollutants. The sea salt content in the precipitation decreases sharply with distants from the sea. Long range transported air pollutants have mainly their sources on the European continent and in England. The gradients in content of S and N are therefore decreasing from south to north in the Nordic countries. In the Barents region the local sources in Russian Kola are most important. Some of the patterns seen in water chemistry can clearly be related to the chemistry of precipitation.

3.1.4 Soils

Soil thickness is important for the contact time between water and materials in the soil. Thick soil allowes longer contact time thus water from catchments with thick soils have usually higher concentrations of ions than water from catchments with thin and patchy soils. This soil type dominates large parts of the Barents region. The soil type is also important. Soils with high content of organic matter, which are found in tundra areas in Kola and boggy areas in Finland, northern Sweden and Norway, gives high input of organic acids to the lakes. This affects both the pH and the ion compostion in the lakes, a pattern which is common amongs the lakes in the area.

The investigated area in the Barents region exhibits a large range in all these factors, from dry to wet, from coastal near sea salt influenced lakes to inland not-sea salt influenced lakes, from lakes a with high deposition of long-range transported air pollutants, to pristine and "clean" areas, from gneissic areas with low weathering rates in the bedrock, to limestone areas with high weathering rates, from areas with thin and patchy soil to areas with thick and boggy soil, from mountainous non forested areas to forested areas. The water chemistry in each of the analysed lake is a function of all these factors. However it is still possible to see geographical patterns in water chemistry, which will be discussed in the following.

4. Results

The results are presented as point maps for non-marine sulphate, non-marine base cations, alkalinity, pH and organic carbon for all the sampled lakes (Figures 7.1 to 7.5) and cumulative distribution curves for organic carbon, non-marine base cations, total phosphorus and chloride for the different countries are shown in figure 8. The variation as percentiles (2.5, 10, 25, 50, 75, 90 and 97.5) for a number of variables are presented in table 4.

Table 4. **Percentiles for chemical variables in the Barents region. The values are weighted to represent the whole lake populations.**

Alk, µeq/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	0.4	10.5	30.5	88.3	240.9	446.4	838.4
Sweden	<0.0	16.4	58.8	114.4	189.1	312.4	648.4
Finland	2.0	28.1	66.8	116.3	177.0	238.5	615.2
Russian Kola	<0.0	<0.0	32.2	78.7	170.4	266.0	557.5

pH	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	5.32	5.85	6.35	6.80	7.22	7.48	7.80
Sweden	5.53	6.20	6.57	6.84	7.05	7.30	7.62
Finland	5.53	6.11	6.57	6.81	7.01	7.17	7.49
Russian Kola	4.49	4.80	5.92	6.45	6.79	7.11	7.34

SO4*, µeq/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	8.2	11.8	16.5	26.9	43.7	86.3	146.1
Sweden	10.8	15.3	21.7	29.9	43.7	69.6	132.9
Finland	13.6	16.4	25.3	34.7	48.5	71.9	109.3
Russian Kola	0.6	10.1	20.1	35.5	64.5	106.3	352.4

BC*, µeq/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	10.1	24.1	65.3	144.6	311.4	550.4	1171.6
Sweden	30.6	51.8	115.2	188.1	278.4	437.7	835.0
Finland	43.9	99.6	141.8	196.4	265.8	353.0	739.4
Russian Kola	28.4	51.2	95.4	172.0	277.4	391.4	1018.9

Cl, µeq/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	9.7	13.6	25.8	61.0	128.2	254.2	422.0
Sweden	7.8	10.2	14.0	18.5	26.2	37.7	74.1
Finland	5.3	10.1	13.2	19.9	35.5	45.5	64.6
Russian Kola	14.8	22.3	35.9	59.7	102.1	154.1	264.8

Table 4 cont.

TOC, mg/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	<0.2	0.24	0.49	1.44	3.23	6.70	9.69
Sweden	0.54	1.09	2.32	3.99	5.99	8.44	11.34
Finland	1.05	2.28	3.82	5.28	6.82	8.17	12.48
Russian Kola	2.22	3.51	4.86	7.62	11.82	17.36	26.92

NO3, µeq/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	0.1	0.1	0.1	0.2	0.9	2.3	6.2
Sweden	0.1	0.1	0.2	0.4	0.8	1.4	3.3
Finland	0.2	0.2	0.2	0.2	0.5	1.0	2.5
Russian Kola	0.0	0.0	0.0	0.1	0.3	1.5	10.8

Tot-P, µg/l	2.5%	10.0%	25.0%	50.0%	75.0%	90.0%	97.5%
Norway	<1.0	1.0	1.5	2.6	5.0	9.8	29.3
Sweden	3.0	3.4	5.1	7.9	13.0	19.3	31.1
Finland	1.3	2.7	3.9	6.1	12.4	20.3	29.8
Russian Kola	1.0	1.5	3.2	6.1	10.1	20.2	49.3

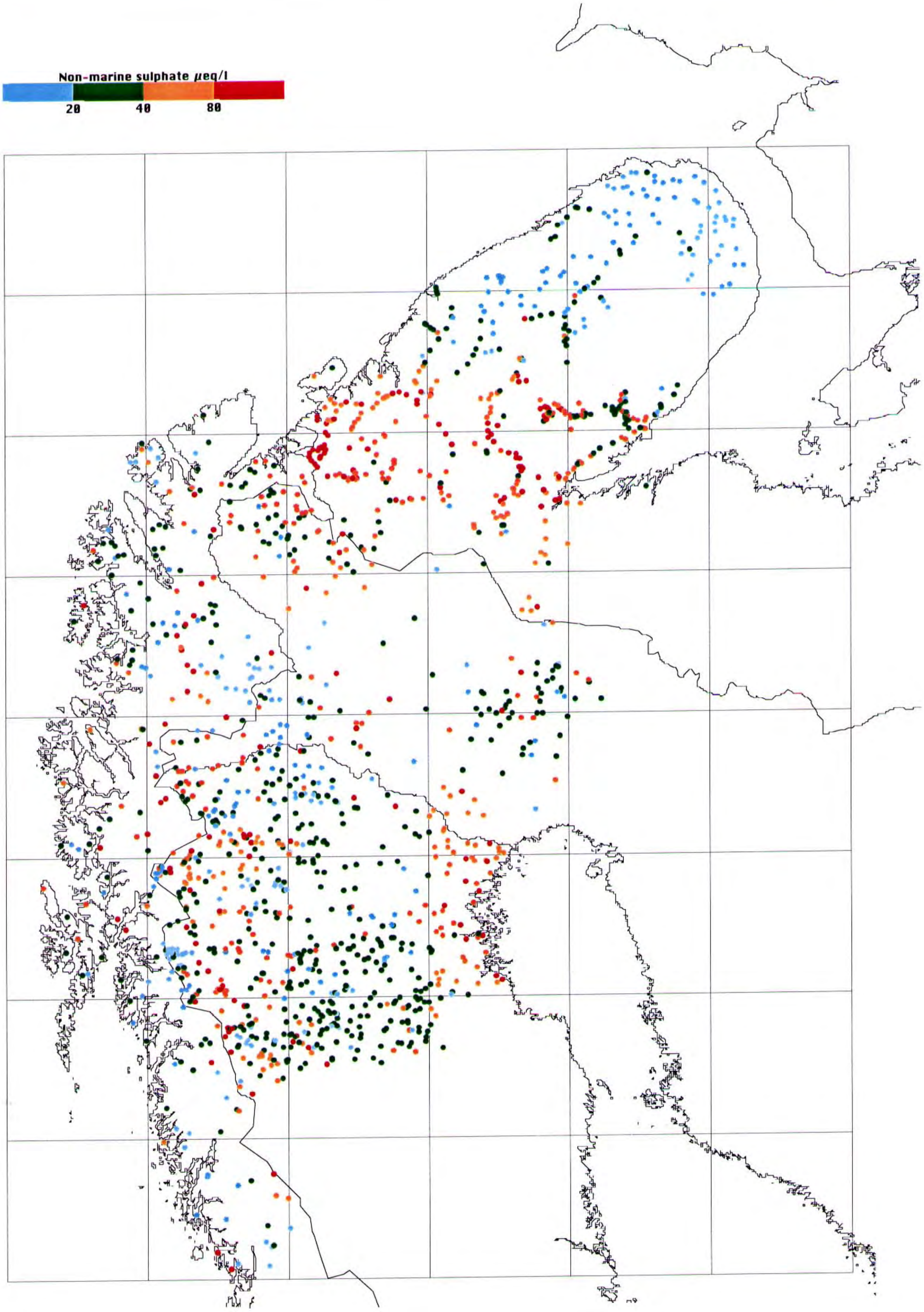


Figure 7.1. **Point maps for non-marine sulphate for all the sampled lakes in the Barents region.**

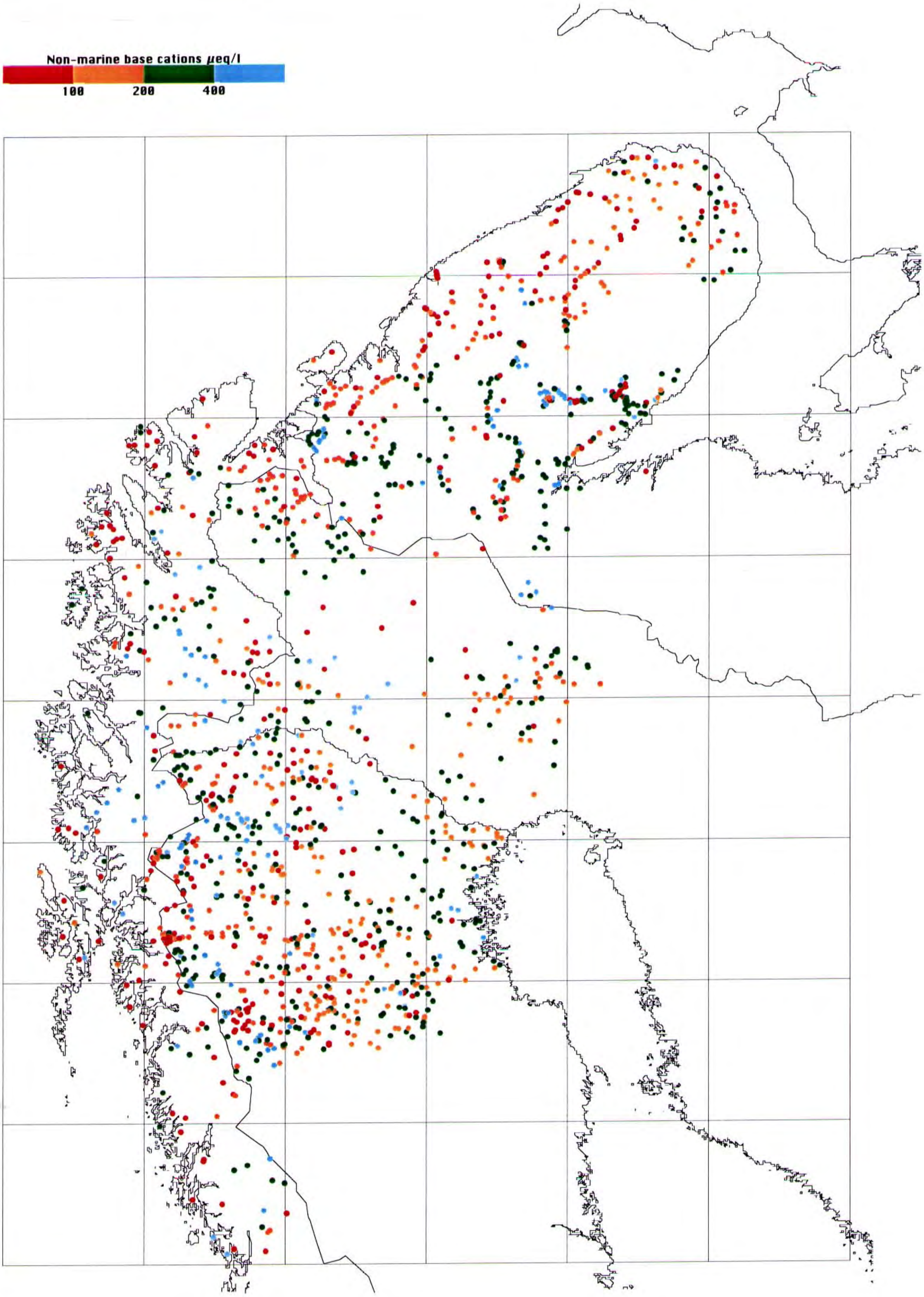


Figure 7.2. **Point maps for non-marine base cations for all the sampled lakes in the Barents region.**

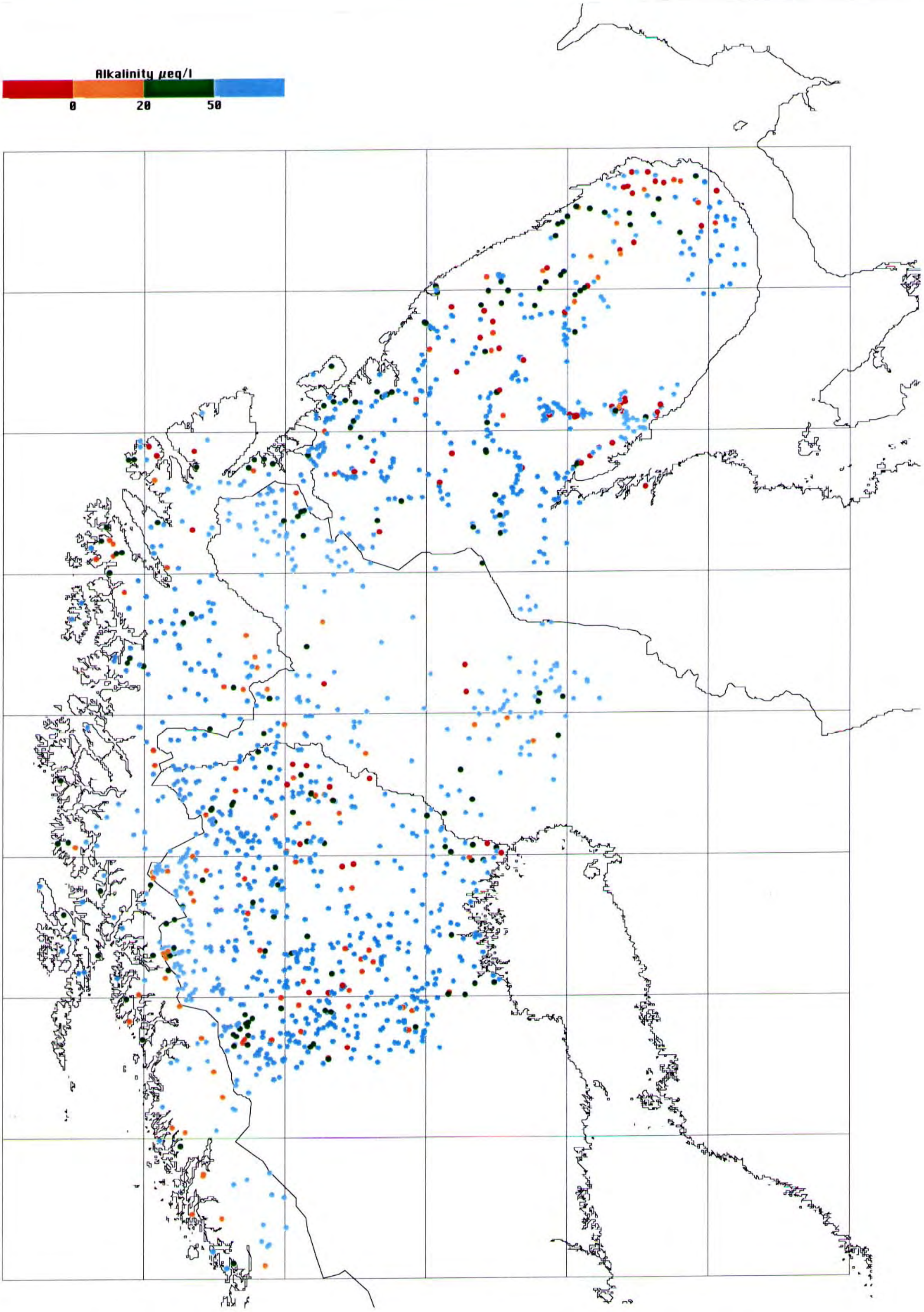


Figure 7.3. Point maps for alkalinity, for all the sampled lakes in the Barents region.

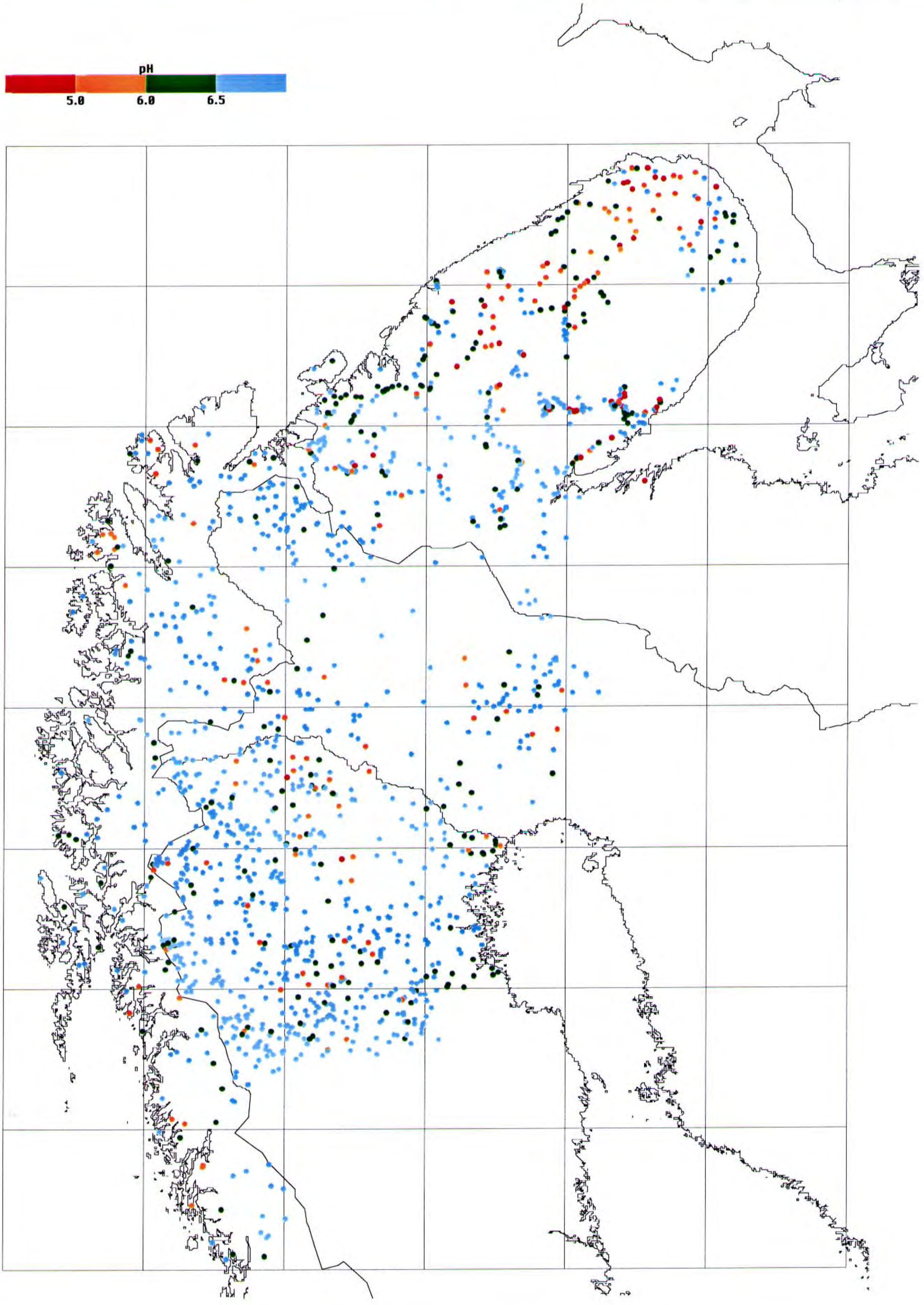


Figure 7.4. Point maps for pH for all the sampled lakes in the Barents region.

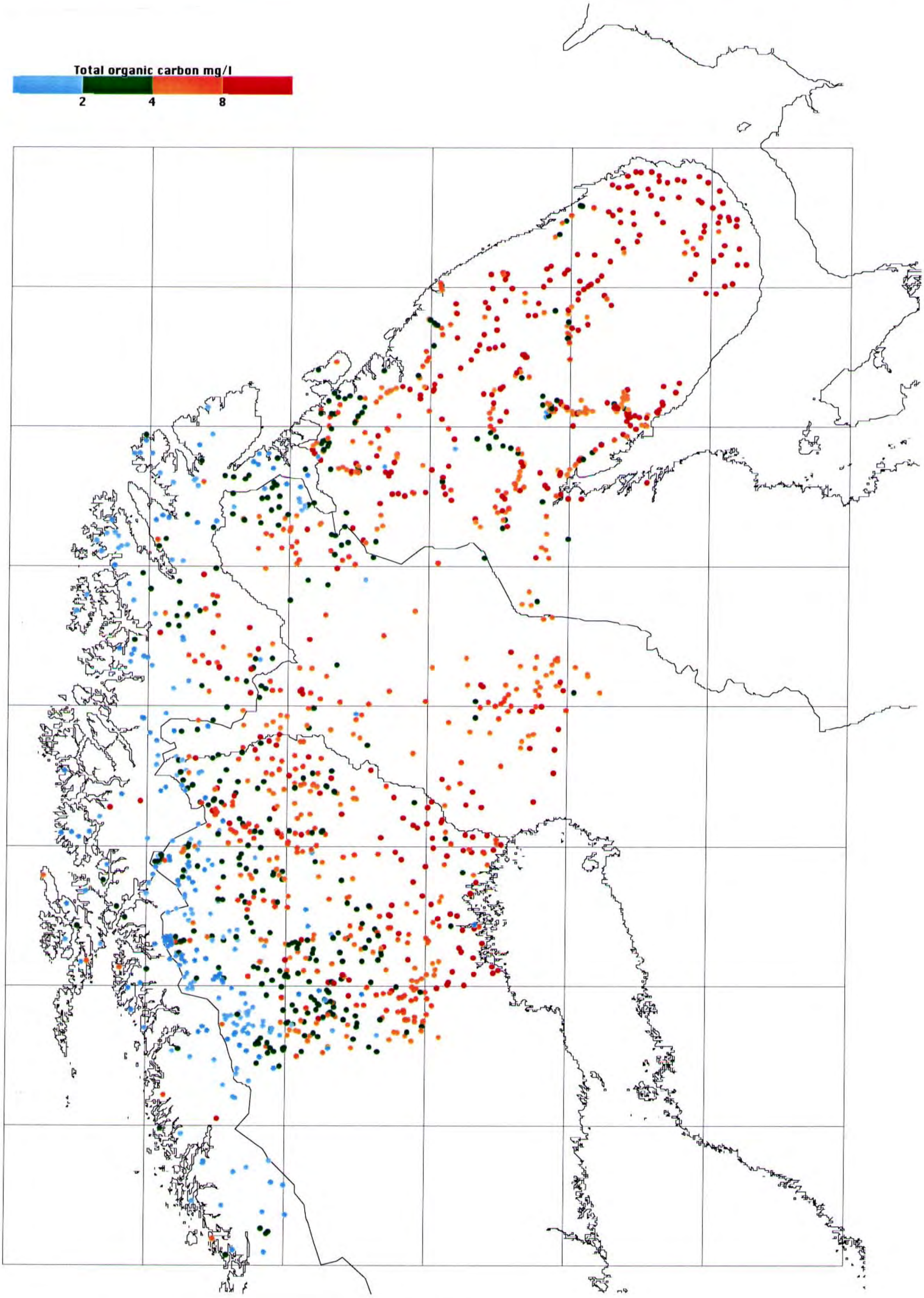


Figure 7.5. Point maps for organic carbon for all the sampled lakes in the Barents region.

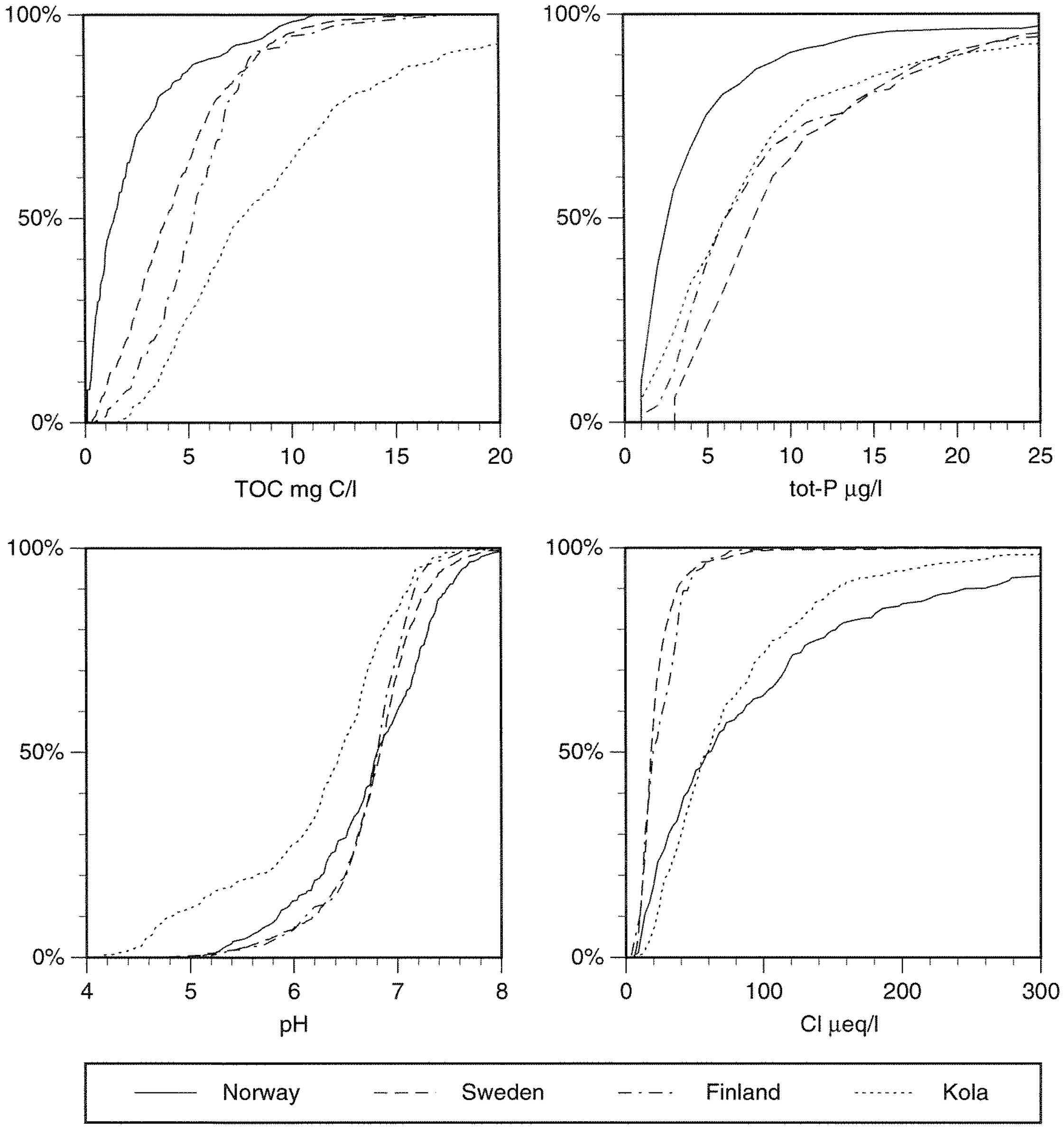


Figure 8. **Cumulative frequency distribution curves for organic carbon, total phosphorus, pH and chloride.**

5. Discussion

5.1 Comparisons of water quality within the Barents region and relative to the national surveys

In order to facilitate the evaluation of the conditions in the Barents region comparisons are made between the median situations in the different areas as well as between these areas and those in the whole countries (Figure 7). The reason for this simplified comparison is the fact that in most cases the median values for the countries rank in the same order as major parts of the distribution curves. Where appropriate, reference is also made to the cumulative curves of the water quality showing the whole distribution of the variables (Figure 8) and to the point maps (Figures 7.1 to 7.5). For comparisons with the lake populations for the whole countries (Finland, Norway and Sweden) we refer to figure 9.

5.1.1 Base cations (BC*)

The areas with the highest base cation values in the lakes correspond with areas having basic/mafic rocks (volcanogenic) and metasediments (Svekokarelian); south-central Kola, central Finnmark and central Lapland as well as scattered areas in the Swedish mountains. Low base cation concentrations, giving the greatest sensitivity to acidification, are found scattered all over the area and are most abundant in areas having granite and granitic gneisses; the northern part of Kola, the coastal areas in Norway and western part of Norrbotten county.

Norway has the highest number of lakes with low concentrations of base cations; 40% of the lakes have < 100µeq/l, while Finland only have 10% of such lakes. Sweden and Kola have respectively 21 and 26% of such acid sensitive lakes. On the other hand, Norway also has the highest number of lakes with very high concentrations of base cations; 11% of the lakes have > 500µeq/l, compared to 4 - 6% in the other countries.

In general, the Norwegian Barents lakes have almost two times higher base cation concentrations than the country as a whole, while the Swedish and Finnish Barents lakes have somewhat lower concentrations than for the whole countries.

5.1.2 Sulphate (SO_4*)

Sulphate is considered to be the major driving force leading to acidification of surface waters. In order to exclude marine sulphate, which obscures the interpretations of the results, the non-marine fraction of sulphate (SO_4*) is presented.

Sulphate is normally a "mobile anion", which means that nearly all of the sulphate in deposition is transported through the catchment and out in runoff. There is little or no net storage of sulphate in the catchment. As sulphate moves through the catchment, equivalent concentrations of cations are also transported. These cations are mainly H^+, aluminium (Al^{n+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}).

High sulphate concentrations are most common in the western part of Kola, particularly around the smelters in Nikel and Monchegorsk. Over 10% of the lakes in Kola exceed 100 µeq/l sulphate. High concentrations are also found scattered around the whole Barents region of the Nordic countries. Most of these lakes probably have a significant input of sulphate from geological sources, reflecting the diverse geology in the area. Eastern Kola represents the largest area with consistently low (< 20 ueq/l) sulphate levels, reflecting low sulphur deposition in the area.

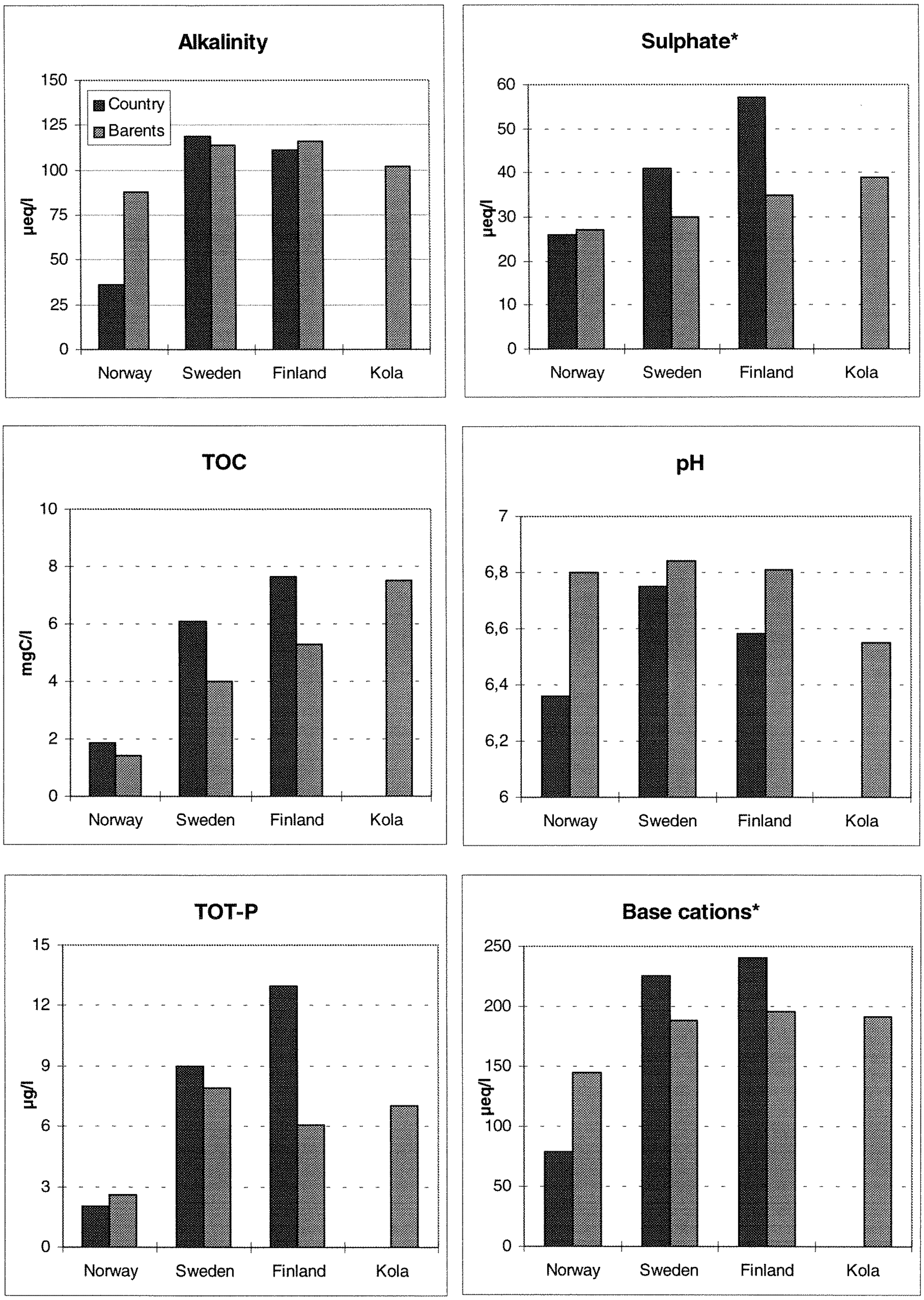


Figure 9. Median-values for some components in the Barents region compared with the meadians for the country as a whole.

In Finland and Sweden the sulphate concentrations are generally lower than for the country as a whole, while the Norwegian Barents lakes have a distribution very similar to the whole country. One should expect lower concentrations in the North than in the South (except in the eastern part of Finnmark) due to higher sulphur depositions in the south. It is therefore likely that geologically derived sulphate is more common in Northern Norway than in Southern Norway.

5.1.3 Alkalinity

Low alkalinity lakes (<20 µeq/l) are most abundant in the northern parts of Russian Kola. Here, the higher content of organic matter of the lakes in the eastern parts and the higher anthropogenic sulphate content in the western parts lowers the alkalinity in general. In the northern parts of the Nordic countries both the geological conditions and the precipitation amounts determine the alkalinity values, depending on the weathering rate of the minerals in the soil and dilution by precipitation, respectively. Acid-sensitive lakes are frequently located next to well buffered lakes. For such lakes the deposition of sulphate is a less important factor in reducing the alkalinity, except in the Sør-Varanger area in Norway close to the smelters with higher sulphate deposition. In general, low alkalinity lakes are rare in the Nordic countries and are scattered throughout the whole region.

Russian Kola has the highest number of lakes with zero alkalinity (15%). In the Nordic countries only about 2% of the lakes have zero alkalinity. About 1/3 of the lakes in Kola and Norway have alkalinity < 50 µeq/l, compared to 1/5 of the lakes in Sweden and Finland.

There are relatively fewer low alkalinity lakes in the Barents region than in the countries as a whole.

5.1.4 Nitrate

The nitrate concentrations of the lakes in the Barents region are generally very low. More than 75% of the lakes have < 1 µeq/l NO_3^-. Therefore, the nitrogen deposition is at present not significant for the acidification of Barents lakes. In the Nordic countries the nitrate concentrations are generally lower in the Barents region than in the countries as a whole. This is in good agreement with the low N depositions in the Barents region.

5.1.5 pH

pH values below 5.5 are most abundant in the northern part of Russian Kola (19%). Such lakes are rare in the Barents region of the Nordic countries. Russian Kola also exhibits the highest frequency of lakes with pH below 6.0 (28% of the lakes), followed by Northern Norway (14%), Norrbotten (7%) and Lapland (7%). In general, the lakes of the Barents region of the Nordic countries are less acid than the lake populations in the whole countries.

5.1.6 Organic carbon (TOC)

There is a pronounced west to east gradient in TOC concentrations; the coastal areas in Norway usually have < 2 mg C/l, while lakes having > 8 mgC/l are abundant in the eastern parts of Kola, Lapland and Norrbotten. The topograhically flat areas with peatland accumulation in the eastern Kola and around the Bothnian Bay are reflected in high TOC values. The mountain lakes in the border area between Norway and Sweden are typically situated in areas with a lower percentage of organic soils in the catchments, and furthermore, they are subjected to higher precipitation amounts. Fifty percent of the lakes in Russian Kola have TOC values above 7.6 mgC/l, while the 50-percentiles for Lapland, Norrbotten and Northern Norway are 5.3, 4.0 and 1.4 mgC/l, respectively.

In the Nordic countries there is a tendency towards lower TOC-values in the Barents region than in the countries as a whole. This pattern has also been shown for Finland by Kortelainen (1993) who interprets this to be caused by a colder climate with lower primary production as well as lower decomposition rates.

5.1.7 Total phosphorus

The geographical distribution of total phosphorus is very similar to the total organic carbon. The transport of phosphorus is biogeochemically related to to the dissolved organic humus material of the lakes, especially in northern parts of the countries where agricultural, fertilized soils are rare. Probably due to geological characteristics, the highest phosphorus concentrations are found in Sweden and the lowest ones in Norway.

Lakes with low concentrations of tot-P (< 5µg/l) are most common in Norway (75% of the lakes). Sweden, Finland and Kola have respectively 23, 40 and 40% of low phosphorus lakes. High concentrations (>10µg/l) are most common in Sweden (35% of the lakes), followed by Finland (30%), Kola (25%) and Norway (10%).

In Finland, the median phosphorus concentration in Barents region is less than half of the value for the whole country, while the distributions in Sweden and Norway are quite similar in the north and south.

5.2 Critical loads and exceedance

Critical loads have been widely accepted as a basis for control strategies for regional air pollution. In order to gain more insight in the magnitude and spatial variation of critical loads, the UN/ECE Excecutive Body of the Convention on Long-Range Transboundary Air Pollution (LRTRAP) has set up a Task Force on Mapping Critical Levels/Loads under the Working Group on Effects. The data from individual countries are collected, mapped and reported by the Coordination Center for Effects (CCE), located at the National Institute of Public Health and the Environment (RIVM) in Bilthoven, the Netherlands.

In the Lökeberg meeting document (Grennfelt and Törnelöf, 1992) two models, one empirical and one process oriented, for calculating critical loads of acidifying deposition (both S and N) to surface waters were presented. The first model, the Steady-State Water Chemistry (SSWC) model (UN/ECE, 1996), enables the calculation of critical loads of acidity and present exceedances of incoming total acidity (including nitrogen) over the critical loads. The process-oriented First-Order Acidity Balance (FAB) model (Posh et al. 1997) allows the simultaneous calculation of critical loads of acidifying N and S deposition and their exceedances. The FAB model is based on the steady-state mass balance principle widely used in many models for computing critical loads for forest soils.

The Steady-State Water Chemistry Method (SSWC) includes both S and N acidity, in such a way that present N-leaching (N_{leach}) is considered in the calculation of critical load exceedance (present Ex_{Ac}). To do this, we must ensure that no other antrophogenic sources of NO_3 than long range transported nitrogen compounds are "discharged" into the surface water. For the present lake surveys we cannot separate the different nitrogen sources from another in all lakes. In the Barents region, however, the nitrogen deposition is low and not of the same importance as in the southern parts in the nordic countries. Thus we will restrict the calculations here to deal with critical loads of acidity and exceedance of sulphur acidity only. The FAB-model can also be applied to the lake survey data, but this will require additional model input data that is not available at present. It will, however, be possible to work out acceptable estimates for the N input data when all background data for the lakes are available in the near future.

We have applied the SSWC-method to the lake survey data in the Barents region and calculated the critical loads for sulphur acidity using the variable ANC limit (ANC_{var}) for all lakes (Henriksen et al. 1995). National runoff values for 1961-1990 were used. In the exceedance calculations, data for national S-deposition were used.. Table 7 shows the critical load percentiles for the countries using ANC_{var} compared with whole country values.

The critical loads of acidity in the Barents region are highest in Norway, while they are largely at similar levels in the other three areas (Figure 10). For Norway, the critical loads in the Barents region are substantially higher than for the whole country, because the most sensitive areas are located in southern Norway. For Finland and Sweden the opposite is the case.

The critical loads are exceeded in all countries, the highest percent of exceeded lakes are found in Russian Kola and Norway, while Sweden shows the lowest percent of exceeded lakes (Figure 11). For Norway and Sweden the percent of exeeded lakes are higher for the whole country than for the Barents region.

Table 5. **Critical load percentiles for the Barents region. Unit: meq/m^2/yr. The values for the whole country represent the total lake population (see Henriksen et al. 1997 in prep.), while the values for the Barents region are percentiles of the anlysed lakes**

Percentile	10	25	50	75	90
Norway					
Barents	**33**	**47**	**101**	**223**	**425**
Country	15	28	56	115	271
Sweden					
Barents	**23**	**42**	**64**	**100**	**192**
Country	21	39	61	107	215
Finland					
Barents	**32**	**48**	**64**	**86**	**108**
Country	32	46	63	86	117
Russian Kola					
Barents	**24**	**40**	**66**	**94**	**141**

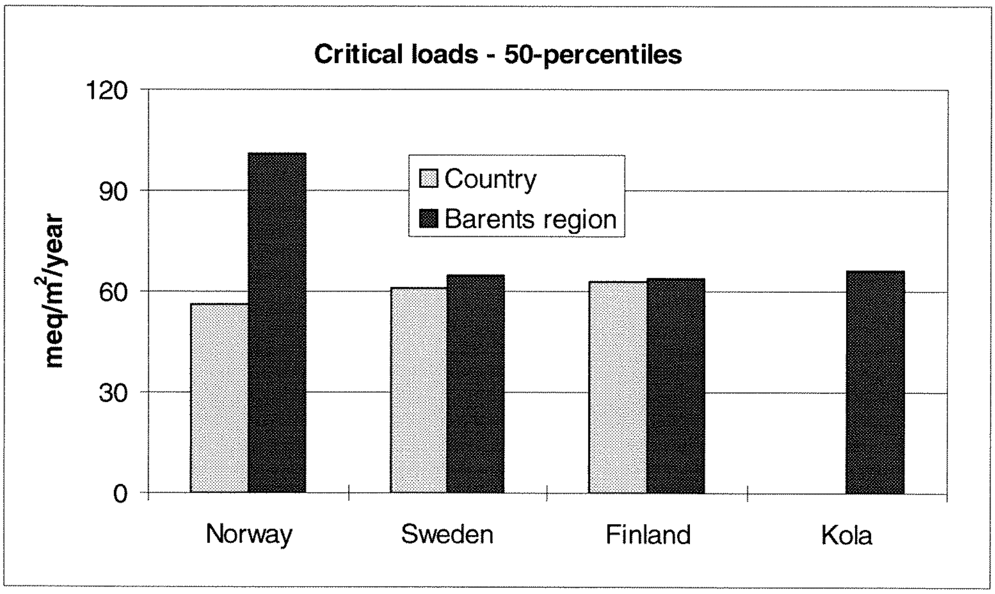


Figure 10. **50-percentile values for the Barents region compared with the values for the whole countries. The values for the whole country represent the total lake population (see Henriksen et al. 1997 in prep.), while the values for the Barents region are the 50-percentile of the anlysed lakes**

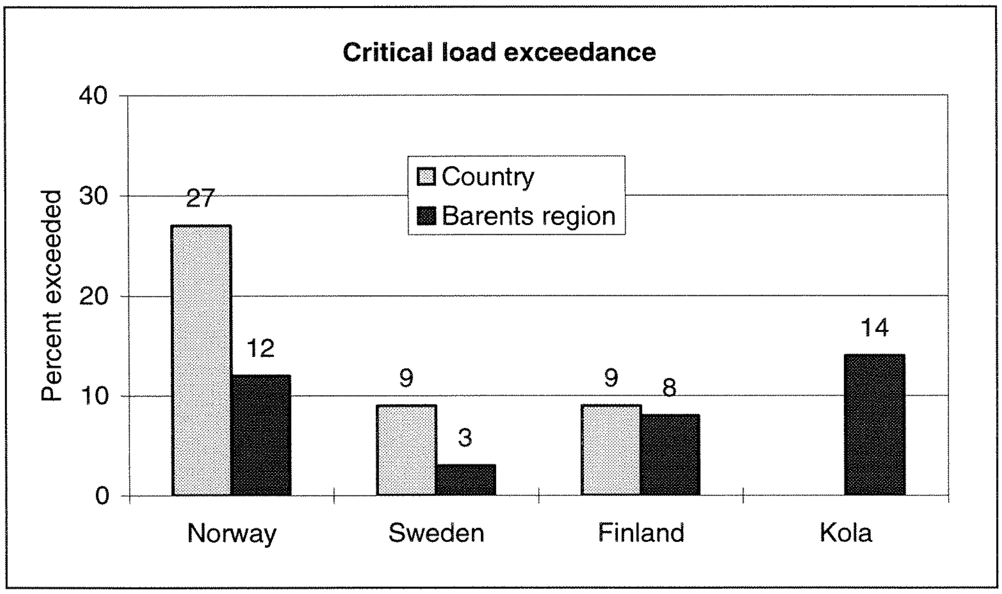


Figure 11. Percent exceedance of critical loads for lakes in the Barents region compared with the values for the whole countrie. The values for the whole country represent the total lake population (see Henriksen et al. 1997 in prep.), while the values for the Barents region are based on the number of anlysed lakes.

6. Conclusions

The most acid lakes in the Barents region are found in Russian Kola, where also the organic carbon content are highest. In general, the lakes of the Barents region of the Nordic countries are less acid than the lake populations in the whole countries.

In Finland and Sweden the sulphate concentrations are generally lower than for the country as a whole, while the Norwegian Barents lakes have a distribution very similar to the whole country. One should expect lower concentrations in the north than in the south (except in the eastern part of Finnmark) due to higher sulphur depositions in the south. It is therefore likely that geologically derived sulphate is more common in Northern Norway than in Southern Norway.

Although the Norwegian Barents lakes have the lowest base cation concentrations they are almost two times higher than for the country, while the Swedish and Finnish Barents lakes have somewhat lower concentrations than for the whole countries.

In the Nordic countries the nitrate concentrations are generally lower in the Barents region than in the countries as a whole. This is in good agreement with the low N depositions in the Barents region.

The critical loads of acidity in the Barents region are highest in Norway, while they in general are similar levels in the other three areas. For Norway, the critical loads in the Barents region are substantially higher than for the whole country. For Finland and Sweden the opposite is the case. The critical loads are exceeded in all countries in the Barents region, the highest percent of exceeded lakes are found in Russian Kola and Norway, while Sweden shows the lowest percent of exceeded lakes. For Norway and Sweden the percent of exeeded lakes are higher for the whole country than for the Barents region.

The data from the lake monitoring programs in the Nordic countries and Russian Kola show that the lakes in the area give a rapid response to reduced sulphur depositions. The planned reconstruction of "Pechenganikel" smelter will give significant reduction in emissions of sulphur and heavy metals resulting in recovery of the ecosystems in the area. Due to accumulated heavy metals in soils and lake sediments, the reduction of heavy metal concentrations will probably be a much slower process. It is important to continue environmental research and monitoring in the border areas. Model calculations using the MAGIC-model on data for river Dalelva in Eastern Finnmark (heavily polluted by the smelter emissions) indicate that the river will become cronically acid within 50 years if present sulphur deposition continues. On the other hand, a 95% reduction in sulphur deposition today will result in pristine water chemistry within a period of 10 to 20 years (Wright and Traaen 1992). A similar study using the SMART model was applied to Christmas lakes in northeastern Finland, 40 km away from Nikel smelters (Kämäri et al. 1995). Also this model indicates that the future sulphur deposition will have to be very low in order to to stop and reverse the ongoing acidification. However, since the present base saturation in soil is fairly high, over 50 percent, there is still several years time to reduce the sulphur deposition to values which the system can tolerate. A follow up monitoring programs in this area will give an unique opportunity to study the reversibility of acidification at several ecosystem levels.

7. References

Bernes, C. 1986. Sura och försurade vatten. SNV Monitor 1986.

Forsius, M., V. Malin, I. Mäkinen, J. Mannio, J. Kämäri, P. Kortelainen and M. Verta 1990. Finnish lake acidification survey: Survey design and random selection of lakes. Environmetrics 1, 73-88.

Grennfelt, P and Thörnelöf, E. (eds.) 1992. Critical loads for nitrogen, Nord 1992:41, Nordic Council of Ministers, Copenhagen, Denmark.

Henriksen, A., Lien, L., Traaen, T.S., Sevaldrud, I.S. and Brakke, D. 1988. Lake acidification in Norway - present and predicted chemical status. Ambio 17, 259-266.

Henriksen, A., Kämäri, J., Posch, M., Lövblad, G., Forsius, M. and Wilander, A. 1990. Critical loads to surface waters in Fennoscandia. Nordic Council of Ministers. Miljørapport 1990:124.

Henriksen, A., Kämäri, J., Posch, M., Forsius, M., Wilander, A., Tarvainen, T. and Baxendale, H. 1994a. Critical loads for acidification of surface waters in Northern Fennoscandia (Nordkalotten). Nordkalottens Miljøråd. Rapport nr. 33. 22pp.

Henriksen, A., Kämäri, J., Posch, M., Forsius, M., Wilander, A. and Moiseenko, T. 1994b. Critical loads for surface waters in Scandinavia and the Kola region. In: H. Raitio and T. Kilponen: Critical Loads and Critical Limit Values. proceedings of the Finnish-Swedish Environmental conference, october 27-28, 1994, Vaasa, Finland.

Henriksen, A., Posch, Hultberg, H. and Lien, L. 1995. Critical loads of acidity for surface waters - Can the ANC_{limit} be considered variable? Water Air Soil Poll. **85**, 2419-2424.

Henriksen, A, Skjelkvåle, B.L., Lien, L., Traaen, T.S., Mannio, J., Forsius, M., Kämäri, J., Mäkinen, I., Berntell, A., Wiederhom, T. Wilander, A., Moiseenko, T., Lozovik, P., Filatov, N., Niinioja, R., Harriman, R. and Jensen, J.P. 1996. Regional Lake Surveys in Finland - Norway - Sweden - Northern Kola - Russian Karelia - Scotland - Wales 1995. Coordination and Design. Acid Rain Research Report 40/1996. Norwegian institute for Water Research, Oslo, Norway. 30 pp.

Henriksen, A., Skjelkvåle, B.L., Traaen, T.S., Fjeld. E., Mannio, J., Forsius, M., Vuorenmaa, J.,Kortelainen, P., Wilander, A., Moiseenko, T. Harriman, R., and Jensen, J.P. 1997. Regional lake Surveys in Finland, Norway, Sweden, Denmark, Russian Kola, Russian Karelia, Scotland and Wales - Results. NIVA-rapport in prep.

Kähkönen, A.-M. 1996. Soil geochemistry in relation to water chemistry and sensitivity to acid deposition in Finnish Lapland. Water Air Soil Poll. 85: 311-327.

Kämäri, J., Posch, M., Kahkonen, A.-M. & Johansson, M. 1995. Modeling potential long-term responses of a small catchment in Lapland to changes in sulphur deposition. Sci.Tot. Environ. 160/161: 687-701.

Kortelainen, P. 1993. Content of total organic carbon in Finnish lakes and its relationship to catchment characteristics. Can. J. Fish. Aquat. Sci. 50: 1477-1483.

Leinonen, L. 1996. (ed.). Air quality measurements 1994. Finnish Meteorological Institute. 236 pp.

Leinonen, L. And Juntto, S. 1992. (eds.). Air quality measurements 1991. Finnish Meteorological Institute. 220 pp.

Posch, M., J. Kamari, A. Henriksen, M. Forsius and A. Wilander, 1997. Exceedance of critical loads for lakes in Finland, Norway and Sweden: Reduction requirements for acidifying nitrogen and sulfur deposition. Environmental Management 21(2): 291-304.

SFT (Norwegian Pollution Control Authority) 1988. Norwegian Monitoring Programme for Long-Range Transported Air Pollutants, Annual Report for 1987, SFT-report 333/88. (In Norwegian).

SFT (Norwegian Pollution Control Authority) 1995. Norwegian Monitoring Programme for Long-Range Transported Air Pollutants, Annual Report for 1994, SFT-report 628/95. (In Norwegian).

Traaen, T.S., T. Moiseenko, V. Dauvalter, S. Rognerud, A. Henriksen and L. Kudravseva, 1991. Acidification of surface waters, nickel and copper in water and lake sediments in the Russian-Norwegian border areas. Progress report for 1989-1990. Working Group for Water and Environmental Problems under the Norwegian-Soviet Environmental Protection Commission. Oslo (NIVA) and Apatity (INEP).

Traaen, T.S., Henriksen, A., Kallqvist, T. og Wright, R. R. 1993. Acidification and heavy metal pollution in the border areas Norway/Russia. Investigations on water chemistry 1986-1992. SFT-report 511/93. NIVA-report no. 2862, 47pp. (In Norwegian).

UN/ECE. 1996. Manual on Methodologies and Criteria for Mapping Critical Levels/Loads and geographical areas where they are exceeded. Federal Environmental Agency (Umweltbundesamt), Berlin, Germany. 144 pp.

Wilander, A. 1997. Referensjøarnas vattenkemi under 12 år; tillstånd och trender (Water chemistry in refernce lakes during 12 years; status and trends). SNV rapport 4652.

Wright, R.F. & Traaen, T.S. 1992. Dalelva, Finnmark, northernmost Norway: prediction of future acidification using the MAGIC model. Statlig program for forurensningsovervåking, Norwegian State Pollution Control Authority (SFT), report no. 486/92, TA-835/1992. NIVA report no. 2728. Oslo.

Acid Rain Research Reports

1/1982 Henriksen, A. 1982. Changes in base cation concentrations due to freshwater acidification. 50 pp. Out of print.

2/1982 Henriksen, A. and Andersen, S. 1982. Forsuringssituasjonen i Oslomarkas vann. 45 pp. Out of print.

3/1982 Henriksen, A. 1982. Preacidifcation pH-values in Norwegian rivers and lakes. 24 pp. Out of print.

4/1983 Wright, R.F. 1983. Predicting acidification of North American lakes. 165 pp.

5/1983 *Schoen, R.*, Wright, R.F. and *Krieter, M.* 1983. Regional survey of freshwater acidification in West Germany (FRG). 15 pp.

6/1984 Wright, R.F. 1984. Changes in the chemistry of Lake Hovvatn, Norway, following liming and reacidification. 68 pp.

7/1985 Wright, R.F. 1985. RAIN project. Annual report for 1984. 39 pp.

8/1985 *Lotse, E.* and *Otabbong, E.* 1985. Physiochemical properties of soils at Risdalsheia and Sogndal: RAIN project. 48 pp.

9/1986 Wright, R.F. and Gjessing, E. 1986. RAIN project. Annual reportfor 1985. 33 pp.

10/1986 Wright, R.F., Gjessing, E., Semb, A. and Sletaune, B. 1986. RAIN project. Data report 1983-85. 62 pp.

11/1986 Henriksen, A., Røgeberg, E.J.S., Andersen, S. and Veidel, A. 1986. MOBILLAB-NIVA, a complete station for monitoring water quality. 44 pp.

12/1987 Røgeberg, E.J.S. 1987. A coulometric Gran titration method for the determination of strong and weak acids in freshwater. 28 pp.

14/1988 Hauhs, M. 1988. Water and ion movement through a minicatchment at Risdalsheia, Norway. RAIN project. 74 pp.

15/1988 Gjessing, E., Grande. M. and Røgeberg, E.J.S. 1988. Natural Organic Acids. Their Role in Freshwater Acidification and Aluminium Speciation. 28 pp.

16/1988 Wright, R.F. 1988. RAIN project. Annual report for 1987. 77 pp.

17/1988 Wathne, B.M and Røgeberg, E.J.S. 1988. Buffering effects of river substrates under acidic conditions. 19 pp.

18/1989 *Lotse, E.G.* 1989. Soil Chemistry 1983-86 at the RAIN Project Catchments. 66 pp.

19/1989 *Reuss, J.O.* 1989. Interpretation of Soil Data from the RAIN Project. 81 pp.

20/1990 Skjelkvåle, B.L. and Wright, R.F. 1990. Overview of areas sensitive to acidification: Europe. 20 pp.

21/1990 Hindar, A. 1990. Chemistry and fish status of 67 acidified lakes at the coast of Aust-Agder, Southern Norway, in relation to postglacial marine deposits. 47 pp.

22/1990 Henriksen, A. Lien, L. and T. Traaen, T.S. 1990. Critical Loads for Surface Waters. Chemical Criteria for Inputs of Strong Acids. 45 pp.

23/1990 Wright, R.F. 1990. Reversibility of acidification: soils and surface waters. 39 pp.

24/1991 Wright, R.F. RAIN project. Report for the years 1988, 1989 and 1990. 156 pp.

25/1991 Wright, R.F., Holmberg, M., Posch, M. and Warfvinge, P. 1991. Dynamic models for predicting soil and water acidification: Application to three catchments in Fenno-Scandia. 40 pp.

26/1992 Wohlfeil, I.C. and Müller, D.I. 1992. RAIN-project: Vegetation mapping at Risdalsheia 1991. 42 pp.

27/1992 Rosseland, B.O. and Kroglund, F. 1992. Reversibility of acidification; Fish responses in experiments at Risdalsheia. 50 pp.

28/1992 Wathne, B.M., Norton, S.A. and Henriksen, A. 1992. Buffering capacities and effects of river substrates during acidic episodes. 24 pp.

29/1992 Henriksen, A., Mill, W.A., Kot, M., Rzychon, D. and Wathne, B.M. 1992. Critical loads of acidity to surface waters: A case study from Polish Tatra Mountains. 34 pp.

30/1992 Kroglund, F., Dalziel, T., Rosseland, B.O., Lien, L., Lydersen, E. and Bulger, A. 1992. Restoring Endangered Fish In Stressed Habitats. ReFISH project 1988-1991. 43 pp.

31/1992 Rosseland, B.O., Brandrud, T.E., Raddum, G.G. 1992. Effects of Aluminium in Acidified Aquatic Ecosystems. 34 pp.

32/1993 Henriksen, A., Forsius, M., Kämäri, J., Posch, M. and Wilander, A. 1993. Exeedance of Critical Loads for Lakes in Finland, Norway and Sweden: Reduction Requirements for Nitrogen and Sulfur Deposition. 46 pp.

33/1993 Wathne, B.M., Mill, W.A., Kot, M., Rzychon, D., Henriksen, A., and Tørseth, K. 1993. Critical loads of acidity to lakes in the Polish Tatra Mountains. A study of the yearly variations in the precipitation and water chemistry. 37 pp.

34-A/94 Lydersen, E. 1994. Long term monitored catchments in Norway - a hydrologic and chemical evaluation -, 306 pp. + Appendix.

34-B/94 Lydersen, E. 1994. Long term monitored catchments in Norway - a hydrologic and chemical evaluation -, Summary Report, 66 pp.

35/1994 Wright, R.F. 1994. Modelling long-term hydrochemical response at ENCORE catchments in the UK and Norway. 42 pp.

36/1994 Wright, R.F. 1994. RAIN PROJECT. Risdalsheia data report for June 1990 - May 1994. 165 pp.

37/1995 Závodský, D., Wathne, B.M., Henriksen, A., Sverdrup, H. et al. 1995. Mapping critical levels/loads for the Slovak Republic. 74 pp.

38/1995 Wright, R.F. 1995. NITREX: Phase 2 Final Report 56 pp.

39/1995 Wright, R.F. 1995. NIVA contributions to ACID REIGN 95? Conference in Gothenburg, Sweden, 26-30 June 1995. 244 pp.

40/1996 Henriksen, A. et al. 1996. Regional Lake Surveys in Finland - Norway - Sweden - Northern Kola - Russian Karelia - Scotland - Wales 1995. 30 pp.

41/1996 Norton, S.A., Appleby, P.G., Dauvalter V. and Traaen T. 1996. Trace metal pollution in Eastern Finnmark, Norway and Kola Peninsula, Northwestern Russia as evidenced by studies of lake sediment. 18 pp.

42/1996 Wright, R.F. 1996. Nitrex: Phase 3 Final Report. 28 pp.

43/1996 Závodský, D., Wathne, B.M., Henriksen, A., Sverdrup, H. et al. 1996. Mapping critical levels/loads for the Slovak Republic. Final Report. 93 pp.

44/1997 Lydersen, E., Rzychon, D., Worsztynowicz, A., Tørseth, K. Hanssen, J.E., Mill, W.A., Kot, M., Henriksen, A., Wathne, B.M. 1997. Critical loads of acidity to lakes in the Polish Tatra Mountains- Final Report. 49 pp.

45/1997 Henriksen, A., Mannio, J., Wilander, A., Moiseenko, T., Traaen, T.S., Skjelkvåle, B.L.S., Fjeld, E. and Vuorenma, J. 1997. Regional Lake Surveys in The Barents region of Finland - Norway - Sweden and Russian Kola 1995 - Results.

PARTICIPATING INSTITUTIONS

Finnish Environment Institute
P.O. Box140, FIN-00251 Helsinki, Finland

Department of Environmental Assessment
Swedish University of Agricultural Sciences
P.O. Box 7050, S-750 07 Uppsala, Sweden

Institute of North Industrial Ecology Problems
Kola Centre of The Russian Academy of Sciences
14 Fersman Str. 184200 Apatity, Murmansk region, Russia

Norwegian Institute for Water Research
P.O. Box 173 Kjelsås, N-0411 Oslo, Norway

Norwegian Institute for Water Research

P.O. Box 173 Kjelsås Telephone: + 47 22 18 51 00
N-0411 Oslo Telefax: + 47 22 18 52 00

By ordering the report, please use
serial number 3633-97.

ISBN 82-577-3191-9