029 **FAGRAPPORT**

Impacts of pollution on freshwater communities in the border region between Russia and Norway

III. Results of the 1990-96 monitoring programme

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Anatoli Lukin
Ann Kristin Lien Schartau
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Availability: Open

Project no.: 13526

Signature of personal responsible:
Ann Kristin L. Schartau

Nøst, T., Lukin, A., Schartau, A.K.L., Kashulin, N., Berger, H.M, Yakovlev, V., Sharov, A. & Dauvalter, V. 1997. Impacts of pollution on freshwater communities in the border region between Russia and Norway. III. Results of the 1990-96 monitoring programme. - NINA Fagrapport 29: 1-37.

Trondheim, may 1997

ISSN 0805-469X
ISBN 82-426-0831-8

Management areas:
Environmental pollution
Miljøforurensninger

Editor:
Ann Kristin Lien Schartau
NINA•NIKU, Trondheim

Design and layout:
NINA•NIKUs Graphic Office

Type: NINA•NIKU

Prints: Strindheim Trykkeri AL

No of copies: 300

Printed on environment paper

Address to contact:
NINA•NIKU
Tungasletta 2
N-7005 Trondheim
Tel: +47 73 58 05 00
Fax +47 73 91 54 33

Assignment for:
Directorate for Nature Management, Norway
Norwegian Ministry of the Environment
Academy of Sciences of The USSR/Russia

Abstract

Nøst, T., Lukin, A., Schartau, A.K.L., Kashulin, N., Berger, H.M, Yakovlev, V., Sharov, A. & Dauvalter, V. 1997. Impacts of pollution on freshwater communities in the border region between Russia and Norway.III. Results of the 1990-96 monitoring programme. - NINA Scientific Report 29: 1-37

This report summarise the results and conclusions of the investigations in the border region between Russia and Norway, primary in selected monitoring lakes during 1990-96. The results of the 1996 investigations are given a more thorough presentation. Results on species composition, abundances and biomasses of phytoplankton, zooplankton, zoobenthos and fish communities, as well as population parameters (length and age distribution) for different fish species are presented. Pathological state and trace metal accumulation in fish are analysed. The biological results are related to analyses of chemical parameters in lake sediments and water.

During the period of study (1990-96) adverse effects of trace metal pollution near the industrial centres of Nikel and Zapolyarny were recorded. Trace metal accumulation, pathological anomalies in fish and low invertebrate diversity were observed. Indications of acidification impacts were only found in the Jarfjord Region in Norway. Impacts of pollution on freshwater communities decrease with distance from the sources. However, the causes and consequences are difficult to follow due to 1) different loads and compositions of pollutants within small areas, 2) geological complexity and 3) the biotic relationships which may differ between lakes. Although there exist significant variations in water quality and biological parameters from one year to another, the results indicate a slight improvement in the limnological state of the lakes from 1990 to 1996, especially in the acidified lake Dalvatn in the Jarfjord Region.

The six-year study provides a satisfactory basis for evaluating the biological benefits to freshwater communities of future purification processing of emissions from the Pechenganickel factories. Unlike in other polluted areas in Scandinavia and Northern Europe, local emissions completely dominate the pollutant load in the border region between Russia and Norway. This fact makes the region unique for studies of the effects of pollutants and the recovery of freshwater communities. We recommend an intensive monitoring programme on freshwater communities following purification processing of emissions from the Pechenganickel factories.

Key words: Freshwater communities - pollution - acidification - heavy metals - Kola Peninsula.

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Abstract

Влияние загрязнения на пресноводные экосистемы в приграничных районах Норвегии и России.

В предлагаемом заключительном отчете представлены результаты исследований пресноводных экосистем в приграничном районе между Россией и Норвегией, проведенные на отобранных для мониторинга озерах, за период с 1990 по 1996 гг. В отчете приводится характеристика состава и биомассы фитопланктона, зоопланктона, зообентоса и рыбного сообщества, включающего организмы и популяции разных видов рыб. Оценка состояния организма рыб приводиться на основе патологоморфологического и гистологического анализов, кроме того определены концентрации тяжелых металлов в органах и тканях рыб. Полученные результаты сопоставлялись с химическими показателями донных отложений и воды, из исследованных озер. В течение периода исследований изучалось негативное воздействие тяжелых металлов, поступающих из индустриальных центров (п.г.т. Никель, г. Заполярный), на водные экосистемы.
Влияние процессов закисления на водные экосистемы было обнаружено только в районе Ярфиорда (Норвегия). Влияние промышленных выбросов снижалось по мере удаления от источника загрязнения. Таким образом, довольно трудно проследить причины и следствия эффекта загрязнения из-за: 1) различной нагрузки и состава загрязнителей, в пределах небольшой территории, 2) разнообразие геологического строения и 3) биотических взаимоотношений, которые могут различаться между разными озерами. Хотя, качество воды и биологические парамстры существенно изменяются год от года, полученные результаты показывают незначительное улучшение в лимнологическом статусе озер, за период с 1990 по 1996 г. г. Эти изменения наиболее характерны для закисленного озера Дальватн в районе Ярфиорда.
Исследования 1990-1996 г.г. представляют пользу для оценки биоты в будущих процессах очищения пресноводных экосистем, испытывающих воздействие комбината "Печенганикель". В отличие от других загрязненных территорий Скандинавии и северной Европы, местные выбросы преобладают в нагрузке загрязняющих веществ на российско-норвежской границе. Этот факт делает данный регион уникальным для изучения эффектов загрязнения и восстановления пресноводных экосистем и их сообществ. Мы рекомендуем интенсивную программу мониторинга для изучения будущих процессов самоочищения пресноводных экосистем.

Ключевые слова: пресноводные сообщества, загрязнения, закисление, тяжелые металлы, Кольский полуостров.

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Preface

The impact of pollution on the environment of the Kola Peninsula has increased during recent decades due to the activity of a large number of mining factories and metallurgical industries. As a consequence a bilateral agreement between Russia and Norway was established in 1988. Under the terms of this agreement, a cooperative study on freshwater communities in the border area started in 1990. A baseline study of the pollution impact on freshwater communities in the border region was carried out in 1990-1992 (Nøst et al. 1991, Langeland 1993). The main co-operating institutions have been INEP (Institute of North Industrial Ecology Problems, Kola Science Centre, Apatity) and NINA (Norwegian Institute for Nature Research, Trondheim). The baseline study was followed by a joint Russian-Norwegian monitoring programme in selected lakes for the period 1993-1996. The monitoring programme was performed every year except in 1994. The results of the investigations in 1993 and 1995 are presented in Langeland et al. (1994), Lukin et al. (1995) and Nøst et al. (1996). The aim of this report is primarily to summarise the results and conclusions from the lakes monitored in 1990-96. The results of the investigations in 1996 are given a more thorough presentation. The Norwegian project leaders were Arnfinn Langeland (1990-1995) and Ann Kristin Schartau (1995-1997). The Russian project leaders were Valery Jakovlev (1990-1992) and Anatoli Lukin (1990-1996).

In 1996 field investigations took place between September 3 and September 8. The following persons participated in the fieldwork in 1996: Anatoli Lukin, Nikolai Kashulin and Andrey Sharov from INEP, and Terje Nøst and Hans Mack Berger from NINA.

We thank the following for assistance in analyzing water and biological material in the laboratory: J.Sharova, and O.Vandysh, INEP, S. Lierhagen (chemistry) and B. Walseng (littoral crustaceans) NINA, H. Huru (zoobenthos) University of Tromsø, Norway, H. Muladal (zoobenthos) Akvaplan-NIVA, Norway and Ø. Løvstad, (phytoplankton) Limnoconsult, Norway.

The following persons have also made important contributions to this report (in alphabetical order):
H.M. Berger, fish communities
V. Dauvalter, lake sediments
N. Kashulin and A. Lukin, fish pathology
T. Nøst, zooplankton
A.K.L. Schartau, water chemistry, phytoplankton and trace metal accumulation
A. Sharov, phytoplankton
V. Yakovlev, zoobenthos

The monitoring programme has been financed by the Norwegian (Directorate for Nature Management and Ministry of Environment) and Russian (Academy of Sciences of the USSR/Russia) environmental authorities.

Trondheim, May 1997

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1 Introduction

The Pechenganickel factories in the Russian towns of Nikel and Zapolyarny are the main sources of pollutants which affect the environment in the border region between Russia and Norway. As a result of long-term pollution impacts in this region, damage to terrestrial and aquatic ecosystems is obvious. High concentrations of pollutants in the atmosphere and effects on vegetation are evident even on the Norwegian side. The pollutant load from the Pechenganickel factories mainly consists of nickel (Ni), copper (Cu), sulphur dioxide (SO_2) and dust (Hagen et al. 1990, Sivertsen 1990). Trace metals are assumed to be deposited near the sources, while gases may be transported longer distances and then precipitate as acid deposits. Emissions of SO_2 from the Pechenganickel factories have been measured since 1973. The highest annual emission of SO_2 were registered between 1974 and 1988 (300,000 - 400,000 tons) (Løbersli & Venn 1994). Since 1988, emissions have been reduced to an annual level of 200,000 - 300,000 tons.

During the past few years severe impacts related to the pollutant load on both the terrestrial (Løbersli & Venn 1994) and freshwater (Nøst et al. 1991, Langeland 1993, Langeland et al. 1994, Hesthagen et al. 1997) biota have been documented. Impacts on freshwater communities were most pronounced near the factories, but more remote areas are also affected.

This report summarise the results and conclusions of the studies made in the border region, primarily in selected monitoring lakes during the period 1990-96. The report should also be regarded as an annual report for the 1996 investigations. An evaluation of these results and of the process of reconstruction of the air purification systems of the factories will form the basis for further investigations in the border region.

The report presents results regarding species composition, abundances and biomasses of phytoplankton, zooplankton, zoobenthos and fish communities. Pathological states and trace metal accumulation in fish are analysed. The biological results are related to analyses of chemical parameters in lake sediments and water.

2 Study area

The study area near the Russian-Norwegian border is located at latitude 69-70(N and longitude 29-31(E. The area was divided into four regions (cf. Langeland et al. 1993); 1) Nikel Region, 2) Pechenga River System, 3) Pasvik River System including Lake Kuetsyarvi and 4) Jarfjord Region.

The monitoring programme included eight lakes (**figure 1**, **table 1**); four lakes in the Nikel Region (Rousenyarvi, Shouniyarv and two small lakes near Nikel town; Lake Nikel 1 and Lake Nikel 2), Lake Maayarvi in the Pechenga River System and three lakes in the Jarfjord Region on the Norwegian side (Dalvatn, F. Guokkolobbalat and S. Skardvatn). During the study period the sampling frequency differed between the localities (**table 2**). In 1996 all the lakes were sampled.

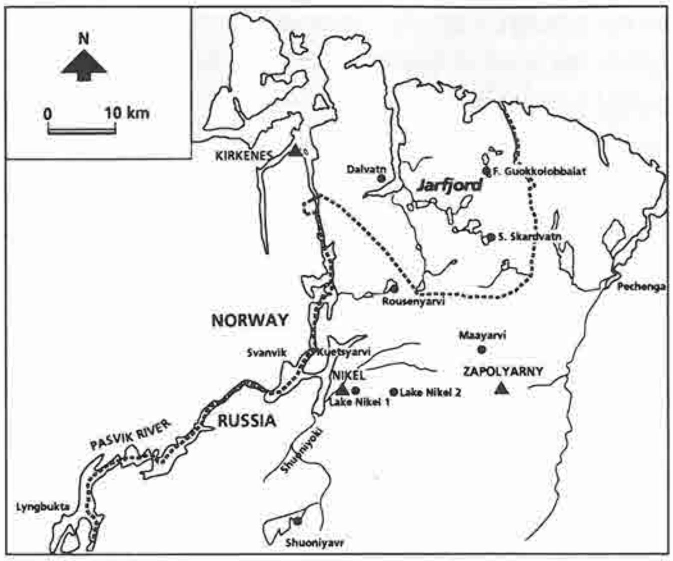


Figure 1
Map of study area with the investigated lakes.

The pollutant load differs from one region to another. The Pasvik River System drains the Nikel town area through Lake Kuetsyarvi. In the other regions pollutants are mainly transported by air. The pollutant load is thus determined by the distance from the emission sources and by wind direction. The immediate surroundings of the factories receive the largest amounts of pollutants in the form of gases and dust. Prevailing winds near the factories are mostly north-east, partly north and north-west. This means that the north-eastern regions of Norway including the Jarfjord

Table 1*. Site description of monitored localities.*

Locality		Zone	UTM-OV	UTM-NS	Area (ha)	m a.s.l.
Store Skardvatn	SS	36W VC	412800	7725200	80	238
Første Guokkolobbalat	FG	36W VC	414250	7734250	20	186
Dalvatn	Da	36W UC	398100	7734300	35	132
Shuoniyavr	Sh	36W UB	384900	7686100	850	190
Rousenyarvi	Ro	36W UC	398500	7717500	200	99
Maayarvi	Ma	36W VC	409500	7708200	25	180
Lake Nikel 1	LN1	36W UC	393000	7703500	10	50
Lake Nikel 2	LN2	36W UC	398400	7704100	20	100

Region, also receives air transported pollutants (Scholdager et al. 1983). However, the load in this area is lower than in the areas near the sources.

The geology of the border region is complex, with hard bedrock predominating in the Jarfjord region and more soluble and richer (more Ca and Mg) bedrock in the other regions (Atlas.1971, Sigmond et al. 1984).

The climate is influenced by warm currents from the Northern Atlantic and by cold flows from the Arctic (Yakovlev 1991). The annual mean temperature in the border area is low, e.g. -0.3 °C in Pasvik, Norway. Annual precipitation in Pasvik is low, 358 mm (Bøyum 1970, NVE 1987). Surface water systems drain into the Barents Sea. Mean annual runoff in the Pechenga River System is in the range of 600-800 mm.

3 Material and methods

The sampling programme in the lakes monitored in 1990-96 included water chemistry, phytoplankton, zooplankton, zoobenthos and fish. Data from the programme for 1990-95 have been presented in earlier reports; Langeland (1993), Langeland et al. (1994), Nøst et al. (1991), Nøst et al. (1996). This report presents some complementary and summarised results from 1990-95, and the results of the 1996 study and also discuss samples of lake sediments taken in 1992. Lake sediments are included in the monitoring programme on water quality in the border region (INEP and NIVA: Norwegian Institute for Water Research). Some data on the metal content of sediments have been published earlier (Traaen et al. 1990, 1991, Norton et al. 1992, 1996, Rognerud & Fjeld 1990, 1993, Rognerud et al. 1993, Moiseenko et al. 1995, Dauvalter 1992, 1994, 1997).

3.1 Water chemistry

Water samples were collected from depths of 0.2-1 m for analysis of various chemical parameters, including a number of trace elements such as the heavy metals chrome (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), lead (Pb), and cadmium (Cd), as well as aluminium (Al). The samples were stored under cool and dark conditions until analysis. Analysis were carried out at NINA's analytical laboratory using standard methods (**appendix 1**).

3.2 Sediments

Sediment samples were collected from the lakes in September 1992 using an ordinary gravity sediment corer as described by Skogheim (1979). In Maayarvi, Rousenyarvi and Shuoniyavr the upper 10-cm and lower 1-cm layers of the sediment were collected and sectioned in 1-cm layers for analysis. The upper and lower 1-cm layers were sampled from the other five lakes. The sediment samples were dried for 6 h at 105°C and water content was expressed as a percentage of wet weight. The sediment samples were then ignited for 4 h at 550°C for determination of the loss of ignition as an indirect index of organic matter content (Håkanson 1980). Concentrations of Ni, Cu, Co, Zn, Cd, Pb, Fe, Mn, Al, K, Na, Ca and Mg in the sediments were analysed by atomic absorption spectrophotometry (Perkin Elmer 460 and 560) using the standard addition technique. For metal analyses

Table 2. *Sampling in monitored lakes in 1990-1996. Locality code as indicated in Table 1.*

Loc.	Water chemistry						Lake sediments	Phytoplankton						Zooplankton						Zoobenthos				Fish					
	1990	1991	1992	1993	1995	1996	1992	1990	1991	1992	1993	1995	1996	1990	1991	1992	1993	1995	1996	1990	1991	1992	1996	1990	1991	1992	1993	1995	1996
SS		x	x	x	x	x	x				x	x	x		x	x	x	x	x		x	x			x	x	x	x	x
FG				x	x	x	x				x		x				x	x	x			x	x			x	x	x	x
Da	x			x	x	x	x				x	x	x	x			x	x	x	x			x	x			x	x	x
Sh		x		x	x	x	x				x	x	x			x	x	x	x		x	x			x	x	x	x	x
Ro		x		x	x	x	x				x		x			x	x	x	x					x	x	x	x	x	x
Ma	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	
LN1		x	x	x	x	x	x		x	x	x		x		x	x	x	x	x	x	x	x	x						
LN2	x	x	x		x	x	x		x	x		x	x	x	x	x		x	x	x	x	x							

~0.4 g sediment sample (dry wt.) was taken and digested in a Teflon 'bomb' for 4 h at 140°C with 2 ml concentrated nitric acid. Hg was determined using cold vapour atomic absorption.

Analyses were done at INEP's and NINA's laboratories. A more detailed description of the analytical methods is given in Rognerud et al. (1993) and Dauvalter (1994).

In order to determine the anthropogenic influence on the lake ecosystems, the trace metal contamination factor (C_f) for each metal (Ni, Cu, Co, Zn, Pb, Cd, Hg) was calculated as the quotient of concentrations from the uppermost to the deepest layers, according to the method suggested by Håkanson (1980).

3.3 Phytoplankton

Phytoplankton samples were taken from all the lakes (**table 2**). Two different approaches were taken concerning the sampling methods and the analysis of the phytoplankton.

1) A rough estimate of the main phytoplankton taxa: in 1991-1996 phytoplankton were collected as mixed samples (100 ml) from depths of 0-5 m, using a tube sampler (length: 1 m). Phytoplankton samples were preserved in 2 % Lugol's solution. Subsamples were settled overnight in 50 ml chambers, and enumerated using a Nikon TMS Inverted microscope (Utermöhl 1958). The nomenclature is in accordance with Tikkanen (1986). Phytoplankton biomass was calculated using standard cell volumes, based on approximating shapes to regular geometric figures, and then converting cell volumes to biomass units (Willén1976). The total population biomass of each algal species (g wet weight per m^3) was determined by multiplying density by cell biomass. The total algal biomass was determined by adding the biomass value for individual species. The samples were analysed by Øyvind Løvstad, Limnoconsult, Norway.

2) In 1995 and 1996 more detailed studies of phytoplankton were carried out. One-litre samples from the surface of the lake were preserved in 2 % Lugol's solution and neutralised formaldehyde. Species were identified and enumerated using a Zeiss inverted microscope. The nomenclature is in accordance with Tikkanen (1986). The volume of phytoplankton species was calculated using regular geometric figures (Tikkanen 1986). These samples were analysed by Andrey Sharov, INEP.

3.4 Zooplankton

Quantitative zooplankton samples were taken with a 5 l tube sampler, 1 m in length. The water was sieved through a net with a mesh size of 45 µm. In Lake LN1, Lake LN2, Rousenyarvi and Shuoniyavr, mixed samples were taken from depths of 0-5 m. In Maayarvi and the three Norwegian lakes (Dalvatn, S. Skardvatn and F. Guokkolobbalat) mixed samples were obtained from 0-5 m and 5-10 m. Three replicates were collected from each depth interval. Additional qualitative samples were collected from each lake using vertical net hauls from the bottom to the surface (net area 660 cm^2) and a mesh size of 90 µm. A few samples (2-4) of littoral crustaceans were also taken from each lake in 1995-96 using horizontal net hauls along the shoreline (5-10 m). All samples were fixed in Lugol's solution.

Calculations of biomass (dry weight) were based on the relationships between body weight (w) and body length (L) according to Bottrell et al. (1976) and Langeland (1982).

3.5 Zoobenthos

Within the border region most zoobenthos samples were taken in 1990-92, but some samples were also taken in 1993 and 1996. Samples were taken one to three times a year in 1990-92 (June-July, July-August, August-September), in August 1993 and July 1996. Samples were collected from different habitats; lakes (littoral and profundal zones), inlets and outlets of lakes, streams and rivers, at a total of 134 stations: 42 from the Nikel Region/Pechenga River System, 69 from Jarfjord Region and 23 from the Pasvik River system

Qualitative samples from littoral zones of lakes and from running waters were made by a kicking technique described by Frost et al. (1971). The duration of the sampling was 1-3 min. and the mesh size was 0.5 mm. One to three samples were usually taken from each station. Quantitative samples were taken using an Ekman grab, covering an area of 213 cm^2. Three to five samples were collected from each site. In larger lakes (Kuetsyarvi, Saraslaki, Maayarvi, S. Skardvatn and Skrukkebukta) sampling was carried out at several depths (shore - maximum depth). In addition, samples from Lake Kuetsyarvi were taken from various depths along six transects. The samples were usually washed in a sieve with a 0.25 mm mesh. All animals were picked out and preserved in 70% ethanol.

3.6 Fish

All monitored lakes were sampled in the period 1990-1996 (**table 2**). In 1996 fish were sampled in five lakes; Rousenyarvi, Shuoniyavr, Dalvatn, S. Skardvatn and F. Guokkolobbalat using multi-mesh gillnets (Nyberg & Degerman 1988, Appelberg et al. 1995). The nets, which have a depth of 1.5 m and a length of 30 m, consist of 12 different mesh sizes ranging from 5 to 55 mm. The nets were set out separately from the shoreline.

All fish were analysed for body length and weight, sex, gonad maturity, fat content of intestine and stomach fullness. Scales, otholiths, shoulder- and opercular bones were collected for age determination according to standard methods (Jonsson 1976, L'Abée-Lund 1985). The stomach contents of a sample (up to 20) of fish were collected for food items and preserved in 70 % ethanol. The stomach content was determined to prey group according to the method described by Hynes (1950).

Streams and inshore areas in all lakes were electrofished in August/September every year from 1990 to 1995. Natural tip lengths of all fish were measured in field and fish caught near Nikel were preserved in 70% ethanol for further analyses at the laboratory.

Pathological and morphological examinations were carried out on each population, and visible symptoms of diseases and parasitic infection were recorded. Such studies have been shown to be useful to reveal anthropogenic impacts on water systems. Visual observations of diseases were made according to a four-point scale (0,1,2,3) defined as 0=absence of visible deviations from normal, 1=initial stage of disease, 2=indices of medium infection and 3=irreversibility of disease. Additional histological analyses were made on important organs (liver, gills and kidney) to support the pathological observations. The histological analyses considered lipoid degeneration of the liver, connective tissue expansions, nephrocalcitoses in kidneys and «anaemic» ring in the gills.

Trace metal contents of tissue and organs were determined for the following species: brown trout, Arctic char, perch, and pike. Subsamples were collected from the gills, liver, kidney, muscle and skeleton in 1990-1992, while only subsamples of liver and kidney from brown trout and Arctic char were collected in 1995. The 1990 and 1991 samples were analysed at INEP (Nøst et al. 1991) while the samples from 1991 (parallels), 1992 and 1995 were analysed at NINA (Langeland 1993).

4 Results and discussion

4.1 Water chemistry

The number of chemical parameters included in the monitoring program have changed in the course of period of investigation. All results from the period 1990-1995 have been presented in earlier reports (Langeland 1993, Langeland et al. 1994, Nøst et al. 1996). The results from 1996 are presented in **appendix 2** in this report. A selection of chemical parameters from the period 1990-1996 are presented as a box-plot in **figure 2**.

In general, the highest values of most of the chemical parameters were found in the Russian localities. Temporal variations in water quality were also greatest in these localities, especially in Lake LN1 and Lake LN2.

The range in pH was between 5.55 and 7.40 (**figure 2**) with the highest values in the Nikel Region. Low pH values were measured in the Jarfjord locality Dalvatn (pH: 5.55-5.91).

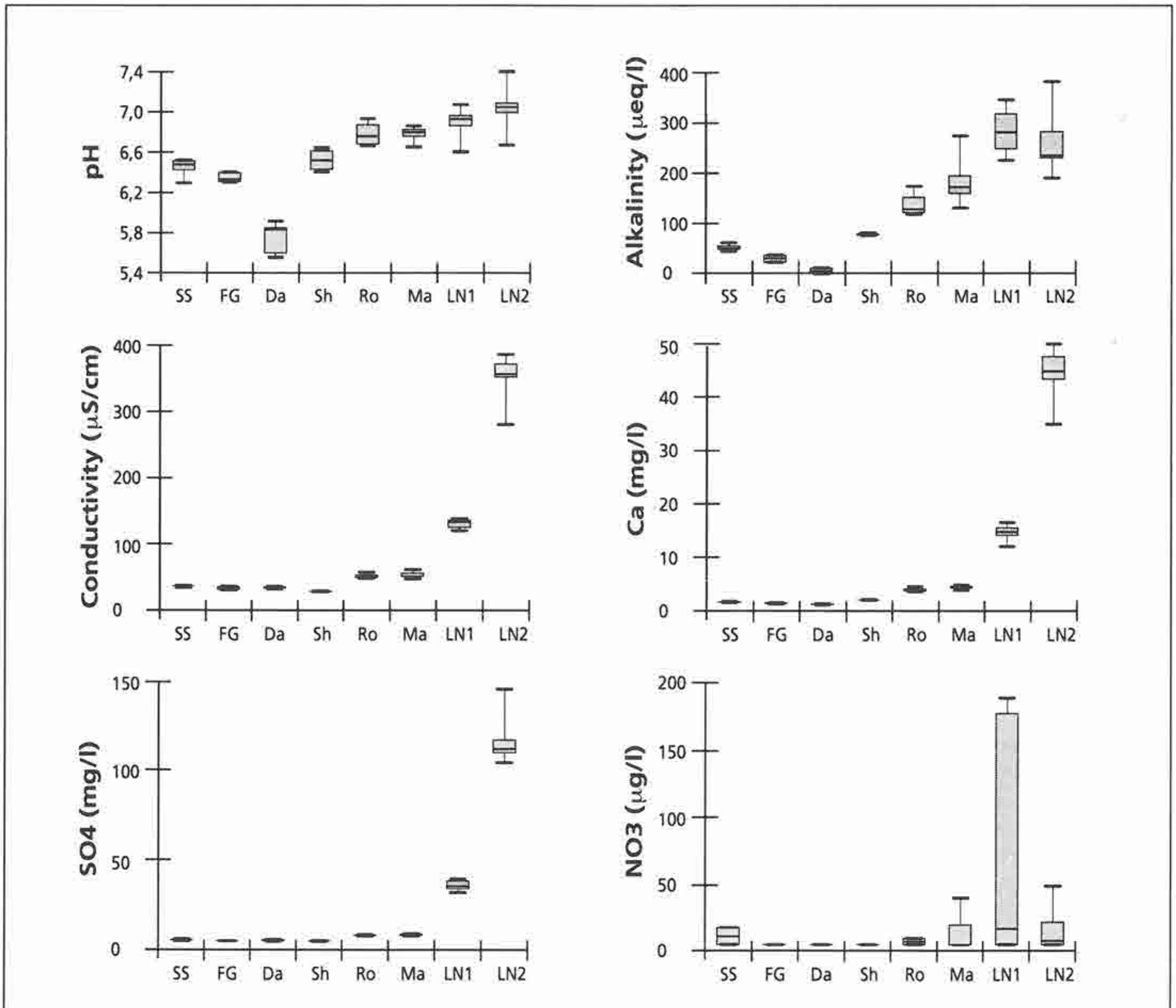


Figure 2

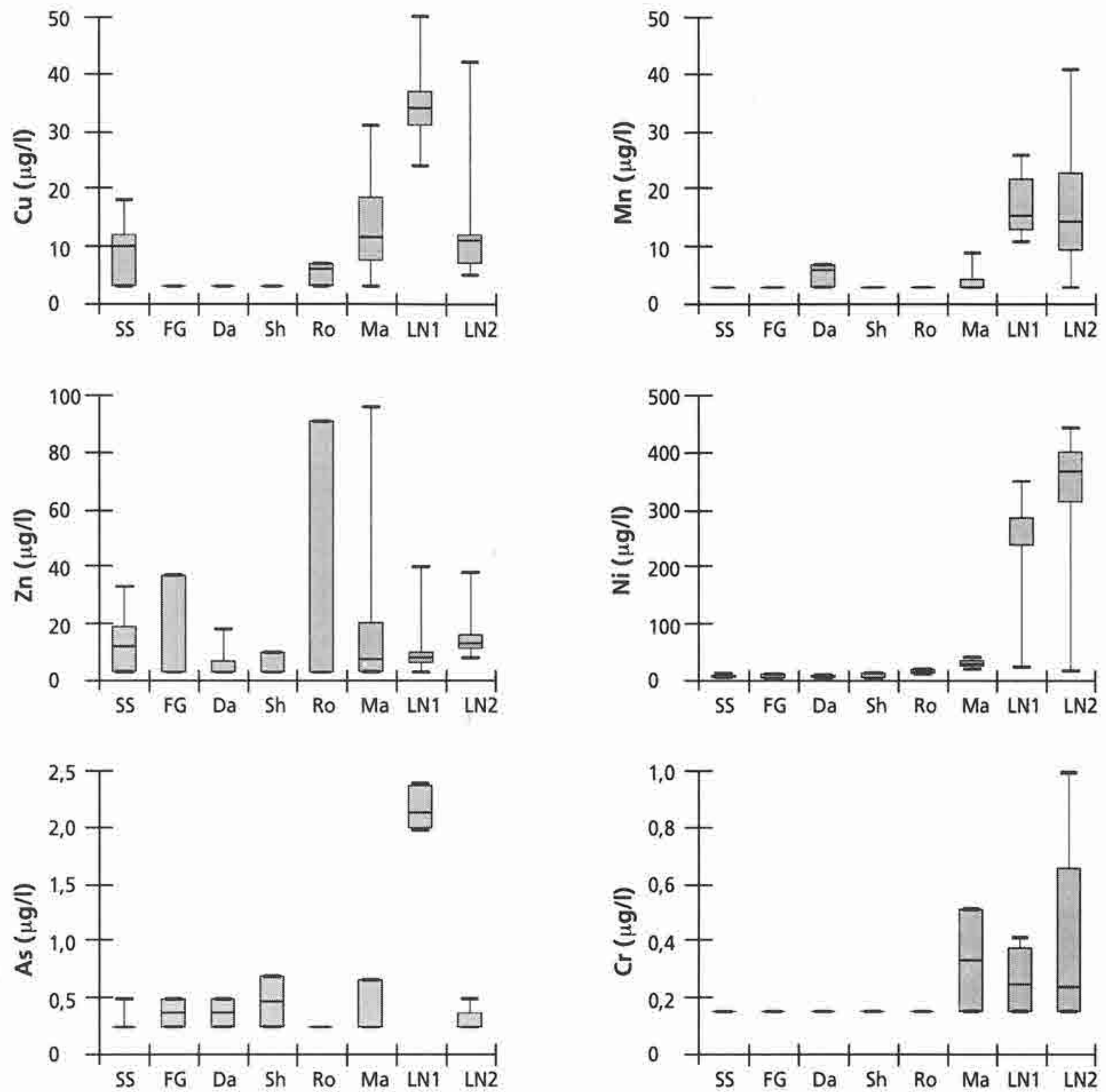


Figure 2
Box and whisker plot (minimum, 25% percentile, median, 75% percentile, maximum) of pH, alkalinity, conductivity, calcium (Ca), sulphate (SO_4), nitrate (NO_3), copper (Cu), manganese (Mn), zinc (Zn), nickel (Ni), arsenic (As), and chrome (Cr) from the lakes monitored in 1990-1996. Note: The start of the investigation period varies between 1990 and 1993, cf. ***table 2****. Detection threshold (in µg/l): Cu/Mn/Zn: 6; Ni: 20 (1990-91), 12 (1992-93), 2 (1995-); As: 0.5; Cr: 0.3. Values below the detection threshold are defined as half the value of the detection limit.*

Concerning alkalinity and calcium concentrations (Ca), high values were found in two localities near Nikel, LN1 (224-343 µeq/l, 11.98-16.48 mg Ca/l) and LN2 (189-379 µeq/l and 34.85-49.87 mg Ca/l), respectively. High values were also measured in Rousenyarvi and Maayarvi, whereas both alkalinity and calcium concentration were low in the Norwegian lakes, especially in Dalvatn (0-13 µeq/l, respectively 1.14-1.33 mg Ca/l).

High conductivity values were measured in lakes LN1 (120-138 µS/cm) and LN2 (280-386 µS/cm) due to elevated concentrations of calcium, sulphate, nitrogen, phosphorous and most trace metals. Relatively high conductivity levels were also measured in Maayarvi and Rousenyarvi, but these only seldom exceeded 60 µS/cm. In Shuoniyavr (28-29 µS/cm) and in the Norwegian lakes (31-37 µS/cm) the conductivity was relatively low and showed little variability over time.

Sulphate (SO_4) varied between 4.17 and 145.85 mg/l throughout the area investigated. Similar patterns as for Ca were found, with high values in the localities near Nikel. The concentrations were far higher in Lake LN2 (104.74-145.85 mg/l) than in Lake LN1 (32.18-39.54 mg/l).

High levels of nitrogen, measured as nitrate (NO3), were measured in Lake LN1 (<10-189 µg/l), which may receive input from the town of Nikel. A few analyses of total nitrogen in 1992 gave a maximum of 381 µg tot-N/l in Lake LN1 (Langeland 1993). The concentrations of total nitrogen are 2-3 times higher than for most of the lakes in this area. In the lakes Shuoniyavr, F. Guokkolobbalat and Dalvatn nitrate concentrations never exceeded the detection threshold of 10 µg/l.

Contents of metals were generally highest in the Nikel Region, especially in Lake LN1 and Lake LN2, whereas the metal concentrations in the Jarfjord Region only seldom exceeded the detection threshold (**figure 2**). High values of copper were obtained in Maayarvi and in the Nikel lakes, with a maximum of 50 µg/l in Lake LN1. Even higher values (125 µg Cu/l in Lake LN2) were found in samples from deeper water layers (Langeland 1993). In S. Skardvatn a maximum of 18 µg Cu/l was measured in June 1992.

The manganese concentrations (Mn) were high in Lake LN1 (11-26 µg/l) and in Lake LN2 (<6-41 µg/l). A few values above the detection limit of 6 µg Mn/l were obtained in Dalvatn and in Maayarvi.

The concentration of zinc (Zn) showed a different pattern to that of most other heavy metals in the border region, with relatively small differences between localities. The highest values were obtained in Rousenyarvi (<6-91 µg/l) and Maayarvi (<6-96 µg/l), while the lowest values were measured in Dalvatn and Shuoniyavr, with few values above the detection threshold of 6 µg Zn/l.

Concentrations of nickel (Ni) followed the same pattern as for Cu, with the highest values in the Nikel Region, and most values below the detection threshold in the Norwegian lakes and in Shuoniyavr. The highest values were obtained in Lake LN1 (24-350 µg/l) and Lake LN2 (17-443 µg/l).

The arsenic (As) content of the monitoring lakes showed the same pattern as for Cu. The highest values of As were measured in Lake LN1 (1.99-2.41 µg/l) whereas the levels in all other monitoring lakes were below the detection limit of 0.5 µg/l most of the time.

Chrome (Cr) showed a similar pattern to those of Mn and Ni, although all values were low. A maximum of 0.99 µg/l was obtained in Lake LN2 and elevated levels of Cr were also found in Lake LN1 and Maayarvi.

Changes in some chemical parameters through time are shown in **figure 3** and **figure 4**.

In Dalvatn, the pH rose from 5.55 in September 1990 to 5.91 in September 1996. A slight increase in pH during the study period was also observed in the Russian lakes Rousenyarvi, Maayarvi and Shuoniyavr. This is in accordance with a general fall in concentrations of non-marine sulphate in surface waters in this region. Changes in pH values in Lake LN1 and Lake LN2 are not associated with corresponding changes in level of sulphate (**figure 3**).

Any changes in the effluents of heavy metals would be expected to produce corresponding changes in the concentrations of the-

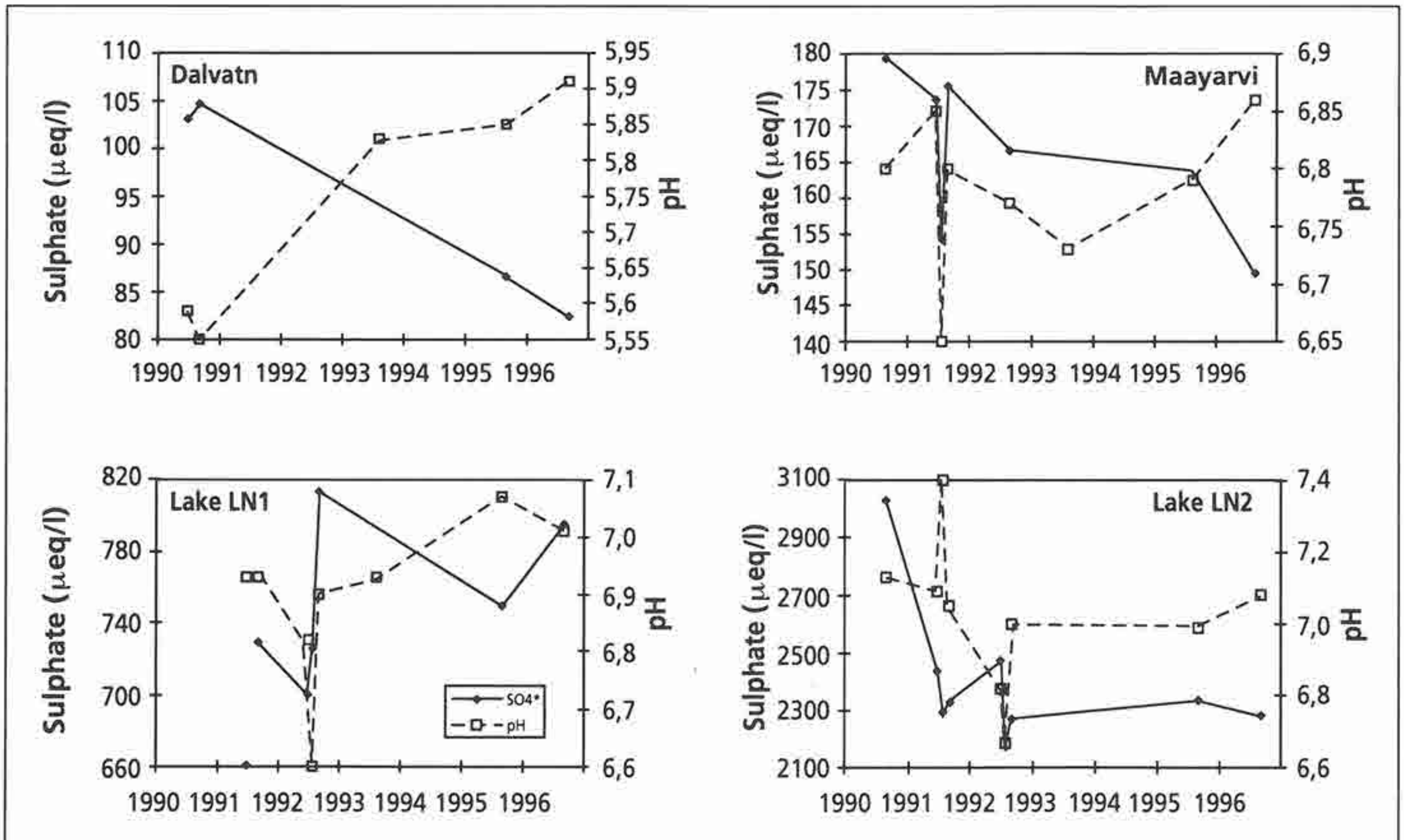


Figure 3
pH and concentrations of non-marine sulphate (SO_4) in Dalvatn, Maayarvi, Lake LN1 and Lake LN2 during the investigation period 1990-1996.

se elements in the most polluted lakes, LN1 and LN2. The concentrations of Cu and Ni in these lakes are shown in **figure 4**. The results from the August/September samples show a falling trend in concentrations of Ni in Lake LN2 from September 1990 (403 µg/l) to September 1996 (293 µg/l). This trend however, is not matched by any of the other heavy metals from Lake LN2 nor the metal concentrations in Lake LN1.

High values of most of the chemical parameters were found in the Russian localities. This is especially true of the lakes close to Nikel and the Pechenganickel factories (Lake LN1 and Lake LN2) but, also to a lesser extent of the lakes within 15 km north and north-west of Nikel town, Rousenyarvi and Maayarvi, which have elevated levels of calcium, sulphate, nitrate, and heavy metals such as copper, nickel, zinc and chrome. Variations in water quality were also highest in these localities, especially in the Nikel lakes. The Russian lake Shuoniyavr, about 20 km south of Nikel town, as well as the Norwegian lakes S. Skardvatn and F. Guokkolobbalat in the Jarfjord Region, are almost unaffected. However, Lake Dalvatn, also situated in the Jarfjord Region, is affected by acidification and shows low pH and alkalinity values. The concentrations of non-marine sulphate in Dalvatn and S. Skardvatn are at the same level, but the sum of strong acid anions (SO_4, NO_3, Cl) is higher in Dalvatn (241-262 µeq/l) than in S. Skardvatn (225-250 µeq/l). The difference is probably due to the stronger influence of marine components, as chlorides, in Dalvatn. Less soluble and poorer bedrock (with low levels of calcium and magnesium) in the catchment area of Dalvatn is assumed to be the main reason why this lake is more severely affected by acidification than the other lakes.

Generally, variations in most chemical parameters were too high and the number of samples were too few to allow us draw any conclusions about changes in the water quality during the study period. However, rising levels of pH and alkalinity in Dalvatn during the monitoring period are in general agreement with the conclusions of other studies in the border region; monitoring of pollution of surface waters (Traaen & Rognerud 1996) and monitoring of air pollution (data from NILU presented in Traaen & Rognerud 1996). The total amount of strong acid anions shows falling trend in all Norwegian lakes as well as in the Russian lakes Rousenyarvi, Maayarvi, and Shuoniyavr.

The differences in water chemistry between Lake LN1 and Lake LN2 need a more thorough discussion. Lake LN1 is situated within 1 km from the Pechenganickel factories but shows lower levels of most chemical parameters than Lake LN2, which is situated about 3 km from the factories. The catchment area of Lake LN2 is many times larger than the catchment area of Lake LN1 and the former lake may therefore receive larger quantities of pollutants. This is especially true just after a rainy period when large amounts of pollutants in the catchment area are washed into the lake. Higher variations in most chemical parameters in Lake LN2 than Lake LN1 are probably also explained by this situation. On the other hand, Lake LN1 also receives effluents directly from the settlement of Nikel town, which could explain the high levels of nitrate in this lake.

4.2 Sediments

Concentrations of trace metals in sediment samples taken from the deepest part of the cores (usually more than 20 cm) of the investigated lakes are at the same levels (**appendix 3**) as non-polluted parts of north-eastern Norway and north-western Kola Peninsula (cf. Rognerud & Fjeld 1990, 1993, Dauvalter 1994, 1997), and are therefore used as background (or reference) values.

Changes in the vertical distributions of trace metals in sediments as concentrations increase towards the sediment surface are most evident in Maayarvi, followed by Rousenyarvi and Shuoniyavr. This pattern is particularly typical for Ni, Cu and Co (**figure 5**). Pb, Cd and Mn also show this pattern of vertical distribution. The influence of acid precipitation is probably caused by lower Al concentrations in the upper sediment layers of Rousenyarvi.

The highest Ni and Cu concentrations, which exceed background values by factors of 10-130, were found in sediments of Lake LN1 and Lake LN2 (**appendix 3**). Ni and Cu concentrations in sediments of Maayarvi and Rousenyarvi were also very high (20-45 times higher than background values). The concentrations of these metals decreased very sharply with increasing distance from the factories; in Shuoniyavr and the Norwegian lakes at Jarfjord. The same pattern of distribution in lake sediments between lakes was recorded for the other trace metals studied, but to a slighter extent. The exception was Pb, which had relatively high concentrations in the Norwegian lake sediments. This peculiarity in the border region between Norway and Russia has been observed earlier (Dauvalter, 1994, 1997).

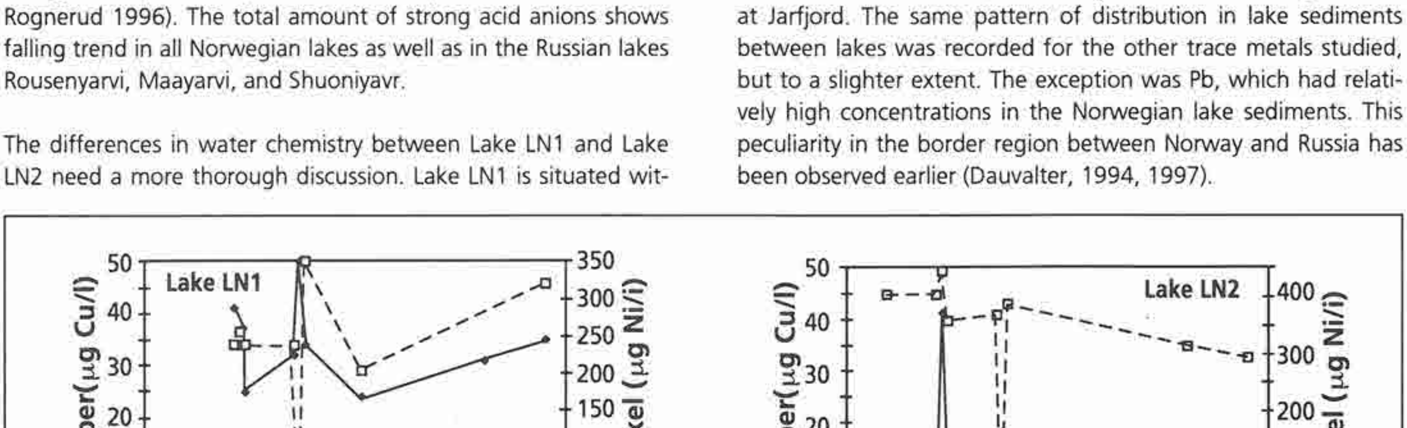


Figure 4
Concentrations of nickel (Ni) and copper (Cu) in Lake LN1 and Lake LN2 during the investigation period 1990-1996.

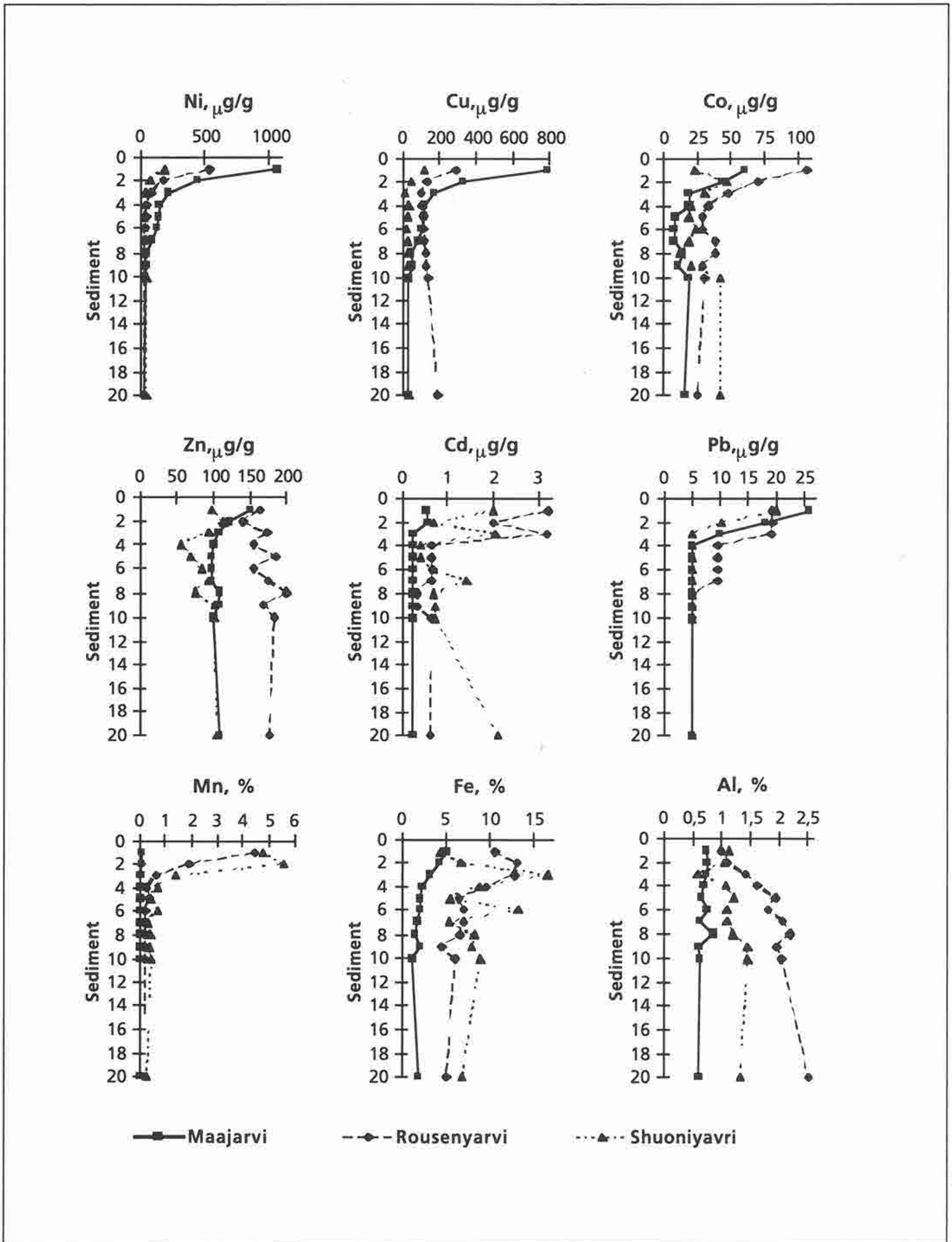


Figure 5
Distribution of metal concentrations (μg/g dry weight) in sediments cores in Maayarvi, Rousenyarvi and Shuoniyavr.

The atmospheric emissions of trace metals from the Pechenganickel factories are probably the main sources of increasing concentrations of the elements observed in the surface sediments of the lakes. Maximum values of the contamination factor (C_f) for trace metals were noticed for sediments in Lake LN1 and Lake LN2 which lie within 3 km of the Pechenganickel Company. According to classification by Håkanson (1980) these lakes had very high C_f values for Ni, Cu, Pb and Hg, considerable values for Co and Cd and moderate values for Zn. Maayarvi had a very high C_f value for Ni, Cu and Hg, considerable for Co, and moderate for Cd, Pb and Zn. Very high C_f values for Ni, considerable for Co, Cd and Hg and moderate for Pb and Cu were calculated for sediments in Rousenyarvi. The prevailing south-westerly winds distribute the pollution plume of the Pechenganickel factories mainly in a north-easterly direction, leaving the lakes more than 20 km south from the Nikel town almost unaffected (Rognerud et al. 1993). Nevertheless, the sediments of lake Shuoniyavr (15 km south of the Pechenganickel factories) are characterised by considerable C_f values for Ni and Cu. The lakes on the Norwegian side had C_f values between low and moderate, with the exception of Pb in Dalvatn and S.Skardvatn (very high values) and Ni in Dalvatn (considerable values).

4.3 Phytoplankton

1) Total biomass (g wet weight/m^3) and the composition of the phytoplankton in the period 1991-1996 is shown in **figure 6** and the phytoplankton data from 1996 is presented in **appendix 4**. High biomass values were recorded in Lake LN1 (0.95-5.62 g ww/m^3). In the other Russian lakes as well as the lakes in the Jarfjord Region, values above 0.5 g ww/m^3 were seldom recorded. The lowest phytoplankton biomasses were measured in F. Guokkolobbalat (0.08-0.09 g ww/m^3) and in Dalvatn (0.12-0.20 g ww/m^3). In these lakes as well as in the Russian lakes Shuoniyavr and Maayarvi there were only small annual variations in total biomass and in algae composition while the variations were considerable in lakes LN1 and LN2.

With few exceptions, bluegreen algae were the dominant group of phytoplankton in the lakes, followed by «others»; of µ-algae and unidentified cysts and flagellates. *Synechococcus* sp. and *Aphanothece* sp. were the most common species of blue-green algae. In Lake LN1, however, *Gomphoshaeria* lacustris, colonial *Rabdoderma* sp. and unidentified bluegreen algae were the dominant species. Green algae (Chlorophyceae) were recorded in Dalvatn (Chlorococcales sp.) and Lake LN1 (Cosmarium sp.) in August 1993, but were observed elsewhere only at low densities. In LN1 the golden alga *Dinobryon* sp. (Chrysophyceae) made up a considerable proportion of the phytoplankton in most years. Dinobryon sp. was also recorded from Lake LN2 in August 1992 whereas another golden alga Mallomonas sp. was recorded from S. Skardvatn in August 1993.

2) A total of 95 species and forms were recorded in the lakes in 1995-96 (**appendix 5**); Chrysophyceae (16), Clorophyceae (17), Conjugatophyceae (6), Cryptophyceae (8), Cyanophyceae (11), Diatomophyceae/Bacillariophyceae (33), Dinophyceae (2), Prymnesiophyceae (1) and Tribophyceae (1).

Maximum phytoplankton biomass (5779.5 mm^3/m^3) was recorded in Lake LN1 in September 1995. This extremely high level of biomass is explained by large amounts of colonial algae (d=4-10 mm), which were impossible to identify. The diatoms *Fragilaria capucina* and *Fragilaria* sp. were subdominant. The Crysophyceaens *Dinobryon sociale* and *Mallomonas lychenensis* were dominant in 1996.

The phytoplankton community of the Lake LN2 was very poor, with 20 species being recorded. The following algae predominated in the total biomass: *Mougeotia* sp. (Conjugatophyceae), *Snowella atomus* (Cyanophyceae) and unidentified cysts (d=10 mm) in September 1995; and the Chlorophyceaens *Dictyosphaerium subsolirium* and *Planktosphaeria gelatinosa* in 1996.

The dominant algae in the phytoplankton of Shuoniyavr were the diatoms *Tabellaria fenestrata* and *T. flocculosa* and the bluegreen algae *Aphanothece minutissima* and *Aphonocapsa delicatissima* in 1995. The Chrysophyceaen *Dinobryon acuminatum* was dominant in 1996.

Maayarvi is unlike the other lakes characterised by a rich species content of phytoplankton (46 species). The dominant species was *Asterionella formosa* in 1995, while *Tabellaria fenestrata* and *Dinobryon acuminatum* were the dominant algae in 1996.

In Rousenyarvi great variation in the phytoplankton community was observed between 1995 and 1996. Total biomasses were 367 and 1414 mm^3/m^3, respectively. The diatoms (*Cyclotella* spp.) predominated both years, but the bluegreens *Aphanothece minutissima* and *Merismopedia tenuissima* made up a considerable part of the abundances in 1995.

The phytoplankton biomass of F. Guokkolobbalat varied considerably, 1335 mm^3/m^3 in September 1995 and less than 200 mm^3/m^3 in 1996. The dominant species in 1995 was *Fragilaria capucina* (1016 mm^3/m^3), whereas the Chrysophyceaen *Dinobryon acuminatum* dominated in 1996. In other lakes at higher altitudes in this watershed, the levels of biomass were similar in 1996, but another Chrysophyceaen, *D. elegans,* predominated in the upper lakes.

The diatoms dominated in S. Skardvatn, with a high density of *Fragillaria capucina* in 1995. The diatoms *Aulacoseira lirata* and *Cyclotella* spp. (d=7-24mm) and the Chrysophyceaen *Mallomonas acaroides* dominated in 1996.

In all the lakes studied, the phytoplankton biomass was lowest in Dalvatn (36-61 mm^3/m^3). Here, the diatom *Aulacoseira italica* var *tenuissima* was dominant in September 1995. The Chrysophyceaen *Dinobryon acuminatum* was dominant in June 1996 and the Chlorophyceaens *Oocystis* spp. were dominant in September 1996.

Considerable variations in biomasses of phytoplankton and species composition between lakes were found. There were also some annual variations in the results from individual lakes. The highest variations, both in total biomass and in algae species composition, were found in the most polluted lakes, LN1 and LN2.

The phytoplankton communities are known to show large variations over time, with changing species composition during the season and high annual variations in total abundances and composition of species. One to three sampling dates per year are far too few for good descriptions of the phytoplankton communities and to dis-

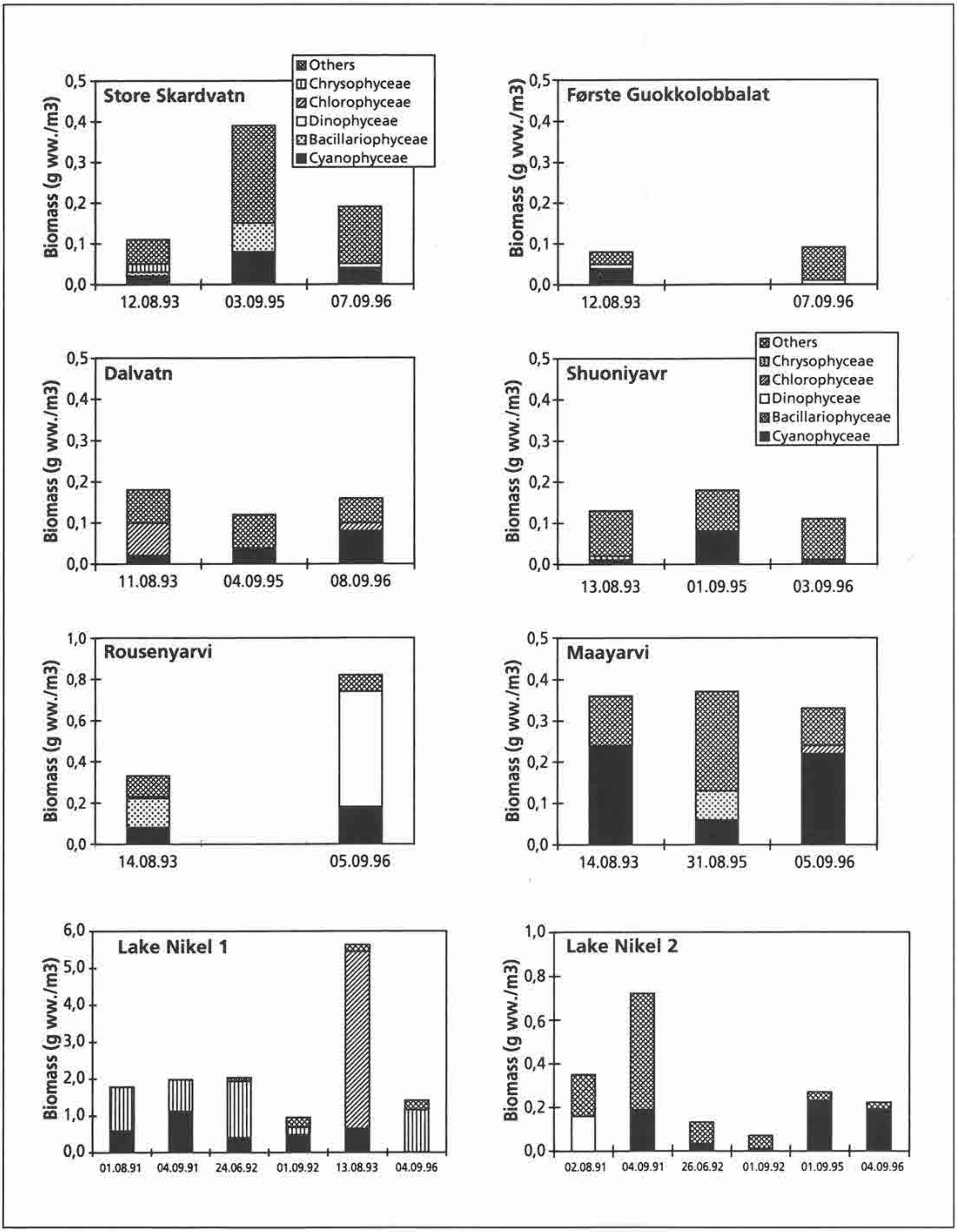


Figure 6
Biomass (g wet weight/m³) of phytoplankton and the composition of the main phytoplankton groups in the monitored lakes during 1990-1996.

cuss relationships between phytoplankton and zooplankton. However, in most years phytoplankton samples were collected at the same time, in August/September, in order to limit these variations.

The results of the two approaches used in the phytoplankton studies are not directly comparable. Sampling methods and the methods used to calculate the biomasses differ. Furthermore, while approach 1 presents the biomass as wet weight per volume of water, approach 2 presents these results as cell-volume per volume of water. The horizontal and vertical distributions of phytoplankton are usually patchy. Samples taken at such relatively close intervals as one metre may be inadequate to give an accurate estimate of abundance. A device such as a pipe or a tube sampler of 1 m in length, which samples the whole of a water column or the productive part of it, is more satisfactory for obtaining an integrated sample. Heterogeneous horizontal distribution is more difficult to take into account. In approach 1 mixed samples from the upper 0-5 m were taken compared to surface samples in approach 2. In spite of this differences, ranking lakes on the basis of phytoplankton biomasses, gave the same results independent of which approach we used. However, the number of species recorded was far higher with approach 2, due to the larger volume of samples analysed and a more detailed study of the species composition.

The results of approach 2 showed that the total phytoplankton biomass was lower in September 1996 than in September 1995 in most of the lakes, except in Maayarvi and Rousenyarvi. In 1996 the phytoplankton community in Maayarvi was dominated by high numbers of Tabellaria fenestrata and *Dinobryon acuminatum* while *Cyclotella bodanica* was the dominant alga in Rousenyarvi. The development of the phytoplankton in the monitoring lakes shows that diatoms and green algae were common in September 1995 and golden algae in 1996. These differences may have been due to low summer temperatures in 1996.

The difference in phytoplankton biomasses between Lake LN1 and Lake LN2 is of great interest. Uncommonly high abundance in the first lake may be related to a very poor grazer community, which comprised only one species of zooplankton (Eudiaptomus graciloides) in small numbers (September samples: 34-531 mg dw./m^2). In contrast, in Lake LN2 the biomasses of the two present species (*Bosmina longispina* and E. *graciloides*) were 213-1145 mg dw./m^2. The production of phytoplankton in these two lakes could also differ because of higher concentrations of phosphorous and nitrogen in Lake LN1 than in Lake LN2. Nor could toxic effects caused by periodically extremely high concentrations of sulphate and Ni together with high levels of most other elements in Lake LN2, resulting in low production and/or low growth of phytoplankton, be neglected as an explanation.

4.4 Zooplankton

Considerable variations in species composition and biomass of zooplankton were recorded in the lakes in 1996 (**appendix 6, figure 7**). A similar situation was observed in earlier years.

Lake LN1 and Lake LN2 clearly showed the lowest species diversity. Only one species of zooplankton was found in Lake LN1 (*Eudiaptomus graciloides*) and two species in Lake LN2 (*E. graciloides* and *Bosmina longispina*). In the other lakes the number of zooplankton species varied between 4 and 8, with the highest number in F. Guokkolobbalat. The total number of crustacean species (planktonic and littoral) was also low in Lake LN1 and Lake LN2 (8-9 species) compared to 13-19 species in the other lakes (**table 3**). The largest number of species was found in Shuoniyavr. *B. longispina* was the only species found in all lakes.

The biomass of zooplankton (mg dry weight/m^2) showed great variations between the lakes and also in each lake during the period of study (1990-96).

In 1996 the biomass in Lake LN1 was 34 mg/m^2, which is the lowest recorded during the period 1990-96 when comparing samples from the same time of the year (52 - 531 mg/m^2). The highest biomass in Lake LN1 was recorded during the summer of 1992 (1100-1200 mg/m^2). In 1996 the zooplankton biomass in Lake LN2 was 595 mg/m^2, compared to a range of 177-1546 mg/m^2 at the same time in 1990-95. B. longispina was the predominant species in Lake LN2.

In the other lakes the biomasses in 1996 seem to be within the ranges found during earlier years. The acid-sensitive cladoceran Daphnia seems to make up a considerable part of the zooplankton community in Maayarvi, S.Skardvatn and Shuoniyavr. However, the occurrence of Daphnia is variable, especially in Maayarvi, where the biomass of Daphnia varied between 27 and 1065 mg/m^2 during the period 1990-96. Daphnia was also found in the two neighbouring lakes F. Guokkolobbalat and A. Guokkolobbalat as well as in Rousenyarvi, but populations seemed to be small. In Rousenyarvi the biomass of daphnids declined from 8 mg/m^2 in 1992 to none in 1995 and 1996. In Dalvatn daphnids have been absent in all samples, except for one individual of *Daphnia longiremis* in 1996. The population of the cladoceran *Holopedium gibberum* seems to have increased during the last years in Dalvatn. In other lakes, especially Rousenyarvi and F. Guokkolobbalat, this species occasionally made a considerable contribution to the zooplankton biomass.

Several factors are assumed to explain the high differences in zooplankton biomasses as well as species composition between years and between lakes. Both abiotic (e.g. temperature, light) and biotic (phytoplankton biomass, competition and especially changes in planktivorous fish predation pressure) relationships as well as impacts of pollutants may influence the zooplankton communities. Obvious effects of pollution are only observed in Lake LN1 and Lake LN2. In both lakes the numbers of species are low and differ from the other lakes in the border region. The great variations in biomasses of E.graciloides in Lake LN1 indicate labile conditions for the survival of the different lifestages. The absence of the acid-sensitive cladoceran, Daphnia, in Dalvatn also indicates pollution impacts. Low abundances of Daphnia in F. Guokkolobbat and Rousenyarvi also seem to be related to pollution impacts.

4.5 Zoobenthos

The most common and distributed mayfly species in the border area were *Baetis rhodani*, *B. subalpinus*, *Ephemerella aurivillii*, *Leptophlebia* spp., *Paraleptophlebia* spp., *Siphlonurus* spp. The

Table 3. *Species composition of Crustacea present in monitored lakes during the period 1990-1996. Locality code as indicated in Table 1. Zooplankton samples are taken with tube sampler and vertical net hauls. Littoral samples are taken with horizontal net hauls along the shore line (5-10 m).*

	SS	FG	Da	Sh	Ro	Ma	LN2	LN1
Cladocera								
Diaphanosoma brachyurum					x			
Holopedium gibberum	x	x	x	x	x	x		
Bosmina longispina	x	x	x	x	x	x	x	x
Daphnia longispina	x	x			x	x		
Daphnia galeata	x	x		x	x	x		
Daphnia longiremis			x	x				
Bythotrephes longimanus		x	x	x	x	x		
Leptodora kindtii						x		
Opryoxus gracilis	x	x	x		x		x	
Polyphemus pediculus	x	x	x		x	x	x	x
Chydorus sphaericus	x	x	x				x	x
Alonopsis elongata	x	x	x	x	x	x	x	
Acroperus harpae	x	x	x	x	x			
Alona affinis	x	x	x		x			
Alona guttata				x				
Alona quadrangularis						x		
Alonella excisa	x	x				x		
Lathonura rectirostris				x				
Rhynchotalona falcata			x	x				
Eurycercus lamellatus		x					x	
Copepoda								
Acanthodiaptomus tibetanus				x		x		
Eudiaptomus graciloides	x	x	x	x		x	x	x
Eudiaptomus gracilis					x			
Heterocope appendiculata			x	x	x			
Cyclops scutifer	x	x	x	x	x	x		
Cycops abyssorum	x	x						
Mesocyclops leuckarti			x					
Eucyclops serrulatus	x							x
Eucyclops macrurus				x				
Eucyclops macruroides			x					
Eucyclops speratus				x				
Paracyclops fimbriatus								x
Macrocyclops albidus	x	x	x	x			x	x
Megacyclops gigas		x					x	x
Acanthocyclops cappilatus	x		x	x				
Acanthocyclops robustus			x	x				
Cladocera, number of species	11	13	11	10	11	10	6	3
Copepoda, number of species	6	5	8	9	3	3	3	5
Zooplankton; number of samples	56	21	35	16	9	56	36	36
Zooplankton; number of sampling dates	8	3	5	4	3	8	9	9
Littoral crustacea; number of samples	4	2	2	4	4	2	3	3
Littoral crustacea; number of sampling dates	2	1	2	2	2	1	2	2

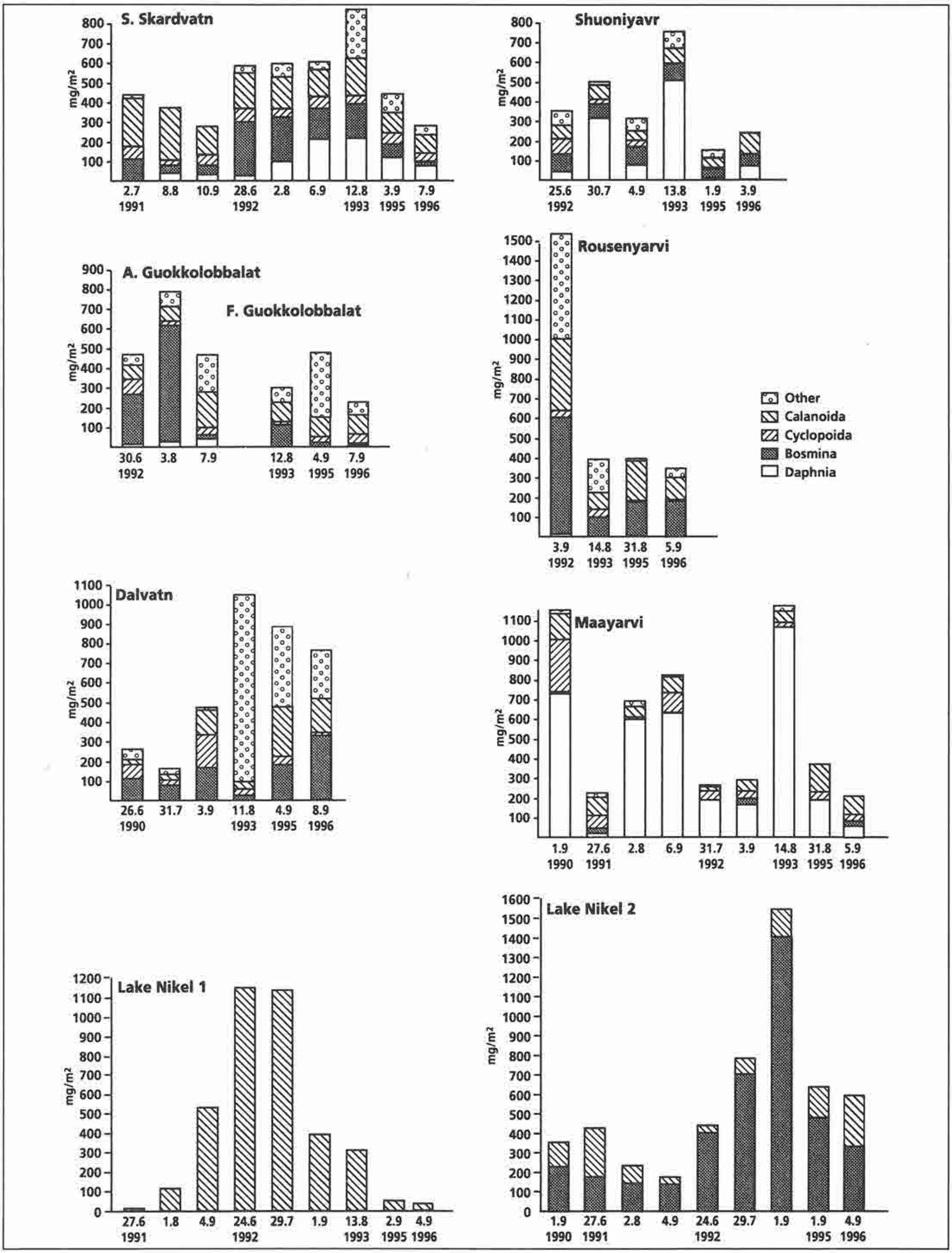


Figure 7.
Biomass (mg dry weight/m²) of zooplankton in monitored lakes in 1990-1996

most sensitive mayfly species to acidification and possibly heavy metal contamination, *B. lapponicus,* was found in two localities in the Jarfjord Region (Oterbekken and Urdalselva Streams), and in Shuoniyoki River and Lake Trifonoyarvi on the Russian side.

The highest species diversity of mayflies (Ephemeroptera) and stoneflies (Plecoptera) was found in the Nikel Region and in two lakes in Jarfjord Region (Otervatn and Rundvatn) (**figure 8**).

Nikel Region and Pechenga River System.
On the Russian side, high species diversity of mayflies and stoneflies is clearly associated with the south-east of Nikel (Shuoniyoki River, Lake Shuoniyavr, Upper Pechenga River), Lake Saraslaki and Pachta Stream, draining the Kuorpukas Mountains. Shuoniyoki River and localities south-east from Nikel seemed to have the highest diversity of mayfly and stonefly species in the border region. A total of 18 species of mayflies and stoneflies was recorded in Shuoniyoki River.

Only two species of mayflies, *B. rhodani* and *Nemoura* sp. were found in the extremely polluted stream Kolosyoki in Nikel town. No mayflies and stoneflies were found in the small Lake LN1, situated about 1 km east of the Nikel smelters. Several species of Orthocladiinae and Tanypodinae chironomids, and caddis flies (Polycentropidae, *Rhyacophila* spp.), water beetles, water bugs and worms dominated in Kolosyoki stream, and the small lakes near Nikel (LN1, LN2 and LN3). In average, the relative abundance of Diptera species in the Nikel Region was high and comparable with other acidified areas (Dalvatn and F. Høgfjellsvatn in the Jarfjord Region) within the border region (**figure 9**). In the Pechenga River System, the highest species diversity was found in Lake Trifonoyarv. In the most polluted localities near the town Zapolyarny chironomid larvae, water bugs and water beetles and worms dominated in the communities. No mayflies and stoneflies were recorded in the extremely polluted streams of Semiaki, Arvaldeym and Chaukilampiyoki in Zapolyarny town.

Snails *(Lymnaea peregra)* were found only in some lakes and streams south-east from Nikel, in the Pechenga River and in Lake Trifonoyarv. The highest abundance of snails was found in the upper Norwegian range of the Pasvik River System. Amphipoda (*Gammarus lacustris*) were found only in Lake Trifonoyarv.

Jarfjord Region.
Species relatively tolerant to acidification, such as mussels (*Pisidium* spp.), chironomids, caddis flies (*Plectrocnemia conspersa, Polycentropus flavomaculatus*) and water beetles (*Elminthidae* spp.), dominated in localities in the Jarfjord Region.

The most common mayflies in the Jarfjord Region were *Baetis* spp., *Ephemerella aurivillii* and *Siphlonurus* spp. and the most common stoneflies were *Nemoura* spp., *Diura nanseni*, *Leuctra fusca, L. digitata, Isoperla* spp. and *Taeniypteryx nebulosa*.

Dalvatn and F. Høgfjellsvatn areas were characterised by the lowest species diversity of mayflies and stoneflies. In lakes Dalvatn and Limgambergtjern only acid tolerant species of mayflies, such as Leptophlebidae and *E. aurivillii,* and stoneflies like Nemouridae, were recorded. The largest numbers of mayfly and stonefly species were recorded in small lakes and streams in Otervatn-Rundvatn area as well as Urdalselva and the S. Skardvatn, Viksjøen and Urdfjellsvatn.

The acid-sensitive species *Gyraulus albus* and *L. peregra* appeared to be the most common snails in the border region, except in the Dalvatn and Guokkolobbalat areas in Jarfjord. The snail *G. albus* was frequently found in the Otervatn-Rundvatn area. However, the second species was restricted to River Urdalselva, several small lakes in Urdalselva area and Lake Rundvatn.

The amphipod *G. lacustris* was found in Lake A. Skardvatn (F. Høgfjellsvatn area), several lakes of the Otervatn-Rundvatn area, in lakes Urdfjellsvatn and S.Skardvatn and some small lakes near Urdfjellvatn. The mean relative abundances of snails and Amphipoda in kick samples were higher in Otervatn-Rundvatn area than in other areas of Jarford Region.

Chironomids and worms made up most of the communities in lake profundal zones, particularly in Dalvatn and Limgambergtjern. The relative abundances of acid-tolerant dipterans in Dalvatn and F. Høgfjellsvatn areas were considerably higher than in Otervatn-Rundvatn area. Acidification did not seem to be so pronounced in Otervatn-Rundvatn area as in the other localities mentioned.

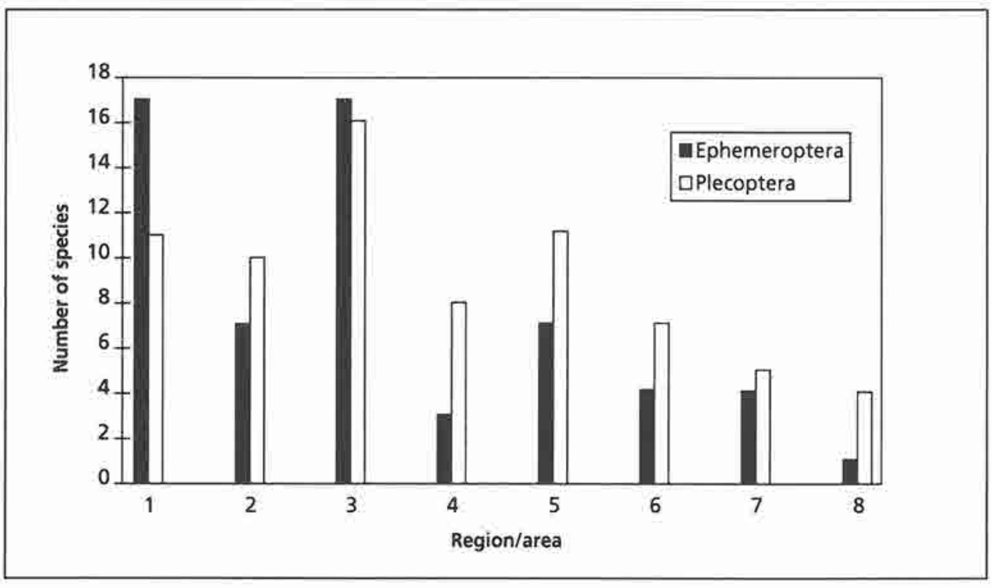


Figure 8.
Numbers of Ephemeroptera and Plecoptera species recorded in study regions/areas in 1990-96. 1= Nikel Region, 2= Pechenga River System (Zapolyarny area), 3= Jarfjord Region I (Otervatn-Rundvatn area), 4= Jarfjord Region II (Dalvatn area), 5= Jarfjord Region III (Lake F.Høgfjellsvatn), 6= Jarfjord Region IV (Guokkolobbalat area), 7= Pasvik River System I (Norwegian part), 8= Pasvik River System II (Lake Kuetsyarvi).

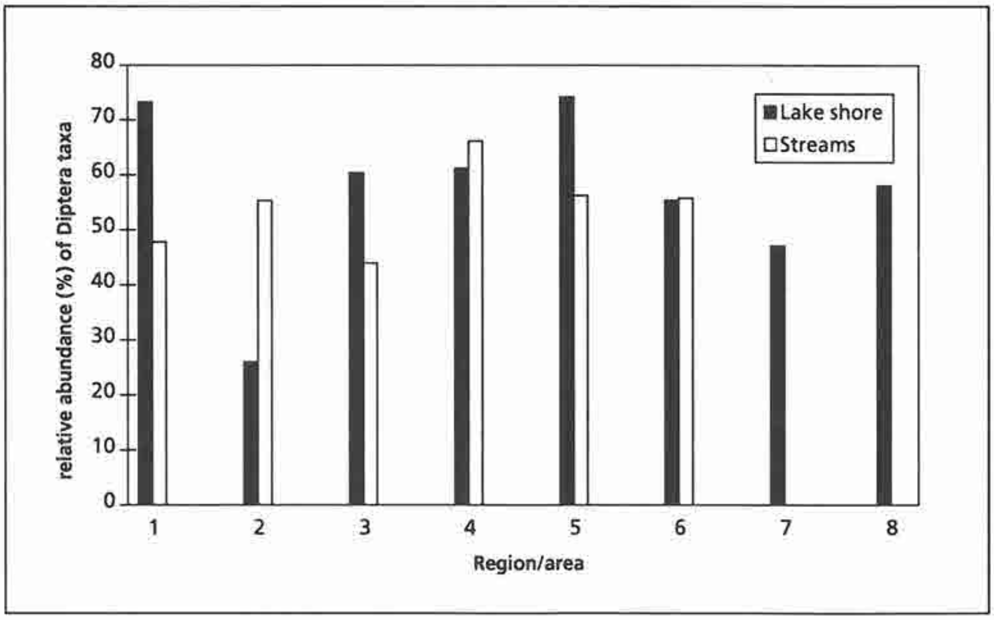


Figure 9
Mean relative abundance (%) of Diptera taxa in kick samples in the study regions/areas (cf. ***figure 8****).*

Pasvik River System.
Very high abundances and biomasses of zoobenthos were recorded in Lake Kuetsyarvi (> 2200 ind./m^2, > 12 g/m^2). Chironomids, molluscs, worms and caddis flies dominated these communities. Relatively high species abundances and biomasses of invertebrates were recorded in the upper and middle parts of the river system (Ruskvatn, Svanvik and Salmiyarvi). The number of individuals in grab samples were almost comparable with Lake Kuetsyarvi. Relatively low zoobenthos densities and biomasses were recorded in lower parts of the river system (Skrukkebukta and Bjørnevatnet).

On the Russian side, the highest species number of benthic fauna was recorded to the south-east of Nikel town in the direction of Prirechny settlement (Shuoniyoki, Shuoniyavr, upper part of the Pechenga River). Localities further north-east of the sources, near Liinakhamari settlement, had somewhat lower diversity and abundance. Lack of occurrence or low diversity of sensitive taxa such as mayflies, stoneflies and amphipods near the Zapolyarny and Nikel factories may indicate severe pollution impacts on invertebrates. In this area chironomids (Tanypodinae), caddis flies (Polycentropidae, *Phyacophila*), water beetles and water bugs were usually dominant in the extremely contaminated lakes and streams.

Absence or low numbers of acid-sensitive mayfly and stonefly species were also recorded in the Jarfjord Region (the lakes Limgambergtjern, Dalvatn, F. Høgfjellsvatn and F. Guokkolobbalat). On the other hand, the relatively high number and abundance of sensitive species (mayflies, amphipods and snails) in the Otervatn-Rundvatn area in the Jarfjord Region, especially at lower elevations, suggests that acidity is not an important variable structuring invertebrate communities there.

The high density and biomass of zoobenthos (presented mainly by pollution-tolerant chironomids, molluscs, caddis flies and worms) in the heavily polluted Kuetsyarvi may indicate higher concentrations of nutrients.

4.6 Fish

4.6.1. Fish communities

The three localities on the Norwegian side were populated by brown trout (*Salmo trutta*) and Arctic char (*Salvelinus alpinus*). In addition up to six other fish species were found in the three localities on the Russian side; perch (*Perca fluviatilis*), pike (*Esox lucius*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*), three-spined stickleback (*Gasterosteus aculeatus*) and nine-spined stickleback (*Pungitus pungitus*) (**table 4**). The largest numbers of fish species were found in Shuoniyavr and Maayarvi.

Table 4. *Fish species recorded in monitored lakes during the period 1990-1996. Locality code as indicated in Table 1.*

Fish species	SS	FG	Da	Sh	Ro	Ma	LN2	LN1
Brown trout - Salmo trutta L.	x	x	x	x	x	x		
Arctic char - Salvelinus alpinus L.	x	x	x	x	x			
Pech - Perca fluviatilis L.				x		x		
Pike - Esox lucius L.				x		x		
Burbot - Lota lota L.				x		x		
Minnow - Phoxinus phoxinus L.				x	x	x		
Three-spined sticleback - Gasterosteus aquleatus			x		x			
Nine-spined sticleback - Pungitus pungitus				x				

The length and age-frequency distribution (**figures 10** and **11**) for 1990 - 1996 shows a relatively stable and quite similar population structure for Arctic char in lakes S. Skardvatn, F. Guokkolobbalat and Dalvatn. In comparison with previous results there seem to be higher densities of the younger age-classes (recruits) in S. Skardvatn and F. Guokkolobbalat in 1996.

The 1996 results show that the Arctic char population in Shuoniyavr is small, whereas the situation for Rousenyarvi seems somewhat better than before. However, Shuoniyavr is the largest of investigated monitoring lakes and the available information is incomplete. The Arctic char population in Rousenyarvi seems to be quite similar to the population in F. Guokkolobbalat. In both lakes there is a dense population of slower growing individuals than in Dalvatn and S.Skardvatn.

The brown trout populations in lakes S. Skardvatn, F. Guokkolobbalat and Dalvatn are quite small due to lack of suitable spawning areas. In Shuoniyavr, Rousenyarvi and Maayarvi only a few individuals of brown trout were found. In addition to the possible scarcity of spawning sites, the low number of brown trout in the Russian lakes may be due to competing species such as perch, pike, burbot and minnow.

Younger specimens of brown trout were caught by electrofishing in the streams or inlets/outlets and near shore areas in S. Skardvatn, Dalvatn, F. Guokkolobbalat and Maayarvi. Minnows and Arctic char were caught in Shuoniyavr and Rousenyarvi. Pachtayoki River and Lake Sarasslaki are the two localities closest (8 - 12 km) to Nikel where salmonids were recorded (Langeland 1993). No fish were caught in the tributaries to lakes LN1 and LN2 near Nikel. However, in the Kolosyoki River, which drains the highly polluted deposits near the factory in Nikel, several specimens of minnows were caught.

The diet of brown trout was usually dominated by terrestrial insects probably caught on the lake surface, and by larvae of aquatic insects (**table 5**). These two food items were also important for Arctic char in Shuoniyavr and Rousenyarvi. In addition, gastropods/molluscs and zooplankton made up a considerable part of the diet of Arctic char in these two lakes. Zooplankton was of substantial importance for the same species in the Jarfjord lakes. *Gammarus* was found in stomachs of brown trout in S. Skardvatn. Piscivorous brown trout and/or Arctic char were recorded in all lakes, except in F. Guokkolobbalat.

The populations of perch and pike appeared to be quite low in both Shuoniyavr and Maayarvi (**figures 10** and **11**) . The catches of both species varied from year to year, and in 1996 only two individuals of each species were caught in Shuoniyavr. These two lakes also have populations of burbot. Catches of this species were low, except for Shuoniyavr in 1996, when 17 individuals of five age classes (three to seven years old) were caught.

All three localities on the Russian side are inhabited by minnows. In Shuoniyavr and Maayarvi the populations are rather dense, whereas in Rousenyarvi only a few individuals are caught. In Rousenyarvi and Shuoniyavr we also found a few three-spined sticklebacks and nine-spined sticklebacks, respectively.

Negative impacts on the structure of fish populations were recorded in all the localities studied on Russian side. No fish were recorded in the lakes near Nikel, except for minnows in Kolosyoki River. In streams and lakes further from the sources of pollution, both Arctic char and brown trout were found (Lake Sarasslaki and Pachtayoki River). Only a few mature fish of older age-classes were caught, while younger premature individuals dominated. The lack of older individuals might have been due to lethal and sublethal effects of trace metal contamination in the organs and tissues of fish in some populations near the pollution sources.

Indications of acidification effects upon freshwater communities are documented in this study (Nøst et al. 1991, Langeland 1993) and have been emphasised by other studies in the same area (Bækken & Aanes 1990, Hesthagen et al. 1997). In the more acid-sensitive areas in the highest small lakes in the Jarfjord Region there are both lost and reduced populations of brown trout and Arctic char. The skewed population structure in Dalvatn and F. Guokkolobbalat, documented by the absence of young specimens and irregular yearly recruitment, was probably due to acidification effects. These correspond to pH minima of 4.55 - 5.08 in streams, which are below critical limits for recruitment of brown trout. Decalcification in some otholiths from both Arctic char and brown trout indicates that the fish populations of both S. Skardvatn and in Rousenyarvi, may have been affected to some extent by acidification (Langeland 1993).

4.6.2 Pathology

Comparison of the fish pathology results from 1990, 1993 and 1996 indicate increase of liver diseases in Rousenyarvi, Dalvatn and S.Skardvatn in 1996 (**table 6**). The livers of the fish caught were yellow and flabby and were easily broken up even under light pressure. Such pathology (2nd and 3rd degree) was observed in 100 % of the fish taken from the lakes mentioned above.

Detailed histological analyses of organs and tissues both of Arctic char and brown trout from Dalvatn and S.Skardvatn (liver, kidney, heart, gill and spleen) were then performed.

The results showed well expressed dystrophic changes in heart, liver and kidneys. In the cytoplasm of hepatocytes and epithelium of kidney tubules fatty-pigments formation was marked. Toxic dystrophies were frequently observed. In hepatocytes mass pycnosis of nucleuses and necrotic parts were marked. Regeneration of the damaged tissues was therefore virtually absent. In Arctic char and brown trout, the complete reduction of lymphoid tissue and extensive haemorrhages were observed on microscopic sections of spleen. The lymphoid tissue had been replaced by nonfunctional connective tissue, that in due course might have led to tumour development.

The most severe degeneration anomalies were observed in the gills of Arctic char: exfoliation of gill epithelium, haemorrhage, bleeding and also attributes of a degeneration of gill cartilage.

Analyses of fish tissues from Dalvatn and S. Skardvatn thus indicated the influence of one or more powerful toxins, presumably of organic origin. Severe damage to fish tissues and death are possible consequences. Reduction in toxin levels will probably result in regeneration of tissues.

If we compare these results with those of fish pathology in previous years (Nøst et al. 1991, Langeland 1993) the 1996 results are unexpected. In 1990 and 1993 no pathological deviations were observed in Arctic char in Dalvatn and S. Skardvatn. However, in Rousenyarvi changes in the gills, livers, kidneys and gonads were marked in 1990-1991, but the weighting corresponded basically to the first and second degree in our classification (Langeland,1993). The negative pathological changes observed in Arctic char and brown trout in all three lakes in 1996 demand a more serious study of the processes that occur in aquatic ecosystems, especially in the vicinity of the source of pollution.

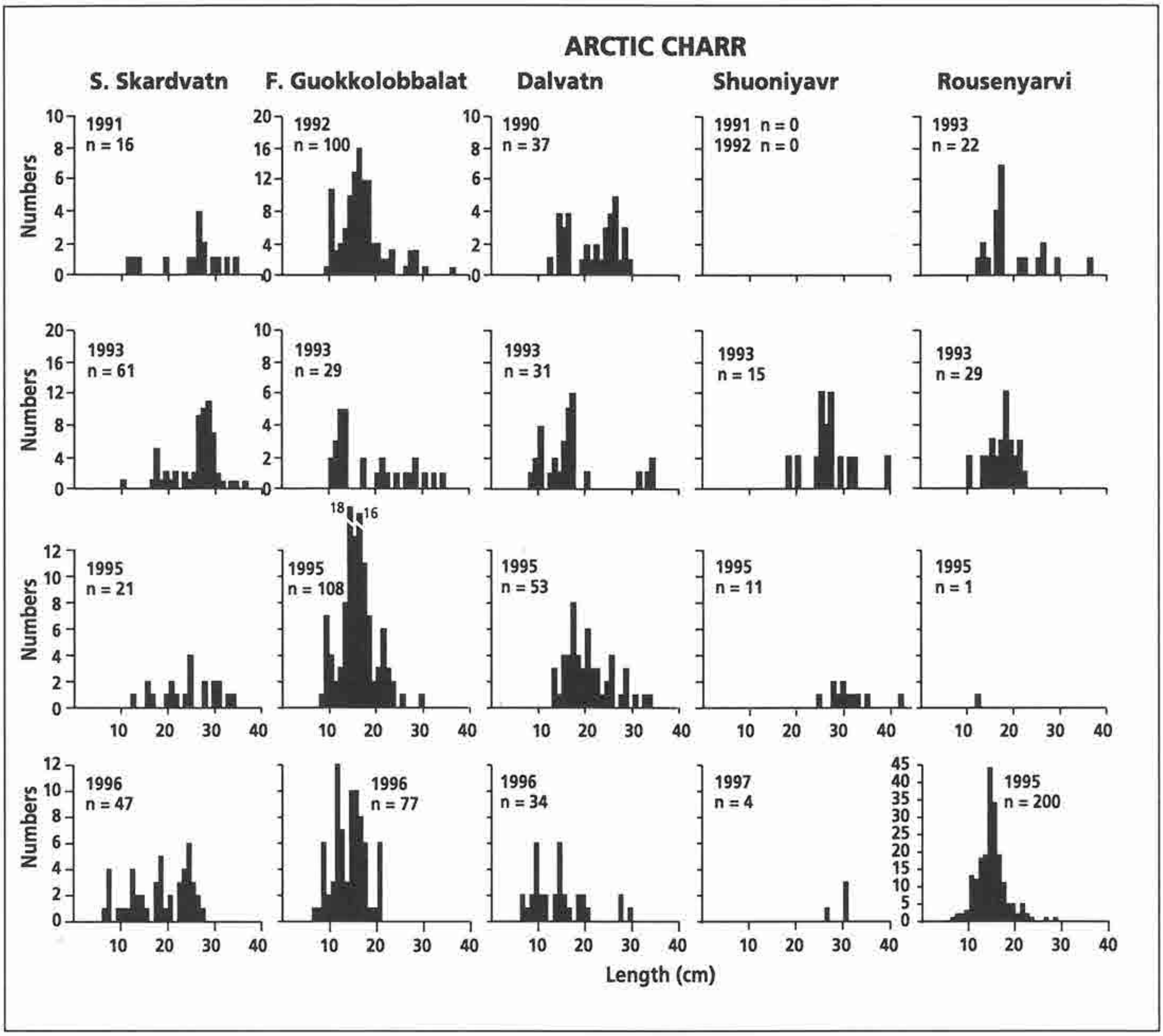
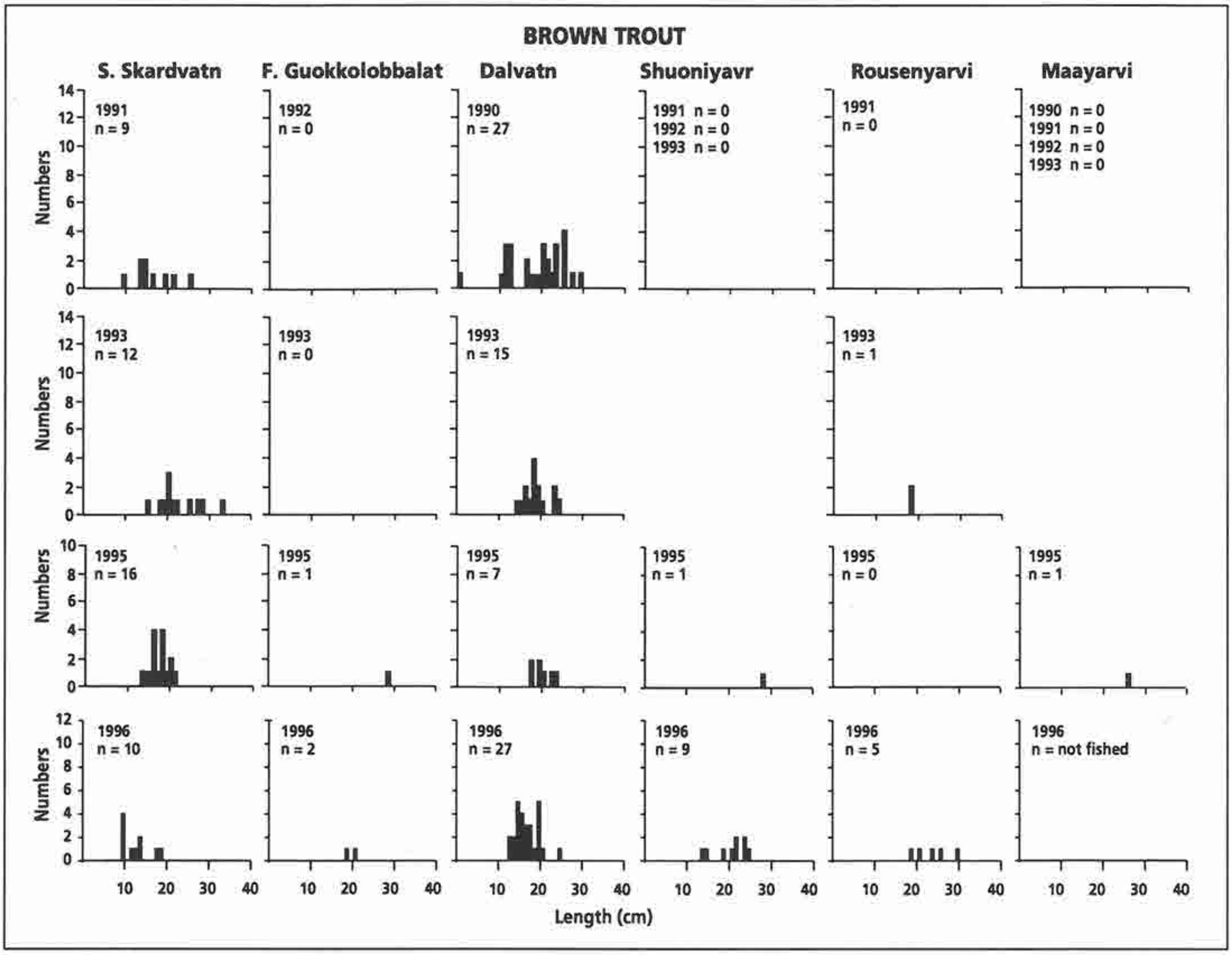
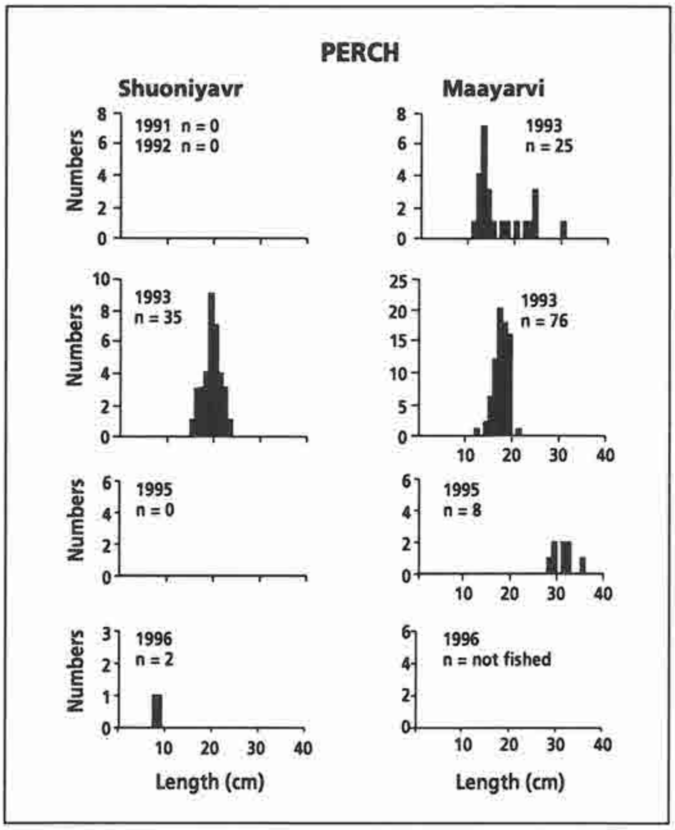
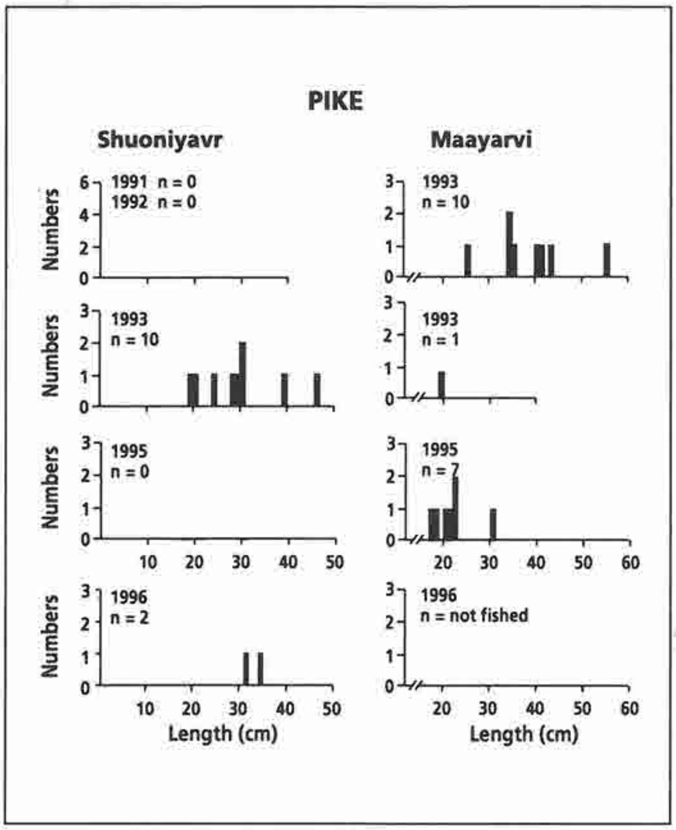


Figure 10
Size distribution (%) of brown trout, Arctic char, perch and pike in lakes in the border area in 1990-1996. N = total catch.


BROWN TROUT
S. Skardvatn
F. Guokkolobbalat
Dalvatn
Shuoniyavr
Rousenyarvi
Maayarvi
1991 n = 9
1992 n = 0
1990 n = 27
1991 n = 0
1992 n = 0
1993 n = 0
1991 n = 0
1990 n = 0
1991 n = 0
1992 n = 0
1993 n = 0
1993 n = 12
1993 n = 0
1993 n = 15
1993 n = 1
1995 n = 16
1995 n = 1
1995 n = 7
1995 n = 1
1995 n = 0
1995 n = 1
1996 n = 10
1996 n = 2
1996 n = 27
1996 n = 9
1996 n = 5
1996 n = not fished
Numbers
Length (cm)


PERCH
Shuoniyavr
Maayarvi
1991 n = 0
1992 n = 0
1993 n = 25
1993 n = 35
1993 n = 76
1995 n = 0
1995 n = 8
1996 n = 2
1996 n = not fished
Numbers
Length (cm)


PIKE
Shuoniyavr
Maayarvi
1991 n = 0
1992 n = 0
1993 n = 10
1993 n = 10
1993 n = 1
1995 n = 0
1995 n = 7
1996 n = 2
1996 n = not fished
Numbers
Length (cm)

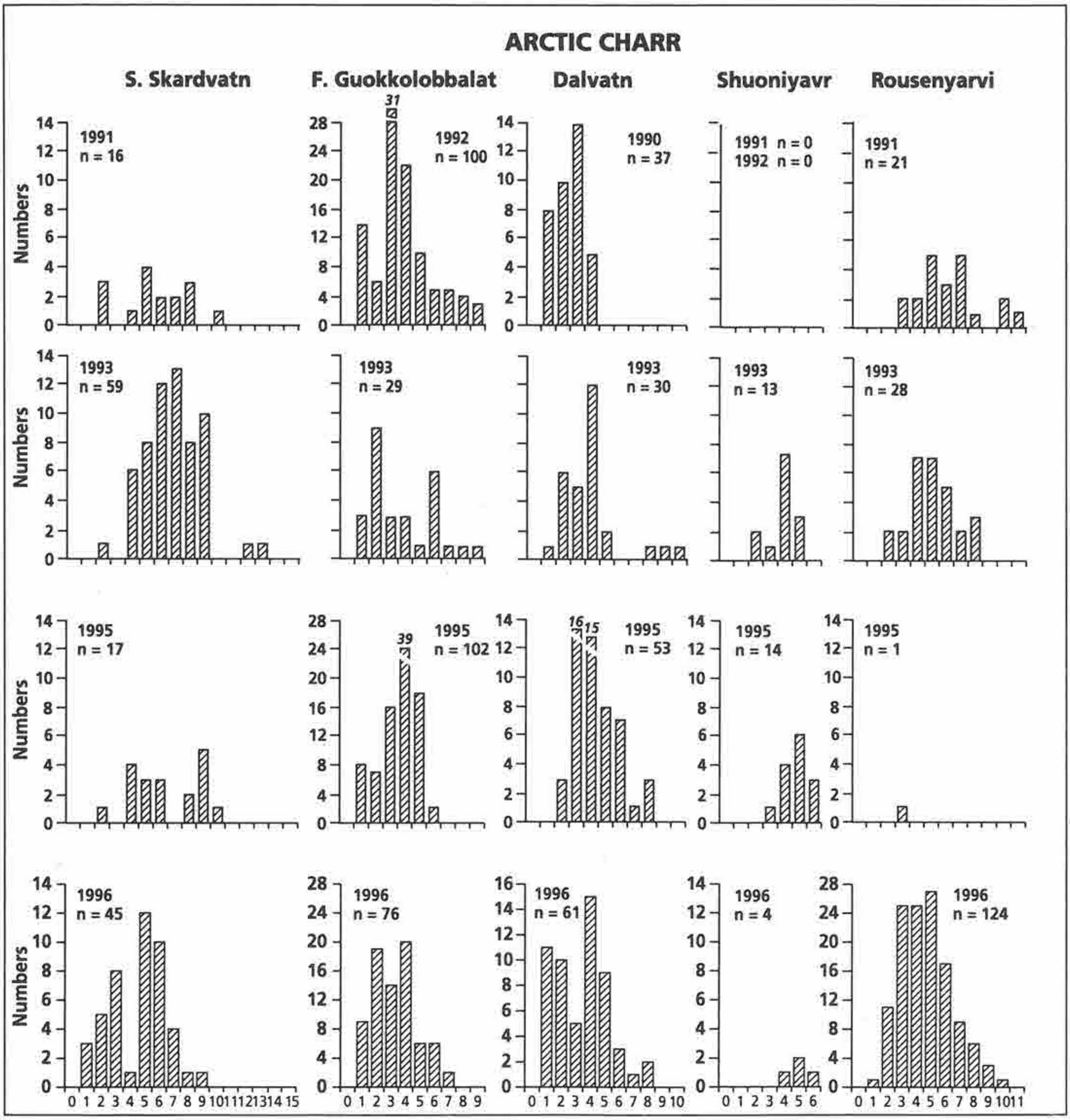
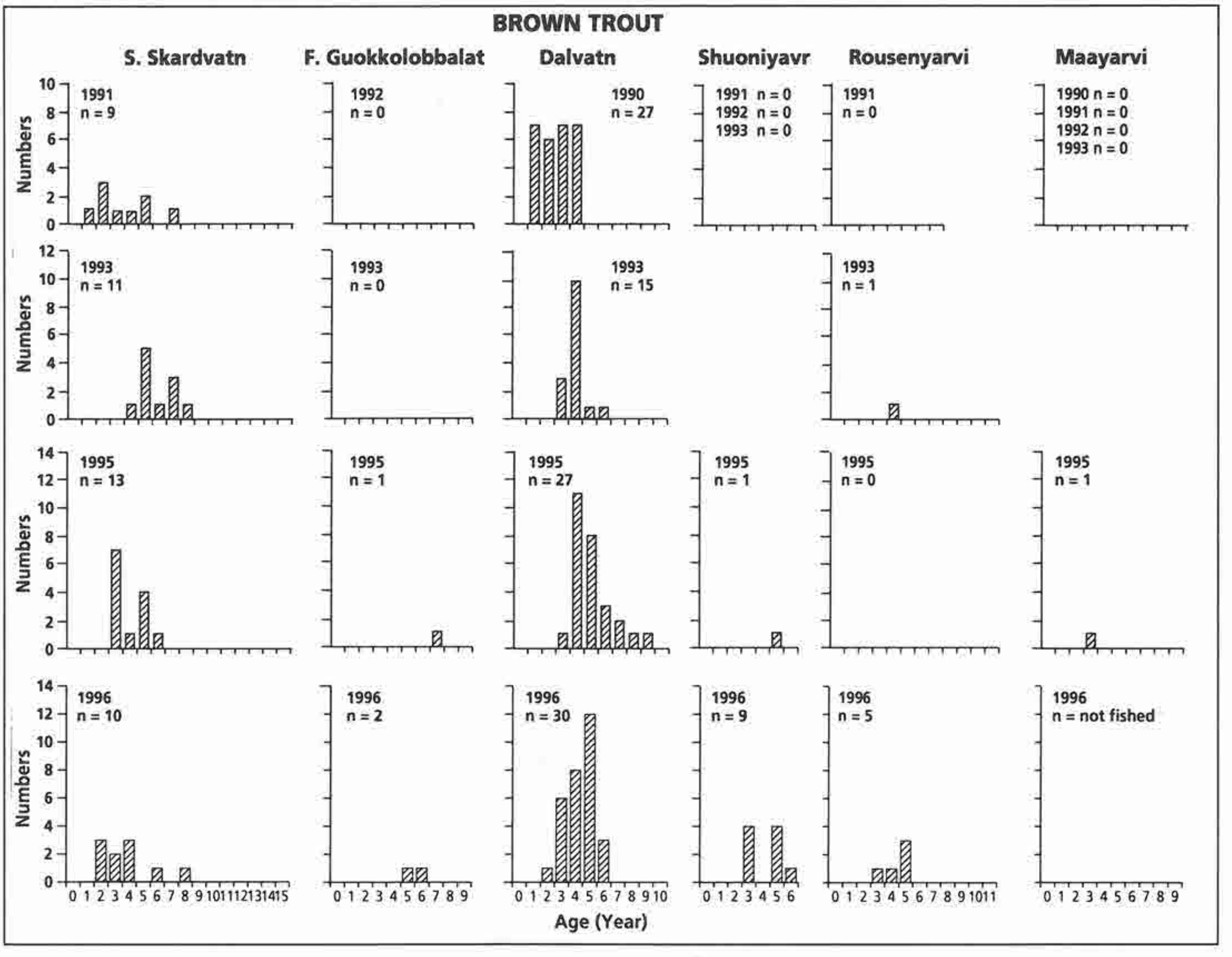
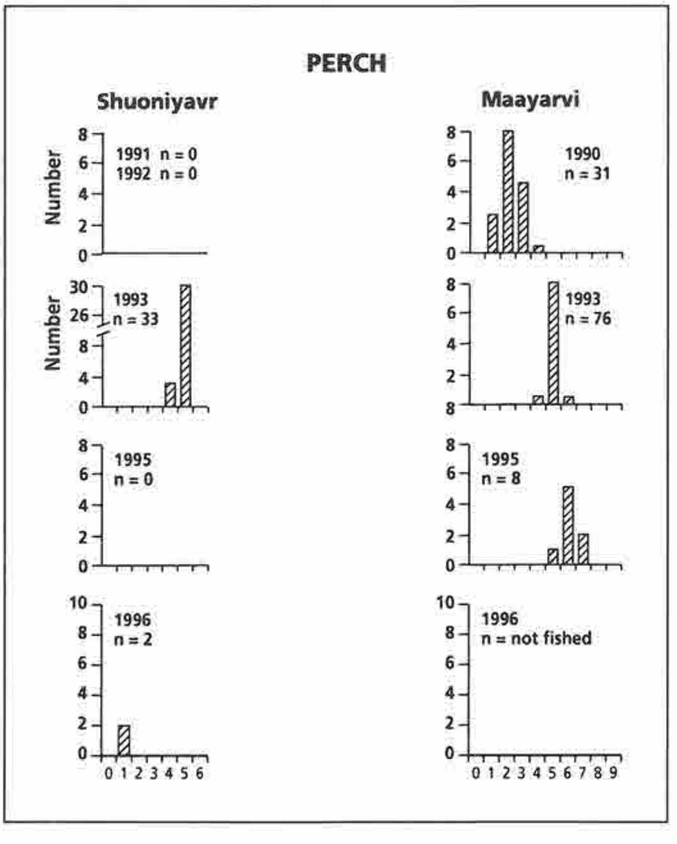


Figure 11
Age distribution (%) of brown trout, Arctic char, perch and pike in lakes in the border area in 1990-1996. N = total catch.


BROWN TROUT
S. Skardvatn
F. Guokkolobbalat
Dalvatn
Shuoniyavr
Rousenyarvi
Maayarvi
Numbers
1991 n = 9
1992 n = 0
1990 n = 27
1991 n = 0
1992 n = 0
1993 n = 0
1991 n = 0
1990 n = 0
1991 n = 0
1992 n = 0
1993 n = 0
1993 n = 11
1993 n = 0
1993 n = 15
1993 n = 1
1995 n = 13
1995 n = 1
1995 n = 27
1995 n = 1
1995 n = 0
1995 n = 1
1996 n = 10
1996 n = 2
1996 n = 30
1996 n = 9
1996 n = 5
1996 n = not fished
Age (Year)


PERCH
Shuoniyavr
Maayarvi
Number
1991 n = 0
1992 n = 0
1990 n = 31
1993 n = 33
1993 n = 76
1995 n = 0
1995 n = 8
1996 n = 2
1996 n = not fished

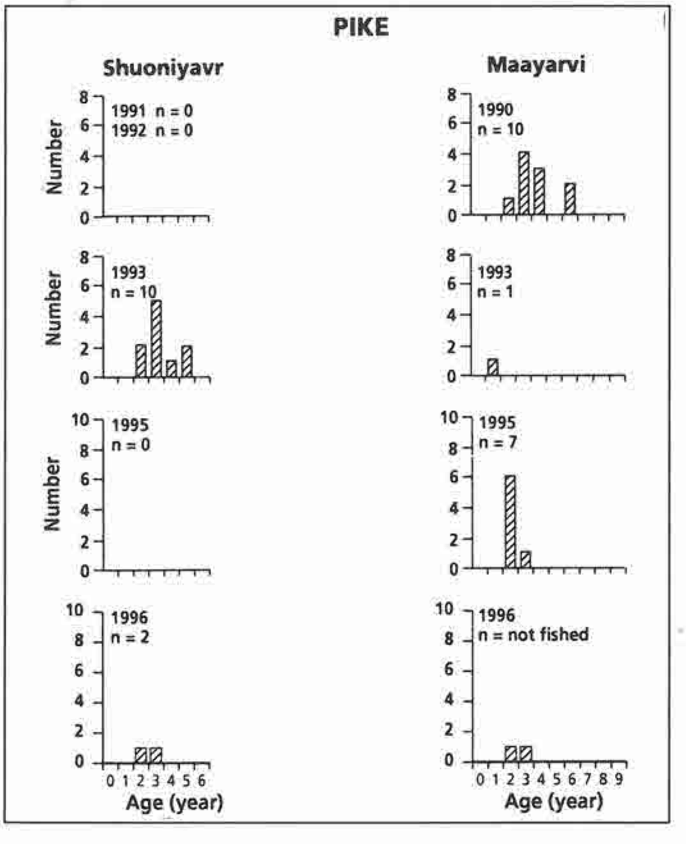

PIKE
Shuoniyavr
Maayarvi
Number
1991 n = 0
1992 n = 0
1990 n = 10
1993 n = 10
1993 n = 1
1995 n = 0
1995 n = 7
1996 n = 2
1996 n = not fished
Age (year)
Age (year)

***Table 5.** Food items (volume %) in stomachs of Arctic char (A) and brown trout (B) in monitored lakes in the border area in 1990-96. Locality code as indicated in Table 1.*

Loc	Year	Species	Number of stomachs	Terrestrial insects	Aquatic insects	Gastropoda/ Mollusca	Eurycercus lamellatus	Gammarus	Zooplankton	Fish
SS	1991	A	11	0	2,7	24,9	6,4	0	66	0
	1993	A	19	0	49,4	10	3,7	0	33,2	3,7
	1996	A	20	20,8	0	0	0	0	79,2	0
	1991	B	9	11,1	83,9	2,2	0	2,8	0	0
	1993	B	16	41,9	43,1	11,3	0	0	3,8	0
	1995	B	4	75	25	0	0	0	0	0
	1996	B	6	63,3	16,7	0	0	20	0	0
FG	1992	A	20	21	0,7	10	14	0	54,3	0
	1993	A	13	18,5	23,1	19,2	1,5	0	37,7	0
	1995	A	20	38	3,5	0	15	0	43,5	0
	1996	A	18	17,5	15,5	10	24,2	0	32,8	0
	1995	B	1	100	0	0	0	0	0	0
	1996	B	1	100	0	0	0	0	0	0
Da	1990	A	4	48	17,7	0	0	0	34,3	0
	1993	A	18	2,2	0	0	0	0	81,1	16,7
	1995	A	18	50,6	0	0	0	0	44,4	5
	1996	A	14	0	1,4	0	0	0	98,6	0
	1993	B	12	77,9	5,4	1,7	0	0	0	15
	1995	B	6	100	0	0	0	0	0	0
	1996	B	9	88,9	11,1	0	0	0	0	0
Sh	1993	A	5	5	36	7	1	0	51	0
	1995	A	3	33,3	0	53,3	0	0	13,3	0
	1996	A	3	33,3	0	33,3	0	0	33,3	0
	1991	B	18	28,4	68,3	3,3	0	0	0	0
	1995	B	1	0	100	0	0	0	0	0
	1996	B	8	37,5	22,5	0	0	0	0	40
Ro	1991	A	10	10	0	10	10	0	20	50
	1993	A	14	47,2	25,7	10,7	1,4	0	7,9	7,1
	1995	A	1	100	0	0	0	0	0	0
	1996	A	22	4,5	4,5	13,6	0	0	68,2	9,1
	1996	B	4	0	92,5	7,5	0	0	0	0

***Table 6.** Relative occurrences (%) of fish disease in selected lakes. 0-absence of visible deviation from normal, 1-initial stage of disease, 2-indices of medium affection, 3- irreversibility of disease.*

			Gills Degree of disease			Liver Degree of disease			Kidney Degree of disease			Gonads Degree of disease			Change of color Degree of disease			Nephrocalcitosis Degree of disease		
Lake	Species	Year	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Rousenyarvi	A.char	1990	0	0	0	9.8	7.8	7.8	15.7	5.9	1.9	21.6	5.9	0						
	A.char	1991	68.2	0	0	50	31.8	4.5	45.5	22.7	13.6	0	0	0						
	A.char	1996	0	0	0	22.8	34.8	42.4												
Kuetsyarvi	whitefish	1991	8.5	2.8	1.2	32.8	23.2	25.9	12.9	10.2	2.8	6.7	5.6	0.6	2.8	0.6	0	2.3	1.1	0.6
	whitefish	1992	5.7	0.8	13	11.5	23.8	34.4	18.1	10.7	15.6	16.4	4.1	12.3	23	36.9	59	0	04.1	6.6
Urdfjellvatn	A.char	1992	0	0	0	92	0	0	64	32	0	0	0	0						
	brown trout	1992	0	0	0	84.6	0	0	84.6	0	0	0	0	0						
S.Skardvatn	A.char	1992	42.9	0	0	71.4	3.6	0	21.4	75	0	3.6	0	0						
	A.char	1996	0	0	0	0	34.7	62.3	32.1	12.6	0	0	0	0						
T.Guokkolobbalat	A.char	1992	0	0	0	66.7	3.3	0	76.8	18.3	1.7	1.7	0	0						
A.Guokkolobbalat	A.char	1992	0	0	0	87.5	12.5	0	95.8	4.2	0	4.2	0	0						
F.Guokkolobbalat	A.char	1992	47.8	0	0	73.9	21.7	0	100	0	0	8.7	0	0						
Dalvatn	A.char	1996	0	0	0	0	47.6	52.3	0	0	0	0	0	0						

4.6.3 Trace metal content

All results dealing with heavy metal concentrations in fish tissues and organs have been presented in previous reports (Nøst et al. 1991, Langeland 1993, Langeland et al. 1995, Nøst et al. 1996). Pooled data on trace metal levels in the livers and kidneys of brown trout and Arctic char in the years 1990, 1992 and 1995 are presented in **figure 12**.

Levels and distribution varied between organs, species and lakes. Accumulations in muscles were usually considerably lower than the levels found in other organs and tissues (Langeland 1993, 1995). With a few exceptions for cadmium in F. Guokkolobbalat, levels were below background levels in muscle of freshwater fish (Grande 1987).

The highest values of most metals were usually found in kidney and liver. High accumulations of nickel and zinc were also recorded in gills (Langeland 1993).

Relatively high values of cadmium were recorded in the kidneys of brown trout and Arctic char from Dalvatn and in kidneys of Arctic char from S. Skardvatn. High values of cadmium were recorded in the liver of both brown trout and Arctic char from F. Guokkolobbalat. Accumulations of cadmium in liver were above the approximate background levels (Grande 1987) for most localities, except for a few samples from Shuoniyavr and Rousenyarvi.

Concentrations of zinc in kidney showed relatively small variations between localities. One high value was recorded in brown trout from Maayarvi. The highest values in liver were found in brown trout from F. Guokkolobbalat and in Arctic char from Shuoniyavr. However, none of these values were above the approximate background levels for zinc in livers of freshwater fish (Grande 1987).

Relatively high values of copper were found in kidney of both brown trout and Arctic char from F. Guokkolobbalat and in brown trout from Maayarvi. Accumulations of copper in liver were relatively high in brown trout from S. Skardvatn, and some high values were also recorded in brown trout from F. Guokkolobbalat, Dalvatn and Maayarvi, and in Arctic char from F. Guokkolobbalat and Shuoniyavr. Most levels in liver of brown trout from S. Skardvatn and Maayarvi were above the background level as indicated by Grande (1987).

The highest values of nickel in kidney were recorded in brown trout from S. Skardvatn, Dalvatn and Maayarvi, whereas the highest values in Arctic char were found in samples from S. Skardvatn, F. Guokkolobbalat and Rousenyarvi. Nickel was not included in the work of Grande (1987). However, when our results on fish kidneys are compared with results from the eastern part of the Kola Peninsula, taken in the same period, most samples from the border region have higher values than these «background levels» (Langeland et al. 1994). In liver, high values were recorded in both brown trout from F. Guokkolobbalat and Maayarvi and Arctic char from F. Guokkolobbalat. Levels in brown trout from S. Skardvatn and in Arctic char from Rousenyarvi were also higher than what we recorded in samples from the eastern part of the Kola Peninsula.

Correlations between trace metal levels in fish tissues and corresponding levels in lake sediments and surface waters were poor. Generally, the most unambiguous result from the study of metal accumulation in fish tissues is the relatively high levels of most metals in the liver, and to a lesser degree also in the kidney, of brown trout and Arctic char from F. Guokkolobbalat.

Several factors have influenced the concentrations of trace metals in the organs and tissues of fish, such as the levels and distribution of pollutants in water bodies, physiological characteristics of the fish and biochemical properties of the metals. The accumulation of metals thus is determined by a balance between the intake rate through the gills and the food, and the capability of the fish to excrete an excess of elements not required for the maintenance of the basic metabolism. Concentrations of metals in fish organs, especially in soft tissues, were inconsistent. The most stable levels have previously been stated to be found in skeletons, reflecting the total load during the whole lifespan (Langeland 1993). The more variable levels in liver and kidney reflect seasonal fluctuations in hydrochemical conditions and diet. Langeland et al. (1995) found no unambiguous correlation between individual age and the level of accumulation of copper, chrome and mercury in fish tissues. The uptake of zinc, which is an essential metal in low concentrations, is probably also homeostatically regulated.

High levels of trace metals, especially cadmium and nickel, in fish tissue from F. Guokkolobbalat could be connected to the acidification of this area. In the area around F. Guokkolobbalat the geology consists of hard bedrock like gneisses and granite, and both fish populations and invertebrates in nearby localities are affected by acidification. Fjeld et al. (1994) studied environmental influences on the accumulation of trace metals in lake sediments in Southern Norway. They found that atmospheric deposition was the main source of increased levels of lead (Pb) and mercury (Hg), whereas acidification increased the mobilisation of nickel and cadmium from the catchment area. However, the contamination factors (Cf) of these metals in F. Guokkolobbalat are low or moderate, and are low compared with the other monitoring lakes (**appendix 3**). Unlike Dalvatn and S. Skardvatn some relatively high values of zinc and nickel were measured in water samples from F. Guokkolobbalat (cadmium was not included in this programme). The combination of periodically high levels of trace metals in the water and low concentrations of other minerals could explain the relatively high levels of these metals in fish tissues from F. Guokkolobbalat. However, this must be considered as a preliminary hypothesis which should be followed by more thorough studies of these trace metal concentrations in surface waters, lake sediments and fish tissues.

Earlier studies (1990-1992), which included a larger number of lakes in the border region, stated that contamination from the smelters was probably the reason for the high concentrations and bioaccumulation of nickel in the Nikel/Zapolyarny area (Langeland et al. 1995).

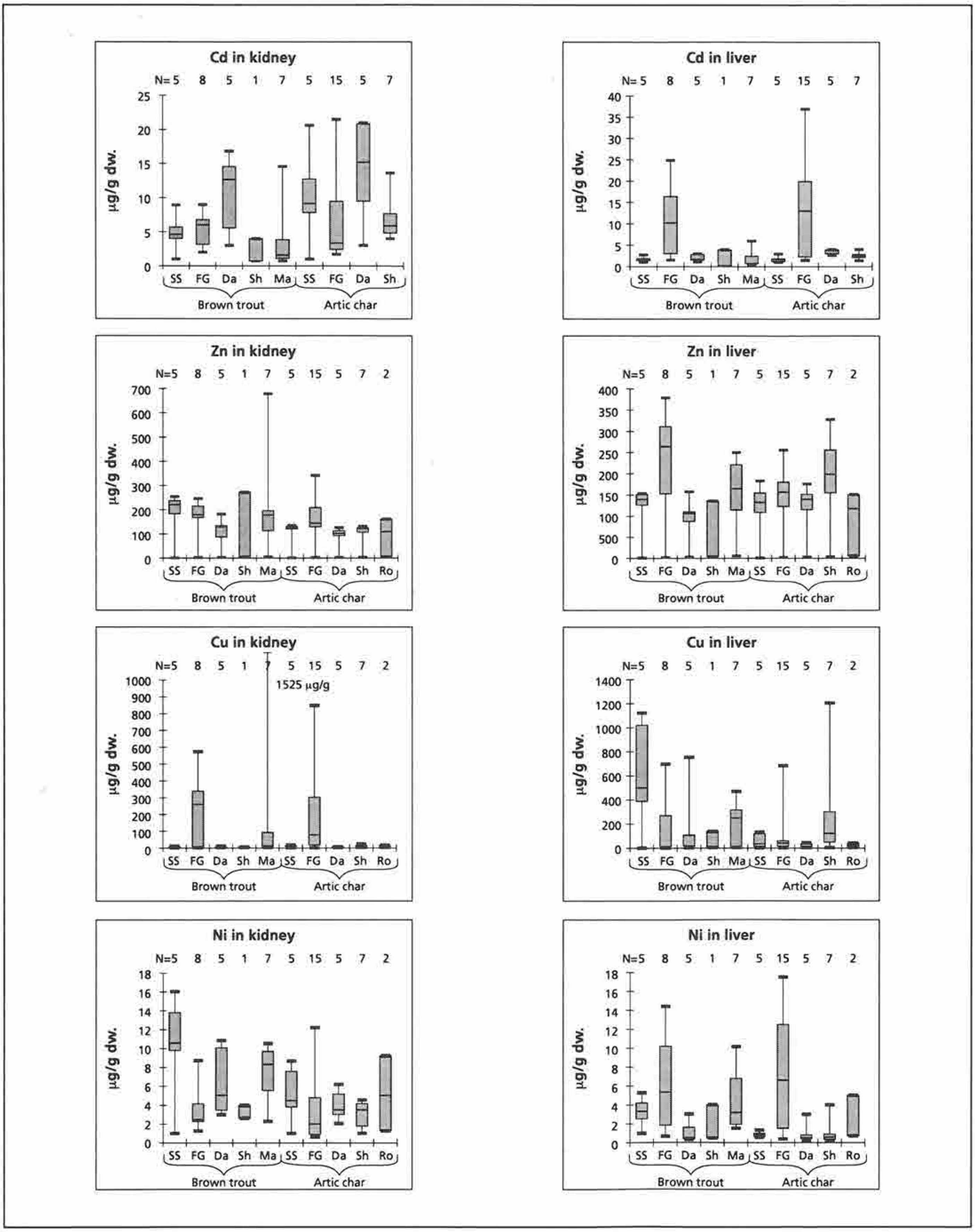


Figure 12
Box and whisker plot (minimum, 25% percentile, median, 75% percentile, maximum) of concentrations (µg/g dry weight) of cadmium (Cd), zinc (Zn), copper (Cu) and nickel (Ni) in kidney and liver of brown trout and Arctic char from the monitored lakes. The data are from 1992 and 1995, except the values on Zn, Cu and Ni in Arctic char from Rousenyarvi, which were analysed at INEP in 1990. Note: wet weight concentrations could be calculated by dividing all levels by five.

5 Conclusions

Trace metal pollution
During the period of study (1990-96) adverse effects of trace metal pollution near the industrial centres Nikel and Zapolyarny were observed. Trace metal accumulation, pathological anomalies in fish and low diversity of invertebrates were observed.

- Low diversities of phytoplankton, zooplankton and zoobenthos were observed in the most polluted localities (Lakes LN1 and LN2).

- No fish species were recorded in lakes close to Nikel town (Lake LN1, Lake LN2 and Lake LN3). The absence of older individuals of brown trout in inlet and outlet streams indicated low survival with age (juvenilization).

- Severe pathological anomalies and diseases were observed in fish near Nikel. A rising incidence of negative pathological changes was observed in the course of the study. In 1996 anomalies were observed on the Norwegian side (Dalvatn and S.Skardvatn), indicating the influence of a powerful toxin or several toxins, presumably of organic origin.

Acidification
Indications of acidification impacts were found only in the Jarfjord Region in Norway.

- Low phytoplankton diversity was observed in Dalvatn.

- Absence or low numbers of acid-sensitive species of zooplankton and zoobenthos and fish were recorded in and near Dalvatn and F. Guokkolobbalat.

Impacts of pollution on freshwater communities decrease with distance from the sources. However, the causes and consequences are difficult to follow due to 1) different loads and composition of pollutants within small areas, 2) geological complexity and 3) biotic relationships, which may differ between lakes. Although there exist significant annual variations in water quality and biological parameters, the results indicate a slight improvement in the limnological state of the lakes from 1990 to 1996. This is especially true of the acidified lake Dalvatn in the Jarfjord Region.

The study provides a satisfactory background for evaluating the biological benefits to freshwater communities of future purification processing of the emissions from the Pechenganickel factories. Unlike in other polluted areas in Scandinavia and Northern Europe, the local emissions totally dominate the load of pollutants in the border region between Russia and Norway. This fact makes the region unique for studies of the effects of pollutants and the recovery of freshwater communities. We recommend an intensive monitoring programme on freshwater communities following the installation of purification equipment at the Pechenganickel factories.

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Appendix

Appendix 1. Methods of chemical analysis

Turb: Turbidity was measured nephelometrically with a HACH model 2100A Turbidimeter in accordance with the Norwegian Standard (NS 4723) modified by Blakar & Odden (1986).

Col: The water-colour was analysed in accordance with NS 4722 using a Shimadzu UV-160 and calculated after Hongve (1984).

Cond: Conductivity was measured in accordance with NS 4721 using a Radiometer model CDM 80 (1990-93) or a Radiometer model CDM 92 (1995-1996), both with a platina-electrode.

pH: pH was analysed in accordance with NS 4720 using a Radiometer model PHM 84 pH meter equipped with separated glass- and calomel-electrodes.

Alk: Alkalinity was determined in accordance with NS 4754 using a Radiometer model TTT 80 Titrator, Radiometer model ABU 80 Autobyrette and a Radiometer model PHM 84 pH meter and the values are adjusted in accordance with Henriksen (1982)

Ca, Mg, Na, K: Cations were determined by atomic absorption spectrophotometry (Perkin-Elmer model 1100 B) in accordance with NS 4775 and NS 4776.

Cl, NO_3, Si: Chloride, nitrate and silicon were determined by cholometry. In the period 1990-1992 the analysis were performed with a FIA Star model 5020 Analyzer in accordance with Tecator application note ASN 63-03/83, ASN 62-01/83 and ASTN 5/84 (modified), respectively. In the period 1993-1996 the parameters were determined in accordance with the following applications: Alpkem P/N 000147 (Cl), ASN 62-01/83 (NO_3), Alpkem P/N 000923 and Alpkem P/N 000365 (Si), using a Alpkem Superflow 3590 as the analysing equipment.

SO_4: Sulphate was determined by the formula: $SO_4 = SSS - (Cl + NO_3)$ where SSS (sum of strong acids anions) was analysed, after passing through a cation exchange resin (Dowex, 50 mesh, H^+), by conductivimetry. The analysing equipments were a Radiometer model CDM 80 connected to the FIA Star model 5020 Analyzer (1990-1992) or a YSI model 35 connected to the Alpkem Superflow 3590 (1993-1996).

Tot-N, Tot-P, PO_4: Nitrogen, phosphorus and phosphate were measured on an Unicam model PU 8600 Spectrophotometer after NS 4743, NS 4725 and NS 4724, respectively.

Trace elements (Cd, Cu, Mn, Ni, Zn, Pb, Cr, As): Trace elements in water (0,04 M Suprapure HNO_3-solution) were determined by atomic absorption spectrophotometry (Perkin-Elmer model 1100 B) in comparison with NIST Standard reference material 1643C.

Analytical procedure for heavy metal analysis in biological material at NINA's analytical laboratory

The biological material analysed at NINA's laboratory were fish organs and fish tissues.

1) Freeze drying process

The samples were freeze-dried for approximately 24 hours to a final pressure of 0.05 mbar at -53°C in CHRIST LDC-1 equipment.

2) Digestion procedure

Subsamples of approximately 0.4 g freeze-dried material was added 4-5 ml cons. HNO_3 (Supra Pure). The digestion-program in a Microwave-oven Milestone MLS 1200 , with bombs SV 140 made of PFA with max. pressure 10 bar, was applied for 10 minutes.

3) Analytical procedure

Perkin Elmer model 1100B, equipped with high sensitivity nebulizer, graphite furnace HGA 700 with autosampler AS 70, and Hydride system FIAS 200 were used as the analytic equipment for analysing heavy metals in the biological material.

High levels of the elements Cd (>0.4 ppm), Pb (>2.5 ppm) as well as all levels of Mn, Zn, Cu and Ni were analysed using flame-mode. Standard wavelengths were used for all elements, and background correction was used for Zn, Pb, Ni and Cd.

The elements Cd and Pb (low levels, see flame) as well as all levels of Cr were analysed using graphite-furnace. Tubes used was pyrolytical with plattform for all elements except for Cr (pyrolytical without plattform). STPF technique according to Perkin Elmers manual for graphite furnace was used for all elements except Cr (not plattform). Modifier used: Palladium, approx. 5 µg/sample, (Cd and Pb) and $Mg(NO_3)_2$, approx. 1 µg/sample (Cr). Peak area was used for all elements.

Hg was analysed using FIAS 200, with $NaBH_4$ used as the reducing agent.

Reference material used to verify the results:

Dog fish liver (DOLT-1) and Dog fish muscle (DORM-1), produced at National Research Council, Canada.

***Appendix 2.** Water chemistry of the localities in 1996. Locality code as indicated in Table 1.*

		SO4	mg/Pt	µS/cm		µekv/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l
Locality	Date		Colour	Cond	pH	Alk	Ca	Mg	Na	K	SO4	Cl	NO3-N
		4,76											
SS	07.09.96	4,71	12	33,4	6,44	45	1,49	0,82	2,85	0,31	4,76	4,45	<10
FG	07.09.96	4,67	8	30,6	6,33	23	1,29	0,66	2,69	0,24	4,71	4,24	<10
Da	08.09.96	4,58	11	31,7	5,91	2	1,14	0,68	2,99	0,21	4,67	5,10	<10
Sh	03.09.96	7,81	16	27,8	6,59	77	2,01	0,67	1,59	0,41	4,58	2,02	<10
Ro	05.09.96	7,73	18	47,8	6,93	117	3,55	1,07	2,99	0,52	7,81	4,40	10
Ma	05.09.96	38,67	29	47,3	6,86	130	3,83	1,11	2,79	0,28	7,73	3,98	<10
LN1	04.09.96	110,03	14	131,8	7,01	291	14,33	2,50	3,82	0,66	38,67	3,56	<10
LN2	04.09.96	0,65	11	280,3	7,08	233	34,85	8,63	3,97	0,56	110,03	3,14	<10

		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ppb	ppb	ppb	ppb
Locality	Date	Si	Tr-Al	Tm-Al	Om-Al	Um-Al	Pk-Al	Cu	Mn	Ni	Zn
SS	07.09.96	1,24	21	8	6	<6	<6	<6	<6	33	13
FG	07.09.96	0,88	34	8	<6	<6	<6	<6	<6	37	12
Da	08.09.96	0,66	56	18	15	<6	<6	<6	7	18	2
Sh	03.09.96	1,29	17	9	<6	<6	<6	<6	<6	10	14
Ro	05.09.96	1,41	23	12	6	6	6	<6	<6	91	20
Ma	05.09.96	1,71	19	8	<6	<6	<6	<6	6	<6	41
LN1	04.09.96	1,78	29	12	6	6	6	35	15	40	320
LN2	04.09.96	3,46	11	11	6	<6	<6	7	11	11	293

Appendix 3. *Concentrations of trace metals (µg/g dry weight) in sediments of the investigated lakes . S and R: -surface and reference sediments, respectively. LOI : loss of ignition. C_f : contamination factor*

Lake	Depth m	Layers cm	LOI %	Ni µg/g	Cu µg/g	Co µg/g	Zn µg/g	Cd µg/g	Pb µg/g	Hg µg/g
Store Skardvatn*	10	S	16	91	54	-	-	0,35	34	0,070
		R	21	34	37	11	125	<0.5	<1	0,035
		C_f		2,7	1,5			0,7	34,0	2,0
F.Guokkolobbalt*	12	S	30	57	55	-	-	0,12	29	0,080
		R	28	35	122	32	148	0,60	8	0,160
		C_f		1,6	0,5			0,2	3,6	0,5
Dalvatn*	21	S	37	156	220	56	126	0,13	80	0,100
		R	29	37	134	38	384	<0.5	8	0,080
		C_f		4,2	1,6	1,5	0,3	0,3	10,0	1,3
Shuoniyavr	17	S	20	189	118	23	98	2	20	0,080
		R	15	44	31	42	106	2,12	<10	0,040
		C_f		4,3	3,8	0,5	0,9	0,9	2,0	2,0
Rousenyarvi	33	S	23	539	292	106	164	3,23	19,4	0,410
		R	27	25	191	25	177	0,61	<9	0,110
		C_f		21,6	1,5	4,2	0,9	5,3	2,2	3,7
Maayarvi	10	S	30	1058	784	60	151	0,54	26	0,430
		R	31	24	30	16	109	<0.50	<10	0,035
		C_f		44,1	26,1	3,8	1,4	1,1	2,6	12,3
Lake Nikel 1*	5	S		7206	6495	142	170	2,50	32	0,410
		R		55	52	25	73	<0.50	<1	0,032
		C_f		131,0	124,9	5,7	2,3	5,0	32,0	12,8
Lake Nikel 2*	5	S		6490	1823	121	439	0,50	11	0,510
		R		52	166	30	185	<0.51	<1	0,025
		C_f		124,8	11,0	4,0	2,4	1,0	11,0	20,4

*- data from Rognerud et al., 1993.

Appendix 4. *Biomass (g wet weight/m³) of phytoplankton in monitored lakes, September 1996. Locality code as indicated in Appendix 1.*

TAXA	SS	FG	Da	Sh	Ro	Ma	LN1	LN2
Cyanophyceae								
Synechococcus sp.	0,02		0,08	0,01	0,10	0,07		
Merismopedia tenuissima								
Aphanothece clathrata	0,02	0,08	0,15					
Aphanothece sp.								
Chroococcus sp.								
Gomphoshaeria lacustris								
cf. Rhabdoderma kol.								
Filamentous BG (d=1.5 µm)								
Coccal BG (d<3 µm)								0,19
Cyanophceae, total biomass	0,04	0,00	0,08	0,01	0,18	0,22	0,00	0,19
Bacillariophyceae*								
Cyclotella (d<10 µm)								
Cyclotella comta (d>10 µm)								
Asterionella formosa								
Tabellaria fenestrata						0,02		
Synedra cf. Acus								
Bacillariophyceae, total biomass	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00
Dinophyceae								
Ceratium hirudinella	0,01	0,01	0,02		0,56			
Gymnodinium sp. (d=10 µm)								
Dinoflagellater (d<10 µm)								
Dinoflagellater (d=10-20 µm)								
Dinophyceae, total biomass	0,01	0,01	0,02	0,00	0,56	0,00	0,00	0,00
Chlorophyceae								
Cosmarium sp. (d=5 µm)								
Chlorococcales sp.								
Chlorophyceae, total biomass	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Others								
Dinobryon sociale							1,16	
Unident. Flagellates (d:10-15 µm)							0,25	
µ-algae (d<5 µm)	0,14	0,08	0,06	0,10	0,08	0,09	0,12	0,03
Others, total biomass	0,14	0,08	0,06	0,10	0,08	0,09	1,53	0,03
Total biomass of phytoplankton	0,19	0,09	0,16	0,11	0,82	0,33	1,53	0,22

*syn. Diatomophyceae

Appendix 5. *Species composition and biomass (mm³/m³) of phytoplankton communities in the monitored lakes in 1995-96. Analysed at INEP.*

LAKE	SS		FG			Da			Sh		Ro		Ma		LN2		LN1		
date	09.95	09.96	09.95	07.96	09.96	09.95	07.96	09.96	09.95	09.96	09.95	09.96	09.95	09.96	09.95	09.96	09.95	07.96	09.96
Diatomophyceae																			
Asterionella formosa	2	4			2	4							128	21		2			
A. distans				2					20	17	21								
A. italica var.tenuissima						16													
A. lirata		83										1158							
Cyclotella bodanica																			
C. comta											136								
Cyclotell spp. (d=7-24)	32	29	10		8				40		28					5			17
Cymbella sp.														3					
Diatoma elongatum	19		100																
Eunotia sp.																		29	49
Fragilaria capucina	274		1016	2			1										260	8	
F. pinnata																		13	39
F. virescens														44					
Fragilaria spp.							1		5		5	40	52	9	11	9	449	76	20
Frustulia rhomboides																			
Gomphonema acuminatum				6					50			4							
G. longiceps var.subclavatum		1																	
Meridion circulare																		10	
Navicula sp.														26					
Nitzschia acicularis	4		61							1			7						
Pinnularia microstauron																	88	32	
Pinnularia sp.									58										
Rhyzosolenia longiseta													10						
Stephanodiscus hantshi																		4	
Stephanodiscus sp.	4													5					
Surirella sp.											7								
Synedra acus	20											7							
S. nana			6										11	1					
S. pulhella																	6		
S. rumpens														3					
Synedra sp.			8														10	10	32
Tabellaria fenestrata		11			9				506				64	343					
T. fenectrata			29											218					
var.asterioneloides									92			43		16					
Cyanophyceae																			
Anabaena sp.	9								31		5		20						
Aphanizomenon flos-aqvae														25					
Aphanocapsa delicatissima									130	25	19	3	33						
Aphanothece minutissima	14	8							324	30	69	5	70	0.1	5				
Merismopedia warmingiana		1						4		5	48	3							
Oscillatoria limnetica									1								57	1	10
O. planktonika										1			1		3				
Oscillatoria sp.														5					
Pseudanabaena constricta					0.1						1		1						
Snowella atomus		0.2	3			1			1	0.1	5	2	8	0.4	32		5	0.1	
S. lacustris														0.1					
Chlorophyceae																			
Ankistrodesmus fusiformis	0.1								0.1		0.1		6						
Chlamydocapsa planctonica		6		1															
Chlamydomonas sp.					3									6		1			
Dictyosphaerium subsolirium												0.1				23			
Didymocystis inconspicua			0.5	0.1	1.5	1	0.1	2				0.3	1		1		5		1
Elakatothrix gelatinosa	1	26	2		0.8				3	0.4			4	0.5					
Golenkinia radiata							3												
Lagerheimia genevensis										0.1									
M. komarkovae														2					
M. mirabile				10						0.1				6					

LAKE	SS		FG			Da			Sh		Ro		Ma		LN2		LN1		
date	09.95	09.96	09.95	07.96	09.96	09.95	07.96	09.96	09.95	09.96	09.95	09.96	09.95	09.96	09.95	09.96	09.95	07.96	09.96
Oocystis romboides	1		21	25	8	5	0.1	4							5				
O. submarina		1			12			6		1				4					
Pandorina morum													4						
Planktosphaeria gelatinosa																35			
Selenastrum bibraianum		2																	
Scenedesmus aculeolatus														2					
S.quadricauda													1						
Cryptophyceae																			
Chroomonas acuta	0.3	17			15	1		1	1		2		4	59					
Chroomonas sp.							0.3												
Cryptomonas gracilis										26				4					
C. phaseolus							3												
C. marssonii	6	15		3				5	32							12			
Cryptomonas sp.					3					17		2	56	16					
Planonephros parvula													13						
Rhodomonas lacustris	6	7	0.4		5				23	16	1		20	7				0.3	2
Chrysophyceae																			
Bitrichia chodatii	2	8	3		8		1	4	2	8		1							
Dinobrion acuminatum			13	31	39		13			153		82		340					
D. bavaricum													19	6					
D. cylindricum									35										
D. divergens	3		2								3		12		3		9	10	20
D. divergens	9			27															
var.schauinslandii		3								6									94
D. elegans		17				1	4	4											
D. pediforme													14	3		8		1120	1707
D. sociale				1															390
D. sociale var.americanum				3					42										
D. suecicum var.longispinum				1									8	2		14			49
Ochromonadales sp.	6	1	1		0.3		2	0.2	1	4			1			11			3
Pedinella sp.	12	4	2	13					17	10	1		1	3	1			13	
Pseudopedinella elastica		69																	
Mallomonas acaroides																			739
M. lychenensis		6							4		5								
Conjugatophyceae																			
Closterium acutum	1												2						
var.variable				6			3											6	
Cosmarium sp.				12														12	
Euastrum denticulatum				13														13	
E. elegans															58				
Mougeotia sp.														21					
Spirogira sp.	4		3																
Dinophyceae																			
Peridinium pusillum				3															
Peridinium sp.							5												
Tribophyceae																			
Isthmochloron trispinatum							3												
Prymnesiophyceae																			
Chrysochromulina sp.																	1505		
unindentified																			
d=4-10	86	3	34	3	3	30	4		14	7	7	65	13	7	3		3311	196	123
cysts d=10							19	7			10	3			60	11		4	
Total biomass	513	370	1315	166	170	59	61	36	1428	375	367	1414	582	1212	176	132	5780	1513	3299

Appendix 6. *Species composition and biomasses (mg m^{-2}) of zooplankton in monitored lakes in 1996. Locality code as indicated in Table 1.*

Art	SS	FG	Da	Sh	Ro	Ma	LN2	LN1
Cladocera								
Bosmina longispina	20,0	8,8	330,8	57,6	182,6	27,0	332,1	0
Daphnia longispina	0,5	0,9	0	0	0	0	0	0
Daphnia galeata	74,0	6,9	0	69,8	0	58,4	0	0
Daphnia longremis	0	0	0,2	0	0	0	0	0
Holopedium gibberum	46,8	61,0	245,1	1,5	46,6	0	0	0
Bythotrephes longimanus	0	4,0	0	0	0	0	0	0
Polyphemus pediculus	0	0	2,7	0	0	0	0	0
Copepoda								
Cyclops scutifer	27,8	44,6	15,2	4,8	7,6	33,8	0	0
Cyclops abyssorum	13,6	1,4	0	0	0	0	0	0
Eudiaptomus graciloides	93,2	98,0	174,2	0	95,0	93,6	263,4	34,2
Eudiaptomus gracilis	0	0	0	95,1	0	0	0	0
Heterocope appendiculata	0	0	0	11,4	18,2	0	0	0

ISSN 0805-469X
ISBN 82-426-0831-8

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