Catalogue of Lakes in the Russian, Finnish and Norwegian Border Area

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INTRODUCTION

The catalogue of lakes represents a collection of data on baseline conditions in the aquatic ecosystems of small lakes in the joint Finnish, Norwegian and Russian border region, which is an area subjected to considerable levels of anthropogenic pollution.

The catalogue contains descriptions of 38 lakes (19 lakes in Russia, 14 lakes in Norway and 5 lakes in Finland) (Fig. I-1). Most of them are small lakes with an area of less than 1 km^2, but there are several larger lakes. The lakes and rivers are located at altitudes of 100 - 300 m above sea level, and the terrain in the watershed ranges from forest to open fell areas. The lakes included in the study are of the headwater, drainage or closed type.

The catalogue is meant for a wide audience: the local population, people involved in economic activities in the border area, recreationists, students, governmental authorities, environmental organizations and ecologists. The catalogue will form a basis for further studies in the region and provide a platform for developing an integrated, harmonised monitoring programme. The data will also assist in developing cost-effective, biological monitoring procedures for the lakes in the region. All the lakes have so far been included in long-term, joint monitoring programmes. In the future, the reports on changes in the environmental conditions in the border area will be based primarily on the results of observations made in these lakes. The documentation and analysis of data on individual water bodies, collected over several years, will make a considerable contribution to reports covering all aspects of the natural environment.

The catalogue is based on the data, collected in connection with the Interreg IIIA Kolarctic project "Development and implementation of an environmental monitoring and assessment programme in the joint Finnish, Norwegian and Russian border area", carried out during 2003-2006, as well as on data from earlier studies in the region.

Detailed information about the structure and organization of the monitoring systems in the three countries, as well as the results of studies and observations conducted within the framework of the project, can be found in the following publications:

Environmental Monitoring Programme in the Norwegian, Finnish and Russian border area. Implementation guidelines.
(www.pasvikmonitoring.org -> more information -> publications 2003-2008)

State of the Environment in the Norwegian, Finnish and Russian Border Area.
The Finnish Environment 6/2007.
(www.ymparisto.fi -> publications -> The Finnish Environment)

And also on the web-page of the current monitoring programme
www/pasvikmonitoring.org.

The catalogue was compiled by researchers from the Institute of the North Industrial Ecology Problems, Kola Science Center RAS, Russia, in collaboration with the Lapland Regional Environment Center, Finland, within the framework of the Interreg IIIA Kolarctic project "Dissemination of information about the state of the environment and monitoring activities in the River Paz catchment area".

The lake studies described in the catalogue were conducted with the support and participation of:

- The Institute of the North Industrial Ecology problems of the North KSC RAS, Russia
- The Lapland Regional Environment Centre, Finland
- The Office of the Finnmark County Governor, Norway
- The Murmansk Department for Hydrometeorology and Environmental Monitoring, Russia
- The Norwegian Institute for Environmental Research, Norway

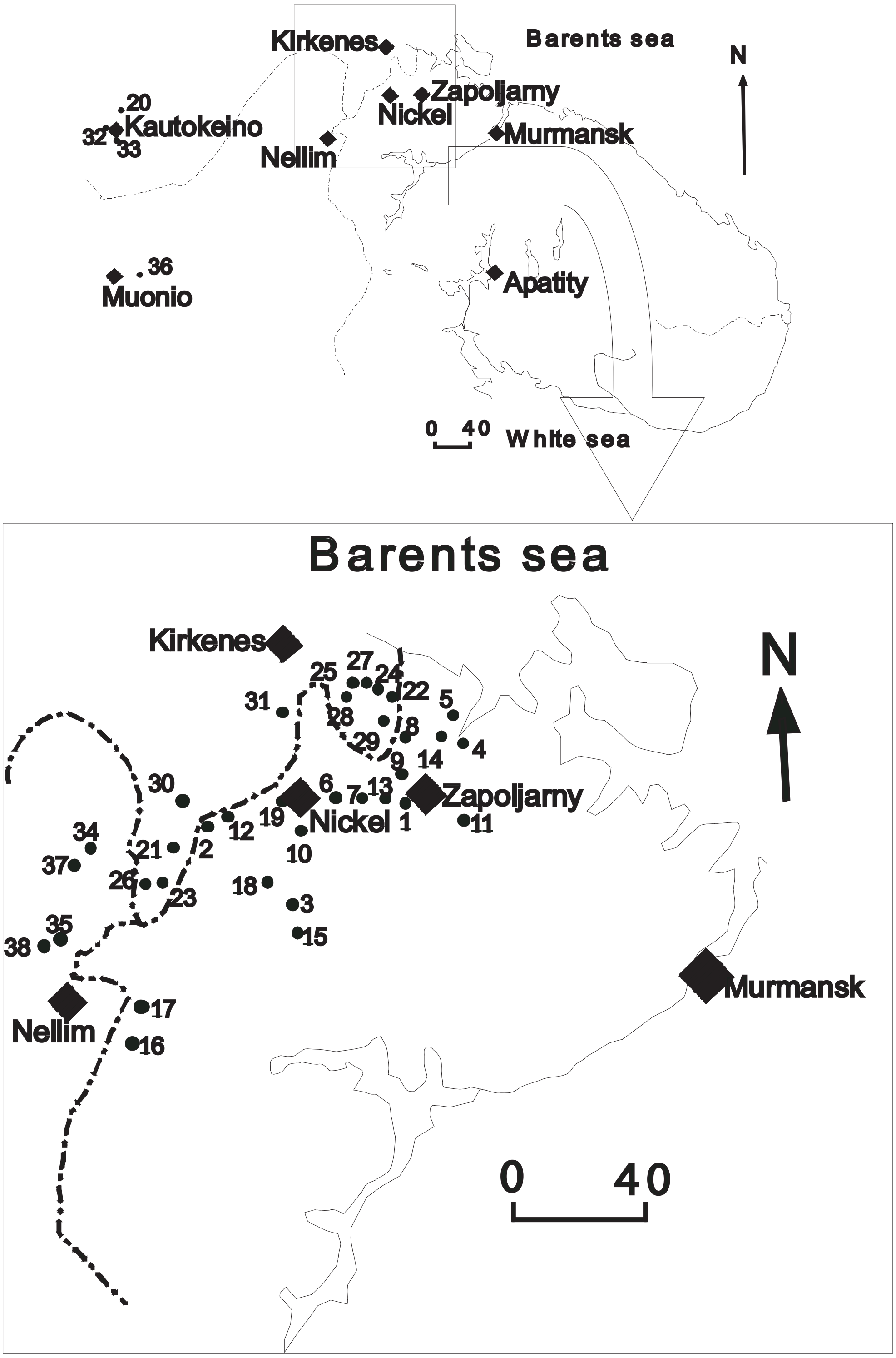


Fig. I-1
Map of the investigated area (the points on a map correspond the lakes):

1. Haukilampi;
2. Kaskamajarvi;
3. Keudsherjaur;
4. Kirikovanjarvi;
5. Kjantejarvi;
6. LN-2;
7. LN-3;
8. Njassukajarvi ;
9. Palojarvi;
10. Peschanoe;
11. Pikku-Heynjajarvi;
12. Porojarvi;
13. Sarijarvi;
14. Trifonajarvi;
15. Alla-Akkajarvi;
16. Kochejaur;
17. Virtuovoshjaur;
18. Shuonijaur;
19. Kuetsjarvi;
20. Biggejavre;
21. Ellentia;
22. Gardsjoen;
23. Gjokvatn;
24. Guokalabbalat;
25. Holmvatn;
26. Isalombola;
27. Kobbholmvatn;
28. Langvatn;
29. N-254;
30. Samettivatn;
31. Skrukkevatn;
32. Stuorajavre;
33. Suopatjavre;
34. Aittojärvi;
35. Kantojärvi,
36. Kivijärvi;
37. Mellalompolo;
38. Suovaselkäjärvi

- The Norwegian College of Fisheries Science, University of Tromsø, Norway
- The Bioforsk Svanhovd Environment Centre, Norway
- The Finnish Meteorological Institute, Finland
- The Finnish Game and Fisheries Research Institute, Finland
- The Finnish Forest Research Institute, Finland
- The Institute of Global Climate and Ecology, Russia

Environmental pollution problems in the far north of Europe

The region has always been famous for its large number of lakes and rivers, with pure fresh water populated by valuable species of fish and invertebrates. The water resources in the north play an important role in the life of the indigenous people and the economy of the whole region. However, major changes at the global scale during the past century have set serious threats on the quality of northern water bodies. The intensive development of industrial production during the 20th century has resulted in the spread of environmental pollutants throughout most parts of the globe. Pollutants that can accumulate and be cycled within ecosystems over a long period of time constitute a considerable threat to the environment. The Murmansk region is one of the most industrialized areas in the Arctic. Long-range, trans-border pollution, carried by air masses from industrial areas in Europe, America and Asia, and the active development of local sources of pollution (mining and ore processing, metallurgical industry, power plants, transport etc.) has brought about a sharp increase in the discharge and deposition of airborne pollutants directly into surface waters, as well as throughout the catchment areas. Pollution accumulates specifically in the water bodies Most of the pollutants deposited in the catchment areas finally end up in the aquatic ecosystems; even though they are partly incorporated into the biogeochemical cycles of terrestrial ecosystems, this usually only means a relatively short time delay.

Heavy metal contamination

Heavy metals belong to the most toxic group of pollutants. They pass into the environment from a wide range of sources, and they can accumulate and be cycled within ecosystems for a long period of time, resulting in a constant increase in their concentrations in natural environments, and have severe toxic effects on biological systems at different trophic levels.

Heavy metals have always been present at varying concentrations in natural environments. They occur in the bedrock, soil, natural water, and in plants and animals. The role of these elements in the complex interactions between the biota and environment is relatively unclear. On the one hand, with rare exceptions, they are essential at low concentrations for the growth and development of all living organisms. A deficit of a specific metal may, for instance, result in functional disturbances in an organism. On the other hand, they are usually highly toxic at elevated concentrations.

Mercury (Hg) and cadmium (Cd) play the most important role in pollution of the Arctic region and they constitute a major threat to ecosystems in the region. They do not have any known biological function, but they can be bioaccumulated and are toxic even in very small amounts. They are present in big quantities even in the regions, distant from anthropogenic sources.

The next metal of considerable concern is lead (Pb), which is also highly toxic. Other metals, such as copper (Cu) and nickel (Ni), have a relatively more restricted distribution and are concentrated in the impact areas of the metallurgical plants.

Acidification of water bodies

Together with heavy metal pollution, the acidification of surface water and catchment areas is intensifying and it has become one of the most urgent problems in recent decades. Acidification is determined by a number of factors: the amount of acid-forming oxides, deposition levels in the catchment area and the duration of acidifying deposition, the geochemical features of the region, hydrochemistry and morphology of the water bodies etc. Acidifying deposition is the main reason for the drop in pH in water bodies in the northern hemisphere. For precipitation to be called "acidic", it should have a pH of less than 5.6. The main acidifying compound in the Arctic is sulphur dioxide. It is formed during the combustion of fossil fuels (coal, brown coal, oil products) and during the roasting and smelting of sulphide ores. Lakes and rivers with a small buffering capacity (small reserves of compounds that neutralize acidic compounds) and low ionic strength are the most sensitive to the influence of acidifying components. Acidification of water bodies is usually accompanied by the dissolution of heavy metals from the bottom sediments, and increased migration of ions such as Cd^{2+}, Pb^{2+}, Hg^{2+}. A sharp reduction in the biodiversity and productivity of water fauna and flora is typical of acidified lakes and rivers. In many cases valuable aquatic species are killed off.

Specific features of the Finnish, Norwegian and Russian border area

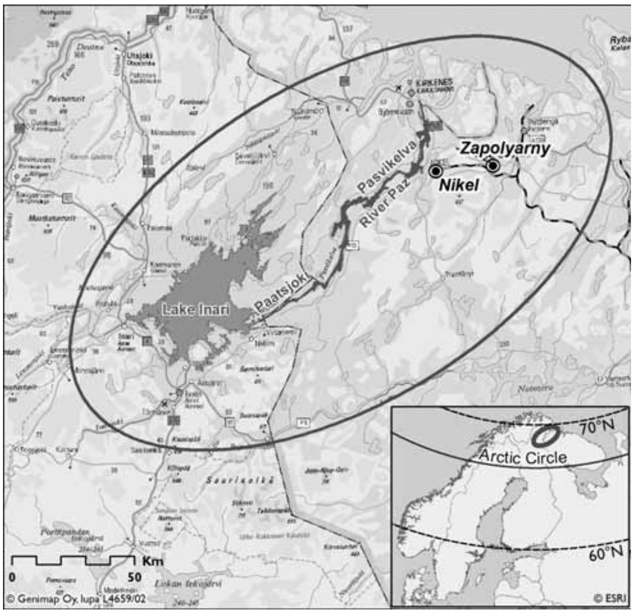


Fig. I-2
The area covered by the project.

The border area of Finland, Norway and Russia is located in the eastern and north-eastern parts of the large watershed Maanselkä, which curves up from south-eastern Lapland far into the north. The watercourses in this region flow via different routes into the Barents Sea.

The River Paz, which links Lake Inari with the Barents Sea, is a regulated watercourse with storage pools, blocked by dams. There is a large number of water bodies in the Vätsäri region, extending to the north-east of Lake Inari, the water bodies covering an area of 50 000 ha out of a total area of 155 000 ha. There is a large number of isolated lakes without any apparent inflowing or outflowing watercourses. One characteristic feature of the Vatsari area is the mosaic structure of lakes, streams, mineral soil and exposed bedrock.

The Jarfjord region is characterized by a high proportion of small lakes, and the basin of the Russian part of the River Paz consists of a multitude of lakes, swamps and rivers with rapids and small waterfalls. The mountain lakes of Jarfjord are located about 30 km to the north of Nickel. The average area of the lakes is 6 ha. The geology of the Jarfjord and Vätsäri areas is dominated by extremely sparingly soluble bedrock, which makes the lakes highly sensitive to a rise in acidity. There are acidification problem in Sor-Varanger: the lakes in this area, lying between Kirkenes and the Russian border, is suffering from a rise in acidity. The watercourses in the border area have, in general, a high degree of water transparency, and low levels of mineralization and organic matter. However, there is also a large number of lakes with a relatively high water colour index, due to the high concentrations of humus material.

Annual precipitation in the area is 450-500 mm, and evaporation about 200 mm. Most of the precipitations fall during the winter period in the form of snow. The ice cover period of the lakes is long and, as a result, the oxygen concentrations in the water at the end of the winter can be extremely low, especially in small, shallow lakes. The small lakes usually freeze over in late October, and the ice cover melts at the beginning of June.

Most of the land is covered by forest. In Finland most of these forests are in nature reserves and forestry plays only a minor role. In Russia and Norway, on the other hand, the protected area is much smaller and commercial forestry is more common. Agriculture is of only minor importance in Finland and Russia, and there are no industrial plants in the Finnish part of the area. A few small companies (farms) are operating along the Norwegian side of the River Paz. The population density in the region is not high, apart from the towns of Nikel and Zapolyarny in Russia along the lower reach of the River Paz. The largest town in the Norwegian part of the region, Kirkenes, is located close to the Varanger Fjord. There are also some small settlements along the River Paz. The largest Finnish settlements are the towns of Inari and Ivalo, which are located on the western and southern shores of Lake Inari.

The region is subjected to serious anthropogenic impacts, including pollution from the Pechenganikel smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Cd, Cr, Zn, As, Hg etc.). SO_2 emissions from the smelter have caused acidification of the surface water and the pollution of ground water as a result of leaching from the surface soil. The area is also exposed to wide range trans-boundary pollutants influence, as is the case throughout the whole of the Arctic.

Structure of the lake catalogue

The lake catalogue includes:

• A general description of the water body (geographical location, landscape characteristics, lakes morphometry)

• Geochemical description (description of the hydrochemical parameters, assessment of pollution levels in the water and bottom sediments, comparison of the results with quality targets)

• Biological description (description of hydrobiological diversity in the lakes, composition of the fish population, including the size, weight, age and sex distribution of the predominant fish species, and assessments of pathological changes in fish and the levels of heavy metal accumulation in fish and their individual organs based on the quality targets).

Table I-1. *List of fishery standard values - the maximum permissible concentrations in water bodies used for fishing.*

Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	SO_4^{2-}	P	Al	Fe	Mn	Sr	Cu	Ni	Zn	Cr	Cd	Co	Pb
mg/l						µg/l										
180	120	40	50	100	0	40	100	10	400	1		10		5	1	6

Water quality

Water quality in the lakes is assessed in accordance with the Russian standards for maximum permissible concentrations (MPC) for fishery water bodies (see Table I-1).

The quality of the lakes was assessed on the basis of the ion composition and total mineralization, as well as indices depicting the trophic status of the water body (concentrations of ions and cations) and the heavy metal concentrations. The acidification of surface water was most clearly evident as a short-term (using during spring flood) reduction in pH (to 5-6) and alkalinity (Alk, μeq/l).

The mineralization index used in Russia is the sum of all mineral compounds dissolved in water, i.e. total concentration of anions and cations, as well as dissolved inorganic matter. Total water mineralization is an important hydrochemical characteristic, which determines the fitness of water for economic utilization.

Eutrophication is the enrichment of water systems by mineral nutrients (P and N) and, combined with biological phenomena, is related to an abundant inflow of mineral components. An excess input and maintenance of high concentrations of mineral nutrients in water result in intensive growth of primary production, deterioration of the water environment, and a decrease in its recreational value. Generally, human activities are the primary cause of disturbances in the natural balance and an imbalance in the input of mass flow into aqueous ecosystems. Arctic ecosystems are the most vulnerable to anthropogenic impacts. The consequences can include qualitative reorganization both at high and lower loads of biogenic elements, a deterioration in water quality, increase in the concentrations of suspended organic matters and a reduction in water transparency, a reduction in dissolved oxygen concentrations in the hypolimnion, and the intensive growth and successive replacement by algae populations and a reduction in the oxygen supply for salmon and whitefish species.

Numerous studies have show that the critical levels of P and N in fresh waters, when a transition occurs from the meso- to the eutrophic type, are $P_{tot} \geq 0.01$ mg/l $N_{tot} \geq 0.3$ mg/l.

Bottom sediments

In most water systems the concentrations of elements in the upper layers of the bottom sediments are much higher than those of elements dissolved in the water column. Bottom sediments act as "reserves" of many pollutants. Studying the chemical composition of bottom sediments provides reliable data about the distribution, geochemical migration and availability of elements and compounds to living organisms inhabiting the water bodies, and it also enables their impact on the ecosystem to be determined or predicted. Data on the chemical composition of bottom sediments are also required for modelling the transport of pollutants in aqueous systems and the environment as a whole, for assessing the geochemical cycles, and for determining the availability of elements in ecological systems.

A summary table is presented for each lake giving the organic matter content (LOI%, i.e. loss in weight on ignition) and the concentrations of the main pollutants (Ni, Cu, Co, Zn, Cd, Pb, As Hg) in the uppermost (0-1 cm) and the deepest (pre-industrial level) layer in the bottom sediments (usually 20-25 cm deep). Joint international studies have demonstrated that the sedimentation rate in the lakes of northern Fennoscandia generally doe not exceed 1 mm per year. As a result, the upper layer provides an index of the recent load on the lake, and the deepest layer the background one, i.e. representing natural concentrations during the pre-industrial period, when there was no major anthropogenic impact on the environment and aquatic ecosystems. Graphs showing the depth distribution of a number of polluting elements in the lake in question were constructed on the basis of the results of chemical analyses on the bottom sediments.

In cases where the age of the bottom sediments had been determined, the distribution of the elements was plotted against the dated bottom sediments. This provided an overall picture of the history of pollution of the lake and its watershed area.

Contamination level assessment

Håkanson's method was used to assess the contamination level in the lakes (Håkanson, 1980).
The value of the contamination factor (Cfi) was determined for each element:

$$C_f^i = \frac{C_{0-1}^i}{C_n^i}$$

where C_{0-1}^i = the element concentration (i = Ni, Cu, Co, Zn, Cd, Pb, As, Hg) in the uppermost layer (0-1 cm) of bottom sediments, taken from the deepest part of the water area (accumulation zone), and C_n^i = background (pre-industrial) concentration in the bottommost layer of the bottom sediment column.

The contamination factor (C_f^i) has been calculated for each pollutant or compound.
If $C_{0-1}^i > C_n^i$, then the element is considered to be a pollutant. If $C_{0-1}^i < C_n^i$, then the element is not regarded as a pollutant.

This approach utilizes the following classification of contamination factors (Håkanson, 1980): $C_f^i < 1$ = low (low level of pollution of the bottom sediment by this element); $1 \leq C_f^i < 3$ = moderate; $3 \leq C_f^i < 6$ = considerable; $C_f^i \geq 6$ = high.

The degree of pollution by chalcophile elements (C_d) was determined as the sum of all contamination factors (C_f^i) for the given lake or the sampling site:

$$C_d = \sum_{i=1}^{n} Cfi = \sum_{i=1}^{n} \frac{C_{0-1}^i}{C_n^i}$$

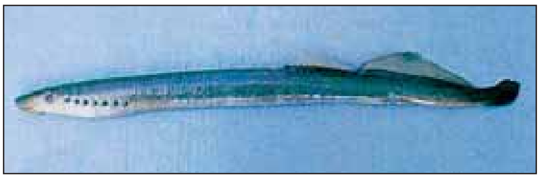
This approach provides a measure of the contamination factor (C_f^i), which depicts the pollution of the water area by both the individual chalcophile elements and their total contribution, which is based on the determination of the degree of contamination, C_d, which, in turn, expresses the overall pollution of the water body by the elements in question.

Similarly, determination of the contamination degree, which comprises the contamination factors of the individual elements, is based on classification of the C_d values, as suggested by Håkanson (Håkanson, 1980), as follows: $C_d < \boldsymbol{n}$ = low; $n \leq C_d < 2\boldsymbol{n}$ = moderate; $2\boldsymbol{n} \leq C_d < 4\boldsymbol{n}$ = considerable; $C_d \geq 4\boldsymbol{n}$ = high pollution (***n*** is the number of elements) Classification of the contamination degree for 8 elements is: $C_d < 8$ = low; $8 \leq C_d < 16$ = moderate; $16 \leq C_d < 32$ = considerable; $C_d \geq 32$ = high.

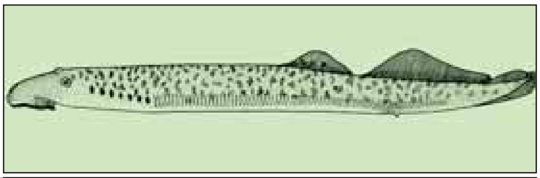
Ichthyofauna of the lakes

According to literature data, the ichthyofauna of Northern Fennoscandia lakes includes 14 species belonging to 11 families, but in our investigations only 10 species (9 families) were registered:

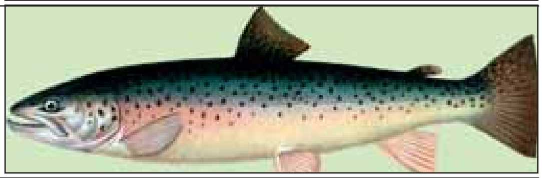
Lamprey family - Petromyzontidae
Lamprey – Lampetra japonica (Martens)



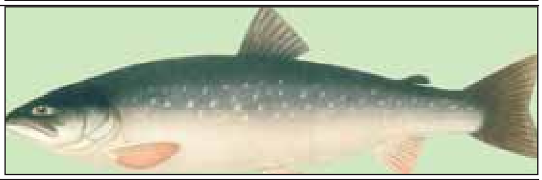
Marine lamprey – Petromyzon marinus L.



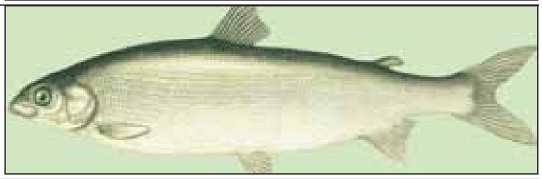
Salmonids family - Salmonidae
Trout – Salmo trutta L.



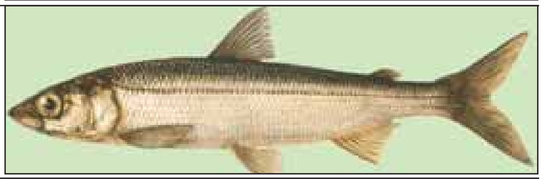
Salmonids family - Salmonidae
Arctic char – Salvelinus alpinus (L.)



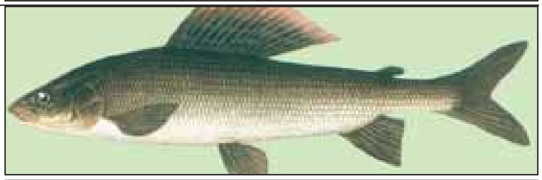
Whitefish family – Coregonidae
Whitefish – Coregonus lavaretus (L.)



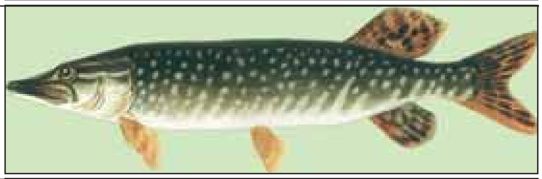
Whitefish family – Coregonidae
Vendace – Coregonus albula (L.)



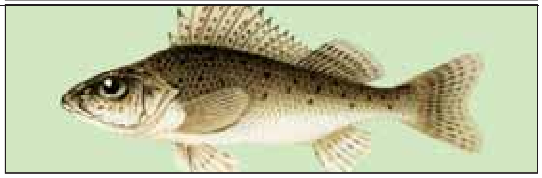
Grayling family – Thymallidae
Grayling – Thumallus thumallus (L.)



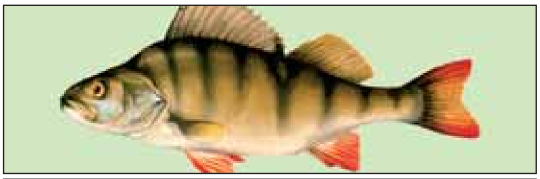
Pickerel family – Esocidae
Pike – Esox lucius L.



Perch family – Percidae
Pope - Gymnocephalus cernuus L.

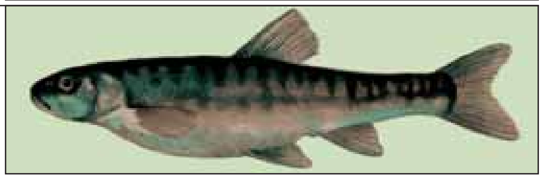


Perch - Perca fluviatilis L.

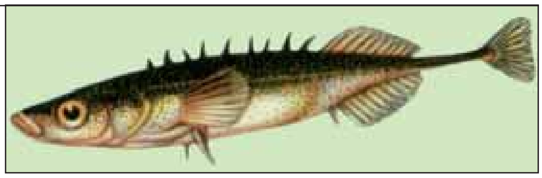


Burbot family – Lotidae
Burbot – Lota lota (L.)

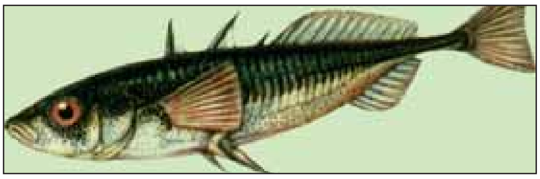
Carp family – Cyprinidae
Minnow - Phoxinus phoxinus



Sharplings family – Gasterosteidae
Nine-spined stickleback - Pungitius pungitius (L.)

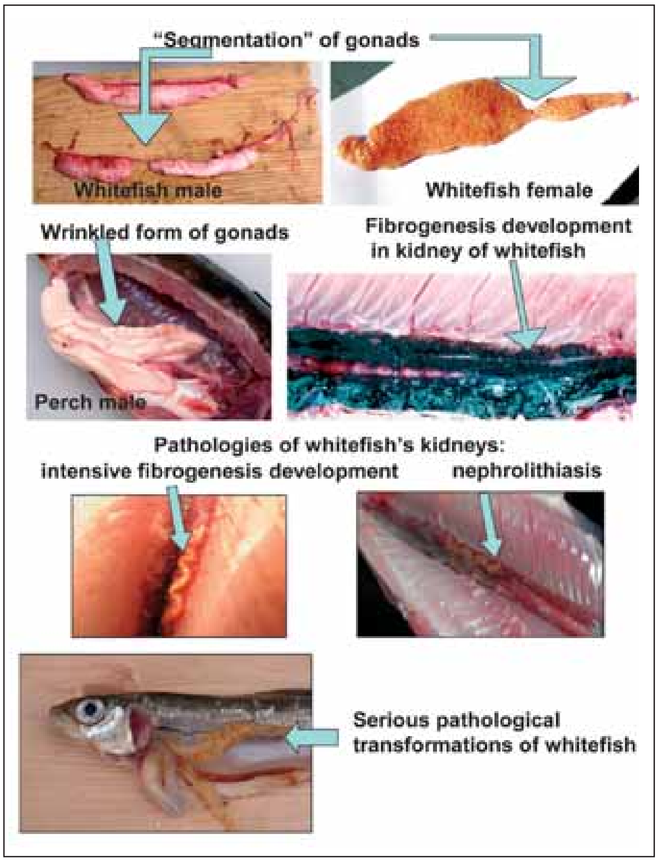


Thornback – Gastrerosteus aculeatus L.



Analyses were carried out on the fish and individual organs (pathological and morphological analysis), and the degree of heavy metal accumulation (Hg, Ni, Cu, Cd and Pb) was determined in order to assess the influence of pollution on the fish present in the lakes. The following maximum allowable values (in µg/g wet weight) for these elements in foodstuffs (fish) have been established in Russia,:

Hg	0.5
Ni	0.5
Cu	20
Cd	0.1
Pb	1



The organs and tissues of the fish in the lakes exhibit certain characteristic pathological changes. The most frequently occurring ones are depicted in the figure below. Only the frequency of occurrence and intensity of the fish pathologies varied in the investigated lakes.

RUSSIAN LAKES

1.1. LAKE HAUKILAMPI

Lake Haukilampi is located in the immediate vicinity of the town of Zalolyarny and runs along the main road to Nikel. The lake is not large (area of the lake is 0.25 km^2) and is a shallow-water (maximum depth 2 m) lake of elongated form and of glacial origin. Its maximum length is 1.6 km, and maximum width 0.4 km. The points of maximum depth (2 m) are scattered throughout the whole water body.

River Pilgujoki flows through the lake and then into River Namajoki. According to the landscape type, the watershed area consists of a combination of flat, low-lying areas of glaciolacustrine flatland and tectonic massifs with scattered outcrops of quaternary deposits reaching a height of 275.8 m (Pilgujoenvara hill). As a result of mining and excavation over a huge area, the natural landscape has been seriously damaged, the hill tops destroyed and the orography changed. The shores of the lake are not high, and are covered by birch stands. The water of the lake is colourless but, during flood periods, the colour of the water increases to 21 deg. The shores of the lake consist of silty deposits.

Physico-geographical characteristics	
Watershed	River Namajoki — River Pechenga
Latitude	69°26.649′
Longitude	30°45.749′
Height above sea level, m	150.0
Maximum length, km	1.6
Maximum width, km	0.4
Maximum depth, m	2
Area, m^2	0.25
Watershed area, km^2	43.3
Study period	1989-2004

1.1.1. Hydrochemistry

Owing to its close proximity to the Pechenganikel smelter complex, the lake is one of the most polluted in the Pechenga area. Airborne pollution emissions have a considerable influence on the water quality.

The water of the lake is neutral and its mean total mineralization is 178 mg/l, and mean alkalinity 228 μeq/l. During flood periods the pH of the water falls to 6.59 and then returns to 7.12. The lake is characterized by high concentrations of base cations and anions, calcium (average 25.1

Hydrochemical properties	
pH	6.86 6.56-7.12
Electrical conductivity, mS/cm	296 62-641
Ca, mg/l	25.1 3.18-66.4
Mg, mg/l	13.5 1.26-36.8
Na, mg/l	7.59 2.85-17.4
K, mg/l	0.74 0.38-1.36
HCO3, mg/l	13.9 9.5-22.5
SO_4, mg/l	113 8.2-320
Cl, mg/l	4.14 3.15-5.67
Total mineralization, mg/l	178 29.1-467
Alkalinity, μeq/l	228 156-368

mg/l) and sulphate (average 117 mg/l) predominating.

Intensive pollution of the water body was observed throughout the monitoring period. Pollutant concentrations are currently very high.

The annual chemical cycle of the lake is characterized by a decrease in the total mineralization of the water to 40.2 mg/l and a drop in pH during floods and times of high precipitation. During low-water periods (summer and autumn) the total mineralization increases to 467 mg/l, the oxidizability decreases and the pH rises.

The concentrations and relationships between the species of mineral nutrients vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest total P concentration in the lake (up to 25 µg/l) typically occurs in autumn, and it is 3 times higher than the concentration in spring and summer. The highest total N concentrations (up to 1760 µg/l) also typically occur during flood periods.

Water colour, deg.	12 5-21
NH_4, µg/l	70 8-213
NO_3, µg/l	577 1-1700
Total N, µg/l	927 250-1760
PO_4, µg/l	1.5 1.0-2.0
Total P, µg/l	9 1-25
Fe, µg/l	214 48-430

According to the concentrations of mineral nutrients, the lake is classified as eutrophic. The lake also has colour values and organic matter concentrations (up to 3.7 mg/l) typical of small water bodies in the region. The mean Fe concentration is 214 µg/l. The trophic type of the water body is to a great extent determined by the proximity of the town of Zapolyarny and the smelter. The bottom of the lake is covered by a thick layer of silt of technogenic origin.

The watershed area of Lake Haukilampi is subjected to major anthropogenic impacts from the "Pechenganikel" smelter, and the water system to effluents from the concentration plant. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co etc.). In the 1990s the maximum concentrations in the water were Cu 11 µg/l and Ni 111 µg/l. Pollution emissions during the monitoring period have resulted in higher concentrations of Cu (up to 16 µg/l) and Ni (up to 167 µg/l).

Cu, µg/l	8.3 4.7-16.0
Ni, µg/l	109 18-167
Al, µg/l	72 46-93
Pb, µg/l	0.2 0.1-0.3

1.1.2. Lake bottom sediments

The sediments in Lake Haukilampi are characterized by high organic matter contents: the LOI (loss in weight on ignition) value in the uppermost 1 cm layer is more than 35% (Table 1). The lake is located at a distance of 3 km from the Pechenganikel smelter complex, and is exposed to high levels of e.g. Ni, Cu, Co, Zn and chalcophile elements (Pb, As, Cd and Hg) emitted from the smelter. The layers most polluted by Ni, Cu and Zn are located in the top 7-8 cm of the lake sediments. This layer is also seriously polluted by chalcophile elements (Fig. 1), suggesting that atmospheric emissions from the smelter are the main sources of pollution in the lake. The contamination factor values for these toxic elements range from 2.2 to 85.1 (Table 1), i.e. the values indicate considerable and high contamination according to the classification of Lars

Håkanson (1980). Nickel has the highest value Cf. According to Håkanson's classification, the degree of contamination (185.2) of this lake is high, and it is the second most contaminated of the studied lakes after Lake Kuetsjarvi, which also receives effluent directly from the Pechenganikel smelter complex.

Table 1. *Organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (17-18 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake		LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Haukilampi	0-1	35.49	1500	6139	2004	266	1.91	5.0	27.8	0.250	
	17-18	30.71	28	72	119	39	0.20	1.3	12.4	0.039	
C_f			**54.1**	**85.1**	**16.9**	**6.8**	**9.7**	**3.9**	**2.2**	**6.5**	**185.2**

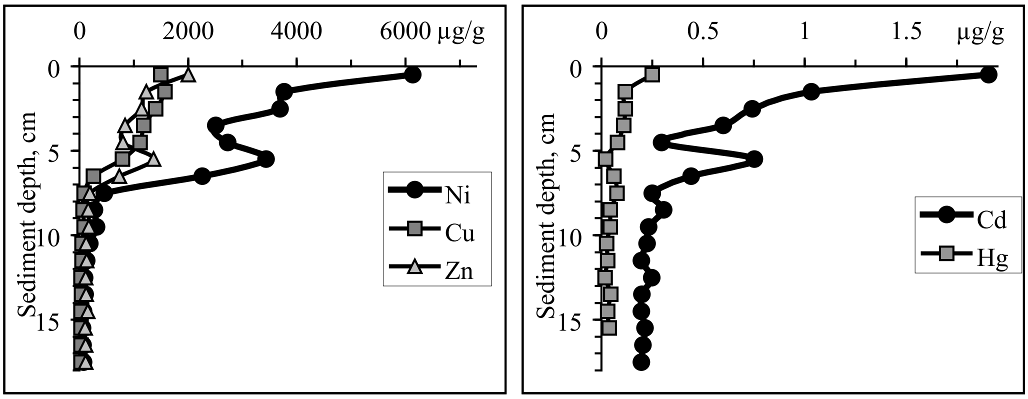


Fig. 1. *Vertical distribution of the concentrations of Ni, Cu, Zn, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Haukilampi.*

1.1.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. According to earlier data for some lakes near Lake Haukilampi (Yakovlev et al., 1991), the biodiversity of plankton and benthos communities is poor. The dominant species are chironomids, water bugs and beetles. Sensitive species (mayfly, caddis fly and cyclopoids) and fish species affected by pollution are absent.

1.2. LAKE KASKAMAJARVI

Lake Kaskamajarvi (watershed of the River Paz) is located near to the settlement of Rajakoski, and 34 km to the south-west of the town of Nikel and 5 km from the river border with Norway. It is a small (area of the lake is 2.36 km^2), shallow (maximum depth 13 m) lake with an indented shoreline and is

Physico-geographical characteristics	
Watershed	River Paz
Latitude	69°16.405′
Longitude	29°26.189′
Height above sea level, m	68.9
Maximum length, km	3.4
Maximum width, km	2.4
Maximum depth, m	13
Area, m^2	2.36
Watershed area, km^2	23.0
Study period	2002-2004

of glacial origin. The maximum length is 3.4 km, maximum width 2.4 km, and the maximum depth occurs in the central part of the lake.

According to the landscape type, the watershed area belongs to the forest-tundra zone with altitudes of up to 351.5 m (Kaskama hill). The south-eastern shore is waterlogged, and the other shores are high and abrupt. Shrubs and birch and pine forests grow along the shoreline. The water of the lake is colourless. Boulder beds, extending to a depth of about 2-2.5 m, occur in almost all parts of the littoral zone. The gaps between the boulders are filled with silt and pebbles.

Hydrochemical properties	
pH	6.95 6.88-7.09
Electrical conductivity, mS/cm	34 32-37
Ca, mg/l	3.22 2.88-3.57
Mg, mg/l	0.77 0.70-0.89
Na, mg/l	1.92 1.88-1.95
K, mg/l	0.39 0.36-0.40
HCO_3, mg/l	9.4 9.2-9.6
SO_4, mg/l	4.19 4.05-4.29
Cl, mg/l	2.06 1.84-2.39
Total mineralization, mg/l	21.9 21.3-22.4
Alkalinity, µeq/l	153 151-157

Water colour, deg.	24 22-25
NH_4, µg/l	12 8-17
NO_3, µg/l	9 1-17
Total N, µg/l	164 123-198
PO_4, µg/l	1 1-1
Total P, µg/l	4 3-5
Fe, µg/l	36 34-41

Cu, µg/l	1.9 1.5-2.4
Ni, µg/l	2.9 2.1-3.8
Al, µg/l	42 38-45
Pb, µg/l	0.1 0.1-0.2

1.2.1. Hydrochemistry

The water of the lake is neutral and is characterized by low total mineralization (average 21.9 mg/l) and alkalinity (average 153 µeq/l). The lake has low concentrations of base cations and anions, calcium (average 3.22 mg/l) and bicarbonate (average 9.4 mg/l) predominating.

The total P and N concentrations are the main criteria used in assessing the development of water eutrophication. The concentrations and relationships between P and N species vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The concentrations of these mineral nutrients during the vegetation period are: total P up to 5 µg/l, and total N up to 198 µg/l.

Based on the concentrations of nutrient elements, the lake is oligotrophic. The lake also has colour values, organic matter concentrations (up to 4.6 mg/l) and Fe concentrations (mean 36 µg/l), typical of small water bodies in this region.

The water exchange index is 0.61, i.e. full water exchange in the lake takes about 6 months. The bottom of the lake is covered with a thick layer of silt comprised of undecomposed zooplankton debris and organic matter; this is of primary importance for the feeding of ichthyofauna. The conditions for the growth of food organisms are obviously very favourable. Due to the fact that most of the lake is not deep, the circulation of mineral nutrient material in water is at its greatest in the summer, which also increases the food producing capacity of the water body.

At the present time the watershed area is subjected to relatively small anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu etc.). Now that emissions have decreased, the mean concentration of Cu is 1.9 µg/l and of Ni – 2.9 µg/l.

1.2.2. Lake bottom sediments

The sediments in Lake Kaskamajarvi are characterized by low organic matter contents: the LOI value in the uppermost 1 cm layer is less than 20 % (Table 2). The lake is located at a distance of 35 km from the Pechenganikel smelter and is exposed to the deposition of heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg) emitted by the smelter. The uppermost 1 – 2 cm layer is the most strongly polluted with Ni, Cu and Co. Pollution by chalcophile elements occurred earlier: the 3-4 cm sediment layer is strongly polluted by these elements (Fig. 2). The contamination factor (C_f) values for these toxic elements range from 1.4 to 5.6 (Table 2), i.e. they correspond to moderate and marked contamination. Lead (Pb) has the highest C_f value. The degree of contamination (C_d) value (20.2) for this lake corresponds to considerable contamination.

Table 2. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (19-20 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Kaskamajarvi	0-1	19.32	77	70	107	32.4	0.30	12.0	7.63	0.116	
	19-20	15.24	53	26	115	13.9	0.09	2.1	4.83	0.057	
C_f			**1.4**	**2.7**	**0.9**	**2.3**	**3.6**	**5.6**	**1.6**	**2.0**	**20.2**

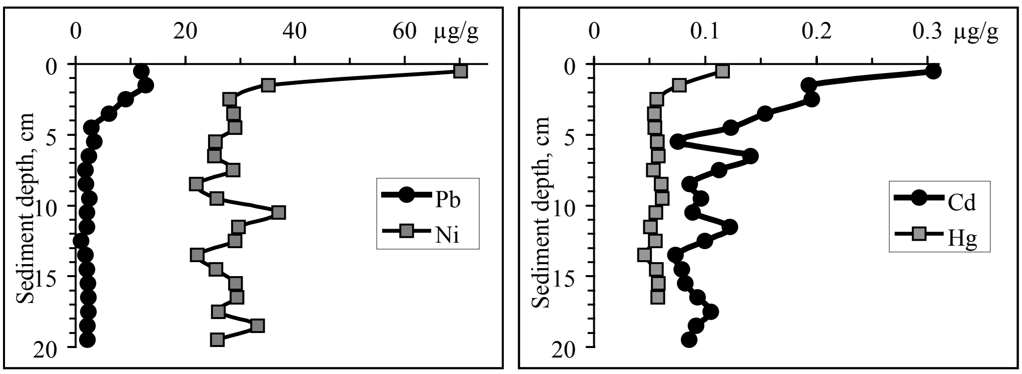


Fig. 2. *Vertical distribution of the concentrations of Ni, Pb, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Kaskamajarvi.*

2.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. As regards the fish fauna, Lake Kaskamajarvi is a typical reservoir for species such as trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*), and nine-spine stickleback (*Pungitius pungitius*).

1.3. LAKE KEUDSHERJAUR

Lake Keudsherjaur (watershed of the River Pechenga) is located 20 km to the south of the town of Nikel. It is a small (area of the lake 0.11 km^2), shallow-water (maximum depth 6 m) oval lake of glacial origin, with a maximum length of 4.0 km and maximum width 1.8 km. The points of maximum depth are scattered throughout the whole water body.

According to the landscape type, the watershed area belongs to the forest-tundra zone with heights of up to 251.8 m. The lakeshores are waterlogged, peaty and covered by shrubs and birch stands. The water of the lake is colourless but, during flood and heavy precipitation periods, the colour of the water increases to 39 deg, and becomes slightly yellowish. Brown silt deposits begin immediately at the waterline.

Physico-geographical characteristics	
Watershed	River Pechenga
Latitude	69°08.853′
Longitude	30°09.193′
Height above sea level, m	211.8
Maximum length, km	4.0
Maximum width, km	1.8
Maximum depth, m	2
Area, m^2	4.66
Watershed area, km^2	10.25
Study period	1990-2005

1.3.1. Hydrochemistry

The water of the lake is close to neutral and is characterized by low total mineralization values (average 14.7 mg/l) and alkalinity (average 83 μeq/l). During flood periods, the pH falls to 5.94 and then increases back to 6.50, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake is characterized by low concentrations of base cations and anions, sodium (average 1.64 mg/l) and bicarbonate (average 5.1 mg/l) predominating.

The maximum degree of pollution of the lake occurred during the period of extremely high emissions from the smelter in the late 1980s and early 1990s. The maximum concentrations of most elements, especially sulphate (up to 8.4 mg/l), Cu and Ni, occurred during this period. At the present time the concentrations of these elements in the water are lower.
The annual chemical cycle in the lake is characterized by the fact that, during flood and high precipitation periods, the inflow of humic-rich water increases and mineralization is reduced to 11.4 mg/l, the oxidizability increases and the pH falls. During low-water periods, mainly in winter and autumn, and when the flow of ground water increases, the total mineralization increases slightly to 25 mg/l, the oxidizability is reduced and the pH rises.

Hydrochemical properties	
pH	6.41 5.94-6.75
Electrical conductivity, mS/cm	25 19-38
Ca, mg/l	1.54 1.20-2.43
Mg, mg/l	0.74 0.57-1.20
Na, mg/l	1.64 1.31-2.33
K, mg/l	0.33 0.29-0.40
HCO_3, mg/l	5.1 3.7-7.8
SO_4, mg/l	3.5 2.2-8.4
Cl, mg/l	1.8 1.4-2.4
Total mineralization, mg/l	14.7 11.4-25.0
Alkalinity, μeq/l	83 60-128

Total P and N concentrations in water are the main criteria used in assessing the development of water eutrophication. The concentrations and relationships between P and N species vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The concentrations of total P (up to 14 µg/l) and total N (up to 276 µg/l) changed slightly during the study period.

According to the concentrations of mineral nutrients, the lake is classified as transitional to eutrophic. The lake also has higher colour values, organic matter concentrations (8.4 mg/l) and Fe concentrations (mean 125 µg/l) compared to other lakes in this region.

The water exchange index is 0.6, i.e. full water exchange in the lake takes about 6 months. The bottom of the lake is covered with a thick layer of silt, which consists of undecomposed zooplankton debris and organic matter. During high water periods and high precipitation in the autumn, the concentrations of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Water colour, deg.	30 22-39
NH_4, µg/l	19 7-28
NO_3, µg/l	3 1-8
Total N, µg/l	226 202-276
PO_4, µg/l	1 1-1
Total P, µg/l	9 1-14

The watershed area of the lake is subjected to anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu etc.). Maximum Ni concentrations (9 µg/l) occurred in the water during the 1990s. At the present time, due to the reductions in emissions, there are higher Cu concentrations (up to 3.8 µg/l) during the summer mean water period, and of Ni (up to 4.4 µg/l) during periods of high water.

Cu, µg/l	2.7 1.9-3.8
Ni, µg/l	4.6 3.1-9.0
Al, µg/l	40 16-93
Pb, µg/l	0.3 0.2-0.5

1.3.2. Lake bottom sediments

The sediments of Lake Keudsherjaur are characterized by relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is slightly below 30% (Table 3). The lake is located at a distance of 28 km from the smelter complex, and is exposed to the deposition of heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 3-4 cm of the lake sediments is the most heavily polluted by Ni, Cu and Co. Pollution by chalcophile elements started earlier: the top 5-7 cm of the sediments especially is polluted by these elements (Fig. 3). The contamination factor values of these toxic elements range from 2.2 to 9.4 (Table 3), i.e. the values correspond to considerable and high pollution contamination. Pb has the highest C_f value. The degree of contamination value (41.5) for this lake corresponds to high contamination.

Table 3. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (15-16 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Keudsherjaur	0-1	27.53	45	65	50	8.7	0.22	12.9	3.36	0.072	
	15-16	27.91	8	15	93	3.9	0.03	1.4	1.16	0.009	
C_f			5.8	4.3	0.5	2.2	8.2	9.4	2.9	8.0	41.5

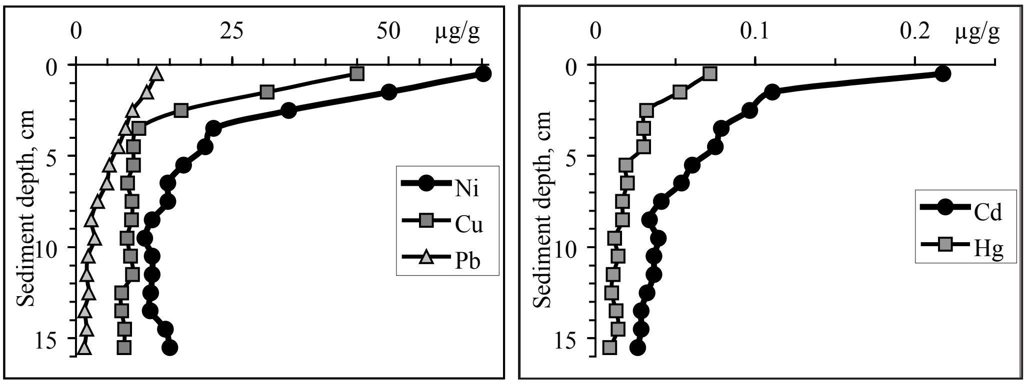


Fig. 3. *Vertical distribution of the concentrations of Ni, Cu, Pb, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Keudsherjaur.*

1.3.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake.

1.4. LAKE KIRIKOVANJARVI

Lake Kirikovanjarvi (watershed of the River Pechenga) is located 4 km to the south of the settlement of Pechenga. It is a small (area of the lake 0.36 km^2), shallow-water (maximum depth 8 m) elongated oval lake of glacial origin. The maximum length is 01.2 km, and maximum width 0.4 km. The point of maximum depth (8 m) is located in the central part of the lake. In the eastern and western parts of the lake the maximum depths are small, up to only 4 m.

According to the landscape type, the watershed area represents a combination of flat, low-lying areas of glaciolacustrine flatlands, and tectonic massifs with a height of upto 180.8 m. The lake shores are high and covered by birch and pine forests. The water of the lake is colourless.

Physico-geographical characteristics	
Watershed	River Pechenga
Latitude	69°30.358′
Longitude	31°13.916′
Height above sea level, m	78.6
Maximum length, km	1.2
Maximum width, km	0.4
Maximum depth, m	8
Area, m^2	0.36
Watershed area, km^2	3.2
Study period	2004

Boulder beds occur in almost all parts of the littoral zone. The gaps between the boulders are filled with sand and pebbles.

1.4.1. Hydrochemistry

The water of the lake is neutral and is characterized by low total mineralization values (average 27.8 mg/l) and low alkalinity (average 135 μeq/l). The lake has low concentrations of base cations and anions, sodium (average 4.24 mg/l) and bicarbonate (average 8.2 mg/l) predominating.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The concentrations of total P are 6 μg/l, and of total N 112 μg/l. The lake also has colour values, organic matter concentrations (up to 5.2 mg/l) and Fe concentrations (mean 47 μg/l) typical of small water bodies in this region. During high water periods and high precipitation events in the autumn, the concentrations of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The water exchange index is 1.1, i.e. full water exchange in the lake takes about one year.

The watershed area of the lake Kirikovanjarvi is subjected to anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Co etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. Copper (up to 4.3 μg/l) and Ni (up to 11.3 μg/l) concentrations in the vicinity of the smelter are substantially higher than in other parts of the region.

Hydrochemical properties	
pH	6.99 6.98-6.99
Electrical conductivity, mS/cm	46 46-46
Ca, mg/l	2.36 2.25-2.47
Mg, mg/l	1.25 1.24-1.26
Na, mg/l	4.24 4.24-4.24
K, mg/l	0.58 0.57-0.58
HCO_3, mg/l	8.2 8.2-8.2
SO_4, mg/l	4.86 4.79-4.83
Cl, mg/l	6.3 6.2-6.3
Total mineralization, mg/l	27.8 27.6-28.0
Alkalinity, μeq/l	135 135-135

Water colour, deg.	19 19-19
NH_4, μg/l	5 2-9
NO_3, μg/l	2 1-2
Total N, μg/l	92 65-119
PO_4, μg/l	1 1-1
Total P, μg/l	6 6-6
Fe, μg/l	47 45-50

Cu, μg/l	4.1 4.0-4.3
Ni, μg/l	10.6 10.0-11.3
Al, μg/l	43 39-48
Pb, μg/l	0.14 0.13-0.21

1.4.2. Lake bottom sediments

The sediments of Lake Kirikovanjarvi are characterized by relatively low organic matter contents, with LOI values in the uppermost 1 cm layer of slightly more than 20% (Table 4). The lake is situated at a distance of 18 km from the smelter, and is exposed to significant atmospheric impacts of emissions from the smelter. This is reflected in the increased concentrations of heavy metals (Ni, Cu, Co), and chalcophile elements (Pb, As, Cd and Hg). The top

3-4 cm of the lake sediments is the most severely polluted by these elements, which are toxic to hydrocoles (Fig. 4).

The contamination factor values for these toxic elements range from 3.9 to 11.4 (Table 4), i.e. the values correspond to considerable and high pollution contamination. Pb has the highest C_f value. The main source of Pb deposition from the atmosphere is the use of gasoline containing the anti-knock additive, tetraethyl-lead. The contamination value (51.6) for this lake corresponds to high contamination.

Table 4. *The organic matter contents (LOI, %) and heavy metal concentrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (20-21 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Kirikovanjarvi	0-1	20.01	202	183	120	34.6	1.00	18.0	4.71	0.214	
	20-21	20.56	32	26	88	8.8	0.09	1.6	0.85	0.040	
C_f			**6.4**	**6.9**	**1.4**	**3.9**	**10.9**	**11.4**	**5.5**	**5.3**	**51.6**

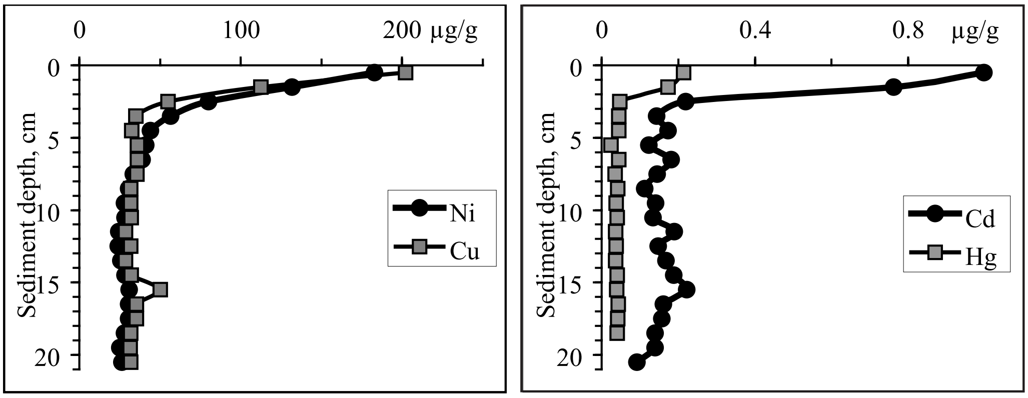


Fig. 4. *Vertical distribution of the concentrations of Ni, Cu, Cd and Hg (μg/g, dry weight) in the sediment core of Lake Kirikovanjarvi.*

1.4.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. Despite the absence of ichthyological data, Lake Kirikovanjarvi is most likely populated by the same freshwater fish species present in the other studied lakes.

1.5. LAKE KJANTEJARVI

Lake Kjantejarvi (watershed of the Barents Sea) is located 2 km to the north of the settlement of Liinakhamari, and is a source of drinking water for the local inhabitants. The road to Nemetskaya Bay on the Barents Sea runs along the edge of the lake. It is a small (area of the lake 0.36 km^2), shallow-water (maximum depth 15.5 m) lake of glacial origin with an indented shoreline. The maximum length is 1.2 km, and maximum width 1.1 km. The point of maximum depth (15.5 m) is located in the central part of the lake.

According to the landscape type, the watershed area belongs to the tundra zone with heights of up to 380.6 m (Iso-Kiventunturi fell). The lake shores are high and rocky, and the water in the lake is colourless.

Boulder beds occur in almost all parts of the littoral zone. The gaps between the boulders are filled with pebbles.

1.5.1. Hydrochemistry

The water of the lake is close to neutral and is characterized by low total mineralization values (mean 19.2 mg/l) and alkalinity (mean 23 μeq/l). The lake has low concentrations of base cations and anions, sodium (average 3.91 mg/l) and chloride (average 6.98 mg/l) predominating.

Physico-geographical characteristics	
Watershed	Pechenga Bay—the Barents sea
Latitude	69°39.427′
Longitude	31°20.936′
Height above sea level, m	66.0
Maximum length, km	1.2
Maximum width, km	1.1
Maximum depth, m	15.5
Area, m^2	0.36
Watershed area, km^2	8.9
Study period	2004

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The mean concentration of total P is 5 μg/l and of total N 107 μg/l. The lake also has colour values, organic matter concentrations (up to 3.7 mg/l) and Fe concentrations (mean 21 μg/l) typical for small water bodies in the region. During high water periods in the summer the concentrations of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The water exchange index, which determines the concentration of mineral nutrients in the lake is 2, i.e. full water exchange in the lake takes about 2 years.

Hydrochemical properties	
pH	6.48 6.41-6.54
Electrical conductivity, mS/cm	39 39-39
Ca, mg/l	1.51 1.50-1.53
Mg, mg/l	0.71 0.70-0.72
Na, mg/l	3.91 3.91-3.91
K, mg/l	0.38 0.37-0.39
HCO_3, mg/l	1.4 0.2-2.6
SO_4, mg/l	4.28 4.13-4.43
Cl, mg/l	6.98 6.82-7.14
Total mineralization, mg/l	19.2 18.3-20.1
Alkalinity, μeq/l	23 3-43

Although the watershed area of the lake is relatively remote from the Pechenganikel smelter (34 km), emissions from the smelter do have an impact on it. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Co etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still influences the quality of the water body. Maximum Cu and Ni concentrations in the near-bottom water layer are 5.2 μg/l and 9.8 μg/l, respectively.

Water colour, deg.	11 10-11
NH_4, μg/l	9 1-17
NO_3, μg/l	5 1-8
Total N, μg/l	107 57-158
PO_4, μg/l	1 1-1
Total P, μg/l	5 4-5
Fe, μg/l	21 19-23

1.5.2. Lake bottom sediments

Cu, µg/l	3.7 2.2-5.2
Ni, µg/l	9.2 8.6-9.8
Al, µg/l	23 21-26
Pb, µg/l	0.20 0.19-0.21

The sediments of Lake Kjantejarvi are characterized by relatively low organic matter contents: the LOI value in the uppermost 1 cm layer is less than 20 % (Table 5). The lake is located at a distance of 33 km from the "Pechenganikel" smelter, and is exposed to the impacts of atmospheric pollution originating from the smelter. This is reflected as an increase in the concentrations of heavy metals (e.g. Ni and Co), and chalcophile elements (mainly Cd, Pb and Hg). The contamination factor values for these elements range from 2.0 to 6.4 (Table 5), i.e. the values correspond to moderate and considerable contamination. Co has the largest C_f value. The degree of contamination value (20.5) for this lake corresponds to considerable contamination.

Table 5. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (15-16 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Kjantejarvi	0-1	18.59	112	159	218	364.5	0.78	46.7	6.18	0.153	
	15-16	15.37	89	54	233	56.8	0.40	13.2	4.53	0.072	
C_f			**1.3**	**2.9**	**0.9**	**6.4**	**2.0**	**3.5**	**1.4**	**2.1**	**20.5**

1.5.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. Despite the absence of ichthyologic data, this lake is a typical salmonid (trout and arctic char) water body.

1.6. LAKE LN -2

Lake LN-2 (watershed of the River Kolosjoki) is located 6 km to the east of the town of Nikel. It is a small (the area of the lake is 0.11 km^2), shallow-water (maximum depth 6 m) elongated oval lake of glacial origin. The maximum length is 0.6 km, and maximum width 0.3 km. The point of maximum depth (6 m) is located in the central part of the lake.

According to the landscape type, the watershed area represents a combination of flat, low-lying areas of glaciolacustrine flatlands, with a height of up to 482 m. The shores of the lake are not high and are covered by peatland. The southern shore is waterlogged, with a cover of dwarf arctic birch and dwarf shrubs. The water of the lake is colourless but, during periods of high precipitation in the summer, the colour of water increases slightly.

Boulder beds are common in almost all parts of the littoral zone, and extend down to a depth of about 2-2.5 m. The gaps between the boulders are filled with silt.

1.6.1. Hydrochemistry

Physico-geographical characteristics	
Watershed	river — Lake Kuetsjarvi — River Paz
Latitude	69°25.454′
Longitude	30°23.747′
Height above sea level, m	210.0
Maximum length, km	0.6
Maximum width, km	0.3
Maximum depth, m	6
Area, m^2	0.11
Watershed area, km^2	2.5
Study period	2003-2007

The lake is, due to its close proximity to the Pechenganikel smelter, one of the most polluted lakes in the Pechenga area. Airborne industrial pollution has a major impact on the quality of the lake water.

The water of the lake is neutral, and its mean total mineralization 164.4 mg/l and mean alkalinity 174 µeq/l. During flood periods the pH falls to 6.73 and then increases back to 7.15, i.e. oxidation processes do not develop as a result of the buffering capacity of water. The lake is characterized by high concentrations of base cations and anions, with calcium (average 31.8 mg/l) and sulphate (average 105 mg/l) predominating.

The concentrations of most elements in the water, especially sulphate (up to 115 mg/l), and Cu and Ni, are currently at a high level.

The annual chemical cycle of the lake is characterized by no significant changes in total mineralization during the flood period and episodes of high precipitation, as well as during low-water periods (mainly in the autumn and winter) when the inflow of groundwater increases.

Hydrochemical properties	
pH	6.97 6.73-7.15
Electrical conductivity, mS/cm	252 229-268
Ca, mg/l	31.8 38.1-34.4
Mg, mg/l	8.77 8.06-9.68
Na, mg/l	3.71 3.05-4.00
K, mg/l	0.61 0.50-0.77
HCO_3, mg/l	10.7 7.6-13.4
SO_4, mg/l	105 96-115
Cl, mg/l	3.04 2.00-4.75
Total mineralization, mg/l	164 146-179
Alkalinity, µeq/l	174 124-220

The concentrations and relationships between mineral nutrient species vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, to the trophicity of the water body. The highest total P concentrations in the lake (up to 13 µg/l) typically occur during the summer, and they are 3 times higher than the concentrations during flood periods. The highest total N concentrations (up to 189 µg/l) also occur during the vegetation period.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values, organic matter concentrations (up to 4.9 mg/l) and Fe concentrations (mean 116 µg/l) are also typical of small water bodies in the region. The water exchange index is 4.3, i.e. full water exchange in the lake takes about 4 years. As the lake is not deep, the circulation of mineral nutrients in the water speeds up during the summer. During high water periods and episodes of high precipitation in the autumn, the concentrations of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The watershed of LN-2 is subjected to severe anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Cd, Cr, Zn, As, Hg etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has a considerable impact on the water body. Copper (up to 13 µg/l) and Ni (up to 340 µg/l) concentrations in the water bodies in the vicinity of the smelter are considerably higher than in other parts of the region.

Water colour, deg.	9 5-12
NH4, µg/l	8 2-27
NO3, µg/l	3 1-10
Total N, µg/l	138 95-189
PO4, µg/l	2 1-7
Total P, µg/l	5 2-13
Fe, µg/l	116 45-250

Cu, µg/l	9.8 6.7-13.0
Ni, µg/l	265 157-340
Al, µg/l	39 14-140
Pb, µg/l	0.3 0.1-1.1

1.6.2. Lake bottom sediments

The sediments of Lake LN-2 are characterized by relatively low organic matter contents: the LOI value in the uppermost 1 cm layer is less than 20% (Table 6). The lake is located at a distance of 8 km from the "Pechenganikel" smelter, and is subjected to severe airborne pollution comprising heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 4-5 cm layer of the lake sediments is heavily polluted by Ni, Cu and Co, as well as by chalcophile elements, originating from the smelter (Fig. 5). The factor values of these toxic elements range from 3.7 up to 36.7 (Table 6), i.e. they correspond to considerable and high contamination. Pb has the highest C_f value. The degree of contamination value (134.0) for this lake corresponds to high contamination, and it is one of most contaminated of the studied lakes.

Table 6. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (17-18 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
LN-2	0-1	17.92	1949	3535	108	123.1	0.93	8.8	31.80	2.890	
	17-18	21.40	53	214	121	26.2	0.25	1.0	4.29	0.052	
C_f			**36.7**	**16.5**	**0.9**	**4.7**	**3.7**	**8.4**	**7.4**	**55.6**	**134.0**

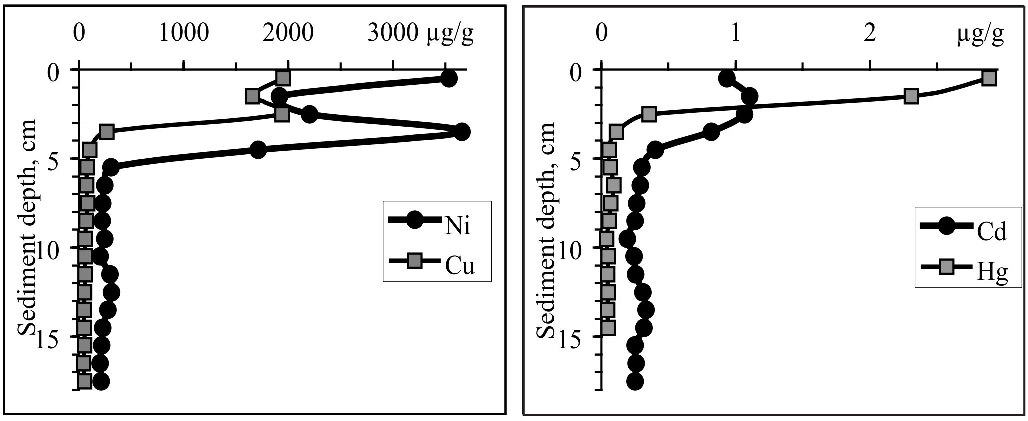


Fig. 5.
Vertical distribution of the concentrations of Ni, Cu, Cd and Hg (µg/g, dry weight) in the sediment core of Lake LN-2.

1.6.3. Hydrobiological studies

The most abundant groups of phytoplankton are diatoms and xantophyta (Sharov, 2004). According to earlier studies (Yakovlev et al., 1991), the lakes close to the "Pechenganikel" smelter have low biodiversity levels. The dominant species are chironomids, water-bugs and beetles. No fish are present in this lake.

1.7. LAKE LN-3.

Lake LN-3 (watershed of the River Kolosjoki) is located 14 km to the east of the town of Nikel, and 9 km to the west of the town of Zapolyarny. It is a small (area of the lake 0.05 km^2), shallow-water (maximum depth 7 m) round lake of glacial origin. The maximum length is 440 m, and maximum width 180 m. The point of maximum depth (7 m) is located in the central part of the lake.

According to the landscape type, the watershed area belongs to the tundra zone with heights extending up to 320 m. The lake shores are not high and are rocky. The water of the lake is colourless.

Boulder beds are present in almost all parts of the littoral zone, and extend down to a depth of about 2-2.5 m. The gaps between the boulders are filled with pebbles.

1.7.1. Hydrochemistry

Physico-geographical characteristics	
Watershed	River Kolosjoki—Lake Kuetsjarv—River Paz
Latitude	69°26.224′
Longitude	30°34.911′
Height above sea level, m	280.0
Maximum length, km	0.44
Maximum width, km	0.18
Maximum depth, m	7
Area, m^2	0.05
Watershed area, km^2	0.61
Study period	2003-2007

The lake is one of the most polluted lakes in the Pechenga area, due to its vicinity to the "Pechenganikel" smelter. Airborne industrial pollution has a major impact on the water quality.

The water of the lake is neutral and the mean total mineralization 29.5 mg/l and mean alkalinity 109 µeq/l. During flood periods the pH of the water falls to 6.56 and then rises back to 6.99, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has high concentrations of base cations and anions, calcium (average 4.8 mg/l) and sulphate (average 10.1mg/l) predominating.

The annual chemical cycle of the lake is characterized by no significant changes in the total mineralization of the water during flood periods and episodes of high precipitations, and during low-water periods (mainly in the winter and autumn) and when the inflow of groundwater increases.

The composition and relationships between mineral nutrient species vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest total P concentration in the lake (up to 11 µg/l) typical occurs during the summer, and the total P concentration is 1.5-2 times higher than during flood periods. The highest total N concentrations (up to 381 µg/l) also typically occur during the vegetation period.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The lake also has colour values, and organic matter (up to 4.6 mg/l) and Fe concentrations (mean 93 µg/l) typical of the small water bodies in this region. The water exchange index is 1.5, i.e. full water exchange in the lake takes about one year and a half. As the lake is not deep, the circulation of mineral nutrients in the water is faster during the summer. During flood periods and high precipitation episodes in the autumn, the concentrations of mineral nutrient species (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The watershed of lake LN-3 is subjected to severe anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Cd, Cr, Zn, As, Hg etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has a considerable impact on the water body. Copper (up to 26.5 µg/l) and Ni (up to 150 µg/l) concentrations in the vicinity of the smelter are substantially higher than in other parts of the region.

Hydrochemical properties	
pH	6.75 6.56-6.99
Electrical conductivity, mS/cm	50 46-55
Ca, mg/l	4.8 4.2-5.7
Mg, mg/l	0.90 0.80-1.03
Na, mg/l	2.62 2.42-2.87
K, mg/l	0.30 0.19-0.58
HCO_3, mg/l	6.7 4.9-8.0
SO_4, mg/l	10.1 8.65-10.4
Cl, mg/l	4.14 3.45-4.95
Total mineralization, mg/l	29.5 26.9-32.8
Alkalinity, µeq/l	109 81-131

Water colour, deg.	4 2-5
NH_4, µg/l	12 1-53
NO_3, µg/l	7 1-36
Total N, µg/l	187 131-381
PO4, µg/l	1 1-2
Total P, µg/l	6 2-11
Fe, µg/l	93 37-230

Cu, µg/l	13.6 7.90-26.5
Ni, µg/l	111 76-159
Al, µg/l	12 4.5-36
Pb, µg/l	0.3 0.1-0.7

1.7.2. Lake bottom sediments

The sediments of Lake LN-3 have relatively high organic matter contents, with LOI values for the whole sediment core of more than 35% (Table 7). The lake is located at a distance of 9 km from the smelter, and subjected to significant airborne pollution of heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 3-4 cm of the lake sediments are the most strongly polluted by Ni, Cu and Co, and the top 5-6 cm also by chalcophile elements (Fig. 6), i.e. pollution by these very toxic elements has begun at an earlier date. The contamination factor values for these toxic elements range from 3.2 up to 36.2 (Table 7), which correspond to considerable and high contamination. Hg (one of the most toxic and dangerous elements for hydrobionts) has the largest C_f value. The degree of contamination value (99.8) for this lake corresponds to high contamination.

Table 7. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (30-31 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
LN-3	0-1	36.61	81	103	72	10.6	0.30	10.4	32.40	0.362	
	30-31	36.56	22	13	54	3.3	0.05	0.7	1.16	0.010	
C_f			**3.6**	**7.8**	**1.3**	**3.2**	**5.5**	**14.3**	**27.9**	**36.2**	**99.8**

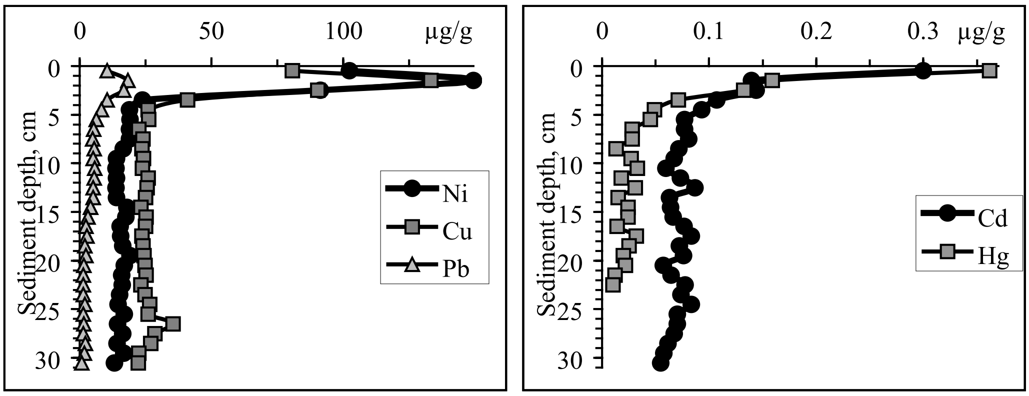


Fig. 6. *Vertical distribution of the concentrations of Ni, Cu, Pb, Cd and Hg (µg/g, dry weight) in the sediment core of Lake LN-3.*

1.7.3. Hydrobiological studies

Lake LN-2 LN-3 has low biodiversity levels. The dominant species are chironomids, water-bugs and beetles. No fish are present in this lake.

1.8. LAKE NJASJUKKAJARVI

Lake Njasjukkajarvi (watershed of the river Pechenga) is located 5 km to the west of the settlement of Pechenga and 3 km to the east of the Russian-Norwegian border. An earth road passes by along the lake to the coast of the Barents Sea. It is a rather large (area of the lake 9.5 km^2), shallow-water (maximum depth 7 m) elongated oval lake of glacial origin. The maximum length is 6.2 km and maximum width 2.6 km. The point of maximum depth (6 m) is located in the central part of the lake. The River Njasukkjajoki flows out of the lake.

According to the landscape type, the watershed area belongs to the forest-tundra zone with heights of up to 292 m (Selkjatunturi fell). The eastern shore of the lake is high and covered by shrubs and birch forest. The watershed area is waterlogged in the south. The water in the lake is colourless.

There are some boulder beds and sandy beaches in the littoral zone. The gaps between the boulders are filled with sand and pebbles.

Physico-geographical characteristics	
Watershed	River Njasukjajokki —River Pechenga
Latitude	69°33.939′
Longitude	31°02.151′
Height above sea level, m	65.8
Maximum length, km	6.2
Maximum width, km	2.6
Maximum depth, m	7
Area, m^2	9.5
Watershed area, km^2	98.0
Study period	2004

1.8.1. Hydrochemistry

The water of the lake is neutral, and is characterized by low total mineralization values (average 26.2 mg/l) and alkalinity (average 120). The lake has low concentrations of base cations and anions, sodium (average 4.08 mg/l) and bicarbonate (average 7.4 mg/l) predominating.

Based on the concentrations of mineral nutrients, the lake is oligotrophic. The concentration of total P is 4 µg/l and total N – 120 µg/l. The lake also has colour values, organic matter concentrations (up to 4.3 mg/l) and Fe concentrations (mean 31 µg/l) typical of small water bodies in the region. During high water periods in the summer the concentrations of mineral nutrient species (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Hydrochemical properties	
pH	6.97 6.94-6.99
Electrical conductivity, mS/cm	43 42-44
Ca, mg/l	2.22 2.15-2.29
Mg, mg/l	1.16 1.16-1.16
Na, mg/l	4.08 4.04-4.13
K, mg/l	0.55 0.54-0.57
HCO_3, mg/l	7.4 7.3-7.4
SO_4, mg/l	4.8 4.7-4.9
Cl, mg/l	6.39 6.22-6.55
Total mineralization, mg/l	26.6 26.2-27.0
Alkalinity, µeq/l	121 120-121

The water exchange index, which determines the concentrations of mineral nutrients in the lake is 1,8, i.e. full water exchange in the lake takes about 2 years. The bottom of the lake is covered with a thick layer of silt, which consists of undecomposed zooplankton debris and organic matter. These properties are of primary importance for the feeding of ichthyofauna. The conditions for the growth of food organisms are obviously highly favourable.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Njasjukkajarvi is relatively distant from the Pechenganikel smelter (20 km), it is subjected to anthropogenic impacts. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co etc.) In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. The average Cu and Ni concentrations are 3.8 μg/l and 12 μg/l, respectively

Water colour, deg.	15 14-15
NH_4, μg/l	7 4-10
NO_3, μg/l	7 7-7
Total N, μg/l	102 91-114
PO4, μg/l	1 1-1
Total P, μg/l	4 4-4
Fe, μg/l	31 24-39

Cu, μg/l	3.8 3.4-4.3
Ni, μg/l	12.2 12.2-12.2
Al, μg/l	27 25-28
Pb, μg/l	0.17 0.15-0.20

1.8.2. Lake bottom sediments

The sediments of Lake Njasjukkajarvi have relatively low organic matter contents: the LOI value in the surface 1 cm layer is less than 20% (Table 8). The lake is located at a distance of 20 km from the smelter, and is subjected to airborne pollution from the smelter that primarily consists of heavy metals (Ni, Cu, Co) and chalcophile elements (mainly Cd, As and Hg). The contamination factor values for these toxic elements range from 1.6 to 3.9 (Table 8), i.e. the values correspond to moderate and considerable contamination. Copper has the highest C_f value. The degree of contamination value (16.5) for this lake corresponds to considerable contamination.

Table 8.
The organic matter contents (LOI, %) and heavy metal concentrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Njasjukkajarvi	0-1	18.23	131	141	101	37.0	0.11	3.0	7.26	0.023	
	14-15	8.34	33	41	101	16.3	0.07	3.2	4.57	0.014	
C_f			**3.9**	**3.4**	**1.0**	**2.3**	**1.7**	**0.9**	**1.6**	**1.7**	**16.5**

1.8.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. The fish fauna in Lake Njasjukkajarvi is characterised by species such as trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*).

1.9. LAKE PALOJARVI

Lake Palojarvi (watershed of the River Pechenga) is located 6 km from the Russian-Norwegian border and 4 km to the north of the town of Zapolyarny, and is a source of drinking water for the local inhabitants. It is a small (area of the lake 2.76 km^2), shallow-water (maximum depth 5 m), almost oval lake of glacial origin. The maximum length is 2.8 km and maximum width 2.2 km. The points of maximum depths (5 m) occur throughout the whole water body.

The lake belongs to the Paz lake-river system, and is connected to the system by a small stream. According to the landscape type, the watershed area consists of a combination of flat low-lying areas of glaciolacustrine flat lands and tectonic massifs with abrupt outcrops of quaternary deposits, with a height of up to 371.6 m (Maatunturi fell). The shores of the lake are not high, and are covered by birch stands. The water of the lake is colourless but, during flood periods, the colour of water increases to 38 deg. and becomes slightly yellowish.

Boulder beds and mudflats occur in the littoral zone. Dark brown silt deposits are predominant throughout the whole area of the lake.

Physico-geographical characteristics	
Watershed	River Namajoki—River Pechenga
Latitude	69°27.076′
Longitude	30°45.356′
Height above sea level, m	155.6
Maximum length, km	2.8
Maximum width, km	2.2
Maximum depth, m	5
Area, m^2	2.76
Watershed area, km^2	86.0
Study period	1990-2007

1.9.1. Hydrochemistry

The lake is one of the most polluted lakes in the Pechenga area owing to its close proximity to the Pechenganikel smelter. Airborne pollution has a considerable impact on the water quality.

The water of the lake is close to neutral and the mean total mineralization is 27.0 mg/l and mean alkalinity 141 µeq/l. During flood periods the pH of the water falls to 6.39 and then returns to 6.97. The lake has high concentrations of base cations and anions, calcium (average 3.15 mg/l) and bicarbonate (average 8.6 mg/l) predominating.

Intensive pollution of the lake occurred during the late 1980s to early 1990s when emissions from the smelter were at peak levels. At that time the concentrations of most elements in the water, especially sulphate (up to 8.84 mg/l), Cu and Ni, also reached their maximum. The concentrations of these elements, as well as other elements that characterize the state of the water, are currently still high.

The annual chemical cycle of the

Hydrochemical properties	
pH	6.71 6.39-6.97
Electrical conductivity, mS/cm	43 39-58
Ca, mg/l	3.15 2.62-4.19
Mg, mg/l	1.21 1.06-1.67
Na, mg/l	2.95 2.61-3.73
K, mg/l	0.43 0.36-0.59
HCO_3, mg/l	8.6 7.0-12.3
SO_4, mg/l	6.49 5.46-9.60
Cl, mg/l	4.19 3.56-5.67
Total mineralization, mg/l	27.0 23.1-37.4

lake is characterised by a reduction in the total mineralization to 23.1 mg/l and fall in pH during flood periods and episodes of high precipitation. During low-water periods, mainly in the autumn and winter, and when the inflow of ground water increases, the total mineralization of the water increases slightly to 37.4 mg/l, the oxidizability is reduced and the pH rises.

The concentrations and relationships between species of mineral nutrients vary according to the season, and the dynamics is to a greater degree determined by the level of production and, consequently, the trophicity of the water body. The highest total P concentration (up to 17 μg/l) typically occurs during flood periods, when it is 2-3 times higher than the total P concentrations during low-water periods. The highest total N concentrations (to 340 μg/l) occur during the winter period.

According to the concentrations of mineral nutrients, the lake is classified as mezotrophic. The lake also has colour values and organic matter concentrations (up to 5.4 mg/l) typical of small water bodies in the region. The mean Fe concentration is 193 μg/l. The trophic type of the water body is to a considerable extent regulated by its close proximity to the town of Zapolyarny and the smelter. The water exchange index is 4.9, i.e. full water exchange in the lake takes about 5 years. The bottom of the lake is covered with a thick layer of silt, which consists of undecomposed organic matter debris.

Water colour, deg.	26 15-38
NH_4, μg/l	19 6-40
NO_3, μg/l	15 1-88
Total N, μg/l	200 116-340
PO_4, μg/l	2 1-2
Total P, μg/l	10 1-17
Fe, μg/l	193 30-500

The watershed of Lake Palojarvi is subjected to major anthropogenic impacts from the Pechenganikel smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Co etc.). SO_2 emissions from the smelter have caused the oxidation of surface water and the pollution of ground water owing to the leaching of elements from the surface soil. Maximum Cu (11 μg/l) and Ni (36 μg/l) concentrations were reported in the water in 1990s. Despite the reduction in emissions from the smelter, elevated Cu (up to 17.4 μg/l) and Ni (up to 62 μg/l) concentrations occurred throughout the study period.

Cu, μg/l	11.1 7.0-17.4
Ni, μg/l	40 25-62
Al, μg/l	26 14-47
Pb, μg/l	0.2 0.1-0.6

1.9.2. Lake bottom sediments

The sediments of Lake Palojarvi are characterized by relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is more than 65% (Table 9). The lake is located at a distance of 20 km from the Pechenganikel smelter and is subjected to high deposition of heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The contamination factor values of these toxic elements range from 2.3 to 36.3 (Table 9), i.e. the values correspond to considerable and high contamination.

Nickel has the highest C_f value. The degree of contamination value (82.6) for the lake corresponds to high contamination.

Table 9. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (19-20 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Palojarvi	0-1	67.87	867	1494	91	63.5	0.68	7.3	17.50	0.194	
	19-20	38.56	33	41	101	16.3	0.17	3.2	4.57	0.037	
C_f			**26.1**	**36.3**	**0.9**	**3.9**	**4.0**	**2.3**	**3.8**	**5.2**	**82.6**

1.9.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake, but it most probably contains fish species such as dwarf burbot (*Lota lota*) and perch (*Perca fluviatilis*).

1.10. LAKE PESCHANOE

Lake Peschanoe (watershed of the River Shunijoki) is located at a distance of 6 km from the town of Nikel. It is a small (area of the lake 1.04 km^2), shallow-water (maximum depth 5 m) round lake of glacial origin. The maximum length is 1.4 km, and maximum width 0.8 km. The point of maximum depth (5 m) is located in the central part of the lake.

According to the landscape type, the watershed area belongs to the tundra zone with a height of 555.3 m (Saraslaki fell). The lakeshores are not high, and are rocky and covered with shrubs and birch stands. There are also areas covered with grass and shrub vegetation. The water of the lake is colourless.

Boulder beds occur in almost all parts of the littoral zone, and extend down to depth of about 2-2.5 m. The gaps between the boulders are filled with pebbles.

Physico-geographical characteristics	
Watershed	River Shunijoki—Lake Kuetsjarvi—River Paz
Latitude	69°22.126′
Longitude	30°17.683′
Height above sea level, m	274.9
Maximum length, km	1.4
Maximum width, km	0.8
Maximum depth, m	5
Area, m^2	1.04
Watershed area, km^2	9.75
Study period	1990-2004

1.10.1. Hydrochemistry

The lake is one of the most polluted lakes in the Pechenga area owing to its close proximity to the Pechenganikel smelter. Airborne pollution has a major impact on the water quality.

The water of the lake is close to neutral and the mean total mineralization is 27.8 mg/l and mean alkalinity 182 µeq/l. The lake has high concentrations of base cations and anions, calcium (average 4.26 mg/l) and bicarbonate (average 11.1 mg/l) predominating.

Based on the concentrations of mineral nutrients, the lake is oligotrophic. The mean concentration of total P in the surface layer is 8 µg/l and of total N 146 µg/l. The lake also has colour values, organic matter concentrations (up to 2.9 mg/l) and Fe concentrations (mean 61 µg/l) typical of small water bodies in the region. The water exchange index is 1.66, i.e. full water exchange in the lake takes about one year and a half. During episodes of high precipitation in the summer the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The watershed of Lake Peschanoe is subjected to severe anthropogenic impacts from the Pechenganikel smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Cd, Cr, Zn, As, Hg etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. The concentrations of Cu (up to 9.6 µg/l) and Ni (up to 40 µg/l) in the vicinity of the smelter are substantially higher than in other parts of the region.

Hydrochemical properties	
pH	7.21 7.19-7.22
Electrical conductivity, mS/cm	42 40-44
Ca, mg/l	4.26 4.23-4.29
Mg, mg/l	0.80 0.78-0.83
Na, mg/l	1.97 1.95-2.00
K, mg/l	0.26 0.25-0.27
HCO_3, mg/l	11.1 11.0-11.2
SO_4, mg/l	7.04 7.03-7.05
Cl, mg/l	2.38 2.28-2.48

Water colour, deg.	8 8-8
NH_4, µg/l	16 9-23
NO_3, µg/l	1 1-1
Total N, µg/l	132 119-146
PO_4, µg/l	1 1-1
Total P, µg/l	7 7-8
Fe, µg/l	61 59-63

1.10.2. Lake bottom sediments

The sediments of Lake Peschanoe have relatively low organic matter contents: the LOI value in the uppermost 1 cm layer is slightly more than 20% (Table 10). The lake is located at a distance of 5 km from the smelter, and is subjected to severe airborne pollution of heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 3-4 cm layer of the lake sediments is the most heavily polluted by these toxic elements (Fig. 7). The contamination factor values for these elements range from 3.3 to 44.7 (Table 10), i.e. the values correspond to considerable and high contamination. Copper has the highest Cf value. The degree of contamination value (99.7) for this lake corresponds to high contamination.

Cu, µg/l	9.6 9.6-9.6
Ni, µg/l	40 40-40
Al, µg/l	11 11-11
Pb, µg/l	0.22 0.21-0.24

Table 10. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (13-14 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Peschanoe	0-1	22.85	733	270	96	49.3	0.73	15.2	19.8	0.199	
	13-14	18.23	16	18	51	7.5	0.08	1.5	5.99	0.023	
C_f			**44.7**	**15.3**	**1.9**	**6.5**	**9.1**	**10.3**	**3.3**	**8.6**	**99.7**

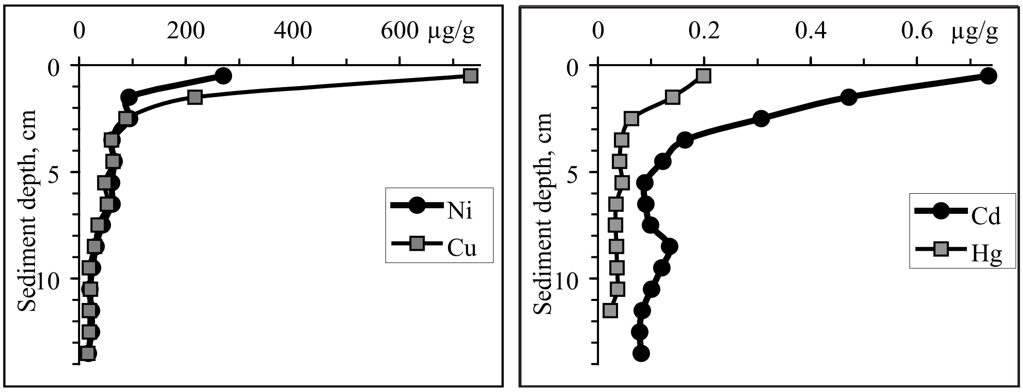


Fig. 7. *Vertical distribution of the concentrations of Ni, Cu, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Peschanoe.*

1.10.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. According to earlier studies (Yakovlev et al., 1991), the lakes near the "Pechenganikel" smelter have low biodiversity levels. The dominant species are chironomids, water-bugs and beetles. Dwarf burbot (Lota lota) should most probably also be present.

1.11. LAKE PIKKU-HEYNJAJARVI

Physico-geographical characteristics	
Watershed	River Pechenga
Latitude	69°23.552′
Longitude	31°12.491′
Height above sea level, m	191.0
Maximum length, km	0.9
Maximum width, km	0.42
Maximum depth, m	11
Area, m^2	0.28
Watershed area, km^2	12.5
Study period	2004

Lake Pikku-Heynjajarvi (watershed of the river Pechenga) is located 15 km to the east of the town of Zapolyarny and 17 km to the south of the settlement of Pechenga. It is a small (area of the lake 0.28 km^2), shallow-water (maximum depth 11 m), oval lake, elongated from the east to the west, and of glacial origin. The maximum length is 900 m and maximum width 420 m. The point of maximum depth (11 m) is located in the central part of the lake.

According to the landscape type, the watershed belongs to the forest-tundra zone with heights of up to 328.0 m (Kjalojarvi fell). The lake shores are high and rocky. The water in the lake is colourless. The summer military training ground of the settlement of Luostari is situated on the lake shore.

Boulder beds occur in almost all parts of the littoral zone, and extend down to a depth of about 2-2.5 m. The gaps between the boulders are filled with silt, sand and pebbles.

1.11.1. Hydrochemistry

The water of the lake is close to neutral and has low total mineralization values (average 15.8 mg/l) and alkalinity (average 53 μeq/l). The lake is characterized by low concentrations of base cations and anions, sodium (average 2.49 mg/l) and sulphate (average 3.8 mg/l) predominating.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The concentration of total P is 10 μg/l and of total N 163 μg/l. The lake also has colour values, organic matter concentration (6.0 mg/l) and mean Fe concentration (201 μg/l) typical of small water bodies in the region. During episodes of high precipitation in the summer the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The water exchange index, which determines the concentration of mineral nutrients in the lake is 3.8, i.e. full water exchange in the lake takes about three and a half years.

The watershed of Lake Pikku-Heynjajarvi is subjected to severe anthropogenic impacts from the “Pechenganikel” smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Co, etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. The concentrations of Cu (up to 4.3 μg/l) and Ni (up to 14.8 μg/l) are higher than in other parts of the region.

Hydrochemical properties	
pH	6.55 6.54-6.55
Electrical conductivity, mS/cm	29 28-29
Ca, mg/l	1.39 1.37-1.41
Mg, mg/l	0.76 0.76-0.76
Na, mg/l	2.49 2.47-2.52
K, mg/l	0.32 0.31-0.33
HCO_3, mg/l	3.3 3.2-3.3
SO_4, mg/l	3.85 3.85-3.85
Cl, mg/l	3.6 3.6-3.7
Total mineralization, mg/l	15.8 15.7-15.8
Alkalinity, μeq/l	54 53-54

Water colour, deg.	27 26-27
NH_4, μg/l	8 7-10
NO_3, μg/l	1 1-1
Total N, μg/l	159 155-163
PO_4, μg/l	1 1-1
Total P, μg/l	9 8-10
Fe, μg/l	201 197-206

Cu, μg/l	4.1 4.0-4.3
Ni, μg/l	14.5 14.2-14.8
Al, μg/l	76 72-81
Pb, μg/l	0.18 0.15-0.21

1.11.2. Lake bottom sediments

The sediments of Lake Pikku-Heynjajarvi have relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is more than 30% (Table 11). The lake is located at a distance of 13 km from the Pechenganikel smelter and is subjected to significant airborne pollution consisting of heavy metals (Ni, Cu, Co) and chalcophile elements (mainly Pb and Hg). The top 2-3 cm layer of the lake sediments is strongly polluted by these elements (Fig. 8). The contamination factor values for these toxic elements range from 2.6 to 17.8 (Table 11), i.e. the values correspond to considerable and high contamination. Nickel has the highest C_f value. The degree of contamination value (41.9) for this lake corresponds to high contamination.

Table 11. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Pikku-Heynjajarvi	0-1	32.42	194	350	101	45.1	0.24	14.8	7.26	0.157	
	14-15	21.49	29	20	137	17.4	0.25	1.6	5.06	0.061	
C_f			**6.6**	**17.8**	**0.7**	**2.6**	**0.9**	**9.2**	**1.4**	**2.6**	**41.9**

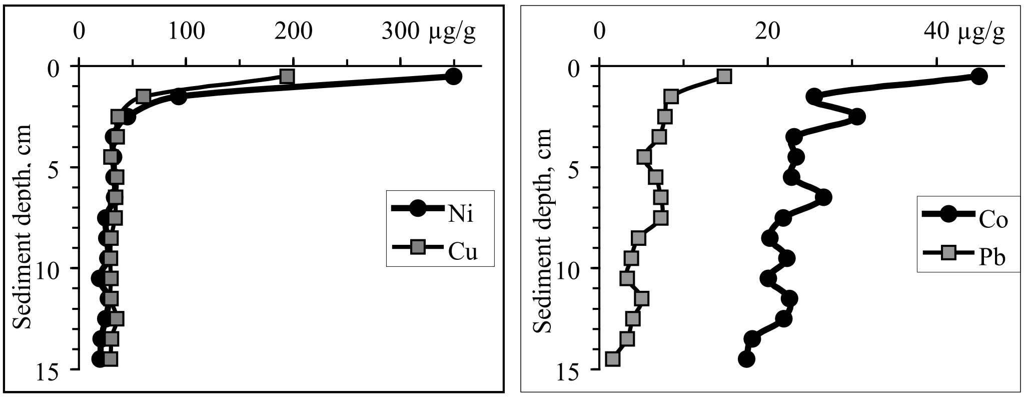


Fig. 8. *Vertical distribution of the concentrations of Ni, Cu, Co and Pb (µg/g, dry weight) in the sediment core of Lake Pikku-Heynjajarvi.*

1.11.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. The lake is most probably inhabited by pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), and nine-spine stickleback (*Pungitius pungitius*).

1.12. LAKE POROJARVI

Lake Porojarvi (watershed of the River Paz) is located 18 km to the south-west of the town of Nikel and 4 km from the Russian – Norwegian border, along the road to the settlement of Rajakoski. It is a small (area of the lake 4.34 km^2), relatively shallow (maximum depth 11.5 m), almost oval lake of glacial origin. The maximum length is 3.8 km and maximum width 2.0 km. The point of maximum depth is located in the central part of the lake.

Physico-geographical characteristics	
Watershed	River Menikkajoki—River Paz
Latitude	69°20.953′
Longitude	29°47.854′
Height above sea level, m	71.4
Maximum length, km	3.8
Maximum width, km	2.0
Maximum depth, m	11.5
Area, m^2	4.34
Watershed area, km^2	54.7
Study period	1989-2004

According to the landscape type, the watershed area belongs to the forest-tundra zone with a height of up to 206.8 m. The southern lake shore is waterlogged, and the northern shore is higher. Shrubs, birch and pine forests grow along the shoreline. The water of the lake is colourless but, during flood periods and episodes of high precipitation, the colour of the water increases to 34 de. There are some boulder beds in the littoral zone, and they extend down to a depth of about 2 – 2.5 m. The gaps between the boulders are filled with pebbles.

1.12.1. Hydrochemistry

The water of the lake is neutral and has higher total mineralization values (average 37.3 μg/l) and alkalinity (average 304 μeq/l) than the other lakes. During flood periods the pH of the water drops to 6.95 and then rises back to 7.38, i.e. oxidation processes do not develop. The lake does not have high concentrations of base cations and anions, but calcium (average 6.12 mg/l) and bicarbonate (average 18.6 mg/l) are predominant.

The annual chemical cycle of the lake is characterized by a significant reduction in the total mineralization, oxidizability and pH during flood periods and episodes of high precipitations when the inflow of humic water increases.

Hydrochemical properties	
pH	7.19 6.95-7.38
Electrical conductivity, mS/cm	50 46-56
Ca, mg/l	6.12 5.98-6.43
Mg, mg/l	0.94 0.88-1.11
Na, mg/l	1.91 1.71-2.23
K, mg/l	0.61 0.50-0.69
HCO_3, mg/l	18.6 17.4-19.8
SO_4, mg/l	6.7 4.9-12.6
Cl, mg/l	2.4 2.1-2.8
Total mineralization, mg/l	37.3 34.0-45.7
Alkalinity, μeq/l	304 285-325

Water colour, deg.	22 15-34
NH_4, μg/l	8 3-15
NO_3, μg/l	28 1-52
Total N, μg/l	190 139-267
PO_4, μg/l	1 1-2
Total P, μg/l	4 1-11
Fe, μg/l	23 16-26

Phosphorus and nitrogen concentrations if water are the main criteria of development of water eutrophication. The concentrations and relationships between these species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest concentrations of total P (up to 11 μg/l) and total N (up to 267 μg/l) occur during the vegetation period.

According to the concentrations of mineral nutrients, the lake is classified as eutrophic. The lake also has colour values, and organic matter (4.6 mg/l) and Fe concentrations (mean 23 μg/l) typical of small water bodies in the region.

The water exchange index is 0.95, i.e. full water exchange in the lake takes about 1 year. During flood periods and episodes of high precipitation in the autumn, the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

At the present time the watershed of Lake Porojarvi is subjected to relatively low anthropogenic impacts from the "Pechenganikel" smelter. However, the water system of the lake is exposed to pollutant emissions from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu etc.). In recent years there has a been a reduction in the deposition load, but higher concentrations of Ni (up to 11 μg/l) still occur during flood periods.

Cu, μg/l	2.4 2.0-3.1
Ni, μg/l	6.2 2.1-11.0
Al, μg/l	18 16-21
Pb, μg/l	0.27 0.09-0.45

1.12.2. Lake bottom sediments

The sediments of Lake Porojarvi have relatively low organic matter contents: the LOI value in the uppermost 1 cm layer is slightly more than 20% (Table 12). The lake is located at a distance of 20 km from the "Pechenganikel" smelter, and subjected to pollution by heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The uppermost 1-2 cm of the lake sediments are the most strongly polluted by Ni, Cu and Co. Pollution by chalcophile elements began earlier because they have accumulated especially in the top 5-6 cm layer (Fig. 9). The contamination factor values of these toxic elements range from 1.9 to 8.9 (Table 12), i.e. the values correspond to moderate to high contamination. Pb has the highest C_f value. The degree of contamination value (30.1) for this lake corresponds to considerable contamination.

Table 12. *The organic matter contents (LOI, %) and heavy metal concentrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (22-23 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Porojarvi	0-1	22.95	131	173	110	27.8	0.50	26.0	38.2	0.215	
	22-23	15.16	68	42	161	11.8	0.09	2.9	13.7	0.058	
C_f			**1.9**	**4.1**	**0.7**	**2.4**	**5.6**	**8.9**	**2.8**	**3.7**	**30.1**

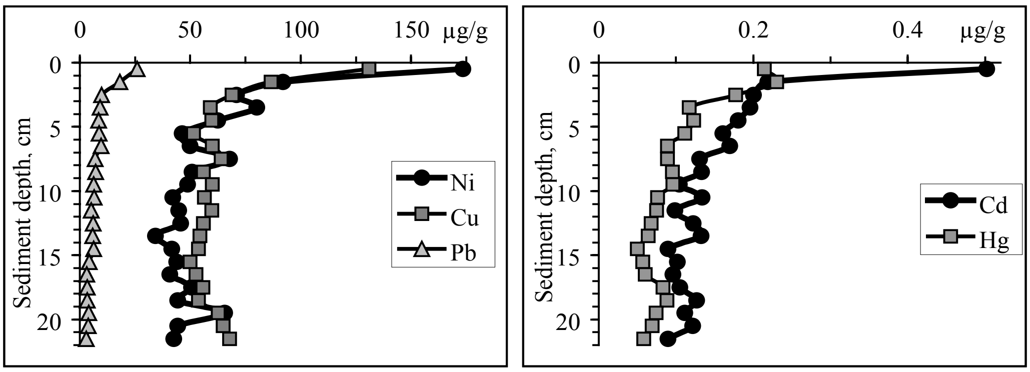


Fig. 9. *Vertical distribution of the concentrations of Ni, Cu, Pb, Cd and Hg (μg/g, dry weight) in the sediment core of Lake Porojarvi.*

1.12.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. Lake Porojarvi is typically populated by fish species such as trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*), and nine-spine stickleback (*Pungitius pungitius*).

1.13. LAKE SARIJARVI

Lake Sarijarvi (watershed of the River Pechenga) is located 15 km to the east of the town of Nikel and 7 km to the west of the town of Zapolyarny. It is a small (area of the lake 0.14 km_2), shallow-water (maximum depth 2 m) almost oval lake of glacial origin with an indented coastline The maximum length is 0.7 km and maximum width 0.3 km. The point of maximum depth (2 m) is located in the southern part of the lake. The Kola Ultra-deep Well is located 1.5 km from the lake.

According to the landscape type, the watershed area belongs to the tundra zone with heights of up to 517.5 m (Vilgiskoddeoajvi fell). The lake shores are not high, and are rocky and covered with grass and shrub vegetation. The water of the lake is colourless.

Boulder beds occur in almost parts of the littoral zone. The gaps between the boulders are filled with pebbles.

Physico-geographical characteristics	
Watershed	River Namajoki—River Pechenga
Latitude	69°24.590′
Longitude	30°37.484′
Height above sea level, m	318.0
Maximum length, km	0.7
Maximum width, km	0.3
Maximum depth, m	2
Area, m^2	0.14
Watershed area, km^2	12.5
Study period	2004-2005

1.13.1. Hydrochemistry

The lake is one of the most polluted lakes in the Pechenga area, due to its close proximity to the Pechenganikel smelter. Airborne pollution has a major impact on the water quality.

The water of the lake is neutral, and the mean total mineralization is 31.2 mg/l and mean alkalinity 151 µeq/l. The lake has relatively low concentrations of base cations and anions, with calcium (average 4.66 mg/l) and sulphate (average 11.3 mg/l) predominating.

Based on the concentrations of mineral nutrients, the lake is classified as mezotrophic. The concentration of total P in the surface horizon is 20 µg/l and

Hydrochemical properties	
pH	6.92 6.80-7.04
Electrical conductivity, mS/cm	50 49-50
Ca, mg/l	4.66 4.62-4.70
Mg, mg/l	1.19 1.16-1.22
Na, mg/l	2.14 2.08-2.21
K, mg/l	0.23 0.22-0.23
HCO_3, mg/l	9.2 8.7-9.8
SO_4, mg/l	11.3 11.0-11.7
Cl, mg/l	2.39 2.29-2.48
Total mineralization, mg/l	31.2 30.7-31.6
Alkalinity, µeq/l	151 142-160

of total N 112 µg/l. The colour values, and organic matter (2.8 mg/l) and Fe concentrations (mean 71 µg/l) of the lake water are typical of the small water bodies in the region. During episodes of high precipitation in the summer the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Water colour, deg.	5 5-5
NH_4, µg/l	22 16-28
NO_3, µg/l	5 4-5
Total N, µg/l	112 96-129
PO_4, µg/l	1 1-2
Total P, µg/l	14 7-20
Fe, µg/l	71 67-75

The watershed of Lake Sarijarvi is subjected to strong anthropogenic impacts from the "Pechenganikel" smelter. The main pollutants are sulphur compounds and heavy metals (Ni. Cu, Cd, Cr, Zn, As, Hg, etc.). In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. The concentrations of Cu (up to 4.5 µg/l) and Ni (up to 28.6 µg/l) in the vicinity of the smelter are substantially higher than in other parts of the region.

Cu, µg/l	4.5 4.4-4.5
Ni, µg/l	25 23-28
Al, µg/l	25 25-25
Pb, µg/l	0.3 0.3-0.4

1.13.2. Lake bottom sediments

The sediments of Lake Sarijarvi have relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is about 30% (Table 13). The lake is located at a distance of 6 km from the Pechenganikel smelter and subjected to high airborne pollution by heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 3-4 cm layer of the lake sediment is the most heavily polluted by Ni, Cu and Co, as well as by chalcophile elements (Fig. 10). This means that pollution by chalcophile elements started at the same time as the pollution by heavy metals emitted by the smelter. The contamination factor values for these toxic elements range from 4.8 to 43.2 (Table 13), i.e. the values correspond to considerable and high contamination. Nickel has the highest C_f value. The degree of contamination value (105.9) for this lake corresponds to high contamination.

Table 13. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Sarijarvi	0-1	28.05	540	1157	116	60.0	0.66	10.2	7.50	0.154	
	14-15	22.92	21	27	66	10.7	0.14	0.96	1.62	0.016	
C_f			**25.5**	**43.2**	**1.8**	**5.6**	**4.8**	**10.7**	**4.6**	**9.8**	**105.9**

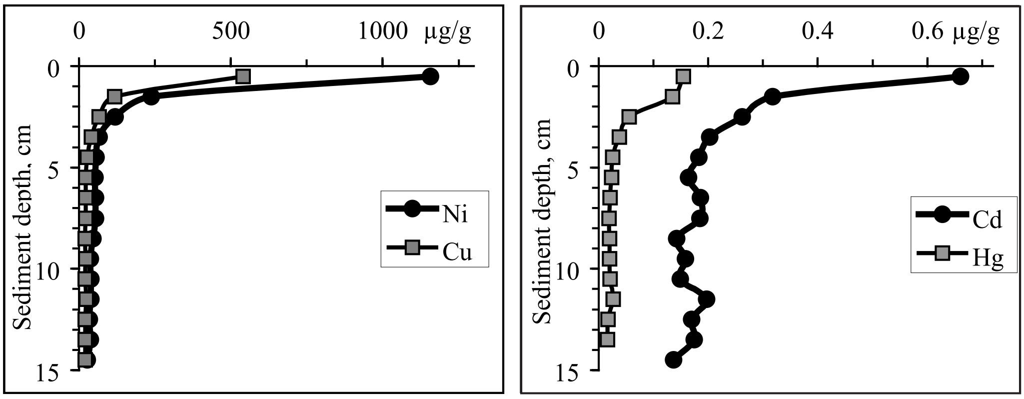


Fig. 10.
Vertical distribution of the concentrations of Ni, Cu, Cd and Hg (μg/g, dry weight) in the sediment core of Lake Sarijarvi.

1.13.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. According to earlier studies (Yakovlev et al., 1991), the lakes near the Pechenganikel smelter have low biodiversity levels. The dominant species are chironomids, water-bugs and beetles. The electrofishing surveys in 2004 and 2005 showed that burbot (*Lota lota*) was the most frequently caught species in some lakes near the towns of Nikel and Zapolyarny (Lappalainen et al., 2007).

1.14. LAKE TRIFONAJARVI

Lake Trifonajarvi (watershed of the Barents Sea) is located 2 km to the west of the settlement of Liinakhamari and 7 km to the north of the settlement of Pechenga.

The road to Liinakhamary passes along the side of the lake. It is a small (area of the lake 5.08 km^2), relatively deep-water (maximum depth 11 m) oval lake of glacial origin and with abrupt shores. The maximum length is 3.8 km and maximum width 2.0 km. The point of maximum depth is located in the central part of the lake. The River Trifonajoki flows out of the lake.

According to the landscape type, the watershed area belongs to the forest-tundra zone with heights of up to 253.4 m (Tyuristunturi fell). The lake shores are high and rocky, and in some parts covered with shrubs and birch stands. The water of the lake is colourless.

Boulder beds occur in almost all parts of the littoral zone. The gaps between the boulders are filled with pebbles.

Physico-geographical properties	
Watershed	Pechenga Bay—Barents Sea
Latitude	69°37.852′
Longitude	31°15.941′
Height above sea level, m	13.2
Maximum length, km	3.8
Maximum width, km	2.0
Maximum depth, m	11
Area, m^2	5.08
Watershed area, km^2	27.0
Study period	1991-2004

1.14.1. Hydrochemistry

The close proximity of the sea and presence of naval bases substantially influences the water quality of the lake. The water is neutral and has low total mineralization (mean 33.3 mg/l) and alkalinity (mean 93 μeq/l). During flood periods the pH of the water drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake is has low concentrations of base cations and anions, with sodium (average 6.49 mg/l) and chloride (average 10.7 mg/l) predominating.

The annual chemical cycle of the lake is characterized by an insignificant decrease in total mineralization, oxidizability and pH during flood periods and episodes of high precipitation when there is an increase in the inflow of humic water into the lake.

Hydrochemical properties	
pH	6.79 6.68-6.88
Electrical conductivity, mS/cm	59 54-65
Ca, mg/l	2.17 1.95-2.48
Mg, mg/l	1.28 1.16-1.45
Na, mg/l	6.49 6.10-7.07
K, mg/l	0.65 0.61-0.71
HCO_3, mg/l	5.7 4.8-6.1
SO_4, mg/l	6.2 4.7-8.2
Cl, mg/l	10.7 9.4-12.6
Total mineralization, mg/l	33.3 29.9-36.4
Alkalinity, μeq/l	93 79-100

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The concentration of total P is 5.5 μg/l and of total N 216 μg/l. The lake also has colour values, and organic matter (3.0 mg/l) and Fe concentrations (mean 50 μg/l) typical of small water bodies in the region. During episodes of high precipitation in the summer the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

The water exchange index, which regulates the concentrations of mineral nutrients in the lake, is 0.6, i.e. full water exchange in the lake takes about 6 months. The bottom of the lake is covered with a thick layer of silt, which consists of undecomposed zooplankton debris and organic matter. This is of primary importance for the feeding of ichthyofauna. Obviously, Conditions for the growth of food organisms are obviously highly favourable.

Water colour, deg.	12 8-23
NH_4, μg/l	11 4-23
NO_3, μg/l	16 3-44
Total N, μg/l	216 77-473
PO_4, μg/l	2 1-5
Total P, μg/l	5 3-8
Fe, μg/l	50 10-115

The low concentrations of micronutrients in the water body are related to the low rate of chemical weathering of the mineral material in the watershed. Although the watershed of Lake Njasjukkajarvi is relatively remote from the Pechenganikel smelter (28 km), it is still subjected to anthropogenic impacts. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.) In spite of the fact that emissions from the smelter have been reduced to approximately one third of the peak levels in the late 1970s, the deposition of pollutants still has an impact on the water body. The average Cu and Ni concentrations are 1.9 μg/l and 7.6 μg/l, respectively.

Cu, μg/l	1.9 1.1-2.6
Ni, μg/l	7.6 5.5-9.9
Al, μg/l	48 11-69
Pb, μg/l	0.38 0.21-0.50

1.14.2. Lake bottom sediments

The sediments of Lake Trifonajarvi have extremely low organic matter contents: the LOI value in the uppermost 1 cm layer is slightly more than 6% (Table 14). The lake is located at a distance of 27 km from the Pechenganikel smelter and is subjected to airborne pollution by heavy metals (Ni and Cu) and chalcophile elements (Pb, Cd and Hg). The top 3-4 cm of the lake sediments are the most strongly polluted by these elements (Fig. 11). The contamination factor values for these toxic elements range from 2.8 to 5.5 (Table 14), i.e. the values correspond to considerable contamination. The chalcophile elements, Pb and Hg, have the highest C_f values. The degree of contamination value (22.6) for this lake corresponds to considerable contamination.

Table 14.
The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (9-10 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Trifonajarvi	0-1	6.51	164	164	144	46	0.26	20.9	7.41	0.138	
	9-10	6.94	54	58	140	40	0.10	3.9	7.17	0.025	
C_f			**3.1**	**2.8**	**1.0**	**1.1**	**2.6**	**5.4**	**1.0**	**5.5**	**22.6**

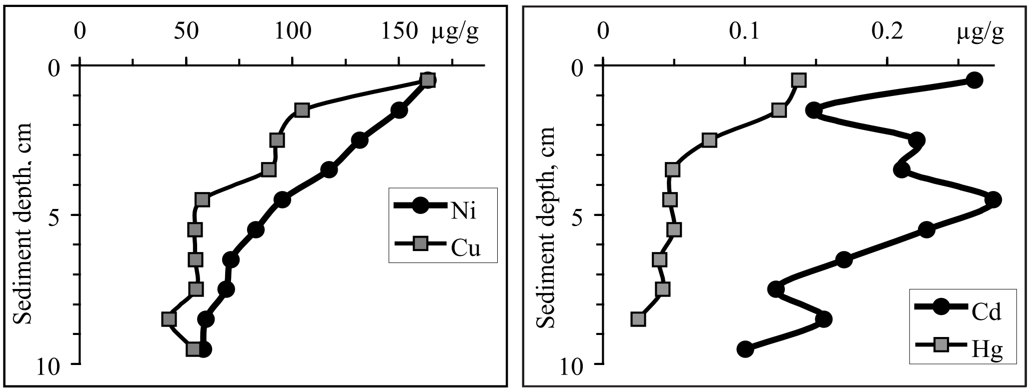


Fig. 11.
Vertical distribution of the concentrations of Ni, Cu, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Trifonajarvi.

1.14.3. Hydrobiological studies

According to earlier data (Yakovlev et al., 1991), the benthic fauna of this lake is relatively abundant and includes organisms of different systematic groups (amphipoda, chironomids, caddis flies, oligohaets and mayfly). The plankton community is represented by cladocera and copepods. Despite the absence of ichthyologic data, this lake is a typical salmonid (trout and arctic char) water body.

1.15. LAKE ALLA-AKKAJARVI

Lake Alla-Akkajarvi (watershed of the River Lotta) is located 44 km to the south of the town of Nikel. It is a relatively large (area of the lake is 19.88 km^2), not deep (max. depth 15 m) elongated lake of glacial origin. The maximum length is 14.6 km and maximum width 2.8 km. The deepest points in the lake are to be found in its western part. The lake is intensively used by inland water transport.

According to the landscape type, the watershed belongs to the tundra zone with heights of up to 288 m (Kuotesvarr fell). The northern shore of the lake is waterlogged. The southern shore is higher but, despite this, it is also waterlogged in places. Shrubs, and birch and pine stands grow along the shores. The water of the lake is yellowish and, during the flood period and episodes of high precipitation, the colour of the water increases to 44 deg. The shores are rocky. An uninhabited settlement (Prirechny), country houses and the slag heaps from an abandoned mine are located along its eastern shore.

Physico-geographical characteristics	
Watershed	River Akkim— River Lotta— River Tuloma
Latitude	69°00.987′
Longitude	30°15.884′
Height above sea level, m	154.5
Maximum length, km	14.6
Maximum width, km	2.8
Maximum depth, m	15
Area, m^2	19.88
Watershed area, km^2	315.0
Study period	1995-2007

1.15.1. Hydrochemistry

The water of the lake is close to neutral and has a low total mineralization (mean 18.1 mg/l) and alkalinity (mean 139 μeq/l). During the flood period the pH falls to 6.59 and then rises back to about 6.83, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 2.16 mg/l) and bicarbonate (average 8.5 mg/l) predominating.

The annual chemical cycle of the lake is characterized an insignificant decrease in mineralization, oxidizability and pH during flood periods and episodes of high precipitation when the inflow of humic water increases.

Hydrochemical properties	
pH	6.75 6.59-6.83
Electrical conductivity, mS/cm	28 23-33
Ca, mg/l	2.16 1.76-2.43
Mg, mg/l	0.88 0.74-1.05
Na, mg/l	1.52 1.31-1.74
K, mg/l	0.50 0.41-0.59
HCO_3, mg/l	8.5 6.5-10.7
SO_4, mg/l	2.96 2.51-3.81
Cl, mg/l	1.51 1.17-2.00
Total mineralization, mg/l	18.1 15.2-21.2
Alkalinity, μeq/l	139 106-175

The P and N concentrations in water are the main criteria used for assessing the development of water eutrophication. The concentrations and relationships between the species of these mineral nutrients vary according to the season, and the dynamics is to a greater extent regulated by the level of production and, consequently, the trophicity of the water body. The highest concentration of total P in the lake (up to 22 µg/l) and of total N (up to 311 µg/l) are typical for the vegetation period.

According to the concentrations of mineral nutrients, the lake is classified as eutrophic. The lake also has colour values, and organic matter (7.4 mg/l) and Fe concentrations (mean 176 µg/l) typical for water bodies in the region.

Water colour, deg.	31 18-44
NH_4, µg/l	20 2-103
NO_3, µg/l	2 1-5
Total N, µg/l	216 161-311
PO_4, µg/l	2 1-10
Total P, µg/l	11 4-22
Fe, µg/l	176 98-360

The water exchange index, which regulates the concentration of mineral nutrients in the lake, is 0.82, i.e. full water exchange in the lake takes about 1 year. During flood periods and episodes of high precipitation in the autumn, the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Cu, µg/l	2.0 0.9-4.5
Ni, µg/l	17.2 3.6-41.4
Al, µg/l	45 11-139
Pb, µg/l	0.67 0.01-2.37

The maximum pollution of the lake occurred in the middle of the 20th century, when the mine near the settlement of Prirechny was operating. At the present time the watershed of Lake Alla-Akkajarvi is subjected to anthropogenic impacts from the Pechenganikel smelter. The water system of the lake is also subjected to the effect of the smelter emissions. The main pollutants are sulphur compounds and heavy metals (Ni. Cu etc.). Due to the substantial size of the watershed, the impact of reduced emissions still results in higher concentrations of Cu (up to 4.5 µg/l) and Ni (up to 41.4 µg/l) during periods of high water.

1.15.2. Lake bottom sediments

The sediments of Lake Alla-Akkajarvi have relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is 35% (Table 15). The lake is located at a distance of 45 km from the "Pechenganikel" smelter. The lake is affected by heavy metal (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg) in the form of airborne emissions from the smelter and effluent from the Cu-Ni mine. The top 3 cm layer of the lake sediments is the most polluted by Ni, Cu and Co. Pollution by chalcophile elements began earlier because the top 10 cm layer of the sediments is especially polluted by these elements (Fig. 12). The contamination factor values for these toxic elements range from 2.5 to 13.5 (Table 15), i.e. the values correspond to high and considerable contamination. The most toxic chalcophile element, Hg, has the highest C_f value. The contamination factor values for the other heavy metals correspond to moderate contamination. The degree of contamination value (72.7) for this lake corresponds to high contamination.

Table 15. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (26-27 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Alla-Akkajarvi	0-1	35.20	112	321	95	23.0	0.36	28.2	3.83	0.134	
	26-27	29.48	12	12	103	9.0	0.05	2.6	1.86	0.010	
C_f			**9.4**	**27.0**	**0.9**	**2.5**	**6.6**	**10.7**	**2.1**	**13.5**	**72.7**

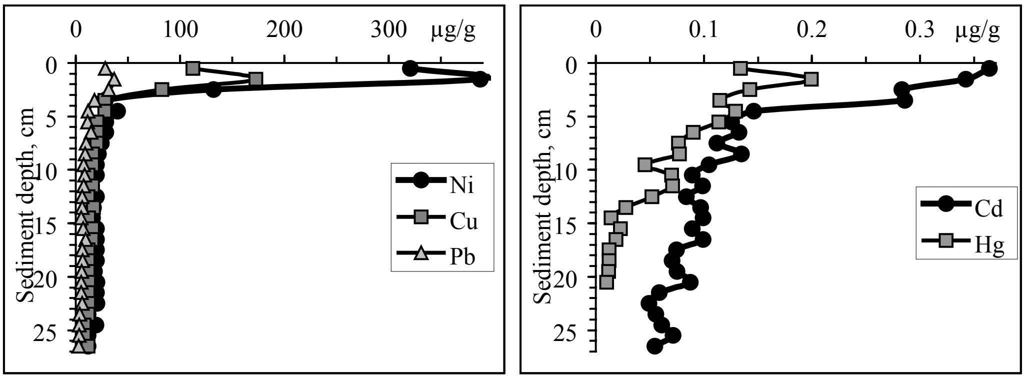


Fig. 12. *Vertical distribution of the concentrations of Ni, Cu, Pb, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Alla-Akkajarvi.*

1.15.3. Hydrobiological studies

No direct hydrobiological investigations have been carried out in this lake. The typical fish fauna in Lake Alla-Akkajarvi are trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*).

1.16. LAKE KOCHEJAUR

Lake Kochejaur (watershed of the River Madsash – tributary of the River Lotta) is located 6 km from the Russian-Finnish border, 110 km to the south-west of the town of Nikel, and 15 km to the north of the "Lotta" border crossing point. It is a small (area of the lake 3.2 km^2), shallow-water (average depth 2 m, maximum depth 8 m), elongated (north to south) oval lake of glacial origin. The maximum length is 5.6 km and maximum width 1 km. The point of maximum depth (8 m) is located in the central part of the lake. In the northern and southern parts of the lake the maximum depths are small – only down to 4 m. The lake bay, adjoining the lake in the south, contains shallow water (1-2 m).

The lake belongs to the lake-river system of the River Madsash, which flows into and out of a small shallow-water stretch in the southern part of Lake Kochejaur. According to the landscape type, the watershed consists of a combination of flat low-lying areas of glaciolacustrine flatland, with denudation and denudation-tectonic massifs with abrupt outcrops of quaternary deposits reaching to a height of 187 m. The lake shores are high and covered with pine forest. Waterlogged shores with protrusions of dwarf arctic birch and dwarf shrubs occur in places. The bogginess coefficient is 14.8%. The water of the lake is colourless but, during high precipitation episodes in the summer, the colour of water increases to 32 deg. and becomes slightly yellowish.

Boulder beds occur in almost all parts of the littoral zone, and extend down to a depth of about 2-2.5 m. The gaps between the boulders are filled with pebbles. Dark green silt deposits are predominant at a depth of ca. 2-3 m.

Physico-geographical characteristics	
Watershed	River Madsash—River Lotta
Latitude	68°35.853′
Longitude	28°40.250′
Height above sea level, m	133.1
Maximum length, km	5.6
Maximum width, km	1.0
Maximum depth, m	8
Area, m^2	3.2
Watershed area, km^2	27.5
Study period	1989-2007

Hydrochemical properties	
pH	7.08 6.88-7.29
Electrical conductivity, mS/cm	30 28-41
Ca, mg/l	2.92 2.69-3.63
Mg, mg/l	1.02 0.89-1.35
Na, mg/l	1.39 1.26-1.88
K, mg/l	0.43 0.37-0.58
HCO_3, mg/l	12.9 11.8-16.5
SO_4, mg/l	2.75 2.04-6.40
Cl, mg/l	1.10 0.80-2.10
Total mineralization, mg/l	22.4 20.0-31.3
Alkalinity, µeq/l	212 193-270

1.16.1. Hydrochemistry

The water of the lake is neutral, close to the oxidation point; it is characterized by low total mineralization (average 22.4 mg/l) and alkalinity (average 212 µeq/l). During flood periods the pH of the water falls to 6.88 and then rises back to 7.13, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 2.92 mg/l) and bicarbonate (average 12.9 mg/l) predominating.

Intensive pollution of the lake occurred during the period of peak emissions from the Pechenganikel smelter in the late 1980s and early 1990s. At that time there were maximum concentrations of most elements, especially sulphate (up to 6.4 mg/l), Cu and Ni. At the present time, however, the concentrations of these elements, as well as of other elements that characterize the sate of the water body, are lower.

The annual chemical cycle of the lake is characterized by a reduction in total mineralization to 20 mg/l, an increase in the oxidizability and a drop in pH during the flood period and when high precipitation episodes result in an increased inflow of humic water into the lake. During low-water periods, which mainly occur in winter and autumn, and when the inflow of groundwater increases, the total mineralization increases slightly to 31.3 mg/l, the oxidizability is reduced and the pH rises.

The P and N concentrations of water are the main criteria used in assessing the development of water eutrophication. The concentrations and relationships between the species of these mineral nutrients vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest total P concentration in the lake (up to 12 µg/l) typically occurs in the summer, when it is 3 times higher than the concentrations during the flood period. The highest total N concentrations (up to 256 µg/l) occur during the vegetation period. In 1991, however, the maximum total N concentration was 583 µg/l; such a high concentration has subsequently not been recorded.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The lake also has colour values, and organic matter (up to 5.6 mg/l) and Fe concentrations (mean 54 µg/l) typical of small water bodies in the region. The trophic type of the water body is to a considerable degree determined by the location of the River Madsash in the hydrographic system. The water exchange index is 0.96, i.e. full water exchange in the lake takes about 1 year. Due to specific morphometric features, which determine the inflow and outflow in the southern part of the lake, the natural water exchange of the lake is actually slow. Because suspended particles are deposited more effectively, the bottom of the whole lake is covered with a thick layer of silt. The silt consists of undecomposed zooplankton debris and organic matter, which is of primary importance for the nutrition of whitefish species. The conditions for the growth of food organisms are obviously highly favourable. Because most of the lake is not deep, the circulation of mineral nutrients in the water is faster in the summer; this also increases the production capacity of the water body. During periods of high water and high precipitation episodes in the autumn, the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Water colour, deg.	20 11-32
NH_4, µg/l	7 1-23
NO_3, µg/l	4 1-38
Total N, µg/l	224 139-583
PO_4, µg/l	1 1-3
Total P, µg/l	5 1-14
Fe, µg/l	54 14-159

The low concentrations of micronutrients in the water indicate a low input to the water body from the chemical weathering of mineral material in the watershed. As noted above, peak emissions from the Pechenganikel smelter during the late 1980s and early 1990s resulted in high concentrations of Cu (18 µg/l) and Ni (3 µg/l) in the water. At the present time, airborne pollutant deposition results in a higher content of Cu (up to 3.4 µg/l) and Ni (up to 3.6 µg/l) during snow melt.

Cu, µg/l	1.70 0.20-18.0
Ni, µg/l	0.9 0.1-3.0
Al, µg/l	31 5-46
Pb, µg/l	0.3 0.1-0.8

1.16.2. Lake bottom sediments

The sediments of Lake Kochejaur have very high organic matter contents: the LOI value in the uppermost 1 cm layer is more than 50% (Table 16). This is due to the fact that the lake is relatively shallow and highly productive. The lake is located at a distance of 110 km from the Pechenganikel smelter. As a result, the lake is mainly subjected to pollution by chalciphile elements, such as Pb and Cd. The uppermost 5 cm of the lake sediments is the most heavily polluted (Fig. 13). The contamination factor values of these two elements are 14.1 and 3.9, respectively (Table 16), i.e. the values correspond to high and considerable contamination. The contamination factor values for other heavy metals correspond to moderate contamination. The degree of contamination value (26.3) for this lake corresponds to considerable contamination.

Table 16.
The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (18-19 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Kochejaur	0-1	51.96	16	25	84	10.3	0.62	25.4	2.60	0.016	
	18-19	41.44	16	20	69	8.8	0.16	1.8	1.13	0.012	
C_f			**1.0**	**1.3**	**1.2**	**1.2**	**3.9**	**14.1**	**2.3**	**1.4**	**26.3**

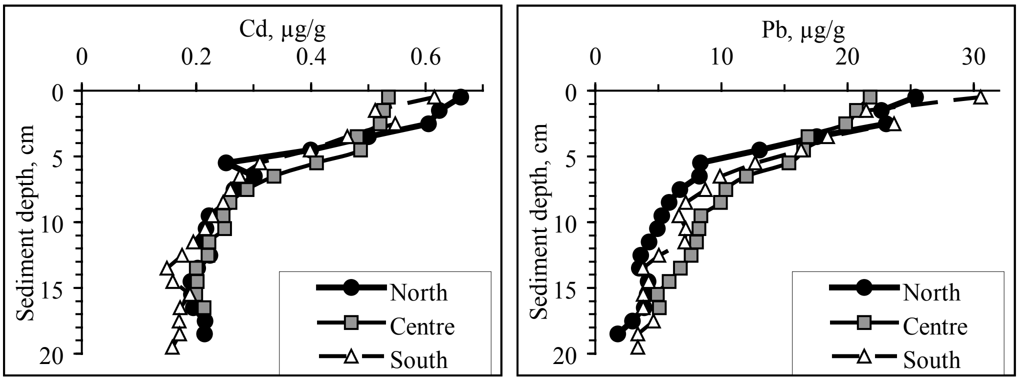


Fig. 13.
Vertical distribution of the concentrations of Cd and Pb (µg/g, dry weight) in sediments from the northern, central and southern parts of Lake Kochejaur.

1.16.3. Hydrobiological studies

Ichthyofauna. Studies on the fish community of Lake Kochejaur were conducted in 1990-1992, and in 2002 and 2005.

The Ichthyofauna of the lake consists of eight species belonging to eight fish families: trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus Thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*), and nine-spine stickleback (*Pungitius pungitius*). Overall, whitefish and perch are the dominant species in Lake Kochejaur (Fig.14). Pike, trout, grayling and burbot occur in isolated parts of the lake, and minnow and nine-spine stickleback in the littoral parts of the lake.

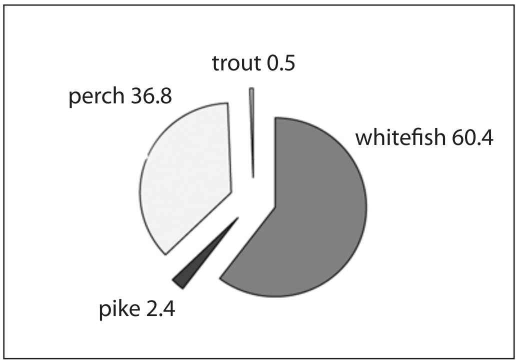


Fig. 14.
Distribution of fish species in Lake Kochejaur

Sparsely rakered whitefish are present in the lake (up to 30 gill rakers). The mean length varies from 24.5 to 29.6 cm, and mean weight from 258 to 323 g (Fig. 15). The maximum length can reach 56.5 cm and weight 2575 g. Fish with a weight up to 400 g and length 25-30 cm are the most numerous (Fig. 15). The age limit of whitefish is 17+, although specimens of younger age groups (1+) and specimens older than 10 years are occasionally caught (Fig. 16). The reason for the absence of young fish is the silting up of the water body and a lack of spawning areas. At the same time the lake provides favourable conditions for fish feeding. This is the reason for the feeding migration of whitefish from other water bodies and the irregular age distribution of the fish. The sex distribution of the fish is regular, with a slight predominance of females. Some individuals in this lake become mature at the age of 3. The weight and size of fish spawning for the first time do not exceed 71 g and 19.2 cm, respectively.

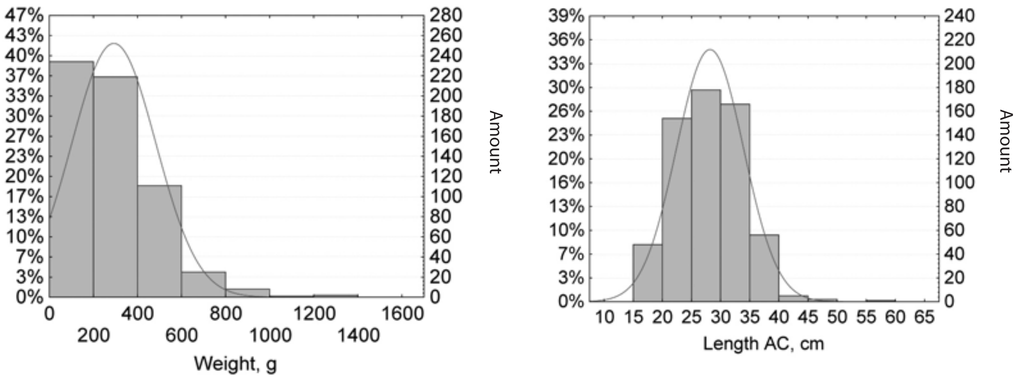


Fig. 15.
Size and weight distribution of the sparsely rakered whitefish in Lake Kochejaur.

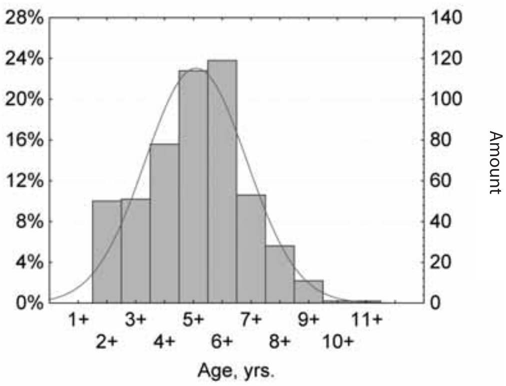


Fig. 16.
Age distribution of the sparsely rakered whitefish in Lake Kochejaur.

The size of some specimens of trout reaches 37.5 cm, with a weight of 617 g. The mean size and weight of pike do not exceed 42.4 cm and 591 g, respectively. Fish of age 5-7 years are the most abundant.

The mean size of perch inhabiting the lake is 37.5 cm, and the mean weight 276 g. However, fish can weigh over one kilogram (1380 g) and have a length of 43.3 cm. The bulk of the population consists of fish weighing less than 200 g with a length of 25-30 cm (Fig. 17). The age limit of perch in the lake is 14 years, but the fish of age class 5-6 years constitute the bulk of the population.

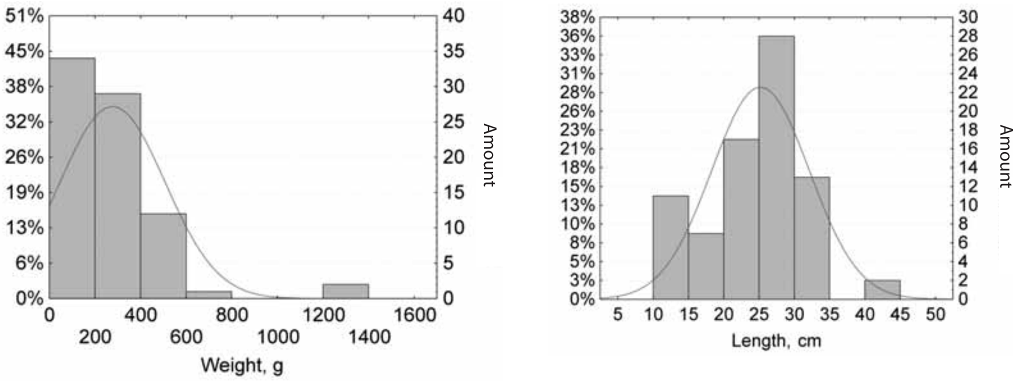


Fig. 17.
Size and weight distribution of perch in Lake Kochejaur.

Fish pathology
Despite the considerable remoteness of the lake from anthropogenic emission, the fish have pathological changes in their organs and tissues. The most frequently occurring pathologies of whitefish are pathologies of the liver (54 – 68 %), kidneys (54 – 75%) and reproductive organs (26 – 30%). The pathologies of whitefish organs are currently in the initial stage, and are mainly associated with changes of the colour of organs and fatty degenerations (pale liver); connective tissue expansions (kidneys and gonads); segmentation and asynchronous maturation of gonads. Gonad pathologies are the most typical for male specimens of perch; their gonads resemble in appearance a brain structure. Pathological changes in the fish may indicate airborne pollution of the water body.

Heavy metals in fish
The heavy metal (Cu, Ni, Pb) concentrations in fish muscle do not exceed the standard values (Table 17). However, the Hg concentrations in the muscles of perch are higher than the standards, and in trout they are very close to the standard values (Table 2). Copper concentrations (µg/g of wet weight) in the other organs of whitefish are higher than in the muscles: liver (up to 7.4 µg/g), kidneys (up to 4.3 µg/g), and gills (up to 0.5 µg/g). The same applies to Ni in liver (up to 0.2), kidneys (up to 0.4) and gills (up to 0.3).

Comparative analysis of metal accumulation in different fish species shows that Cu is more strongly accumulated in the liver of whitefish. The Ni concentrations in liver and Hg concentrations in muscles are higher than those in perch. Pike has the highest concentrations of Pb in muscles (Fig. 18). An upward trend in heavy metal concentrations in fish organs was observed throughout the study period, and this is related to airborne pollution of the water body.

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g dry weight)**
Whitefish			
Hg	0.5	0.12	0.55
Ni	0.5	0.23	1.10
Cu	20	0.17	0.79
Pb	1.0	0.01	0.07
Perch			
Hg	0.5	0.56	2.86
Ni	0.5	0.18	0.90
Cu	20.0	0.18	0.91
Pb	1.0	0.02	0.08
Pike			
Hg	0.5	0.29	1.41
Ni	0.5	0.15	0.73
Cu	20.0	0.32	1.56
Pb	1.0	0.04	0.20
Trout			
Hg	0.5	0.4	1.57
Ni	0.5	0.2	0.96
Cu	20.0	0.3	1.15
Pb	1.0	-	<0,05

* Source: Sanitary..., 1986.

Table 17.
Standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Kochejaur (in µg/g wet and dry weight).

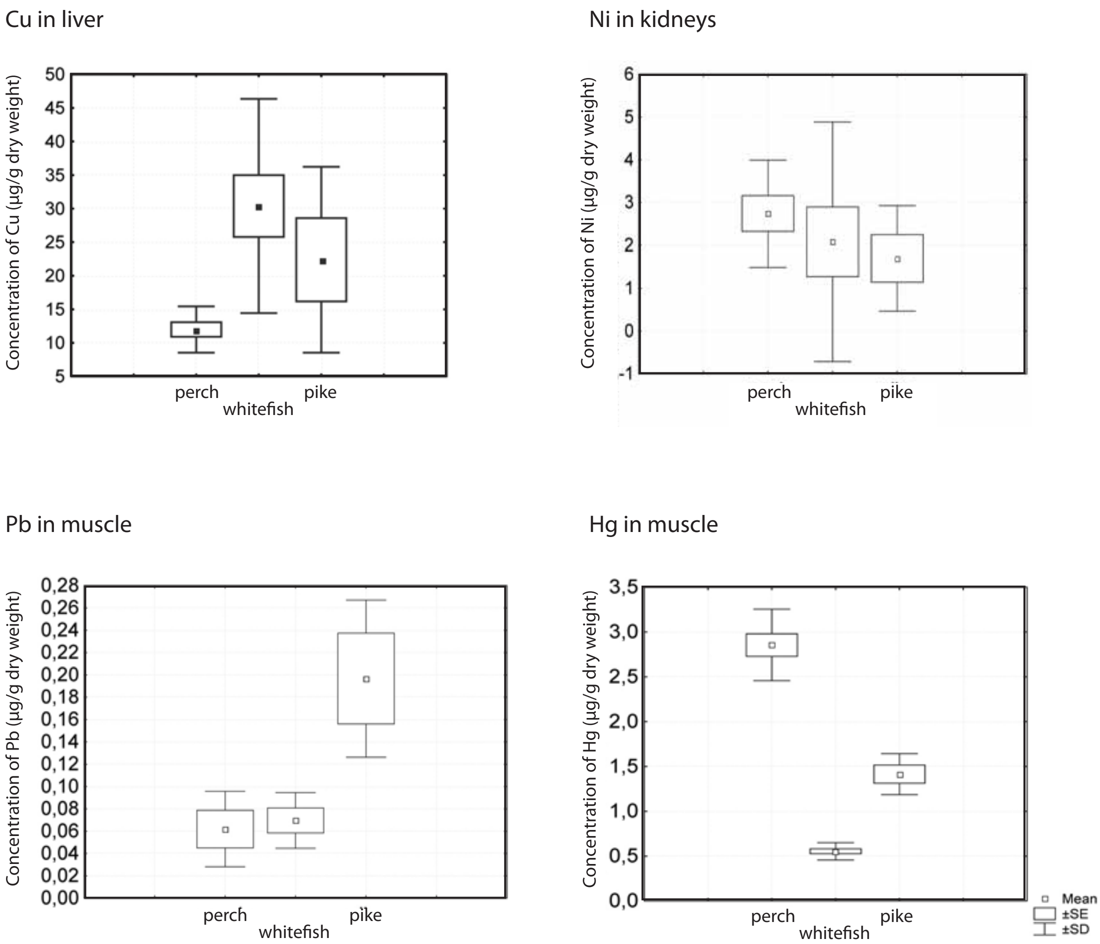


Fig. 18. *Accumulation of Cu (liver), Ni (kidneys), Pb and Hg (muscle) in fish from Lake Kochejaur (µg/g dry weight).*

1.17. LAKE VIRTUOVOSHJAUR

Lake Virtuovoshjaur (watershed of the River Puldshkash – tributary of theRriver Nautsijoki) is located 2.5 km from the Russian-Finnish border, 91 km to the south-west of the town of Nikel, and 35 km to the north of the “Lotta” border crossing point. It is a small (area of the lake 1.25 km^2), shallow-water (average depth 2-5 m, maximum depth 13 m), complex-shaped lake, close to oval with an indented coastline, and of glacial origin. The maximum length is 1.8 km, and maximum width 1 km. The points of maximum depth (13 m) are located in the northern and southern parts of the lake. In the centre of the lake the maximum depth is shallow – up to 2.5 m. A lake bay, which adjoins the lake through a stony channel in the southern part, has shallow water with a depth of 1-2 m and a length of 1.2 km.

The lake belongs to the lake-river system of the River Puldshkash, which originates in the south in Russia and then flows through a system of five lakes into Finland, and then flows back into Lake Puldshekjarvi in Russia. Lake Virtuovoshjaur is linked to Lake Puldshekjarvi by a small stream, which flows out of its northern border. According to the landscape type, the watershed consists of a combination of flat, low-lying depressions of glaciolacustrine flatland, and denudation and denudation-tectonic massifs with abrupt outcrops of quaternary deposits with a height up to 254 m and, in the south, up to 400.6 m (Konnostunturi fell). The lake shores are high, sometimes abrupt, and covered with pine forest. The south-eastern shores are waterlogged with intrusions of dwarf birch and dwarf shrubs. The water of the lake is colourless but, during episodes of high precipitation in the summer, the colour of water increases to 39 deg and becomes slightly yellowish.

There are some boulder beds and sandy beaches with a length of 40 m in the littoral zone. The boulder beds extend to a depth of about 2 m. The gaps between the boulders are filled with sand and pebbles. Dark green silt deposits are predominant at a depth of ca. 1.5-2.0 m.

Physico-geographical characteristics	
Watershed	River Puldshkash—River Nautsijoki—River Paz
Latitude	68°45.894′
Longitude	28°47.548′
Height above sea level, m	182.0
Maximum length, km	1.8
Maximum width, km	1.0
Maximum depth, m	13
Area, m^2	1.25
Watershed area, km^2	13.7
Study period	1989-2007

1.17.1. Hydrochemistry

The water of the lake is neutral, with a tendency to acidification; it has a low total mineralization (average 17.0 mg/l) and alkalinity (average 133 µeq/l). During flood periods the pH falls to 6.12 and then gradually rises back to 6.66. The lake has low concentrations of base cations and anions, with calcium (average 1.82 mg/l) and bicarbonate (average 8.2 mg/l) predominating.

Severe pollution of the lake occurred during the period of peak emissions from the Pechenganikel smelter in the late 1980s and early 1990s. Maximum concentrations of most elements were recorded, especially of sulphate (up to 6.9 mg/l), Cu and Ni. Currently the concentrations of these elements, as well as of other elements that characterize the state of the water, are lower.

The annual chemical cycle of the lake is characterized by a reduction in total mineralization to 12.9 mg/l, an increase in the oxidizability and a fall in pH during flood periods and episodes of high precipitation when the inflow of humic water increases. During low-water periods (mainly in the winter and autumn) and when the inflow of groundwater increases, the total mineralization increases slightly to 25.6 mg/l, the oxidizability drops and the pH increases.

Hydrochemical properties	
pH	6.66 6.12-6.96
Electrical conductivity, mS/cm	25 21-34
Ca, mg/l	1.82 1.37-2.51
Mg, mg/l	0.94 0.74-1.29
Na, mg/l	1.38 1.15-1.95
K, mg/l	0.37 0.30-0.52
HCO_3, mg/l	8.2 5.7-11.4
SO_4, mg/l	3.01 2.08-6.90
Cl, mg/l	1.26 0.83-2.28
Total mineralization, mg/l	17.0 12.9-25.6
Alkalinity, µeq/l	133 93-187

The P and N concentrations of water are the main criteria used for assessing the development of water eutrophication. The concentrations and relationships between the species of these mineral nutrients vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest concentrations of total P in the lake (up to 13 µg/l) typically occur in the summer and autumn, when the concentration is 2-3 times higher than during the flood period. The highest concentrations of total N (up to 349 µg/l) occur in the spring and beginning of summer. In 1991, however, the maximum total N concentration was 468 µg/l during the ice-coverperiod.

Based on the concentrations of mineral nutrients, the lake is classified as oligotrophic. The lake also has colour values, and organic matter (up to 6.6 mg/l) and Fe concentrations (mean 146 µg/l) typical of small water bodies in the region. The trophic type of the water body is to a considerable degree determined by the location of the River Puldshekjarvi in the hydrographic system: the lake belongs to a lake-river system of a small stream that flows into Lake Puldshekkjarvi. The water exchange index is 0.84, i.e. full water exchange in the lake takes about 8 months. As suspended particles are deposited more intensively in the lake, the bottom of the lake is completely covered with a thick layer of silt consisting of undecomposed zooplankton debris and organic matter. This is of primary importance for the feeding of whitefish species. The conditions for the growth of food organisms are obviously highly favourable. Due to the fact that most of the lake is not deep, the circulation of mineral nutrients in the water is faster in the summer; this also increases the production capacity of the water body. During high water periods and episodes of high precipitation in the autumn, the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Water colour, deg.	30 17-39
NH_4, µg/l	13 2-51
NO_3, µg/l	8 1-42
Total N, µg/l	241 165-468
PO_4, µg/l	2 1-4
Total P, µg/l	6 1-13
Fe, µg/l	146 16-460

The low concentrations of micronutrients in the water indicate a low input to the water body from the chemical weathering of mineral material in the watershed. During the period of peak emissions from the smelter in the late 1980s and early 1990s, the Ni and Cu concentrations in the lake water were not excessively high. At the present time, however, airborne pollution results in higher concentrations of Cu (up to 3.4 µg/l) and Ni (up to 3.6 µg/l) during the open-water period. Because of the relatively small area of the watershed area, the Cu and Ni concentrations do not increase during snowmelt and periods of high water. When the water is acidified during flood periods, the concentrations of Al (up to 82 µg/l) and Mn (up to 80 µg/l) increase as a result of dissolution and weathering of the soil in the watershed.

Cu, µg/l	1.2 0.5-3.4
Ni, µg/l	1.2 0.5-3.6
Al, µg/l	52 12-82
Mn, µg/l	14.3 1.0-80.0
Pb, µg/l	0.4 0.1-1.2

1.17.2. Lake bottom sediments

The sediments of Lake Virtuovoshjaur have relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is 40% (Table 18) owing to the high productivity of the lake. The lake is located at a distance of 90 km from the Pechenganikel smelter, and is mainly subjected to pollution mainly by chalcophile elements

(Pb, As, Cd and Hg). The top 5-7 cm layer of the lake sediments is the most polluted by these elements (Fig. 19). The contamination factor values for these toxic elements range from 2.3 to 29.1 (Table 18), i.e. the values correspond to high and considerable contamination. The most toxic of the four chalcophile elements, Hg, has the highest C_f value. The contamination factor values of the other heavy metals are moderate. The degree of contamination value (44.6) for this lake corresponds to high contamination.

Table 18. *The organic matter contents (LOI, %) and heavy metal concnetrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (16-17 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Virtuovoshjaur	0-1	39.92	23	25	56	9.0	0.30	26.9	2.33	0.083	
	16-17	36.43	18	19	83	11.6	0.08	4.9	1.02	0.003	
C_f			**1.3**	**1.4**	**0.7**	**0.8**	**3.7**	**5.5**	**2.3**	**29.1**	**44.6**

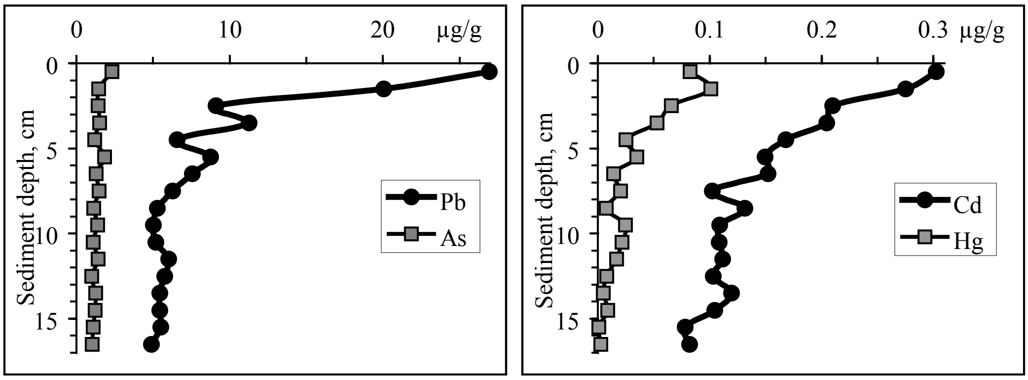


Fig. 19. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Virtuovoshjaur.*

1.17.3. Hydrobiological studies

Ichthyofauna. Studies were conducted on the fish community in Lake Virtuovoshjaur in 1992 and 2005.

The Ichthyofauna of the lake consists of seven species belonging to seven fish families: whitefish (*Coregonus lavaretus*), grayling (*Thumallus Thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*). Overall, whitefish and perch predominate in Lake Virtuovoshjaur (Fig. 20). Pike, trout, grayling and burbot are occasionally caught, and minnow and nine-spine stickleback in the littoral parts of the lake.

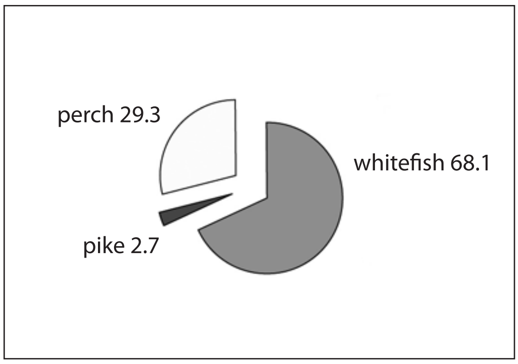


Fig. 20. *Distribution of fish species in Lake Virtuovoshjaur.*

Sparsely rakered whitefish is present in the lake (up to 30 gill rakers). Its mean length is 19.6 cm, and weight 94 g (Fig. 21). Whitefish can reach a maximum length of 38 cm and maximum weight 714 g. Fish with a weight to 100 g and length 16-20 cm are the most numerous (Fig. 21). The age limit of the whitefish is 9+: 3-year old specimens predominate and fish older than 7 years are only occasionally caught (Fig.

22). The sex distribution of the fish is regular, with a slight predominance of males. Some individuals in the lake become mature at the age of 3, with a minimum weight of 40 g and length 16.5 cm.

The size of some pikes reaches 54.4 cm with a weight of 1195 g. The mean size and weight do not exceed 45.2 cm and 688 g, respectively. 7-year old fish are the most abundant.

The mean size of perch inhabiting the lake is 24.3 cm, and mean weight 240 g. The bulk of the population consists of fish with a weight of less than 400 g and length 25-30 cm, although specimens with a weight of 1460 g and length of 42.6 cm can be found (Fig. 23). The age limit of perch in the lake can reach 16 years, but 6- to 8-year-old fish constitute the bulk of the population.

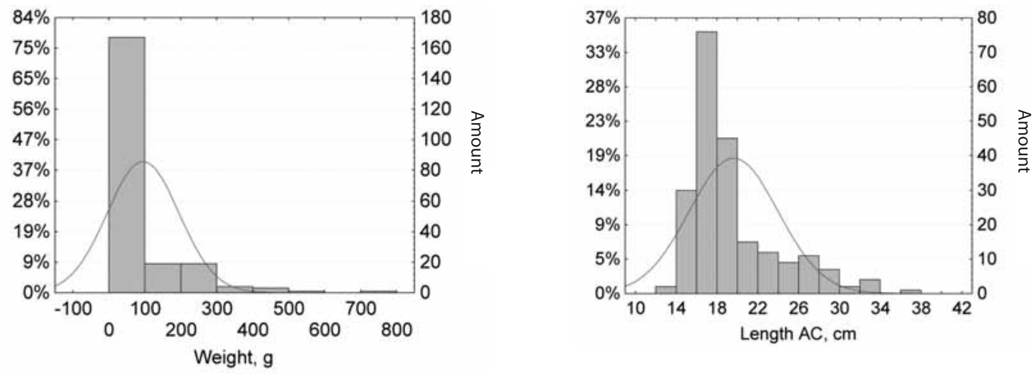


Fig. 21.
Size and weight distribution of the sparsely rakered whitefish in Lake Virtuovoshjaur.

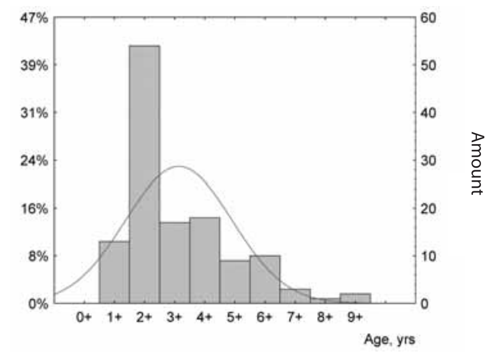


Fig. 22.
Age distribution of the sparsely rakered whitefish in Lake Virtuovoshjaur.

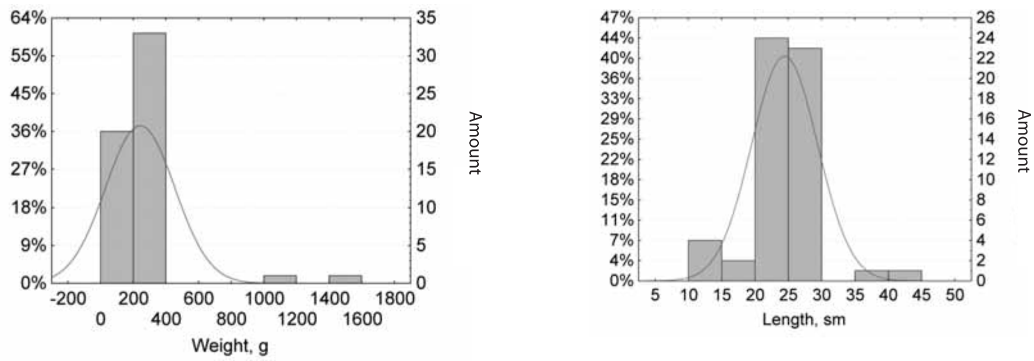


Fig. 23.
Size and weight distribution of the perch in Lake Virtuovoshjaur.

Fish pathology
The whitefish in this water body have similar changes in their organs and tissues as the fish in Lake Kochejaur. The most frequently occurring pathologies of whitefish are pathologies of the kidneys (60-88 %), liver (27-67%) and gills (34%). The pathologies of whitefish organs are currently at the initial stage, and are mainly associated with changes in the colour of organs and fatty degenerations (pale liver); connective tissue expansions (kidneys and gonads); segmentation and asynchronous maturation of gonads.

Heavy metals in fish
The heavy metal (Cu, Ni, Pb and Hg) concentrations in the muscles of fish do not exceed the standard values (Table 19). However, the Cu concentrations (µg/g of dry weight) in the other organs of whitefish are higher than those in the muscles: liver (up to 41.5 µg/g), kidneys (up to 48.9 µg/g), gills (up to 2.0 µg/g). The same applies to Ni in liver (up to 1.4), kidneys (up to 6.6), gills (up to 2.0), skeleton (up to 5.6 µg/g). The Cd concentrations in the kidneys of whitefish reach 5.3 µg/g dry weight.

The analysis of metal accumulation in different fish species shows that Cu is more strongly accumulated in the liver of whitefish, and Ni in the kidneys. The Hg concentrations in the muscles of pike are considerably larger than the concentrations in perch and whitefish. Perch has the highest concentrations of Cd in the muscles (Fig. 24).

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g of dry weight)**
		Whitefish	
Hg	0.5	0.08	0.38
Ni	0.5	0.20	0.93
Cu	20	0.25	1.14
Cd	0.1	0.002	0.01
Pb	1	0.02	0.10
		Perch	
Hg	0.5	0.16	0.79
Ni	0.5	0.13	0.64
Cu	20	0.14	0.69
Cd	0.1	0.002	0.01
Pb	1	-	<0.05
		Pike	
Hg	0.5	0.31	1.55
Ni	0.5	0.19	0.92
Cu	20	0.15	0.72
Cd	0.1	0.002	0.01
Pb	1	-	<0.05

* Source: Sanitary..., 1986.

Table 19.
Standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Virtuovoshjaur Lake (in µg/g wet and dry weight).

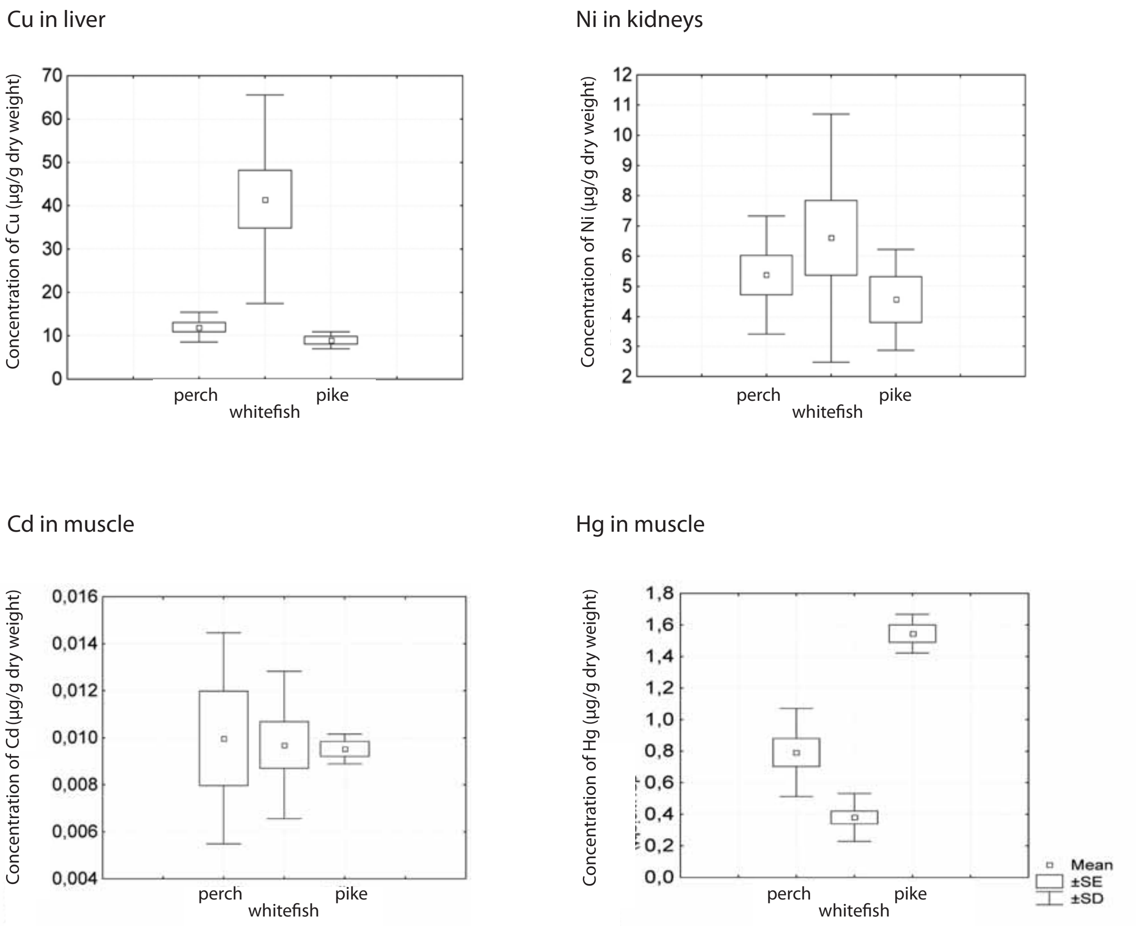


Fig. 24. *Accumulation levels of Cu (liver), Ni (kidneys), Cd and Hg (muscle) in fish from Lake Virtuovoshjaur (µg/g dry weight).*

1.18. LAKE SHUONIJAUR

Lake Shuonijaur (watershed of the River Shunijoki) is located at a distance of 20 km to the south of the town of Nikel. It is a rather large (area of the lake 11.3 km^2), shallow-water (average depth 4-6 m, maximum depth 10 m), oval-shaped lake, elongated in the east-west direction, and of glacial origin. The maximum length is 7.2 km and maximum width 2.8 km. The point of maximum depth is located in the central part of the lake. In the western and eastern parts of the lake the maximum depths are smaller – up to 5 m.

Physico-geographical characteristics	
Watershed	River Shunijoki—Lake Kuetsjarvi—River Paz
Latitude	69°15.449’
Longitude	30°04.968’
Height above sea level, m	180.1
Maximum length, km	7.2
Maximum width, km	2.8
Maximum depth, m	10
Area, m^2	11.3
Watershed area, km^2	285.8
Study period	1990-2007

According to the landscape type, the watershed area belongs to the tundra zone with heights up to 269.6 m (Uajvashvar fell). The northern shore is high and rocky, and the southern waterlogged and covered with shrubs and birch forest. The water of the lake is colourless but, during floods and high precipitation episodes, the colour increases to 30 deg. and becomes slightly yellowish.

Boulder beds occur in almost all parts of the littoral zone, and extend to a depth of about 2-2.5 m. The gaps between the boulders are filled with sand and pebbles. Dark green silt deposits are predominant at a depth of ca. 2-3m.

1.18.1. Hydrochemistry

The water of the lake is close to neutral and has a low total mineralization (15.7 mg/l) and alkalinity (79 μeq/l). During flood periods the pH falls to 6.17 and then rise back to about 6.85, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 2.11 mg/l) and bicarbonate (average 4.8 mg/l) predominating.

Hydrochemical properties	
pH	6.59 6.17-6.85
Electrical conductivity, mS/cm	26 24-32
Ca, mg/l	2.11 1.40-7.29
Mg, mg/l	0.64 0.53-0.80
Na, mg/l	1.64 1.41-2.00
K, mg/l	0.38 0.31-0.47
HCO_3, mg/l	4.8 4.3-5.5
SO_4, mg/l	4.1 3.1-8.5
Cl, mg/l	2.0 1.7-2.4
Total mineralization, mg/l	15.7 13.6-26.0
Alkalinity, μeq/l	79 70-90

The effects of pollution first appeared in the lake during the period of peak emissions from the Pechenganikel smelter in the late 1980s and early 1990s. Maximum concentrations of most elements, especially sulphate (up to 8.5 mg/l), Cu and Ni, occurred during this period. At the present time, however, the concentrations of these elements, as well as of other elements that determine the state of the water body, are lower.

The annual chemical cycle of the lake is characterized by a reduction in total mineralization (up to 13.6 mg/l), an increase in the oxidizability and a drop in pH during flood periods and high precipitation episodes when the inflow of humic water increases. During low-water periods (mainly in the autumn and winter) and when the inflow of groundwater is higher, the total mineralization increases slightly to 26. mg/l, the oxidizability drops and the pH increases.

The enrichment of water with P and N is one of the most important criteria used in assessing the development of water eutrophication. The concentrations and relationships between the species of these mineral nutrients vary according to the season, and the dynamics is to a greater degree determined by the level of production and, consequently, the trophicity of the water body. The concentrations of total P (up to 6 μg/l) and total N (up to 190 mg/l) changed slightly during the study period. In 1993 the maximum concentration of total N in the near-bottom layer during the ice-cover period was 549 μg/l, but a peak value of this magnitude has never been found since.

Based on the concentrations of mineral nutrients, the lake is characterized as oligotrophic. The lake also has colour values, and organic matter (up to 4.5 mg/l) and Fe concentrations (mean 26 μg/l) typical of small water bodies in the region. In 1990 the maximum concentration of Fe during the ice-cover period was 1571 μg/l.

The water exchange index, which regulates the concentrations of mineral nutrients in water, is 1.99, i.e. full water exchange in the lake takes about 2 years. Because suspended particles are effectively deposited in the lake, the lake bottom is completely covered with a thick layer of silt, comprising undecomposed zooplankton debris and organic matter. This feature is of primary importance for the feeding of ichthyofauna. The conditions for the growth of organisms are obviously highly favourable. Due to the fact that most of the lake is not deep, the circulation of mineral nutrients in the water is faster in the summer; this also increases the production capacity of the water body. During high water periods and high precipitation episodes in the autumn, the concentrations of species of mineral nutrients (PO_4^{3-} and NO_3^-) that determine the lake productivity are low.

Water colour, deg.	19 10-32
NH_4, µg/l	7 1-22
NO_3, µg/l	16 1-98
Total N, µg/l	192 100-597
PO_4, µg/l	1 1-2
Total P, µg/l	4 2-6
Fe, µg/l	123 5-1571

Cu, µg/l	4.7 2.0-11.0
Ni, µg/l	7.4 4.7-17.0
Al, µg/l	40 14-194
Pb, µg/l	0.22 0.10-0.56

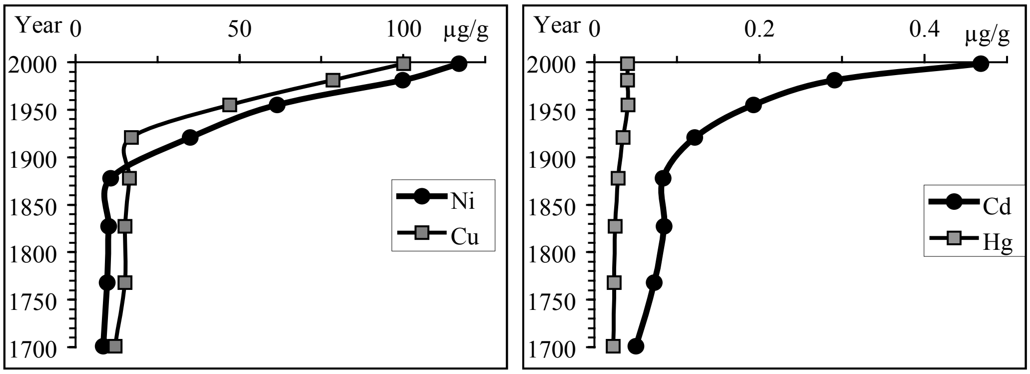
The watershed of Lake Shuonijaur is subjected to the impact of pollutants emitted by the "Pechenganikel" smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu etc.). Maximum concentrations of Cu (up to 7.5 µg/l) and Ni (17 µg/l) were recorded in the water in the 1990s. At the present time, due to the reduction in the airborne pollution load, higher Cu (up to 11 µg/l) concentrations occur during the flood period when the snow melts in the watershed, and of Ni (up to 182 µg/l) during flood periods and the autumn low-water periods.

1.18.2. Lake bottom sediments

The sediments of Lake Shuonijaur have somewhat lower organic matter contents: the LOI value in the uppermost 1 cm layer is slightly less than 30% (Table 20). The lake is located at a distance of 20 km from the Pechenganikel smelter, and is subjected to airborne pollution by heavy metals (Ni, Cu, Co) and chalcophile elements (Pb, As, Cd and Hg). The top 3-4 cm layer of the lake sediments is the most polluted by Ni, Cu and Co. Pollution by chalcophile elements started earlier: these elements are present in the top 6-7 cm layer especially (Fig. 25).

Table 20. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Shuonijaur	0-1	29.76	100	117	63	7.8	0.47	12.1	2.03	0.040	
	14-15	21.97	14	13	47	1.7	0.06	0.8	0.74	0.013	
C_f			**7.3**	**9.3**	**1.3**	**4.6**	**8.5**	**14.9**	**2.7**	**3.1**	**51.7**



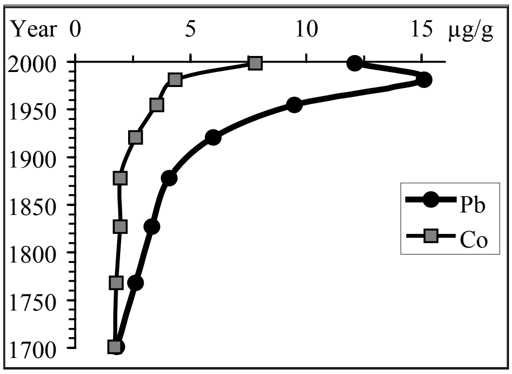


Fig. 25.
Vertical distribution of the concentrations of Ni, Cu, Co, Pb, Cd and Hg (µg/g, dry weight) in a dated sediment core from Lake Shuonijaur.

Sediment dating has been carried out on the cores. Pollution by Ni, Cu and Co, i.e. heavy metals emitted into the atmosphere by the Pechenganikel smelter, started in the beginning of the 20th century. Pollution by chalcophile elements started at the end of the 19th century, and was primarily due to long-range, airborne transport from industrial sources in Western Europe. It increased considerably at the beginning of the 20th century, and was connected with the start of activities at the "Pechenganikel" smelter. The contamination factor values for these toxic elements range from 2.7 to 14.9 (Table 20), i.e. the values correspond to considerable and high contamination. Lead has the highest C_f value. The degree of contamination value (51.7) for this lake corresponds to high contamination, and this is one of the highest values among the studied lakes.

1.18.3. Hydrobiological studies

Hydrobiological indices
30 species of phytoplankton were registered in lake Shuonijaur, the most numerous species being diatoms, cyanobacteriae and yellow-green algae (Kashulin, 2004). The species composition of the ground fauna of the River Sgunijoki, which flows out of Lake Shuonijaur, consists of about 25 species. The zoobenthos consists of chironomids, dayflies, caddis flies and stone flies (Yakovlev et al., 1991).

Ichthyofauna. Studies on the fish community of Lake Kuetsjarvi were conducted in 1992 and in 2005.

According to these studies, the ichthyofauna of the lake consists of five species belonging to four fish families: arctic char (*Salvelinus alpinus*), trout (*Salmo trutta*), perch (*Perca fluviatilis*), burbot (*Lota lota*) and nine-spine stickleback (*Pungitius pungitius*). Ovewrall, trout and arctic char are predominant in the lake (Fig. 26). Perch is not so common. Burbot is occasionally caught, and nine-spine stickleback inhabits the littoral zones of the lake.

The mean size and weight of arctic char are 25.5 cm and 222 g. The maximum size can reach 38.5 cm and weight 875 g. The bulk of the population consists of fish with a weight of between 100-200 g and length 20-26 cm. Individuals with a weight of over 500 g and longer than 30 cm occur occasionally (Fig. 27). The age distribution is predominately 4- to 5-year-old fish. Their proportion in the catches is 84 % (Fig. 28). Female specimens predominate over males (1.4:1).

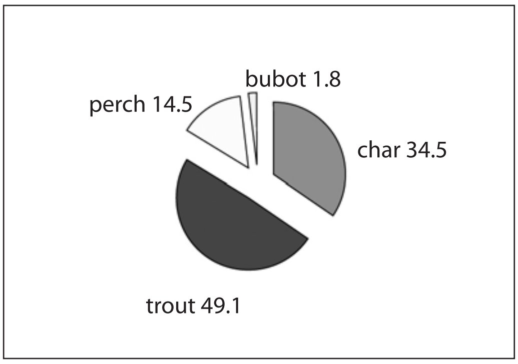


Fig. 26.
Distribution of fish species in Lake Shuonijaur.

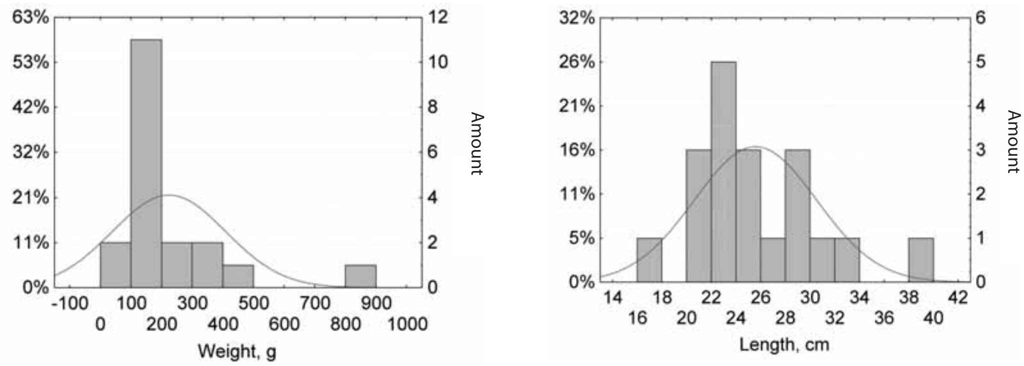


Fig. 27.
Size and weight distribution of arctic char in Lake Shuonijaur.

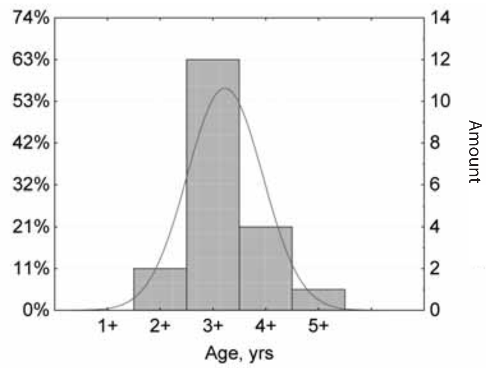


Fig. 28.
Age distribution of arctic char in Lake Shuonijaur.

The mean weight of trout in this lake is 190 g and length 24.4 cm. The size of the fish varies between 47-384 g and 16.5-31.0 cm, respectively. Fish with a weight of 150-200 g and length 22-26 cm are the most abundant (Fig. 29). As is the case for arctic char, the bulk of the trout population (89%) consists of 4- to 5-year-old fish (Fig. 30). Female fish predominate over males (1.3:1).

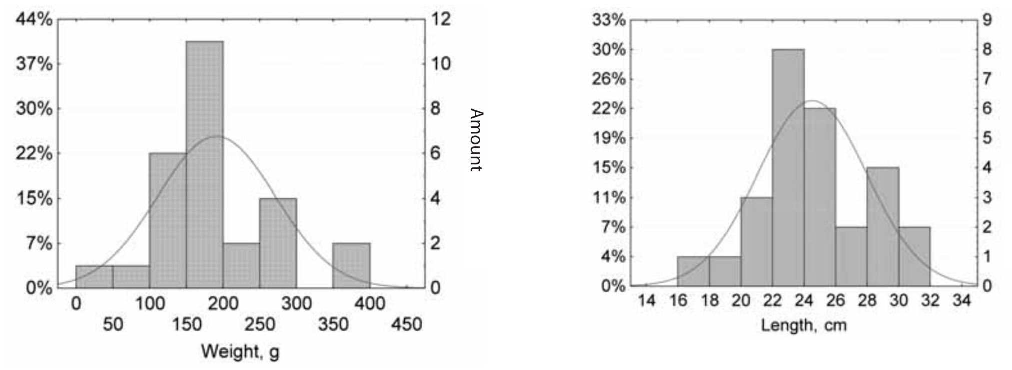


Fig. 29.
Size and weight distribution of trout in Lake Shuonijaur.

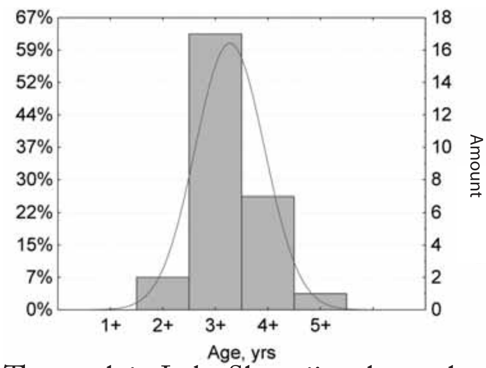


Fig. 30.
Age distribution of trout in Lake Shuonijaur.

The perch in Lake Shuonijaur have a length of 14.5 cm and weight of 51 g. The population is mainly represented be 2-year-old individuals. The length of the largest specimens does not exceed 20.3 cm and a weight of 140 g. In the sex distribution the number of male fish is three times higher than that of females.

Fish pathology

Pathological changes in the organs of arctic char and trout occur most frequently in the kidneys (95 and 96%) and liver (59 and 57%). The pathologies manifest themselves as intensive colour changes of the organs and fatty degenerations (pale liver), and connective tissue expansions (kidneys).

Heavy metals in fish

The concentrations of heavy metals (Cu, Ni, Cd and Hg) in fish muscle do not exceed the standard values (Table 21). Nevertheless, the concentrations of Cu, Ni and Cd (µg/g dry weight) in other organs are much higher than those in the muscles: liver (41.7 for arctic char and 180.0 µg/g for trout), kidneys (20.5 for arctic char and 7.6 µg/g for trout) and gills (over 3 µg/g). A similar distribution is typical for Ni: in liver (2.1 fir arctic char and 1.3 µg/g for trout), kidneys (16.2 for arctic char and 4.6 µg/g for trout) and gills (over 4 µg/g). Cadmium concentrations can reach 28.4 µg/g dry weight.

Analysis of heavy metal accumulation in different fish species showed that Cu accumulates more strongly in the liver of arctic char. However, the trend for Ni is the opposite. There was a high degree of Cd accumulation in the muscles of arctic char, while for Hg it accumulated more strongly in the tissues of trout (Fig. 31).

Table 21. *The standard values for the heavy metal concentration in foodstuffs and in fish muscle in Lake Shuonijaur (in µg/g wet and dry weight).*

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g of dry weight)**
		Char	
Hg	0.5	0.07	0.3
Ni	0.5	0.37	1.58
Cu	20	0.24	1.03
Cd	0.1	0.003	0.01
Pb	1	0.02	0.07
		Trout	
Hg	0.5	0.12	0.49
Ni	0.5	0.18	0.73
Cu	20	0.25	1.04
Cd	0.1	0.002	0.01
Pb	1	0.03	0.13

* Source: Sanitary...,1986.

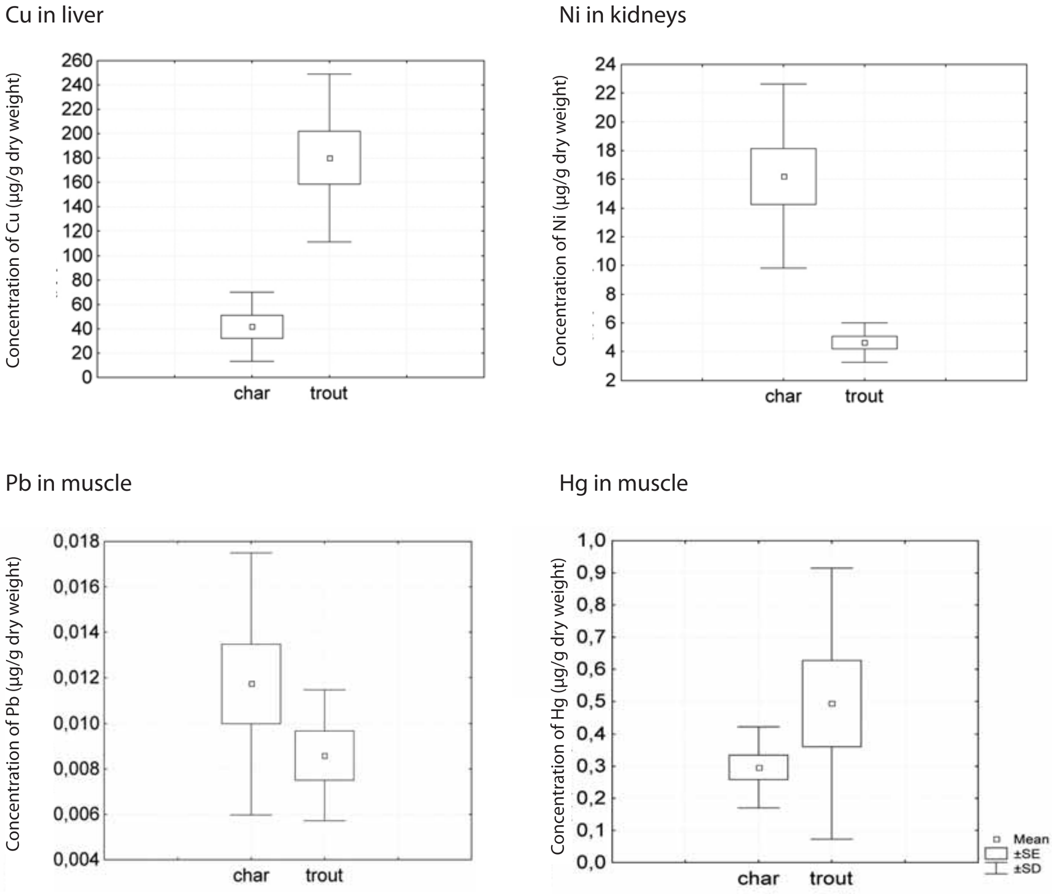


Fig. 31. *Accumulation of Cu (liver), Ni (kidneys), Cd and Hg (muscle) in fish from Lake Shuonijaur (µg/g dry weight).*

1.19 LAKE KUETSJARVI

Physico-geographical characteristics	
Watershed	River Paz
Latitude	69°26.052′
Longitude	30°09.447′
Height above sea level, m	21.3
Maximum length, km	11.6
Maximum width, km	2.8
Maximum depth, m	37
Area, m^2	17.0
Watershed area, km^2	628.4
Study period	1994-2007

Lake Kuetsjarvi (watershed of the River Paz) is located at a distance of 3 km from the Russian-Norwegian border, and close to the town of Nikel. Lake Kuetsjarvi is one of the largest lakes in the Russian border area of (area of the lake 17.0 km^2). The lake is relatively deep (maximum depth 37 m), of elongated shape, and of glacial origin. The maximum length is 11.6 km and maximum width 2.8 km. The point of maximum depth is located in the northern part of the lake, where the depths are significant near the shore. In the central part of the lake the maximum depths reach 10 m. The southern part of the lake is shallow, with a maximum depth of 12 m.

The lake belongs to the lake-river system of the Paz River, to which it is linked by a small stream. According to the landscape type, the watershed consists of a combination of flat, low-lying areas of glaciolacustrine flatland, and denudation and denudation-tectonic massifs with abrupt outcrops of quaternary deposits with a height of up to 631.0 m (Kuorpukas fell). The lake shores are high and covered with pine forests and scree. As a result of mining and excavation over a huge area, the natural landscape is seriously damaged and the fell tops levelled and the orography changed. The water of the lake is colourless but, during flood periods and episodes of high precipitation, the water colour in the southern part of the lake, where the River Shunijoki enters, increases to 50 deg. and becomes yellowish.

There are some boulder beds and sandy beaches (mostly in the southern part) in the littoral zone. The gaps between the boulders are filled with sand and pebbles. Dark green silt deposits predominate in the northern, less polluted part of the lake. In the southern part, where effluent from the Pechenganikel smelter flows into the River Kolosjoki, the silt deposits are almost completely black.

1.19.1. Hydrochemistry

The lake is one of the most polluted lakes in the Pechenga region. The industrial complex, located on its shore, poses a serious threat to natural aquatic environments in the joint Norwegian, Finnish and Russian border area. Granulated waste material, produced in connection with metal production at the smelting plant, has been dumped along the shore of the River Kolosjoki. Toxic compounds are leached from the slag heaps by rainwater, snowmelt and surface runoff. Dust from the slag heaps also has a very severe impact on the environment. Wastewater is discharged directly into the water body.

The water of the lake is neutral and has a total mineralization of 69 mg/l and average alkalinity of 286 μeq/l. During flood periods the pH falls to 6.71 and then rises back to 7.31. The lake has high concentrations of base cations and anions, with calcium (average 10.2 mg/l) and sulphate (average 28.9 mg/l) predominating.

Severe pollution of the lake occurred during the period of peak emissions from the "Pechenganikel" smelter in the late 1980s and early 1990s. Maximum concentrations of most elements, especially sulphate (up to 40.3 mg/l), Cu and Ni, were recorded

Hydrochemical properties	
pH	7.06 6.71-7.31
Electrical conductivity, mS/cm	105 67-137
Ca, mg/l	10.2 6.86-13.5
Mg, mg/l	3.54 2.00-4.97
Na, mg/l	4.24 2.66-6.50
K, mg/l	0.83 0.59-1.16
HCO_3, mg/l	17.5 11.0-21.9
SO_4, mg/l	28.8 16.8-40.3
Cl, mg/l	3.69 2.40-4.87
Total mineralization, mg/l	69.0 43.8-90.5
Alkalinity, µeq/l	287 180-359

Water colour, deg.	24 12-50
NH_4, µg/l	26 2-72
NO_3, µg/l	39 1-320
Total N, µg/l	226 134-390
PO_4, µg/l	4 1-26
Total P, µg/l	18 7-60
Fe, µg/l	85 14-350

Cu, µg/l	8.6 4.5-15.2
Ni, µg/l	106 74-182
Al, µg/l	36 8-126
Pb, µg/l	0.17 0.01-0.78

at the time. The concentrations of these elements, as well as of other elements that characterize the state of the water, are currently still rather high.

The annual chemical cycle of the lake is characterized by a drop in total mineralization to 48.3 mg/l, as well as a drop in pH, during flood periods and episodes of high precipitation when the inflow of humic water increases. During low-water periods (mainly in winter and autumn) and when the inflow of groundwater increases, the total mineralization increases slightly to 90.5 mg/l, the oxidizability drops and the pH rises.

The concentrations and relationships between species of mineral nutrients vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The highest total P concentrations (up to 60 µg/l) typically occur in the summer, when it is 7-8 times higher than during the flood period. The highest total N concentrations (up to 390 µg/l) normally occur during the vegetation period.

Based on the concentrations of biogenic elements, the lake is classified as eutrophic. The lake also has colour values, and organic matter (up to 5.0 mg/l) and Fe concentrations (mean 85 µg/l) typical of small water bodies in the region. The trophic status of the water body is primarily regulated by the proximity of the town of Nikel and the smelter on the shore of the lake. The water exchange index is 1.55, i.e. full water exchange in the lake takes about one year and a half. Suspended particles are strongly deposited in the northern and deepest part of the lake, with the result that the bottom of the lake is completely covered with a thick layer of silt, comprising undecomposed zooplankton debris and organic matter. This feature is of primary importance for the feeding of whitefish species. The conditions for the growth of food organisms are obviously highly favourable.

The watershed of Lake Kuetsjarvi is subjected to severe pollutant impacts resulting from the activities of the Pechenganikel smelter. The water system of the lake is exposed to the direct discharge of pollutants from the metallurgical and smelting industries, and also to the deposition of airborne pollutants. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Cd, Cr, Zn, As, Hg etc.). SO_2 emissions from the smelter have resulted in the oxidation of the surface water, as well as pollution of the groundwater due to the leaching of elements from the soil surface. Maximum concentrations of Cu (7.2 μg/l) and Ni (93 μg/l) were recorded in the water in the 1990s. At the present time, although the airborne deposition load has been reduced, there are higher concentrations of Cu (up to 15.2 μg/l) during flood periods when the snow cover melts, and of Ni (up to 182 μg/l) during high precipitation episodes in the summer.

1.19.2. Lake bottom sediments

Lake Kuetsjärvi receives, via the River Kolosjöki, most fo the effluent from the Pechenganikel smelter. As a result, the main pollutants are Ni, Cu and Co, as well as the chalcophile elements Pb, As, Cd and Hg. The sediments of Lake Kuetsijäri have relatively low organic matter contents: the LOI value in the uppermost 1 cm layer is 20% (Table 22). The most polluted layer is the top 10 cm of the lake sediments (Fig. 32). The pollution factor values of these toxic elements range from 11.6 to 125.7 (Table 22), i.e. the values correspond to high contamination. Ni has the highest C_f value. The degree of contamination value (240.1) for this lake corresponds to high contamination, and has one of the highest values in the River Paz watershed.

Table 22. *The organic matter contents (LOI, %) and heavy metal concentrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (21-22 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	Cd
Kuetsijäri	0-1	21.42	1343	4032	297	184.1	3.14	45.7	43.05	0.417	
	21-22	10.67	40	32	127	15.9	0.10	4.5	2.62	0.049	
Cf			**33.5**	**125.7**	**2.3**	**11.6**	**32.1**	**10.1**	**16.4**	**8.5**	**240.1**

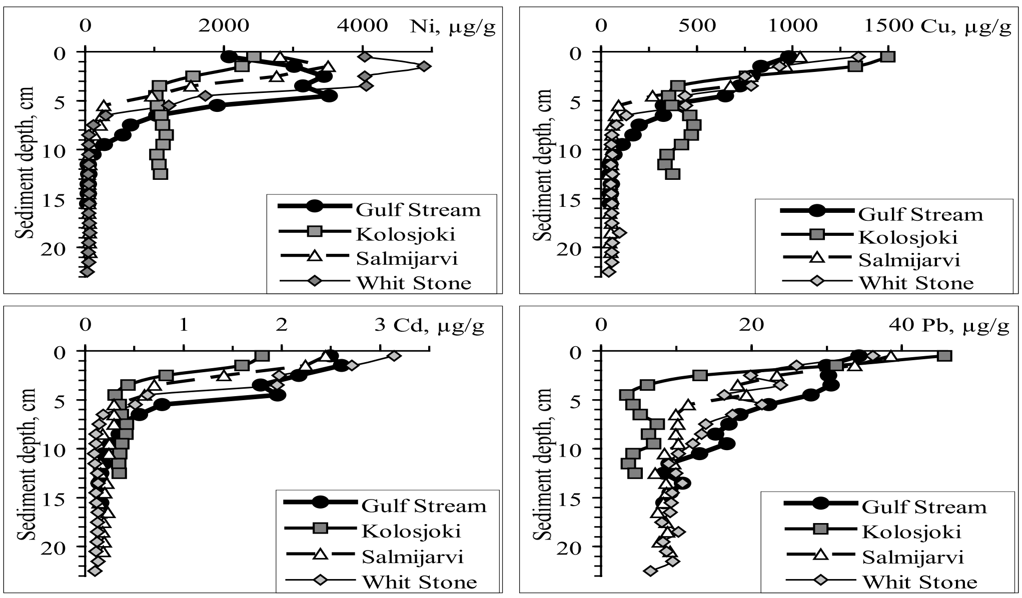


Fig. 32. *Vertical distribution of the concentrations of Ni, Cu, Pb and Cd (μg/g, dry weight) in sediment cores from different parts of Lake Kuetsjärvi.*

1.19.3. Hydrobiological studies

Hydrobiological indices

The phytoplankton communities in Lake Kuetsjarvi, where diatoms predominate, have the highest biomass values (over 1700 mm^3/m^3). There are 54 species of phytoplankton in the lake (Sharov, 2004). According to earlier studies (Yakovlev et al., 1991; Noest et al., 1992), Lake Kuetsjarvi is the richest lake as regards the number of zooplankton species. The density of Cladocerae and Copepoda in the lake is the highest (up to 80000 specimens/m^2) in the water bodies near the Pechenganikel smelter. The lake also has considerable species diversity of ground organisms. The number of zoobenthos species is over 20, of which Chironomids are predominate (60-80%).

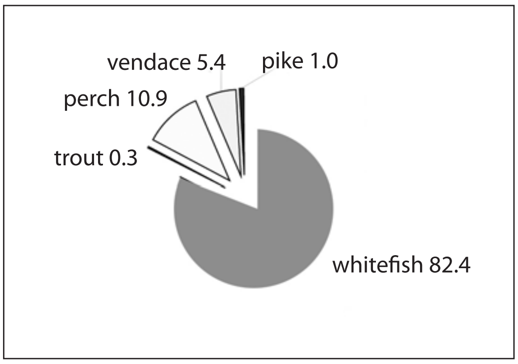


Fig. 33.
Distribution of fish species in Lake Kuetsjarvi.

Ichthyofauna. Studies on the fish community of Lake Kuetsjarvi were conducted in 1990-1992 and in 2002, 2005.

Despite severe pollution by acidifying compounds and heavy metals, the ichthyofauna of the lake is one of the richest ones of the lakes in the study area. The reason for this is that the water body is connected to the River Pasvik (the Barents Sea basin). According to the research data, the ichthyofauna of the lake consists of 9 species belonging to nine families of fish: trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), vendace (*Coregonus albula*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*), and nine-spine stickleback. The thornback (*Gasterosteus aculeatus*) obviously also inhabits the lake. Overall, whitefish and perch predominate in Lake Kuetsjarvi (Fig. 33). Pike, trout, grayling and burbot are occasionally caught.

Two forms of whitefish inhabit the lake: sparsely rakered whitefish (up to 30 gill rakers) and densely rakered whitefish (with 30 - 40 gill rakers).

The mean length and weight of the densely rakered whitefish are 12.2 cm and 28 g, respectively, with maximum values of 29.3 cm and 340 g. The bulk of the population is represented by fish 8-12 cm long and weight of less than 50 g (Fig. 34) with an age of 0+ - 1+ (Fig 36a). A high proportion of the population of sparsely rakered whitefish consists of fish with a weight of 20-40 g and length of 10-16 cm. On the average they are slightly larger than the densely rakered whitefish (14.6 cm and 39 g), although maximum size of the fish is less (25.9 cm and weight 207 g) (Fig. 35). The age distribution of whitefish is dominated by 3-year-old fish; fish older than 6 years are caught only occasionally (Fig. 36b). Female fish of both forms slightly predominate over males (1:1.3). The most typical feature of the whitefish in this lake is early maturation and spawning at an age of one year when they have attained a length of 9.5 cm and weight of 6 g.

The mean size and weight of pike are 372 g and 32.4 cm, but individuals at the age of 6 have a weight of over 1 kg (1079 g) and length of 49.9 cm. The distribution of male and female fish is almost equal. The perch indices of Lake Kuetsjarvi do not exceed 164 g and 19.6 cm. The largest fish can be found near the lake channel and the River Pasvik but, overall, 44% of the fish have a weight of less than 100 g and length of 12-16 cm (Fig. 37). The age of the largest fish does not exceed 7 years. In the sex distribution there are twice as many females as males.

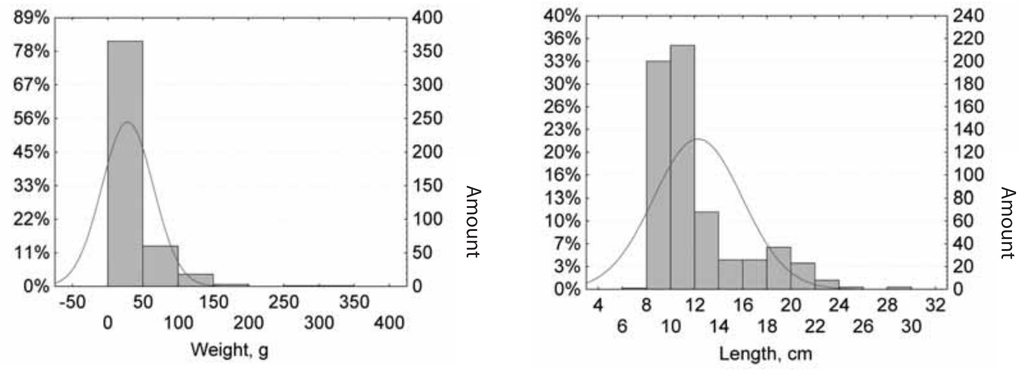


Fig. 34.
Size and weight distribution of the sparsely rakered whitefish in Lake Kuetsjarvi.

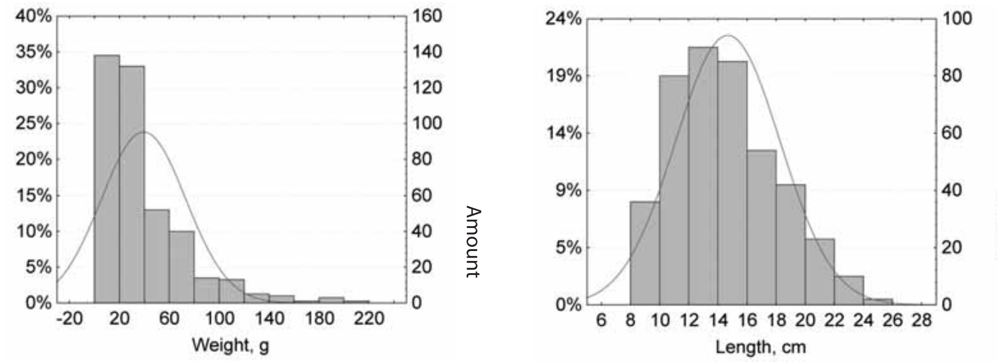


Fig. 35.
Size and weight distribution of the densely rakered whitefish in Lake Kuetsjarvi.

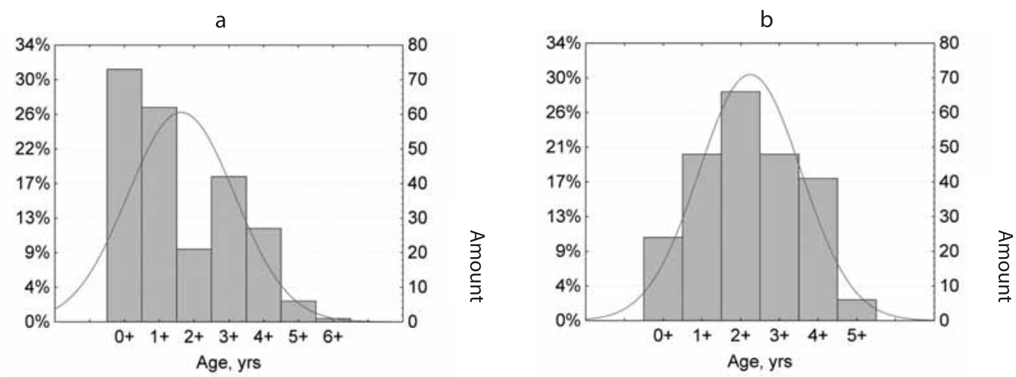


Fig. 36.
Age distribution of the sparsely (a) and densely (b) rakered whitefish in Lake Kuetsjarvi.

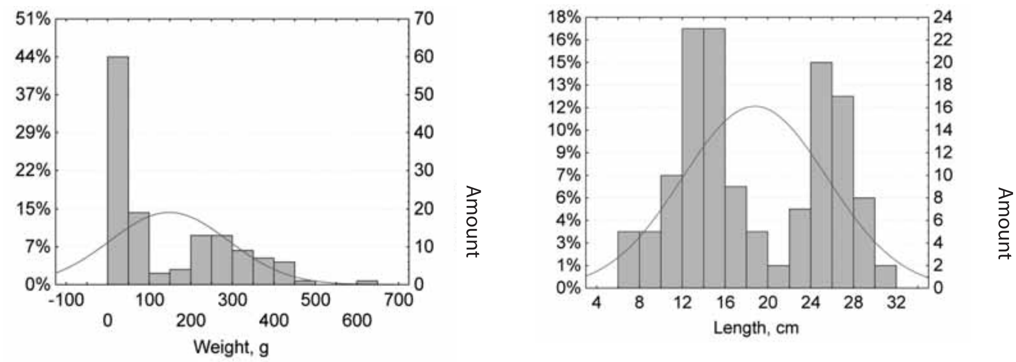


Fig. 37.
Size and weight distribution of the perch in Lake Kuetsjarvi.

Trout is occasionally caught. Some 5-year-old individuals have a length of 39.7 cm and weight of 694 g. The only grayling was a 2-year-old female specimen with a weight of 77 g and length of 21.0 cm. The vendace inhabiting the pelagic zone are of small size (9.3 – 13.6 cm, 6-19 g). The mean values are 10 g and 11.0 cm. Female fish predominate (1.4: 1).

Fish pathology

The most serious and irreversible fish pathologies were recorded in this lake. The frequency of occurrence of pathologies of the liver and kidneys in whitefish varied from 54 to 90% throughout the whole study period. Kidney stones of whitefish, which are typical only of this region, occurred in 21% of the fish. 20% of the fish had serious alternations of their reproductive system (gelatiniforme, asynchronous and asymmetric maturation of the gonads). All the fish had reduced muscle turgor and colour changes of the skin. The muscles of pike had a green hue, and the colour of the liver in 92% of the fish was sandy-grey to dark-green.

Heavy metals in fish

Heavy metal concentrations (Cu, Ni, Pb) in fish muscle does not exceed the standard values. The Ni concentrations in fish muscle are very close to the maximum permissible concentration (Table 23). The accumulation of metals in other fish organs is much higher. For example, the Hg and Pb concentrations in liver, kidneys and gills can be from 2 to 14 times higher than in the muscles. The difference for Cu (liver) and Ni (kidneys) can be even higher (up to 47 and 17 times).

Comparative analysis of metal accumulation in different fish species showed that the concentrations of Cu (liver), Ni (kidneys) and Pb (muscles) are higher in both forms of whitefish than in the other species. Perch had the highest mean Hg concentrations in muscles (Fig. 38).

Table 23. *The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Kuetsjarvi (in µg/g wet and dry weight).*

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g of dry weight)**
Sparely rakered whitefish			
Hg	0.5	0.01	0.03
Ni	0.5	0.31	1.55
Cu	20	0.21	1.05
Cd	0.1	0.01	0.03
Pb	1	0.02	0.09
Densely rakered whitefish			
Hg	0.5	0.01	0.02
Ni	0.5	0.44	2.06
Cu	20	0.24	1.13
Cd	0.1	0.01	0.03
Pb	1	0.02	0.09
Perch			
Hg	0.5	0.03	0.13
Ni	0.5	0.23	1.04
Cu	20	0.13	0.60
Cd	0.1	-	<0.01
Pb	1	0.01	0.06
Pike			
Hg	0.5	0.01	0.07
Ni	0.5	0.22	1.05
Cu	20	0.19	0.91
Cd	0.1	0.06	0.01
Pb	1	0.30	0.07

* Source: Sanitary..., 1986.

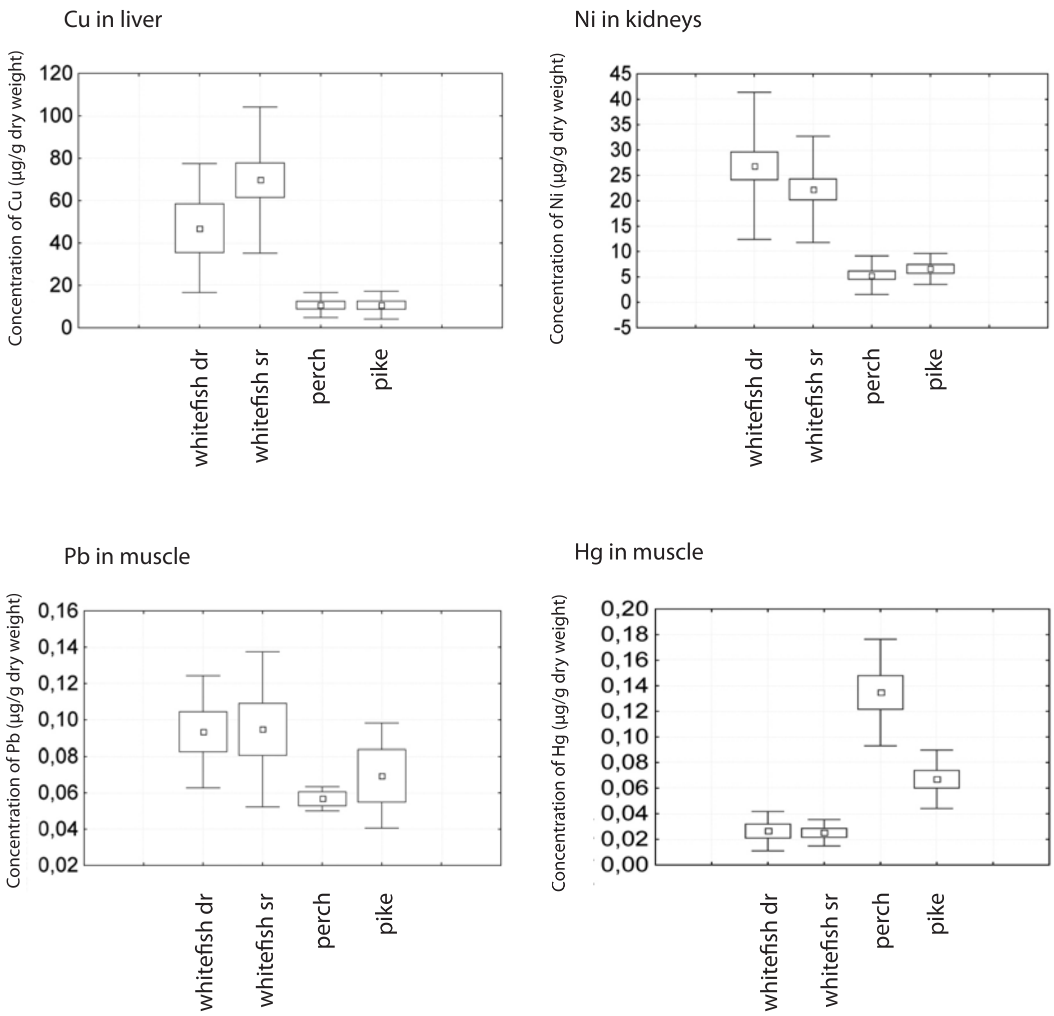


Fig. 38.
Accumulation of Cu (liver), Ni (kidneys), Pb and Hg (muscle) in fish from Lake Kuetsjarvi (µg/g dry weight).

NORWEGIAN LAKES

2.1. LAKE BIGGEJAVRE

Lake Biggejavre (watershed of River Kautokejnoelva) is located 283 km to the west of the town of Nikel. The oval-shaped lake is not large (area of the lake 5.2 km^2) or deep (maximum depth 16 m), and is of glacial origin. The maximum length is 5.2 km and maximum width 1.5 km. The points of maximum depth are located in the central part of the lake.

According to the landscape type, the watershed area belongs to the forest-tundra zone, with heights of upto 600 m. The lake shores are high and stony, with shrubs and birch woodland. The water of the lake is colourless.

Physico-geographical characteristics	
Watershed	River Kautokejnoelva—River Altaelva
Latitude	69°16.264′
Longitude	23°25.685′
Height above sea level, m	383.0
Maximum length, km	5.2
Maximum width, km	1.5
Maximum depth, m	16
Area, km^2	5.2
Watershed area, km^2	120.0
Study period	2005

2.1.1. Hydrochemistry

The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 23.9 mg/l) and alkalinity (average 256 μeq/l). The lake has low concentrations of base cations and anions, with calcium (average 3.84 mg/l) and bicarbonate (average 15.7 mg/l) predominating.

Increased concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationship between species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 6 μg/l and 120 μg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values, and organic matter (4.9 mg/l) and Fe concentrations (average 82 μg/l) are typical for lakes in the region.

Hydrochemical properties	
pH	6.83 6.72-6.95
Electrical conductivity, mS/cm	32 31-34
Ca, mg/l	3.84 3.65-4.04
Mg, mg/l	0.88 0.86-0.90
Na, mg/l	1.10 1.08-1.13
K, mg/l	0.56 0.54-0.58
HCO_3, mg/l	15.7 13.9-17.5
SO_4, mg/l	1.23 1.21-1.25
Cl, mg/l	0.66 0.66-0.66
Total mineralization, mg/l	23.9 21.9-26.0
Alkalinity, μeq/l	256 227-286

Water colour, deg.	26 25-27
NH_4, μg/l	6 3-9
NO_3, μg/l	13 1-26
Total N, μg/l	119 118-120
PO_4, μg/l	1 1-1
Total P, μg/l	6 5-6
Fe, μg/l	82 64-101

Although Cu and Ni are the main pollutants in the effluents and emissions from the "Pechenganickel" smelter, the watershed of Lake Biggejavre is located at a considerable distance from the smelter and the Cu concentrations in the water are 1.7 µg/l, and of Ni 2.2 µg/l.

Cu, µg/l	1.7 1.2-2.2
Ni, µg/l	2.2 0.4-4.0
Al, µg/l	27 27-27
Pb, µg/l	0.2 0.2-0.2

2.1.2. Lake bottom sediments

The sediments in Lake Biggejavre have organic matter contents (LOI) in the uppermost 1 cm layer of about 30% (Table 24). As the lake is located at a distance of about 300 km from the Pechenganickel smelter, emissions of S and heavy metals have relatively little impact on the lake. However, it is subjected to pollution by chalcophile elements, such as Cd, Pb, As and Hg. The top 4-10 cm of the lake sediments are the most polluted. The maximum Cd concentrations occur in the 6-10 cm layer, and of the others chalcophile elements in the uppermost 1 cm layer (Fig. 39). Contamination factor values of these toxic elements range from 1.4 to 18.7 (Table 24), i.e. the values correspond to moderate and high (Pb) contamination. Pb has the maximum C_f value. The contamination factor values of the other heavy metals are low. The degree of contamination value (27.1) for this lake corresponds to considerable contamination.

Table 24. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (25-26 cm) sediment layers. C_f and C_d correspond to contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Biggejavre	0-1	27.63	53	25	62	12.5	0.24	33.8	15.1	0.163	
	25-26	25.31	88	35	79	35.1	0.17	1.8	6.63	0.070	
C_f			**0.6**	**0.7**	**0.8**	**0.4**	**1.4**	**18.7**	**2.3**	**2.3**	**27.1**

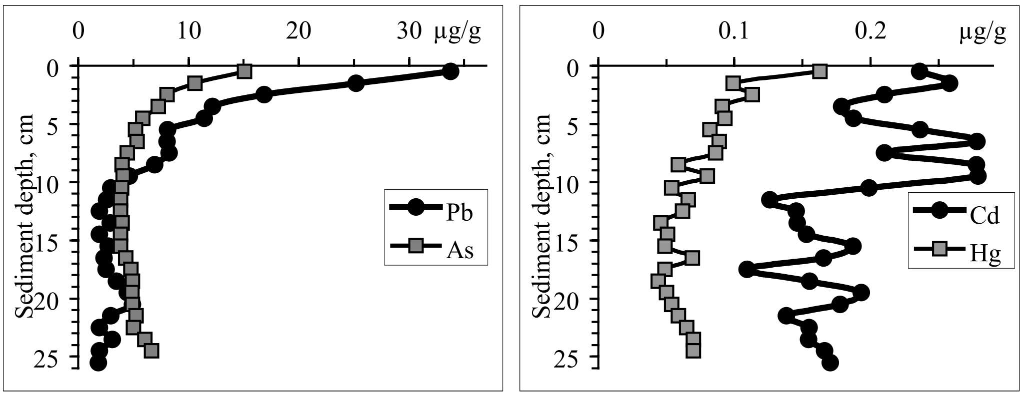


Fig. 39. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Biggejavre.*

2.1.3. Hydrobiology studies

No direct hydrobiological investigations have been carried out in this lake.

2.2. LAKE ELLENTJA

Physico-geographical characteristics	
Watershed	River Ellenelva—River Paz (Tjerebukta)
Latitude	69°12.568′
Longitude	29°07.094′
Height above sea level, m	71.0
Maximum length, km	1.70
Maximum width, km	1.17
Maximum depth, m	10
Area, km^2	1.06
Watershed area, km^2	187
Study period	2002-2003

Lake Ellentja (watershed of the River Paz) is located 53 km to the south-west of the town of Nickel. The oval-shaped lake is not large (area of the lake 1.06 km^2) nor deep (maximum depth 10 m), and is of glacial origin. The maximum length is 1.7 km and maximum width 1.17 km. The points of maximum depth are located in the central part of the lake.

The lake is the most downstream in the lake-river system of the River Ellenelva. According to the landscape type, the watershed belongs to the forest zone, with heights of up to 260 m. The lakeshores are low, waterlogged, and covered by shrubs and pine forest.

2.2.1. Hydrochemistry

Hydrochemical properties	
pH	6.65 6.55-6.80
Electrical conductivity, mS/cm	23 22-26
Ca, mg/l	1.53 1.41-1.77
Mg, mg/l	0.58 0.55-0.65
Na, mg/l	1.52 1.46-1.61
K, mg/l	0.43 0.41-0.48
HCO_3, mg/l	6.4 6.0-7.1
SO_4, mg/l	2.20 2.07-2.37
Cl, mg/l	1.53 1.36-1.77
Total mineralization, mg/l	14.2 13.3-15.8
Alkalinity, µeq/l	105 98-117

Water colour, deg.	16 12-18
NH_4, µg/l	12 6-15
NO_3, µg/l	2 1-2
Total N, µg/l	183 176-195
PO_4, µg/l	1 1-1
Total P, µg/l	4 4-5

The pH in the water of the lake is close to neutral and has low total mineralization (average 14.2 mg/l) and alkalinity (average 105 µeq/l). During floods periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 1.53 mg/l) and bicarbonate (average 6.4 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

The concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season, and the dynamics is to a greater degree determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 5 µg/l and 195 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and organic matter (5.4 mg/l) and Fe concentrations (average 89 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Water colour, deg.	16 12-18
NH_4, µg/l	12 6-15
NO_3, µg/l	2 1-2
Total N, µg/l	183 176-195
PO_4, µg/l	1 1-1
Total P, µg/l	4 4-5
Fe, µg/l	89 82-103

Cu, µg/l	1.9 1.7-2.0
Ni, µg/l	1.7 0.9-2.4
Al, µg/l	28 22-34
Pb, µg/l	0.3 0.2-0.5

Although the watershed of Lake Ellentja is relatively remote from the "Pechenganickel" smelter (distance of 53 km), it is subjected to anthropogenic impacts from the smelter emissions. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, co, etc.). Despite the fact that emissions from the smelter have been reduced to approximately one third of the maximum levels during the late 1970s, the deposition of pollutants still has an effect on the water bodies in the region. The average concentrations of Cu and Ni are 1.9 µg/l and 1.7 µg/l, respectively.

2.2.2. Lake bottom sediments

The sediments of Lake Ellentja have relatively low organic matter contents (LOI) in the uppermost 1 cm layer of about 20% (Table 25). Emissions from the smelter have little impact on the lake, but levels of chalcophile elements such as Pb and Hg are elevated. The uppermost 2-4 cm sediment layers are the most polluted, while maximum concentrations of Hg occur in the 6-7 cm layer (Fig. 40). The contamination factor values for Pb and Hg are 3.8 and 3.4, respectively (Table 25), i.e. the values correspond to considerable contamination. The contamination factor values for other heavy metals are low. The degree of contamination value (13.0) for this lake corresponds to moderate.

Table 25. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (16-17 cm) sediment layers. C_f and C_d refer to contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Ellentja	0-1	24.42	41	36	82	9.4	0.17	13.2	2.72	0.174	
	16-17	18.86	51	32	123	9.5	0.14	3.5	2.80	0.051	
C_f			**0.8**	**1.1**	**0.7**	**1.0**	**1.2**	**3.8**	**1.0**	**3.4**	**13.0**

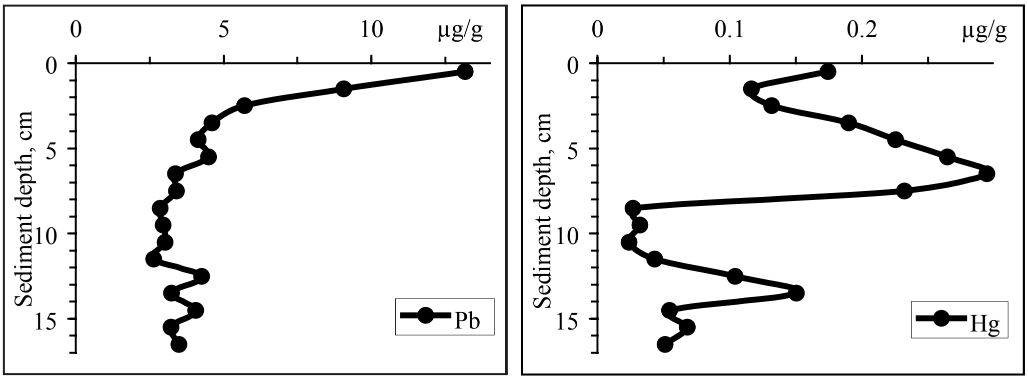


Fig. 40. *Vertical distribution of the concentrations of Pb and Hg (µg/g, dry weight) in the sediment core of Lake Ellentja.*

2.2.3. Hydrobiology studies

No direct hydrobiological investigations have been carried out in this lake.

2.3. LAKE GARDSJOEN

Lake Gardsjoen (watershed of the River Jacobselv) is located 31 km to the north of the town of Zapolyarny. The oval-shaped lake is relatively small (area of the lake 0.75 km^2) and not deep (maximum depth 16 m), and is of glacial origin. The maximum length is 1.65 km and maximum width 0.7 km. The points of maximum depth are located in the central part of the lake.

Physico-geographical charact	
Watershed	River Jacobselv—the Barents Sea
Latitude	69°42.460′
Longitude	30°51.068′
Height above sea level, m	82.0
Maximum length, km	1.65
Maximum width, km	0.7
Maximum depth, m	10
Area, km^2	0.75
Watershed area, km^2	10.5
Study period	2003-2005

According to the landscape type, the watershed area belongs to the tundra zone, with heights up to 282 m. The lake shores are high and covered by shrubs and birch woodland. The water of the lake is colourless both during high water periods and episodes of high precipitation.

2.3.1. Hydrochemistry

The proximity of the sea has considerable influence on the water quality of the lake. The pH in the water is neutral and the water has a low total mineralization (average 20.1 mg/l) and alkalinity (average 60 µeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 3.61 mg/l) and chloride (average 5.82 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 6 µg/l and 126 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and organic matter (3.4 mg/l) and Fe concentrations (average 24 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Gardsjoen is relatively distant from the "Pechenganickel" smelter, it is still subjected to anthropogenic impacts. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.). Despite the fact that emissions from the smelter have been reduced to approximately one third of the maximum levels of the late 1970s, the deposition of pollutants still has an impact on the water bodies in the region. The average concentrations of Cu and Ni are 2.0 µg/l and 4.5 µg/l, respectively.

Hydrochemical properties	
pH	6.57 6.33-6.71
Electrical conductivity, mS/cm	36 34-38
Ca, mg/l	1.61 1.50-1.70
Mg, mg/l	0.74 0.78-0.92
Na, mg/l	3.61 3.40-3.83
K, mg/l	0.34 0.32-0.36
HCO_3, mg/l	3.7 3.3-4.0
SO_4, mg/l	4.22 4.04-4.44
Cl, mg/l	5.82 5.34-6.26
Total mineralization, mg/l	20.1 19.4-20.8
Alkalinity, µeq/l	60 54-65

Water colour, deg.	10 8-11
NH_4, µg/l	4 1-9
NO_3, µg/l	3 1-16
Total N, µg/l	108 86-126
PO_4, µg/l	1 1-1
Total P, µg/l	4 1-6
Fe, µg/l	24.2 17.4-35.7

Cu, µg/l	2.0 1.2-3.6
Ni, µg/l	4.5 3.7-5.7
Al, µg/l	39 30-48
Pb, µg/l	0.3 0.2-0.5

2.3.2. Lake bottom sediments

The sediments of Lake Gardsjoen have relatively low organic matter contents (LOI) in the uppermost 1 cm layer of slightly more than 20% (Table 26). The lake is located at a distance of only 38 km from the Pechenganickel smelter, and is therefore subjected to the deposition of heavy metals (Ni and Co), as well as chalcophile elements such as Hg, Pb and As. The top 2-4 cm sediment is the most polluted. The accumulation of Pb in the sediments started earlier (Fig. 41). The contamination factor values of these metals range from 1.5 up to 5.7 (Table 26), i.e. the values correspond to moderate and considerable (Pb) contamination. Lead has the highest C_f value. The contamination factor values of the other heavy metals are low. The degree of contamination value (15.0) for this lake corresponds to moderate contamination.

Table 26. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (16-17 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Gardsjoen	0-1	21.89	66	72	58	12	0.18	17.7	1.52	0.082	
	16-17	18.91	41	28	81	25	0.23	3.1	0.94	0.056	
C_f			**1.6**	**2.6**	**0.7**	**0.5**	**0.8**	**5.7**	**1.6**	**1.5**	**15.0**

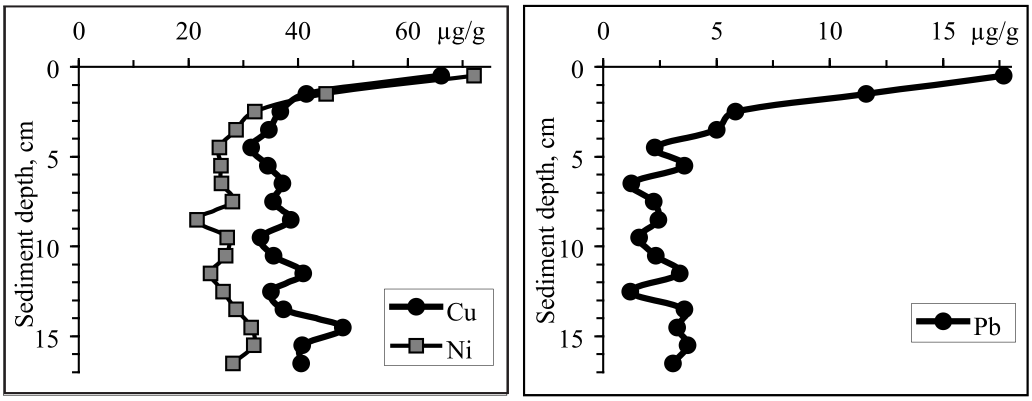


Fig. 41. *Vertical distribution of the concentrations of Cu, Ni and Pb (µg/g, dry weight) in the sediment core of Lake Gardsjoen.*

2.3.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.4. LAKE GJOKVATN

Physico-geographical characteristics	
Watershed	River Gjokbekken—River Paz (Gjokbukta)
Latitude	69°09.181′
Longitude	29°05.910′
Height above sea level, m	96.0
Maximum length, km	1.22
Maximum width, km	0.60
Maximum depth, m	12
Area, km^2	0.62
Watershed area, km^2	6.37
Study period	2004-2005

Lake Gjokvatn (watershed of the River Paz) is located 58 km to the south-west of the town of Nickel. The elongated, oval-shaped lake is relatively small (area of the lake 0.62 km^2), not deep (maximum depth 12 m), and is of glacial origin. The maximum length is 1.22 km and maximum width 0.60 km. The points of maximum depth are located in the central part of the lake.

The lake originates from the River Gjekbekken. According to the landscape type. the watershed belongs to the forest zone, with heights of up to 180 m. The lake shores are high and covered by pine forests and shrub vegetation. Boulder beds occur throughout almost the whole littoral zone.

The water of the lake is colourless, but it occasionally increases to 41 deg. and become yellowish.

2.4.1. Hydrochemistry

The water of the lake is slightly acidified and has a low total mineralization (average 14.1 mg/l) and alkalinity (average 116 µeq/l). During flood periods the pH of the water drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 1.99 mg/l) and bicarbonate (average 7.1 mg/l) predominating.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 8 µg/l and 202 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as mezotrophic. The colour values and the organic matter (8.4 mg/l) and Fe concentrations (average 138 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO43- and NO3-, which determine the lake productivity, are low.

Although the watershed of Lake Gjokvatn is relatively remote from the Pechenganickel smelter (distance of 58 km), it is exposed to anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, co, etc.). Despite the fact that emissions from the smelter have been reduced to approximately one

Hydrochemical properties	
pH	6.53 6.11-6.73
Electrical conductivity, mS/cm	26 24-28
Ca, mg/l	1.99 1.88-2.08
Mg, mg/l	0.64 0.59-0.71
Na, mg/l	1.68 1.52-1.90
K, mg/l	0.60 0.54-0.67
HCO_3, mg/l	7.1 6.5-7.7
SO_4, mg/l	2.38 2.15-2.63
Cl, mg/l	1.60 1.39-1.98
Total mineralization, mg/l	14.1 14.7-17.7
Alkalinity, µeq/l	116 107-126

Water colour, deg.	37 34-41
NH_4, µg/l	9 6-12
NO_3, µg/l	14 3-34
Total N, µg/l	196 192-202
PO_4, µg/l	1 1-1
Total P, µg/l	7 6-8
Fe, µg/l	138 100-200

Cu, µg/l	2.1 0.9-5.5
Ni, µg/l	1.2 0.9-1.6
Al, µg/l	54 40-69
Pb, µg/l	0.6 0.2-1.2

third of the peak levels of the late 1970s, the deposition of pollutants still affects the water bodies in the area. The average concentrations of Cu, Ni and Al are 2.1 µg/l, 1.2 µg/l and 54 µg/l, respectively.

2.4.2. Lake bottom sediments

The sediments of Lake Gjokvatn have organic matter contents (LOI) in the uppermost 1 cm layer of more than 30% (Table 27). Airborne deposition of pollutants from the smelter does not seriously affect water quality of the lake, the pollution mainly consisting of chalcophile elements such as Pb, As, Cd and Hg. The top 4-5 cm sediment layer is the most polluted (Fig. 42). The contamination factor values of these heavy metals range from 1.8 to 5.1 (Table 27), i.e. the values correspond to considerable and moderate (Cd and Hg) contamination. Arsenic has the highest C_f value. The contamination factor values of the other heavy metals are moderate to low. The degree of contamination value (17.2) for this lake corresponds to considerable contamination.

Table 27. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (21-22 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Gjokvatn	0-1	31.61	73	56	134	36	0.67	34.3	3.03	0.309	
	21-22	37.33	151	36	236	25	0.33	8.0	0.60	0.168	
C_f			**0.5**	**1.5**	**0.6**	**1.5**	**2.0**	**4.3**	**5.1**	**1.8**	**17.2**

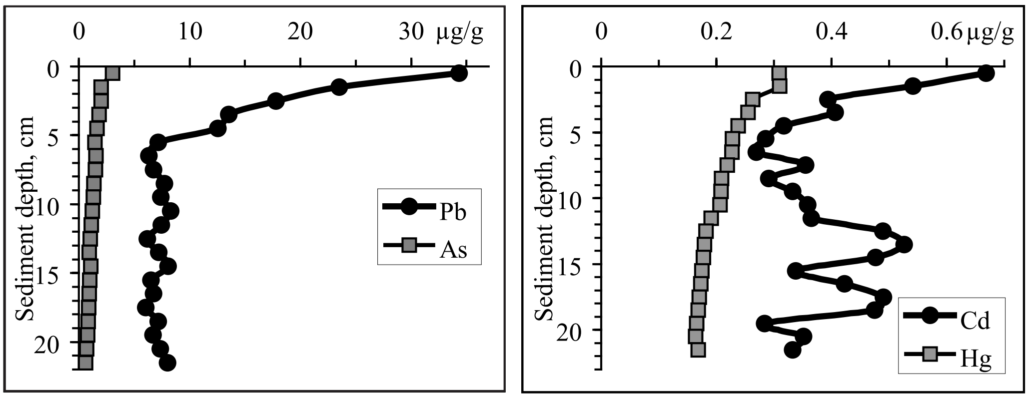


Fig. 42. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Gjokvatn.*

2.4.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.5. LAKE GUOKALABBALAT

Lake Guokalabbalat (watershed of the River Kobbholmselva) is located 30 km to the north of the town of Zapolyarny. The elongated lake is relatively small (area of the lake 0.13 km^2), not deep (maximum depth 11 m), and is of glacial origin. The maximum length is 650 m and maximum width 410 m. The points of maximum depth are located in the central part of the lake.

The lake forms part of a lake-river system. According to the landscape type, the watershed belongs to the tundra zone with heights of up to 349 m. Boulder beds occur throughout almost the whole littoral zone. The lake shores are high and covered by grass and shrub vegetation. The water of the lake is colourless both during high water periods and episodes of high precipitation.

Physico-geographical characteristics	
Watershed	River Kobbholmselva—the Barents Sea
Latitude	69°42.200′
Longitude	30°46.752′
Height above sea level, m	186.0
Maximum length, km	0.65
Maximum width, km	0.41
Maximum depth, m	11
Area, km^2	0.13
Watershed area, km^2	5.25
Study period	1996-2005

2.5.1. Hydrochemistry

The proximity of the sea has a considerable influence on the water quality. The water in the lake is slightly acidified and has a low total mineralization (average 16.6 mg/l) and alkalinity (average 32 μeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 3.13 mg/l) and chloride (average 5.2 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Hydrochemical properties	
pH	<u>6.34</u> 6.09-6.55
Electrical conductivity, mS/cm	<u>31</u> 27-33
Ca, mg/l	<u>1.32</u> 1.10-1.45
Mg, mg/l	<u>0.68</u> 0.62-0.74
Na, mg/l	<u>3.13</u> 2.72-3.50
K, mg/l	<u>0.28</u> 0.23-0.38
HCO_3, mg/l	<u>2.0</u> 1.3-2.5
SO_4, mg/l	<u>4.00</u> 3.81-4.17
Cl, mg/l	<u>5.20</u> 4.37-5.70
Total mineralization, mg/l	<u>16.6</u> 14.4-18.1
Alkalinity, μeq/l	<u>32</u> 22-41

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 5 μg/l and 147 μg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and organic matter (2.6 mg/l) and Fe concentrations (average 15.8 μg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Guokalabbalat is relatively distant from the "Pechenganickel" smelter (distance of 30 km), it is still subjected to the impacts of pollution from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.). Despite the fact that emissions from the smelter have fallen to approximately one third of the peak levels of the late 1970s, the deposition of pollutants still influences the water bodies in the region. The average concentrations Cu and Ni are 1.5 µg/l and 5.1 µg/l, respectively.

Water colour, deg.	7 5-13
NH4, µg/l	12 1-34
NO3, µg/l	6 1-24
Total N, µg/l	97 67-147
PO4, µg/l	2 1-2
Total P, µg/l	4 2-5
Fe, µg/l	15.8 6.6-27.6

Cu, µg/l	1.5 1.0-2.4
Ni, µg/l	5.1 4.4-6.2
Al, µg/l	38 27-54
Pb, µg/l	0.3 0.1-0.7

2.5.2. Lake bottom sediments

The sediments of Lake Guokalabbalat were investigated already more than 10 years ago – sediment core samples were taken on the 18th of July, 1996. However, the concentrations of toxic chalcophile elements such as Hg and As were not determined at that time. The sediments in Lake Guokalabbalat have organic matter contents (LOI) in the uppermost 1 cm layer of slightly more than 20% (Table 28). As the lake is located at a distance of 27 km from the Pechenganickel smelter, emissions from the smelter have a considerable effect on pollutant concentrations (Ni, Cu and Co), and it is also subjected to pollution by chalcophile elements, such as Cd and Pb. The top 1-2 cm layer of the sediments is the most polluted (Fig. 43). There is also an increase in the concentration of heavy metals in the 5-8 cm layer, which is also probably due to pollution from the iron mine near Kirkenes. The contamination factor values of these heavy metals range from 1.5 to 3.9 (Table 28), i.e. the values correspond to moderate and considerable contamination. Nickel has the highest C_f value. The degree of contamination value (13.8) for this lake corresponds to considerable (for six elements) contamination.

Table 28. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (13-14 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Guokalabbalat	0-1	23.63	133	214	146	136	2.18	175	–	–	
	13-14	18.40	86	54	151	45	1.40	64	–	–	
C_f			**1.5**	**3.9**	**1.0**	**3.0**	**1.6**	**2.7**	**–**	**–**	**13.8**

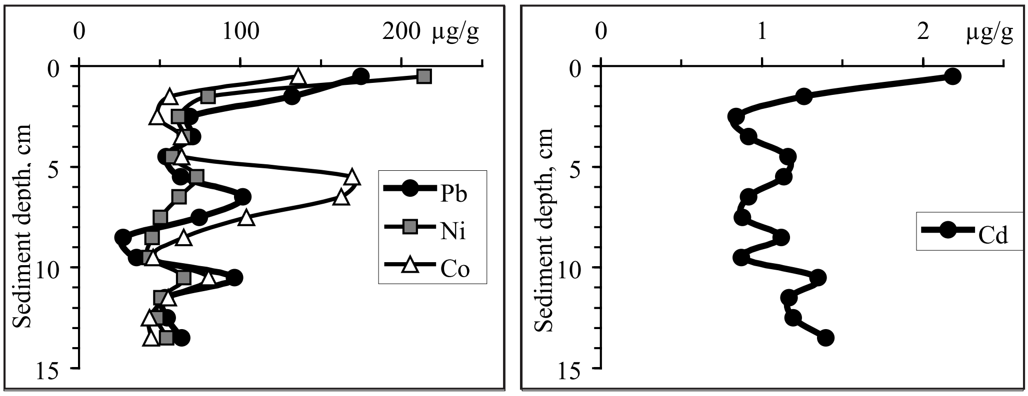


Fig. 43.
Vertical distribution of the concentrations of Ni, Co, Pb and Cd (µg/g, dry weight) in the sediment core of Lake Guokalabbalat.

2.5.3. Hydrobiological studies

Hydrobiological indices

Cyanobacteria are almost completely absent from the phytoplankton communities in Lake Guokalabbalat. The dominant species are the division of yellow-green algae (*Crysophyta*), diatoms (*Bacillariophyta*) and green algae (*Chlorophyta*) (Sharov, 2004).

According to earlier studies, the dominant complex in zooplankton communities of Jarfjord lakes is one species of rotifera (*Kellicotia longispina*) (Yakovlev et al., 1991). The density of Cladocerae and Copepoda does not exceed 15 000 specimens/m^3. Copepods are predominant. The predominant species in the division of benthic communities are mayfly (*Ephemeroptera*) and stoneflies (*Plecoptera*). The relative abundance (%) of acid- and pollution-sensitive species is 1.6. The value of the Shannon diversity index of the benthos is 3.23 (Yakovlev et al., 2007).

Ichthyofauna. Studies on the fish community of Lake Guokalabbalat were conducted in 1995 (Kashulin, 2004). The data indicate that trout and arctic char inhabit the lake. The average length of char is 16.3 cm, and weight 45 g. The size of the larges individuals reaches 30.8 cm and 314 g, respectively. The bulk of the char population consists of 2- to 3-year-old fish (~90%). 3-year-old specimens are predominant, and fish of other age classes are occasionally caught. Males are predominant in the sex distribution (1.3:1).

Heavy metals in fish

Heavy metal (Cu, Ni, Pb, Cd and Hg) concentrations in fish muscle do not exceed the established standard values (Table 29). Nevertheless, the concentrations of Cu (µg/g dry weight) in the liver of char (up to 217.6 µg/g) and trout (up to 266.6 µg/g) are considerably higher than in muscle. The Ni and Cd concentrations in the kidneys of the above fish species reach 5.1 and 5.9 µg/g in char, and 6.2 and 3.9 µg/g in trout, respectively. The variation in the Hg concentrations in this species are not significant.

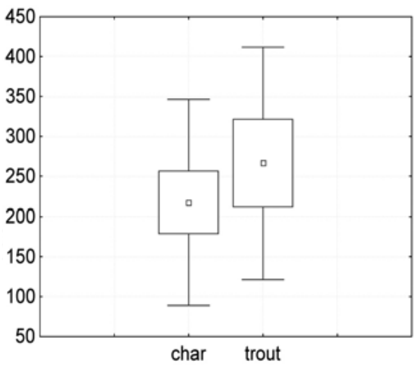
The analysis of heavy metal accumulation in different fish species showed that trout have the highest concentrations of Ni (in kidneys) and Cu (in liver). Lead and Hg accumulate more strongly in char muscle (Fig. 44).

Table 29.
The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Guokalabbalat (in µg/g wet and dry weight).

	Standard value (µg/g wet weight)*	Concentration in muscle (µg/g wet weight)	Concentration in muscle (µg/g dry weight)
		Char	
Hg	0.5	0.07	0.28
Ni	0.5	0.19	0.80
Cu	20	0.37	1.59
Cd	0.1	0.005	0.02
Pb	1	0.04	0.17
		Trout	
Hg	0.5	0.05	0.23
Ni	0.5	0.20	0.89
Cu	20	0.34	1.50
Cd	0.1	0.004	0.02
Pb	1	0.02	0.10

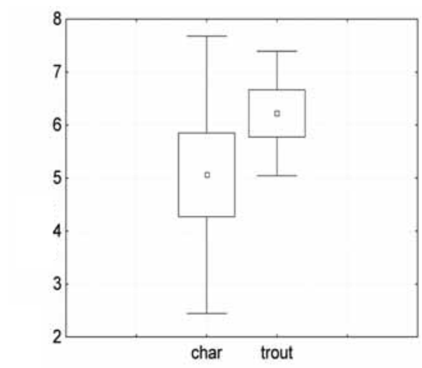
* Source: Sanitary..., 1986

Cu in liver



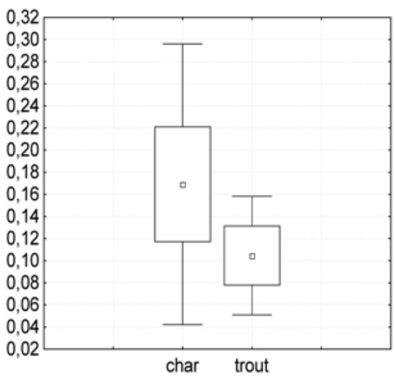
Concentration of Cu in liver (µg/g dry weight)

Ni in kidneys



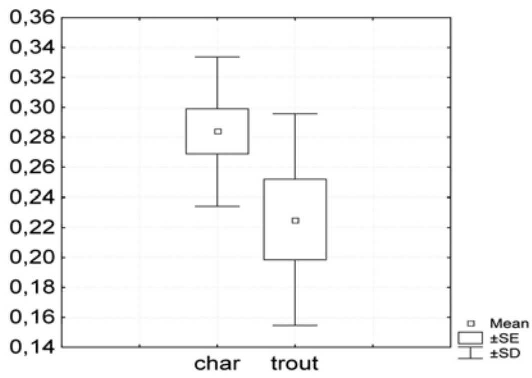
Concentration of Ni in kidney (µg/g dry weight)

Pb in muscle



Concentration of Pb in muscle (µg/g dry weight)

Hg in muscle



Concentration of Hg in muscle (µg/g dry weight)

Fig. 44.
Cu (liver), Ni (kidneys), Pb and Hg (muscle) concentrations in fish from Lake Guokalabbalat (µg/g dry weight).

2.6. LAKE HOLMVATN

Lake Holmvatn (watershed of the River Kobbholmselva) is located 32 km to the north of the town of Zapolyarny. The almost oval-shaped lake is relatively small (area of the lake 0.94 km^2), not deep (maximum depth 15 m), and is of glacial origin. The maximum length is 1.95 km and maximum width 0.85 km. The points of maximum depth are located in the central part of the lake.

The lake forms part of a lake-river system. According to the landscape type, the watershed area belongs to the tundra zone, with heights of up to 349 m. The lake shores are high and covered by grass and shrub vegetation. The water of the lake is colourless.

Physico-geographical characteristics	
Watershed	River Kobbholmselva—the Barents Sea
Latitude	69°42.601′
Longitude	30°45.909′
Height above sea level, m	156.0
Maximum length, km	1.95
Maximum width, km	0.85
Maximum depth, m	15
Area, km^2	0.94
Watershed area, km^2	15.25
Study period	2004-2005

2.6.1. Hydrochemistry

The proximity of the sea has a considerable influence on water quality. The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 17.6 mg/l) and alkalinity (average 44 µeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 3.17 mg/l) and chloride (average 5.07 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Hydrochemical properties	
pH	6.53 6.44-6.58
Electrical conductivity, mS/cm	32 32-33
Ca, mg/l	1.52 1.44-1.59
Mg, mg/l	0.74 0.73-0.75
Na, mg/l	3.17 3.14-3.24
K, mg/l	0.31 0.29-0.33
HCO_3, mg/l	2.7 2.7-2.4
SO_4, mg/l	4.08 4.00-4.12
Cl, mg/l	5.07 5.02-5.11
Total mineralization, mg/l	17.6 17.5-17.7
Alkalinity, µeq/l	44 44-45

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 5 µg/l and 100 µg/l, respectively.

According to the concentrations of minewral nutrients, the lake is classified as oligotrophic. The colour values and organic matter (2.4 mg/l) and Fe concentrations (average 7.1 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Holmvatn is relatively distant from the Pechenganickel smelter (32 km), it is still subjected to the impacts of pollutants from thr smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co etc.). Despite the fact that emissions from the smelter have been reduced to approximately one third of the peak levels of the late 1970s, the deposition of pollutants still has an impact on the water bodies in the area. The average concentrations of Cu and Ni are 2.8 µg/l and 5.8 µg/l, respectively.

Water colour, deg.	6 6-6
NH_4, µg/l	6 4-9
NO_3, µg/l	2 1-3
Total N, µg/l	97 95-100
PO_4, µg/l	1 1-1
Total P, µg/l	4 4-5
Fe, µg/l	7.1 5.5-9.3

Cu, µg/l	2.8 1.6-3.5
Ni, µg/l	5.8 5.0-7.3
Al, µg/l	28 25-33
Pb, µg/l	0.3 0.2-0.3

2.6.2. Lake bottom sediments

The sediments in Lake Holmvatn have very low organic matter contents (LOI): in the uppermost 1 cm layer LOI is less than 20% (Table 30). As the lake is located at a distance of 37 km from the "Pechenganickel" smelter, emissions from the smelter have a relatively small impact on the lake. Pollution by chalcophile elements is also low. Despite this, the maximum concentrations of almost all metals (Ni, Zn, Co, Cd and Hg) occurred in the 2-5 cm sediment layer (Fig. 45). The accumulation of metals in this layer is presumably due to strong pollution from an unknown source. The contamination factor values for these heavy metals range from 0.4 to 3.6 (Table 30), i.e. the values correspond to low and moderate contamination. The degree of contamination value (13.0) for this lake corresponds to moderate contamination.

Table 30. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (12-13 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Holmvatn	0-1	19.45	62	37	98	48	0.16	25.6	1.60	0.048	
	12-13	13.49	67	20	59	13	0.08	21.9	3.94	0.035	
C_f			**0.9**	**1.9**	**1.6**	**3.6**	**2.1**	**1.2**	**0.4**	**1.4**	**13.0**

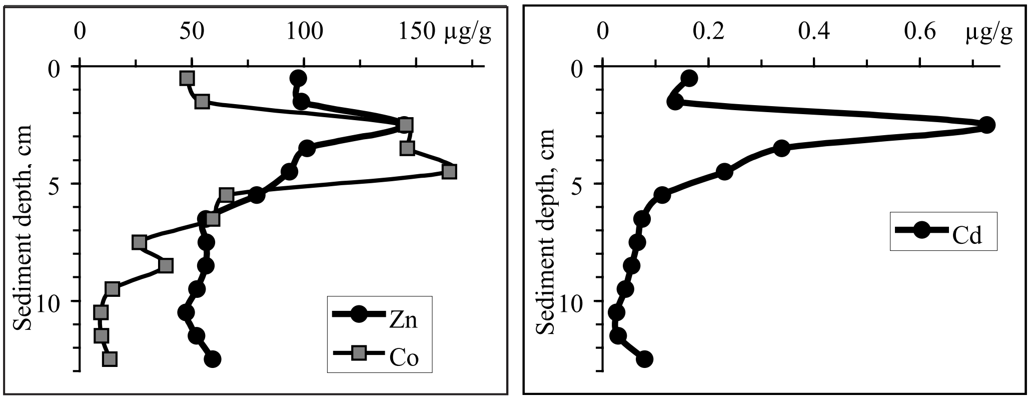


Fig. 45.
Vertical distribution of the concentrations of Zn, Co and Cd (μg/g, dry weight) in the sediment core of Lake Holmvatn.

2.6.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.7. LAKE ISALOMBOLA

Physico-geographical characteristics	
Watershed	River Ellenelva—River Paz (Tjerebukta)
Latitude	69°09.493′
Longitude	28°58.080′
Height above sea level, m	112.0
Maximum length, km	2.65
Maximum width, km	1.07
Maximum depth, m	11
Area, km²	1.62
Watershed area, km²	74.0
Study period	2002-2005

Lake Isalombola (watershed of the River Paz) is located 62 km to the south-west of the town of Nickel. The elongated, oval-shaped lake is not large (the area of the lake is 1.62 km^2) nor deep (maximum depth 11 m), and is of glacial origin. The maximum length is 2.65 km and maximum width 1.07 km. The points of maximum depth are located in the central part of the lake.

The lake forms part of the Ellenelva lake-river system. According to the landscape type, the watershed belongs to the forest zone with heights of up to 260 m. The lake shores are low, and covered by shrub vegetation and pine forests. Boulder beds occur in almost parts of the littoral zone.

2.7.1. Hydrochemistry

The pH of the water in the lake is close to neutral, and the lake has a low total mineralization (average 14.6 mg/l) and alkalinity (average 109 μeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 1.71mg/l) and bicarbonate (average 6.7 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 10 µg/l and 307 µg/l, respectively.

According to the concentrations of mineral nutgrients, the lake is classified as mezotrophic. The colour values and organic matter (4.9 mg/l) and Fe concentrations (average 39 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Although the watershed of Lake Isalombola is relatively remote from the Pechenganickel smelter (62 km), it is subjected to anthropogenic impacts as a result of emissions from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, co, etc.). Despite the fact that emissions from the smelter have fallen to approximately one third of the peak levels of the late 1970s, the deposition of pollutants still affects the water bodies in the area. The average concentrations of Cu and Ni are 1.3 µg/l and 1.4 µg/l, respectively.

Hydrochemical properties	
pH	6.79 6.62-6.98
Electrical conductivity, mS/cm	23 21-24
Ca, mg/l	1.71 1.46-1.81
Mg, mg/l	0.58 0.50-0.63
Na, mg/l	1.52 1.46-1.67
K, mg/l	0.47 0.44-0.50
HCO_3, mg/l	6.7 6.0-7.1
SO_4, mg/l	2.16 2.07-2.25
Cl, mg/l	1.56 1.36-1.85
Total mineralization, mg/l	14.6 13.3-15.8
Alkalinity, µeq/l	109 99-117

Water colour, deg.	13 12-15
NH_4, µg/l	9 7-10
NO_3, µg/l	2 1-4
Total N, µg/l	188 145-307
PO_4, µg/l	2 1-4
Total P, µg/l	6 3-10
Fe, µg/l	39 32-51

Cu, µg/l	1.3 0.5-2.7
Ni, µg/l	1.4 0.6-2.6
Al, µg/l	17 13-20
Pb, µg/l	0.3 0.2-0.6

2.7.2. Lake bottom sediments

The sediments in Lake Isalombola have relatively high organic matter contents (LOI): in the uppermost 1 cm layer it was about 30% (Table 31). The lake is located at a distance of 59 km from the Pechenganickel smelter. As a result, emissions from the smelter have a relatively minor effect on water quality, and the lake is subjected primarily to the deposition of chalcophile elements such as Pb, As, Cd and Hg. The top 3-4 cm sediment layer is the most polluted (Fig. 46). The contamination factor values for these toxic chalcophile metals range from 2.1 to 19.9 (Table 31), i.e. the values correspond to high, considerable and moderate (Hg) contamination. Lead has the highest

C_f value. Contamination factor values for the other heavy metals are moderate. The degree of contamination value (36.0) for this lake corresponds to high contamination.

Table 31. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (22-23 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Isalombola	0-1	29.13	71	28	109	8.3	0.35	21.6	4.56	0.188	
	22-23	23.81	80	13	93	6.7	0.08	1.1	1.02	0.090	
C_f			**0.9**	**2.1**	**1.2**	**1.2**	**4.2**	**19.9**	**4.5**	**2.1**	**36.0**

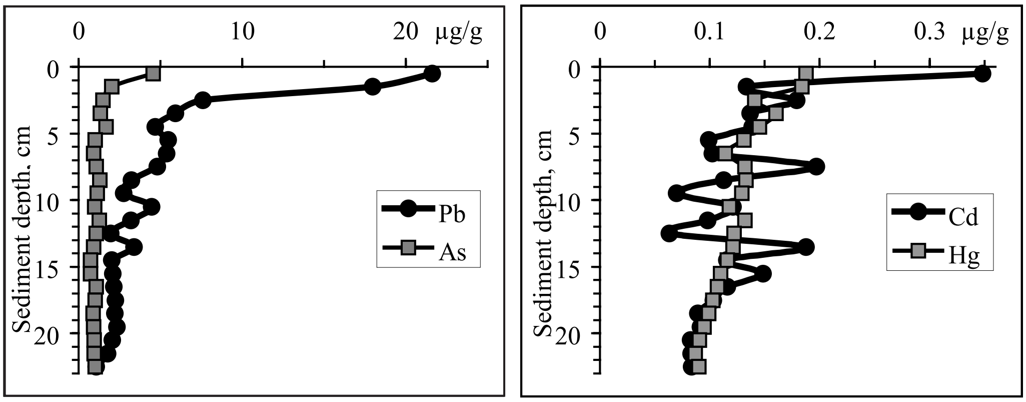


Fig. 46. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Isalombola.*

2.7.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.8. LAKE KOBBHOLMVATN

Lake Kobbholmvatn (watershed of the River Kobbholmselva) is located 34 km to the north of the town of Zapolyarny. The lake is relatively large (area of the lake 4.0 km^2), deep (maximum depth 43 m), has an indented shoreline and is of glacial origin. The maximum length is 4.15 km and maximum width 2.47 km. The points of maximum depth are located in the central part of the lake.

Physico-geographical characteristics	
Watershed	River Kobbholmselva—the Barents Sea
Latitude	69°43.294′
Longitude	30°40.899′
Height above sea level, m	114.0
Maximum length, km	4.15
Maximum width, km	2.47
Maximum depth, m	43
Area, km^2	4.0
Watershed area, km^2	25.1
Study period	2003-2005

The lake forms part of a lake-river system. According to the landscape type, the watershed belongs to the tundra zone, with heights of up to 396 m. Boulder beds occur in almost all parts of the littoral zone. The lake shores are high, and covered by grass and shrub vegetation. The water of the lake is colourless.

2.8.1. Hydrochemistry

The proximity of the sea has aconsiderable influence on the water quality. The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 16.3 mg/l) and alkalinity (average 22 µeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 3.20 mg/l) and chloride (average 5.15 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Hydrochemical properties	
pH	6.26 6.03-6.46
Electrical conductivity, mS/cm	31 30-32
Ca, mg/l	1.24 1.05-1.36
Mg, mg/l	0.68 0.59-0.74
Na, mg/l	3.20 3.14-3.27
K, mg/l	0.31 0.29-0.36
HCO3, mg/l	1.4 0.8-1.8
SO4, mg/l	4.37 4.05-4.57
Cl, mg/l	5.15 5.10-5.43
Total mineralization, mg/l	16.3 14.9-17.4
Alkalinity, µeq/l	22 13-30

Water colour, deg.	4 3-5
NH_4, µg/l	7 4-13
NO_3, µg/l	37 32-51
Total N, µg/l	107 80-154
PO_4, µg/l	1 1-1
Total P, µg/l	3 1-4
Fe, µg/l	6.5 3.8-11.4

Cu, µg/l	1.8 0.3-3.3
Ni, µg/l	5.8 5.4-6.9
Al, µg/l	21 18-24
Pb, µg/l	0.3 0.2-0.4

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 4 µg/l and154 µg/l, correspondingly.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (2.1 mg/l) and Fe concentrations (average 6.5 µg/l) are typical of small water bodies in the region. During flood periods in the summer the average concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Kobbholmvatn is relatively distant from the Pechenganickel smelter (distance of 34 km), it is still subjected to the effects of emissions from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co etc.). Despite the fact that emissions from the smelter have dropped to approximately one third of the peak levels of the late 1970s, the deposition of pollutants still has an impact on the water bodies in the area. The average concentrations of Cu and Ni are 1.8 µg/l and 5.8 µg/l, respectively.

2.8.2. Lake bottom sediments

The sediments of Lake Kobbholmvatn have extremely low organic matter contents (LOI): in the uppermost 1 cm layer it is only slightly more than 3% (Table 32). Owing to the fact that the lake is situated at a distance of 34 km from the smelter, the deposition of pollutants has only a minor effect on water quality. Pollution by chalcophile elements is also relatively insignificant. The contamination factor values for the heavy metals range from 0.5 to 1.1 (Table 32), i.e. almost all the metals, apart from Ni, have low contamination levels. The degree of contamination value (5.2) for this lake corresponds to low contamination.

Table 32. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Kobbholmvatn	0-1	3.45	74	67	107	27	0.13	16.0	1.35	0.022	
	14-15	13.13	130	60	197	61	0.22	33.5	1.53	0.037	
C_f			**0.6**	**1.1**	**0.5**	**0.5**	**0.6**	**0.5**	**0.9**	**0.6**	**5.2**

2.8.3. Hydrobiology investigations

No direct hydrobiology investigations have been carried out in this lake.

2.9. LAKE LANGVATN

Physico-geographical characteristics	
Watershed	River Dammasjoki—Jarfjord (The Barents Sea)
Latitude	69°43.553′
Longitude	30°35.509′
Height above sea level, m	87.0
Maximum length, km	2.23
Maximum width, km	0.57
Maximum depth, m	21
Area, km²	0.87
Watershed area, km²	7.3
Study period	2003-2005

Lake Langvatn (watershed of the River Dammasjoki) is located 34 km to the north of the town of Zapolyarny. The elongated lake is relatively small (area of the lake 0.87 km^2), not deep (maximum depth 21 m), and is of glacial origin. The maximum length is 2.23 km and maximum width 0.57 km. The points of maximum depth are located in the central part of the lake.

The lake belongs to a lake-river system. According to the landscape type, the watershed belongs to the tundra zone, with heights of up to 356 m. Boulder beds occur in almost all parts of the littoral zone. The lake shores are high, and covered by grass and shrub vegetation. The southern shore leads abruptly down to the water. The road to Jacobselv passes along the northern shore. The water of the lake is colourless.

2.9.1. Hydrochemistry

The proximity of the sea has a considerable influence on water quality. The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 18.6 mg/l) and alkalinity (average 33 μeq/l). During flood periods the pH falls slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 3.43 mg/l) and chloride (average 5.76 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 6 μg/l and 205 μg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (2.5 mg/l) and Fe concentrations (average 10.4 μg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Hydrochemical properties	
pH	6.40 6.32-6.55
Electrical conductivity, mS/cm	34 34-37
Ca, mg/l	1.63 1.50-1.70
Mg, mg/l	0.73 0.68-0.80
Na, mg/l	3.43 3.25-3.58
K, mg/l	0.30 0.27-0.38
HCO_3, mg/l	2.1 1.9-2.3
SO_4, mg/l	4.69 4.58-4.81
Cl, mg/l	5.76 5.24-6.26
Total mineralization, mg/l	18.6 17.7-19.5
Alkalinity, μeq/l	33 31-37

Water colour, deg.	6 5-6
NH_4, μg/l	6 3-9
NO_3, μg/l	10 6-13
Total N, μg/l	118 81-205
PO_4, μg/l	1 1-1
Total P, μg/l	4 3-6
Fe, μg/l	10.4 6.8-13.0

Cu, μg/l	1.7 1.2-2.6
Ni, μg/l	3.7 3.0-4.5
Al, μg/l	32 24-38
Pb, μg/l	0.4 0.2-1.0

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. Although the watershed of Lake Langvatn is relatively distant from the Pechenganickel smelter (distance of 34 km), it is still subjected to the impact of emissions from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.). Despite the fact that emissions from the smelter have been reduced to approximately one third of the maximum levels in the late 1970s, the deposition of pollutants still has an influence on the quality of the water bodies in the lake. The average concentrations of Cu and Ni are 1.7 µg/l and 3.7 µg/l, respectively.

2.9.2. Lake bottom sediments

The sediments in Lake Langvatn have organic matter contents (LOI) in the uppermost 1 cm layer ofabout 25% (Table 33). Airborne pollutants from the smelter have a relatively insignificant effect on pollution in the lake. Pollution by chalcophile elements is also relatively minor. Surprisingly, the maximum concentrations of practically all the heavy metals (Cu, Ni, Zn, Co and Cd) occur in the 3-4 cm sediment layer (Fig. 47). The accumulation of metals in this layer is presumably due to strong pollution from an unknown source. The contamination factor values for these heavy metals range from 0.4 to 2.6 (Table 33), i.e. the values correspond to low and moderate contamination. Cobolt has the highest C_f value. The degree of contamination value (10.7) for this lake orresponds to moderate contamination.

Table 33. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (13-14 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Langvatn	0-1	25.24	121	52	110	62	0.19	26	4.14	0.096	
	13-14	20.61	137	31	109	24	0.50	20	3.53	0.056	
C_f			**0.9**	**1.7**	**1.0**	**2.6**	**0.4**	**1.3**	**1.2**	**1.7**	**10.7**

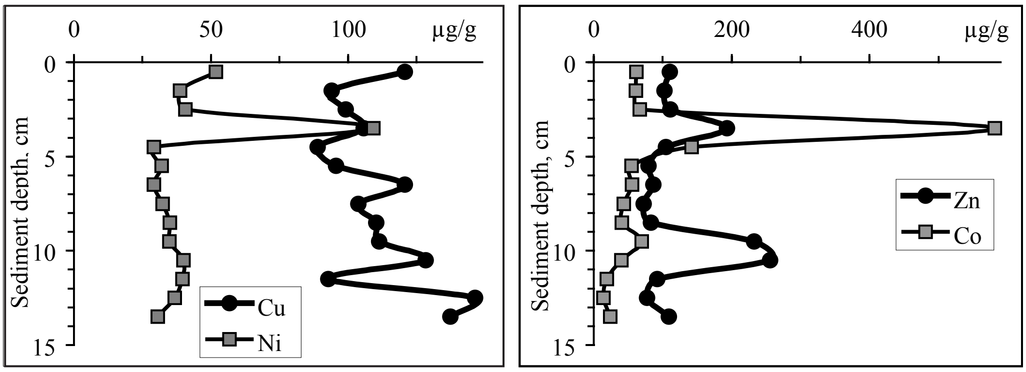


Fig. 47. *Vertical distribution of the concentrations of Cu, Ni, Zn and Co (µg/g, dry weight) in the sediment core of Lake Langvatn.*

2.9.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.10. LAKE N-254

Lake N-254 (watershed of the River Jacobselv) is located 19 km to the north of the town of Zapolyarny. The oval-shaped lake is not large (the area of the lake is 0.09 km^2), nor deep (maximum depth 2.5 m), and is of glacial origin. The maximum length is 500 m and maximum width 250 m. The points of maximum depth are located in the northern part of the lake.

The lake forms part of a lake-river system. According to the landscape type, the watershed belongs to the tundra zone, with heights of up to 405 m (Gouvdoaive fell). Boulder beds occur in almost all parts of the littoral zone. The southern shore is waterlogged. The old road to the settlement of Pechenga (Russia) passes along the northern shore. The water of the lake is colourless.

Physico-geographical characteristics	
Watershed	River Urdalselva—River Jacobselv—the Barents Sea
Latitude	69°35.789′
Longitude	30°44.545′
Height above sea level, m	254.0
Maximum length, km	0.50
Maximum width, km	0.25
Maximum depth, m	2.5
Area, km^2	0.09
Watershed area, km^2	7.62
Study period	2003-2004

2.10.1. Hydrochemistry

The proximity of the sea has a considerable influence on the water quality. The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 22.4 mg/l) and alkalinity (average 114 µeq/l). The lake has low concentrations of base cations and anions, with sodium (average 3.09 mg/l) and bicarbonate (average 7.0 mg/l) predominating.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The average concentrations of total P and total N during the vegetation period are 5 µg/l and 176 µg/l, respectively.

Hydrochemical properties	
pH	6.84 6.83-6.87
Electrical conductivity, mS/cm	36 35-38
Ca, mg/l	2.05 1.92-2.14
Mg, mg/l	1.02 0.94-1.09
Na, mg/l	3.09 2.93-3.18
K, mg/l	0.31 0.29-0.33
HCO_3, mg/l	7.0 6.7-7.1
SO_4, mg/l	4.55 4.34-4.77
Cl, mg/l	4.41 4.13-4.74
Total mineralization, mg/l	22.4 22.1-22.9
Alkalinity, µeq/l	114 110-117

Water colour, deg.	8 7-9
NH_4, µg/l	18 12-29
NO_3, µg/l	1 1-1
Total N, µg/l	158 136-176
PO_4, µg/l	1 1-2
Total P, µg/l	5 5-5
Fe, µg/l	39.0 30.2-59.4

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (3.3 mg/l) and Fe concentrations (average 39 μg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of $PO_4$3- and NO3-, which determine the lake productivity, are low.

The low micronutrient concentrations of the water entering the water body reflect the low level of chemical weathering of the minerals present in the watershed area. The watershed area of Lake N-254 is 19 km from the "Pechenganickel" smelter, and is exposed to the emission of pollutants. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.). Despite the fact that emissions from the smelter dropped to approximately one third of the peak levels of the late 1970s, the deposition of pollutant still has an impact on the water quality. The average concentrations of Cu and Ni are 3.2 μg/l and 6.7 μg/l, respectively.

Cu, μg/l	3.2 2.5-3.8
Ni, μg/l	6.7 5.2-8.7
Al, μg/l	16 12-24
Pb, μg/l	0.3 0.2-0.3

2.10.2. Lake bottom sediments

The sediments in Lake N-254 have relatively high organic matter contents (LOI): in the uppermost 1 cm layer LOI is above 30% (Table 34). As the lake is situated at a distance of 27 km from the Pechenganickel smelter, emissions from the smelter affect the amount of pollution (Ni, Cu, Zn and Co) in the lake. The lake is also subject to pollution by chalcophile elements, such as Cd, Pb and As. The top 2-3 cm sediment layer is the most polluted. The contamination factor values for these toxic heavy metals range from 1.2 to 2.0 (Table 34), i.e. the values correspond to moderate contamination. Zinc has the highest C_f value. The contamination factor value for Hg is low. The degree of contamination value (11.5) for this lake corresponds to moderate contamination.

Table 34. *The contents of organic matter (loss of weight on ignition – LOI, %) and heavy metals (μg/g, dry weight) in surface (0-1 cm) and background (6-7 cm) layers of sediments. C_f and C_d – values of contamination factor and degree of contamination, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
N-254	0-1	32.69	34	53	89	9	0.44	2.58	1.67	0.022	
	6-7	34.06	28	36	45	7	0.33	1.63	0.93	0.025	
C_f			**1.2**	**1.5**	**2.0**	**1.3**	**1.3**	**1.6**	**1.8**	**0.9**	**11.5**

2.10.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.11. LAKE SAMETTIVATN

Physico-geographical characteristics	
Watershed	River Sametti—River Paz
Latitude	69°27.581′
Longitude	29°38.028′
Height above sea level, m	95.0
Maximum length, km	2.95
Maximum width, km	1.15
Maximum depth, m	10
Area, km^2	2.31
Watershed area, km^2	-
Study period	2004-2005

Lake Samettivatn (watershed of the River Paz) is located 26 km to the west of the town of Nickel. The lake is not large (the area of the lake is 2.31 km^2), nor deep (maximum depth 10 m), and is close to oval shape and of glacial origin. The maximum length is 2.95 km and maximum width 1.15 km. The points of maximum depth are located in the central part of the lake.

The lake forms part of a lake-river system, and a larger stretch is located in its northern part. According to the landscape type, the watershed area belongs to the forest-tundra zone, with heights of up to 220 m. Boulder beds occur in almost all parts of the littoral zone. The lake shores are covered by shrub vegetation and pine forests.

2.11.1. Hydrochemistry

Hydrochemical properties	
pH	<u>6.80</u> 6.68-6.88
Electrical conductivity, mS/cm	<u>26</u> 25-27
Ca, mg/l	<u>2.13</u> 2.09-2.19
Mg, mg/l	<u>0.50</u> 0.50-0.51
Na, mg/l	<u>1.78</u> 1.76-1.81
K, mg/l	<u>0.37</u> 0.37-0.38
HCO_3, mg/l	<u>6.0</u> 5.7-6.2
SO_4, mg/l	<u>2.60</u> 2.57-2.62
Cl, mg/l	<u>2.70</u> 2.64-2.76
Total mineralization, mg/l	<u>16.1</u> 15.9-16.3
Alkalinity, μeq/l	<u>99</u> 94-102

The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 16.1 mg/l) and alkalinity (average 99 μeq/l). During flood periods the pH drops slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 2.13 mg/l) and bicarbonate (average 6.0 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability, mineralization and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The maximum concentrations of total P and total N during the vegetation period are 5 μg/l and 156 μg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (4.0 mg/l) and Fe concentrations (average 17.5 μg/l) are typical of small water bodies in the region. During flood periods in summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

The watershed of Lake Samettivatn is located at a distance of 26 km from the Pechenganickel smelter, and is subjected to anthropogenic impacts from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co, etc.). Despite the fact that emissions from the smelter have dropped to approximately one third of the peak levels of the late 1970s, the deposition of pollutants still influences the water quality. The average Cu and Ni concentrations are 2.5 µg/l and 1.8 µg/l, respectively.

Water colour, deg.	9 8-10
NH_4, µg/l	3 1-5
NO_3, µg/l	1 1-1
Total N, µg/l	133 117-156
PO_4, µg/l	1 1-1
Total P, µg/l	4 4-5
Fe, µg/l	17.5 14.0-23.6

2.11.2. Lake bottom sediments

The sediments in Lake Samettivatn have relatively low organic matter contents (LOI): in the uppermost 1 cm layer LOI is about 20% (Table 35). Emissions from the smelter affect the concentrations of pollutants (Ni and Co) in the sediments, and the lake is also subject also to pollution by chalcophile elements, such as Cd, Pb and As. The top 4-5 cm sediment layer is the most polluted (Fig. 48). The contamination factor values for these toxic heavy metals range from 2.0 to 8.9 (Table 35), i.e. the values correspond to moderate, considerable and high contamination. Lead has the highest C_f value. The contamination factor values for the other heavy metals correspond to low contamination. The degree of contamination value (27.9) for this lake corresponds to considerable contamination.

Cu, µg/l	2.5 1.4-4.1
Ni, µg/l	1.8 1.7-2.1
Al, µg/l	17 14-24
Pb, µg/l	0.2 0.2-0.2

Table 35.
The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (18-19 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Samettivatn	0-1	19.16	72	87	82	105	0.37	21.1	9.70	0.082	
	18-19	21.19	133	39	153	14	0.19	2.4	1.81	0.080	
C_f			**0.5**	**2.2**	**0.5**	**7.4**	**2.0**	**8.9**	**5.4**	**1.0**	**27.9**

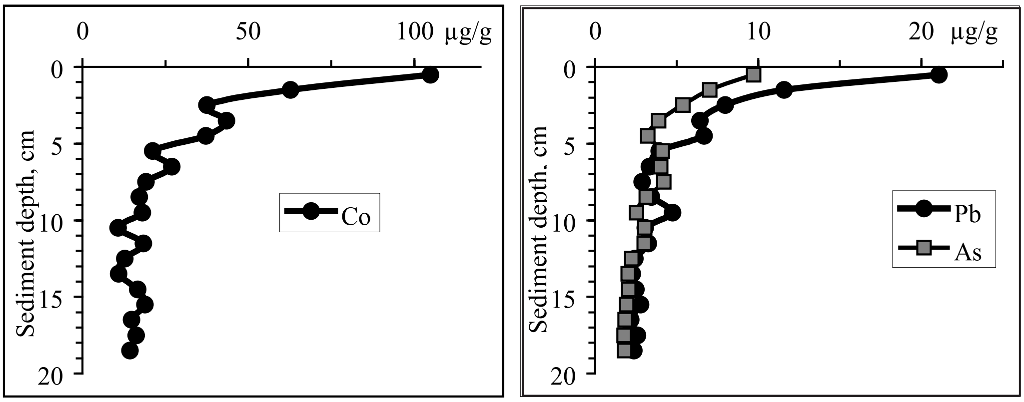


Fig. 48. *Vertical distribution of the concentrations of Co, Pb and As (µg/g, dry weight) in the sediment core of Lake Samettivatn.*

2.11.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.12. LAKE SKRUKKEVATN

Physico-geographical characteristics	
Watershed	River Paz (Skrukkebukta)
Latitude	69°34.183′
Longitude	30°03.023′
Height above sea level, m	56.0
Maximum length, km	2.0
Maximum width, km	0.7
Maximum depth, m	15
Area, km^2	0.91
Watershed area, km^2	4.68
Study period	2004-2005

Lake Skrukkevatn (watershed of the River Paz) is located 18 km to the north of the town of Nickel. The lake is not large (the area of the lake is 0.91 km^2), the maximum depth is 15 m, has a close to oval shape, and is of glacial origin. The maximum length is 2.0 km and maximum width 0.7 km. The points of maximum depth are located in the central part of the lake. The lake is used by inland water transport.

The lake forms part of a lake-river system. According to the landscape type, the watershed belongs to the forest-tundra zone, with heights of up to 152 m. Boulder beds occur in almost all parts of the littoral zone. The lake shores are high, and covered by grass and shrub vegetation and pine forests. The northern shore falls abruptly to the waterline. A road passes along the northern shore. The water of the lake is colourless.

2.12.1. Hydrochemistry

The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 19.8 mg/l) and alkalinity (average 82 µeq/l). During flood periods the pH falls slightly, i.e. oxidation processes do not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 2.80 mg/l) and bicarbonate (average 5.0 mg/l) predominating.

The annual chemical cycle of the lake is characterized by a slight reduction in the oxidizability, mineralization and pH of the water during flood periods when the amount of precipitation and inflow of humic water increase.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The maximum concentrations of total P and total N during the vegetation period are 5 µg/l and 188 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (4.2 mg/l) and Fe concentrations (average 20.7 µg/l) are typical of small water bodies in the region. During flood periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Hydrochemical properties	
pH	6.66 6.61-6.72
Electrical conductivity, mS/cm	34 34-35
Ca, mg/l	2.29 2.25-2.34
Mg, mg/l	0.72 0.71-0.75
Na, mg/l	2.80 2.77-2.88
K, mg/l	0.37 0.37-0.38
HCO_3, mg/l	5.0 4.9-5.1
SO_4, mg/l	4.16 4.05-4.22
Cl, mg/l	4.39 4.36-4.45
Total mineralization, mg/l	19.8 19.5-20.1
Alkalinity, µeq/l	82 81-84

Water colour, deg.	14 14-14
NH_4, µg/l	6 4-8
NO_3, µg/l	12 2-18
Total N, µg/l	142 116-188
PO_4, µg/l	1 1-1
Total P, µg/l	4 3-5
Fe, µg/l	20.7 10.6-41.0

Cu, µg/l	4.3 3.6-4.9
Ni, µg/l	7.2 6.8-8.0
Al, µg/l	51 38-75
Pb, µg/l	0.2 0.2-0.3

The watershed of Lake Skrukkevatn is subjected to severe anthropogenic impacts from the "Pechenganickel" smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Co etc.). Despite the fact that emissions from the smelter have been reduced to approximately one third of the maximum levels of the late 1970s, the deposition of pollutants still influences the water bodies in the area. The average concentrations of Cu and Ni are 4.3 µg/l and 7.2 µg/l, respectively.

2.12.2. Lake bottom sediments

The sediments in Lake Skrukkevatn have relatively low organic matter contents (LOI): in the uppermost 1 cm layer LOI is about 20% (Table 36). As the lake is situated at a distance of only 18 km from the Pechenganickel smelter, emissions have a considerable effect on pollution (Ni and Co) levels in the lake, and the lake is also subjected to pollution by chalcophile elements, such as Hg, Pb and As. The top 2-3 cm layer is the most polluted (Fig. 49). The contamination factor values for these heavy metals range from 1.5 to 6.6 (Table 1), i.e. the values correspond to moderate and high (Co and Pb) contamination. Cobolt has the highest C_f value. The contamination factor values for the other heavy metals are low. The degree of contamination value (20.7) calculated for the lake corresponds to considerable contamination.

Table 36. The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (14-15 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Skrukkevatn	0-1	20.04	95	77	135	139	0.17	20.2	3.50	0.053	
	14-15	17.98	88	44	138	21	0.16	3.4	1.97	0.035	
C_f			**1.1**	**1.7**	**1.0**	**6.6**	**1.1**	**6.0**	**1.8**	**1.5**	**20.7**

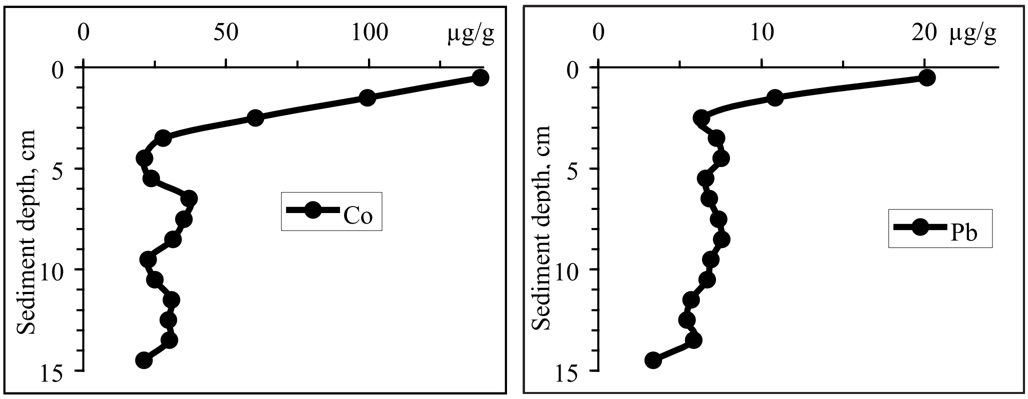


Fig. 49. Vertical distribution of the concentrations of Co and Pb (µg/g, dry weight) in the sediment core of Lake Skrukkevatn.

2.12.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

2.13. LAKE STUORAJAVRE

Physico-geographical description	
Watershed	River Kautokeinoelva —River Altaelva
Latitude	69°06.416′
Longitude	22°50.435′
Height above sea level, m	374.0
Maximum length, km	12.9
Maximum width, km	3.7
Maximum depth, m	21
Area, km²	19.2
Watershed area, km²	-
Study period	2005-2007

Lake Stuorajarve (watershed of the River Kautokeinoelva) is located 312 km to the west of the town of Nickel. The lake is relatively large (area of the lake 19.2 km^2), has a maximum depth of 21 m, and is of oval shape and of glacial origin. The maximum length is 12.9 km and maximum width 3.7 km. The points of maximum depth are located in the northern part of the lake.

According to the landscape type, the watershed belongs to the forest-tundra zone, with heights of up to 772 m (Geshvarre fell). The lake shores are high and stony, and covered by shrubs and birch woodlands. The water of the lake is colourless.

2.13.1. Hydrochemistry

The pH of the water in the lake is neutral, and the water has a low total mineralization (average 32.5 mg/l) and alkalinity (average 315 µeq/l). The lake has low concentrations of base cations and anions, with calcium (average 4.99 mg/l) and bicarbonate (average 19.2 mg/l) predominating.

Elevated concentrations of P and N are important criteria when estimating water eutrophication. The concentrations of and relationships between species of P and N vary according to the season and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The maximum concentrations of total P and total N during the vegetation period are 8 µg/l and 172 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The colour values and the organic matter (4.7 mg/l) and Fe concentrations (average 95 µg/l) are typical of small water bodies in the region.

Nickel and Cu are discharged and emiitted from the "Pechenganickel" smelter. The watershed of Lake Stuorajarve is relatively distant from the Pechenganickel smelter, and the average Cu and Ni concentrations in the water are 1.1 µg/l and 0.9 µg/l, respectively.

Hydrochemical properties	
pH	6.97 6.79-7.30
Electrical conductivity, mS/cm	42 31-59
Ca, mg/l	4.99 3.32-6.93
Mg, mg/l	1.55 1.00-2.24
Na, mg/l	1.05 0.83-1.33
K, mg/l	0.44 0.38-0.54
HCO_3, mg/l	19.2 13.7-23.9
SO_4, mg/l	4.45 2.42-8.65
Cl, mg/l	0.80 0.59-1.12
Total mineralization, mg/l	32.5 22.3-44.2
Alkalinity, µeq/l	315 225-392

Water colour, deg.	19 8-24
NH_4, µg/l	15 6-25
NO_3, µg/l	10 1-22
Total N, µg/l	136 113-172
PO_4, µg/l	1 1-1
Total P, µg/l	6 5-8
Fe, µg/l	95 52-130

Cu, µg/l	1.1 0.9-1.5
Ni, µg/l	0.9 0.3-1.8
Al, µg/l	37 11-53
Pb, µg/l	0.2 0.1-0.4

2.13.2. Lake bottom sediments

The sediments in Lake Stuorajavre have organic matter contents (LOI) in the uppermost 1 cm layer of less than 20% (Table 37). As the lake is located at a distance of about 300 km from the Pechenganickel smelter, emissions from the smelter have almost no effect on water quality in the lake. However, it is exposed to pollution by chalcophile elements, such as Cd, Pb, As and Hg. The top 2-4 cm sediment layer is the most polluted, with maximum Cd and Pb concentrations in the 1-2 cm layer, maximum As in the uppermost 1 cm layer, and maximum Hg in the 2-3 cm layer (Fig. 50). The contamination factor values for these heavy metals range from 1.5 to 2.4 (Table 37), i.e. the values correspond to moderate contamination. Lead has the highest C_f value. The contamination factor values for the other heavy metals are low. The degree of contamination value (11.5) for this lake corresponds to moderate contamination.

Table 37. *The organic matter contents (LOI, %) and heavy metal concentrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (24-25 cm) sediment layers. C_f and C_d are contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Stuorajavre-1	0-1	16.79	48	45	55	38.1	0.21	10.9	4.41	0.126	
	24-25	12.32	73	43	51	34.8	0.14	4.4	3.14	0.055	
C_f			**0.7**	**1.0**	**1.1**	**1.1**	**1.5**	**2.4**	**1.4**	**2.3**	**11.5**

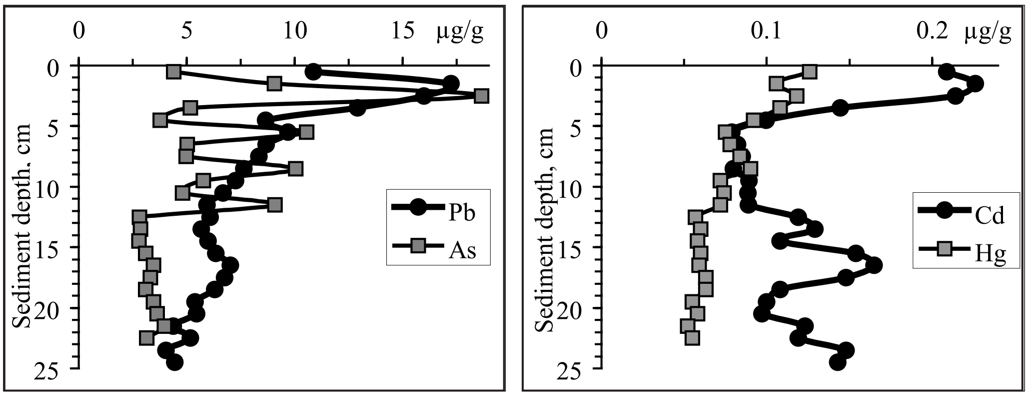


Fig. 50. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (μg/g, dry weight) in the sediment core of Lake Stuorajavre-1.*

2.13.3. Hydrobiological studies

Ichthyofauna. The studies on the fish community of Lake Stuorajavre were conducted in 2005.

The ichthyofauna of the lake consists of nine species belonging to eight fish families: trout (Salmo trutta), arctic char (*Salvelinus alpinus*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*). Overall whitefish and perch are the predominant species in Lake Stuorajavre (Fig. 51). Pike, trout, grayling and burbot are occasionally caught.

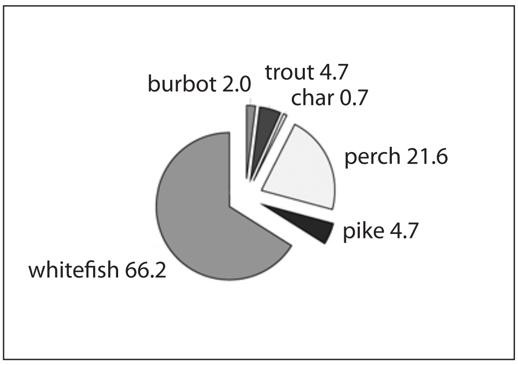


Fig. 51. *Distribution of fish species in Lake Stuorajavre.*

Two forms of whitefish inhabit the lake: sparsely rakered whitefish (up to 30 gill rakers) and densely rakered whitefish (30 to 40 gill rakers). The mean length and weight of the densely rakered whitefish do not exceed 23.7 cm and 145 g, respectively. The largest individuals can reach 27.2 cm and 220 g. The bulk of the densely rakered whitefish population is represented by fish with a length of 22-26 cm and weight 140-160 g (Fig. 52). On the average, the sparsely rakered whitefish are slightly larger than the densely rakered form. The mean weight is 353 g, but fish over one kilogram (1263 g) have been caught. The length of sparsely rakered whitefish reaches 45.2 cm (average 29.7 cm). The most numerous form of this fish are 25-35 cm long, with a weight of 200-400 g (Fig. 53).

The age limit of sparsely rakered whitefish does not exceed 10 years. The bulk of the population (around 80%) consists of 5- to 6-year-old fish (Fig. 54a). Fish in other age classes are only occasionally caught. Males dominate over females (1.4:1). Despite the fact that the age limit of sparsely rakered whitefish is 15 years, specimens from younger age groups and those older than 10 years are absent (Fig. 54b). The population is dominated by 7-year-old fish. Sparsely rakered whitefish, in contrast to the densely rakered form, have higher growth rates in the older age groups. Thus the weight of 10-year-old sparsely rakered whitefish is twice as high as that of similar-aged densely rakered whitefish. The sex distribution of the population is dominated by female fish (1.7:1).

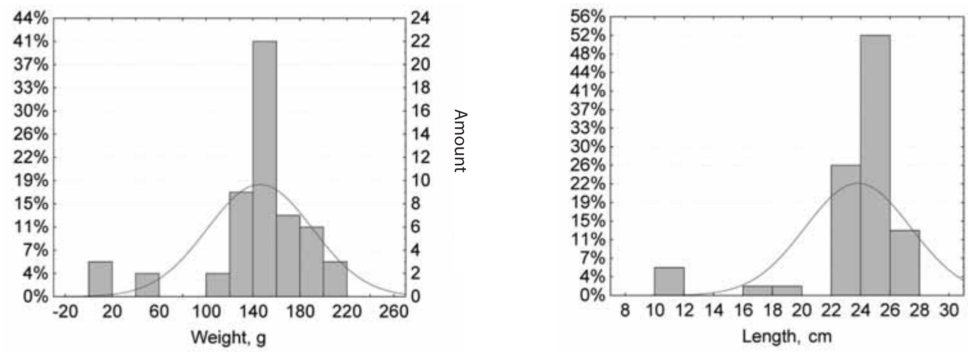


Fig. 52.
Length and weight distribution of the densely rakered whitefish in Lake Stuorajavre.

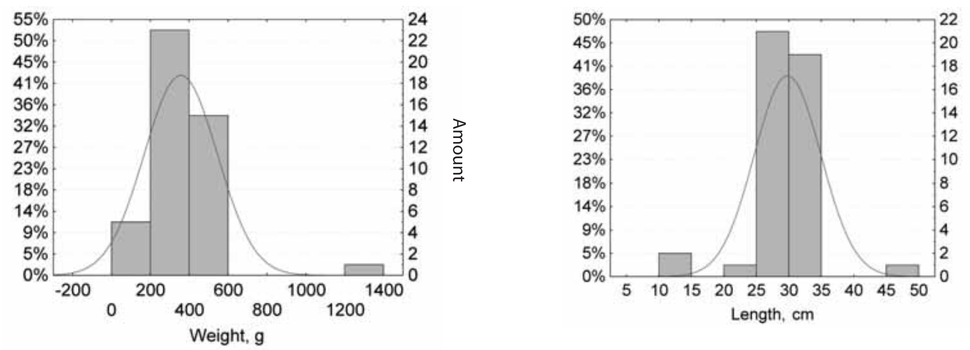


Fig. 53.
Length and weight distribution of the sparsely rakered whitefish in Lake Stuorajavre.

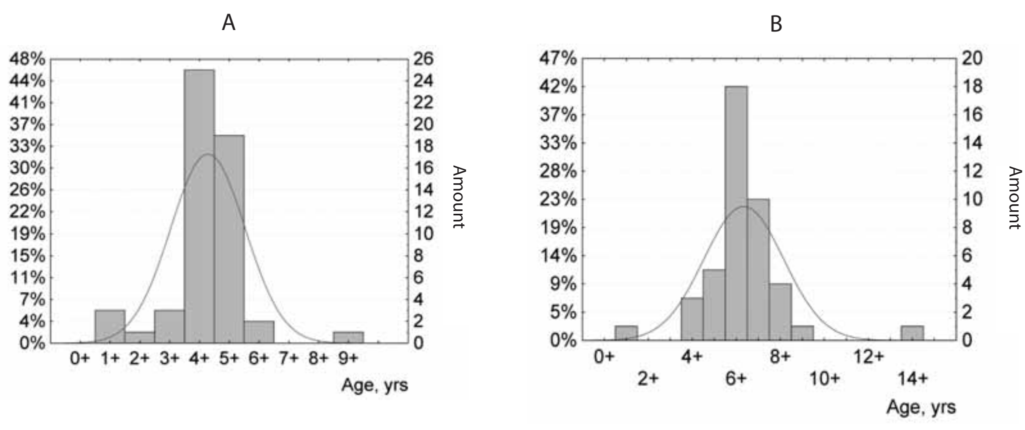


Fig. 54.
Age distribution of the sparsely (a) and densely (b) rakered whitefish in Lake Stuorajavre.

The average weight of trout is 484 g and length 34.9 cm. The length of some trout specimens reaches 44.3 cm with a weight of 810 g. The sex distribution of trout is dominated by males - 1:2.5. The oldest registered trout age is 7 years. Arctic char was represented by a single sample, which was a 5-year-old mature female fish with a weight of 762 g and length of 40 cm.

Perch in Lake Stuorajavre is represented by small-sized fish with an average weight of 89 g and length of 17.7 cm. The largest specimens do not exceed 373 g and length 29.0 cm. Fish with a weight of under 100 g and length of 14 – 16 and 18 – 20 cm dominate in the population (Fig. 55). The sex distribution of fish is characterized by a slight dominance of males (1.3:1).

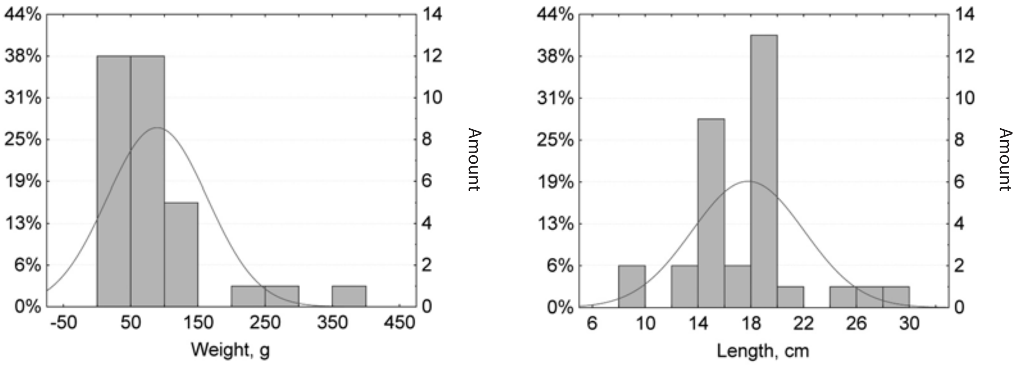


Fig. 55.
Length and weight distribution of perch in Lake Stuorajavre.

Overall, pike has an average weight of 644 g (maximal - 1107 g) and length of 42.3 cm (maximum 49.8 cm). Males dominate over females.

Fish pathology

The most frequently occurring pathologies of whitefish are expansions of the connective tissue and grainy structure of the kidneys (more than 90%). The frequency of kidney pathologies is also high and amounts to 50%; they appear as a change in colour and degeneration of the tissue (pale liver). Disorders in the reproductive system are the rarest, and occur in the form of anisochronous and asymmetric maturation of the gonads (about 6%). In addition, whitefish have irregular rakers line and warp of the rakers in 23% of cases. As regards pike, two fish had an unsatisfactory state of the liver (28.6%). The liver was greenish in colour.

Heavy metals in fish

Heavy metal concentrations (Cu, Ni, Pb, Cd and Hg) in fish muscle do not exceed the established standard values (Table 38).). However, Cu concentrations (μg/g of dry weight) in fish liver are higher than in muscles (from 9.5 μg/g in perch to 132.8 μg/g in trout).). The same holds true for Ni in fish kidney (from 1.1 μg/g in pike to 2.7 μg/g in perch). The concentrations for Ni in skeleton reach 4.4 μg/g (in whitefish) and 5 μg/g (in pike). The Pb concentration is the highest in the gills of sparsely rakered whitefish (0.8 μg/g). Mercury accumulates more strongly in fish kidney, and the highest levels occur in whitefish (1.6-2.9 μg/g) and in trout (1.6 μg/g dry weight).

Analysis of metal concnetrations in different fish species shows that Cu accumulation in trout liver is 6 times higher than that in other fish species (Fig. 56). There are no significant differences in Ni accumulation between the above fish species. The highest

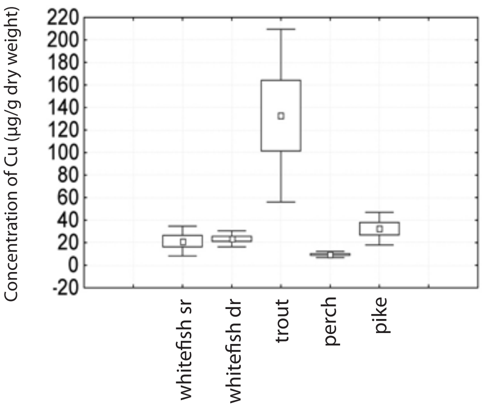
Pb and Hg concentrations in muscular tissue occur in pike. The Hg concentrations in the muscle of pike and densely rakered whitefish are relatively similar (Fig. 56).

	Standard value (µg/g wet weight)*	Concentration in muscle (µg/g wet weight)	Concentration in muscle (µg/g of dry weight)
		Whitefish, sparely rakered	
Hg	0.5	0.07	0.32
Ni	0.5	0.15	0.71
Cu	20	0.16	0.77
Cd	0.1	-	<0.01
Pb	1	0.02	0.11
		Whitefish, densely rakered	
Hg	0.5	0.13	0.68
Ni	0.5	0.12	0.64
Cu	20	0.08	0.40
Cd	0.1	0.002	0.01
Pb	1	0.02	0.08
		Trout	
Hg	0.5	0.13	0.58
Ni	0.5	0.15	0.66
Cu	20	0.25	1.14
Cd	0.1	-	<0.01
Pb	1	0.02	0.05
		Perch	
Hg	0.5	0.13	0.51
Ni	0.5	0.14	0.70
Cu	20	0.13	0.62
Cd	0.1	-	0.01
Pb	1	0.01	0.08
		Pike	
Hg	0.5	0.15	0.73
Ni	0.5	0.15	0.76
Cu	20	0.18	0.88
Cd	0.1	0.002	0.01
Pb	1	0.04	0.18

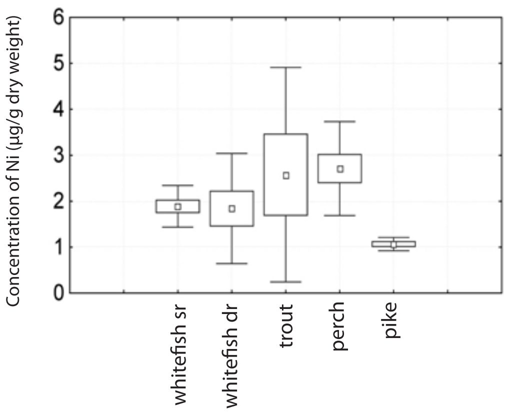
* Source: Sanitary..., 1986.

Table 38.
The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Stuorajavre (in µg/g wet and dry weight).

Cu in liver



Ni in kidneys



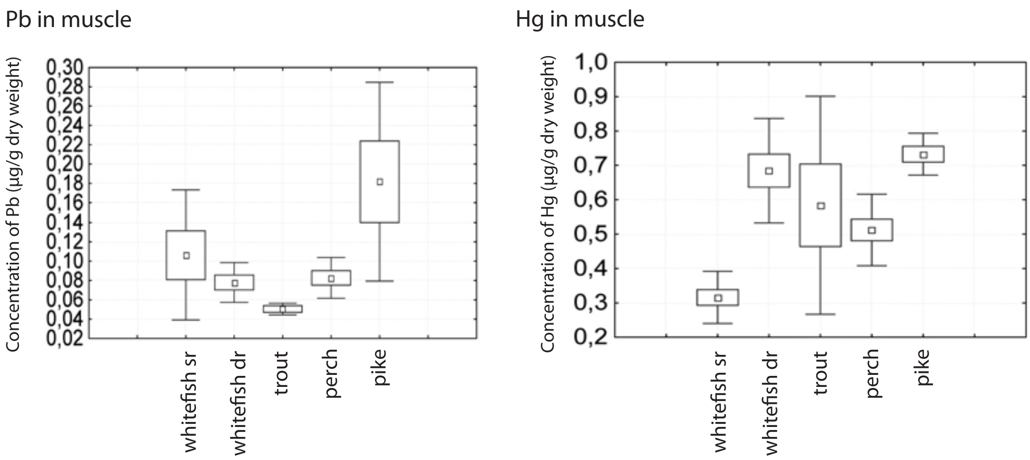


Fig. 56. *Cu (liver), Ni (kidneys), Pb and Hg (muscle) concentrations in fish from Lake Stuorajavre (µg/g dry weight).*

2.14. LAKE SUOPATJAVRE

Lake Suopatjavre (watershed of the River Kautokeinoelva) is located 306 km to the west of the townof Nickel. The oval-shaped lake is not large (area of the lake 1.88 km^2), nor deep (maximum depth 12 m), and is of glacial origin. The maximum length is 4.0 km and maximum width 0.8 km. The points of maximum depth are located in the central part of the lake.

According to the landscape type, the watershed area belongs to the forest-tundra zone, with heights of up to 523 m. The eastern shore is high and marshes are widespread in the south. The lake shores are covered by shrubs and birch woodland. The water in the lake is colourless but, during periods of high water and high precipitation episodes, the colour of the water increases to 69 deg. and becomes slightly yellowish. The lake is used as a landing area for small aircraft.

Physico-geographical characteristics	
Watershed	River Kautokeinoelva—River Altaelva
Latitude	68°56.246′
Longitude	23°05.448′
Height above sea level, m	323.0
Maximum length, km	4.0
Maximum width, km	0.8
Maximum depth, m	12
Area, km^2	1.88
Watershed area, km^2	124.0
Study period	2005-2007

Hydrochemical properties	
pH	6.89 6.56-7.23
Electrical conductivity, mS/cm	34 25-45
Ca, mg/l	3.69 2.48-5.57
Mg, mg/l	1.08 0.70-1.62
Na, mg/l	1.12 0.88-1.57
K, mg/l	0.51 0.46-0.62
HCO_3, mg/l	15.9 10.3-23.8
SO_4, mg/l	2.6 1.9-3.6
Cl, mg/l	0.47 0.39-0.65
Total mineralization, mg/l	25.4 17.1-37.4
Alkalinity, µeq/l	260 168-390

2.14.1. Hydrochemistry

The pH of the water in the lake is close to neutral, and the water has a low total mineralization (average 25.4 mg/l) and alkalinity (average 260 µeq/l). The lake has low concentrations of base cations and anions, with calcium (average 3.69 mg/l) and bicarbonate (average 15.9 mg/l) predominating.

Water enrichment with phosphorus and nitrogen is one of important criteria of water eutrophication. Concentration and correlation of their forms vary according to a season and the dynamics is in greater degree determined by the level of production processes and consequently trophicity of the water body. Concentrations of biogenic elements during vegetation period are as follows: total phosphorus – to 11 µg/l, total nitrogen – to 221 µg/l.

According to concentrations of biogenic elements the lake can be defined as oligotrophic one. The values of color, organic matter (7.3 mg/l) and Fe concentrations (average 210 µg/l) are typical for small water bodies of this region.

Water colour, deg.	44 18-69
NH_4, µg/l	17 2-28
NO_3, µg/l	4 1-9
Total N, µg/l	221 206-243
PO_4, µg/l	1 1-2
Total P, µg/l	11 9-13
Fe, µg/l	210 152-262

Cu, µg/l	0.9 0.6-1.4
Ni, µg/l	1.9 0.2-4.7
Al, µg/l	43 33-50
Pb, µg/l	0.2 0.1-0.4

Nickel and Cu are the main components in the discharges and emissions from the Pechenganickel smelter. The watershed of Lake Suoptajarve is relatively distant from the smelter, and the average Cu and Ni concentrations in the water are 0.9 µg/l and 1.9 µg/l, respectively.

2.14.2. Lake bottom sediments

The sediments in Lake Suopatjavre have organic matter (LOI) contents in the uppermost 1 cm layer of about 30% (Table 39). The lake is located at a distance of about 300 km from the Pechenganickel smelter, and therefore the lake is relatively unaffected by pollutants emitted by the smelter. However, the lake is subjected to pollution by chalcophile elements such as Cd, Pb, As and Hg. The top 2-4 cm layer is the most polluted. Maximum concentrations of Cd and Pb occur in the 1-2 cm layer, and of As and Hg in the uppermost 1 cm layer (Fig. 57). The contamination factor values for these heavy metals range from 2.1 to 3.8 (Table 39), i.e. the values correspond to moderate and considerable contamination. Arsenic has the highest C_f value. Contamination factor values for the other heavy metals are low. The degree of contamination value (15.8) for this lake is on the borderline between moderate and considerable contamination.

Table 39. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (17-18 cm) sediment layers. C_f and C_d are the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	C_d
Suopatjavre	0-1	28.16	13	17	77	18.0	0.23	12.9	6.73	0.065	
	17-18	22.63	17	22	61	19.3	0.11	4.8	1.77	0.018	
C_f			**0.8**	**0.8**	**1.3**	**0.9**	**2.1**	**2.7**	**3.8**	**3.5**	**15.8**

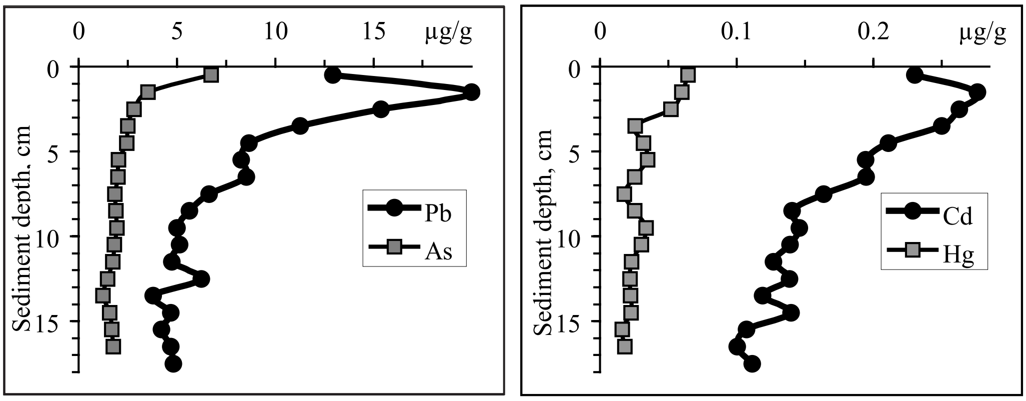


Fig. 57. *Vertical distribution of the concentrations of Pb, As, Cd and Hg (µg/g, dry weight) in the sediment core of Lake Suopatjavre.*

2.14.3. Hydrobiology investigations

No direct hydrobiological investigations have been carried out in this lake.

FINNISH LAKES

3.1. LAKE AITTOJÄRVI

Physico-geographical characteristics	
Watershed	River Paz
Latitude	69°25.575′
Longitude	28°57.482′
Height above sea level, m	164.0
Maximum length, km	1.50
Maximum width, km	0.77
Maximum depth, m	5.0
Area, hectares	57.252
Watershed area, km^2	8.018
Study period	2005-2006

Lake Aittojärvi (watershed of the River Paz) is located 50 km to the west of the town of Nickel and 69.2 km to the north of the settlement of Nellim in Finland. It is a small (area of the lake 57.3 ha), shallow-water (maximum depth 5 m) lake with an elongated oval shape and indented coastline, and is of glacial origin. The maximum length is 1.5 km and maximum width 0.77 km. The point of maximum depth is located in the central part of the lake. The watershed area belongs to the forest zone. The lake shores are high and covered by shrubs and pine forests.

3.1.1. Hydrochemistry

Hydrochemical properties	
pH	6.48 6.06-6.77
Electrical conductivity, mS/cm	21 15-29
Ca, mg/l	1.4 1.0-2.3
Mg, mg/l	0.5 0.4-0.7
Na, mg/l	1.7 1.4-2.2
K, mg/l	0.3 0.2-0.4
HCO_3, mg/l	4.7 3.1-9.6
SO_4, mg/l	2.1 1.6-3.0
Cl, mg/l	1.9 0.8-2.8
Total mineralization, mg/l	12.7 9.8-18.9
Alkalinity, µeq/l	77 51-157

The water of the lake is slightly acid and has a low mean total mineralization (12.7 mg/l) and mean alkalinity of 77 µeq/l. During flood periods the pH of water drops, but acidification does not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with sodium (average 1.7 mg/l) and bicarbonate (average 4.7 mg/l) predominating.

Total P and N concentrations in water are the main criteria used for assessing the development of water eutrophication. The concentrations and relationships between the species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The concentrations of total P and total N during the vegetation period are up to 6 µg/l and 230 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as oligotrophic. The lake also has colour values and organic matter (up to 3.5 mg/l) and Fe concentrations (mean 173 µg/l) typical of small water bodies in the region. During high water periods in the summer, the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Alhough the watershed of Lake Aittojärvi is relatively remote from the Pechenganickel smelter (50 km), it is subjected to the impacts of anthropogenic pollution. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Al, etc.). Despite the fact that emissions from the smelter have decreased to approximately to one third of the peak levels during the late 1970s, the deposition of pollutants still has an effect on the water body. The average Cu, Ni and Al concentrations are 1.1 µg/l, 0.8 µg/l and 21 µg/l, respectively.

Water colour, deg.	12 5-30
NH_4, µg/l	26 5-97
NO_3, µg/l	4 2-12
Total N, µg/l	175 140-230
Total P, µg/l	4 3-6
Fe, µg/l	173 8-770

Cu, µg/l	1.1 1.0-1.3
Ni, µg/l	0.8 0.5-1.4
Al, µg/l	21 11-26
Pb, µg/l	0.05 0.03-0.10

3.1.2. Lake bottom sediments

The sediments of Lake Aittojärvi have high organic matter contents: the LOI value in the uppermost 1 cm layer is more than 56% (Table 40). The lake is

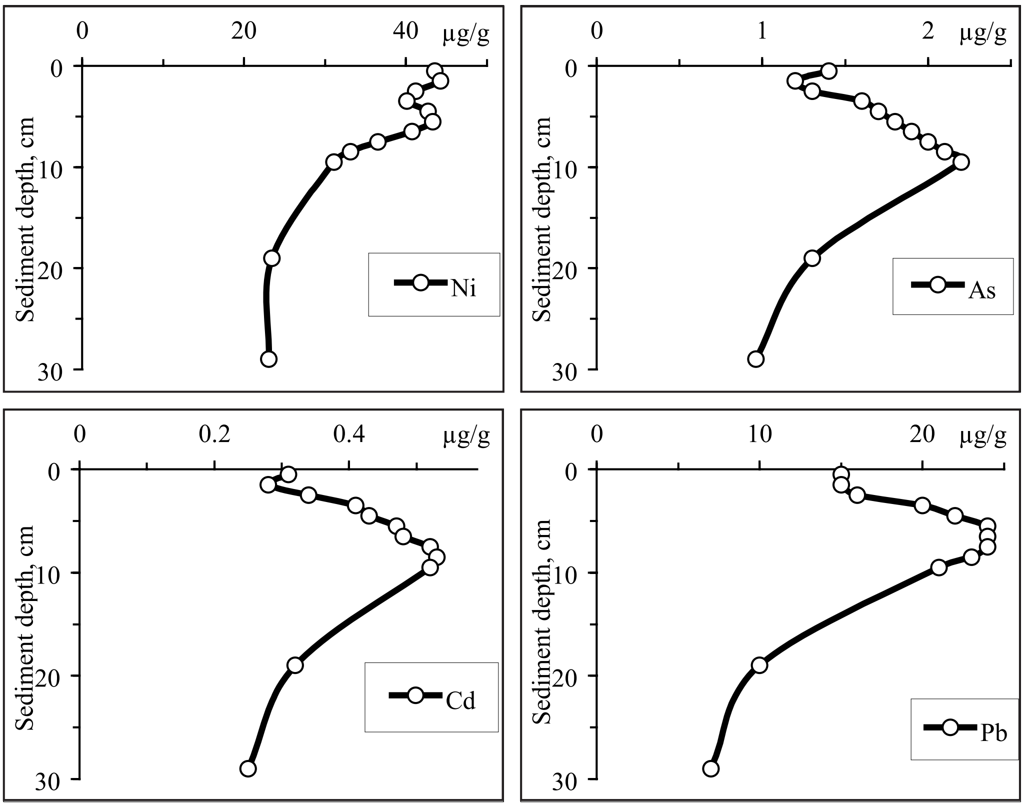


Fig. 58. *Vertical distribution of the concentrations of Ni, As, Pb and Cd (µg/g, dry weight) in the sediment core from Lake Aittojarvi.*

located at a distance of 52 km from the Pechenganikel smelter. As a result, airborne pollution from the smelter has had a relatively smaller impact on the lake, and it is mainly polluted by chalcophile elements (Pb, As and Cd). The maximum concentrations of chalcophile elements occur at depths of 6 to 10 cm, and the concentrations decrease on moving towards the surface (Fig. 58). The uppermost 10 cm layer of the lake sediments is also polluted by Ni. The contamination factor values for these chalcophile elements and Ni range from 1.2 to 2.1 (Table 40), i.e. the values correspond to moderate contamination. Lead has the highest C_f value. The degree of contamination value (8.3) for this lake corresponds to moderate contamination.

Table 40. *The organic matter contents (LOI, %) and heavy metals (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (28-30 cm) sediment layers. C_f and C_d refer to the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Aittojarvi	0-1	56.12	65	44	92	2.0	0.31	15	1.4	
	28-30	34.15	74	22	58	4.0	0.25	7	0.96	
C_f			**0.9**	**2.0**	**1.6**	**0.5**	**1.2**	**2.1**	**1.5**	**8.3**

3.1.3. Hydrobiological studies

Ichthyofauna. Studies on the fish community of Lake Aittojärvi were conducted in 2005.

The most common fish in the lake consist of four species belonging to four families: whitefish (*Coregonus lavaretus*), pike (*Esox lucius*), perch (*Perca fluviatilis*) and grayling (*Thymallus thymallus*). Burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*) obviously also inhabit the lake. Overall, whitefish predominates in Lake Aittojärvi. Other fish species make up 20 % of the catches (Fig. 59).

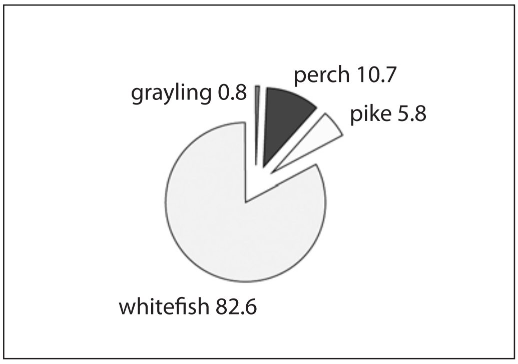
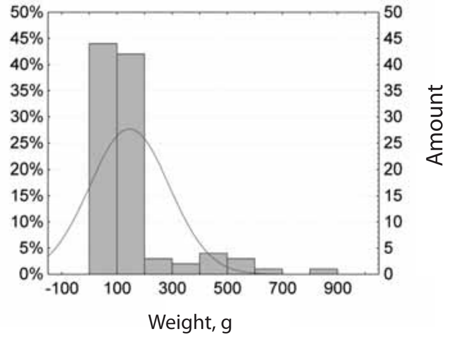


Fig. 59. *Distribution of fish species in Lake Aittojarvi*

Sparsely rakered whitefish inhabits the lake (up to 30 gill rakers). Its mean length is 22.7 cm, and mean weight 144 g. The maximum length does not exceed 40.2 cm and weight 852 g. Fish with a weight of 200 g and length of 20-25 cm are the most numerous (Fig. 60). The bulk of the whitefish population is represented by 3- to 4-year-old fish (61%). Fish older than 7 years are occasionally caught (Fig. 61). The ratio between female and male fish is equal to 1. Early maturity is a specific characteristic of the whitefish in this lake; some individuals in the lake become mature at the age of 1+. The weight and size of fish spawning for the first time do not exceed 53 g and 18.4 cm, respectively.



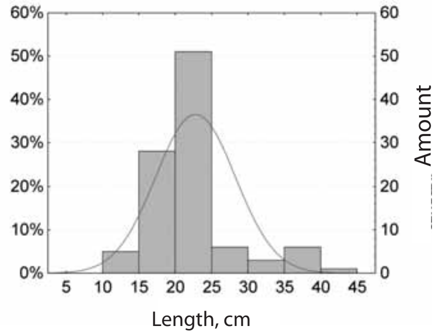


Fig. 60. *Size and weight distribution of the sparsely rakered whitefish in Lake Aittojarvi.*

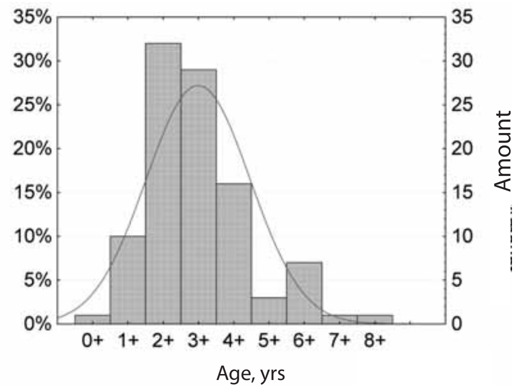


Fig. 61. *Age distribution of the sparsely rakered whitefish in Lake Aittojarvi.*

Pike in the lake are mainly represented by large-sized individuals with an age of 8 to 11 years. The mean size and weight are 2005 g and 58.7 cm, respectively, although specimens with a weight of 4364 g and length of 82.2 cm do occur. The size of perch varies from 7-339 g and 8.6-29.5 cm, respectively. The average size and weight do not exceed 194 g and 22.0 cm. The age limit of perch is 7 years. The ratio between male and female perch and pike is almost 1.

Fish pathology

The most frequently occurring pathologies of whitefish are pathologies of connective tissue expansions in the kidneys (78%). Liver destruction (fatty degenerations, mosaic structure and oblong shape of the liver) occurs in 27% of cases. Changes in the reproductive system and gills are characteristic of 18% and 13% of the fish, respectively.

Heavy metals in fish

The heavy metal (C, Ni, Pb, Cd and Hg) concentrations in the muscles of fish do not exceed the standard values (Table. 41). The Cu concentration (μg/g dry weight) in the liver of whitefish is 50 times higher than that in the muscular tissue, of Ni in the kidneys 10.5 times higher, of Cd in kidneys more than 100 times higher, and of Hg 4 times higher. The corresponding values for pike and perch are insignificant.

Analysis of heavy metal accumulation in different fish species showed that Cu (liver) and Ni (kidneys) are more strongly accumulated in whitefish, while the Cd concentrations of all the fish species are at relatively similar, low levels. As a predator species, pike has a naturally higher degree of Hg accumulation in the muscular tissue compared to that in whitefish and perch (Fig. 62).

	Standard value (µg/g wet weight)*	Concentration in muscle (µg/g wet weight)	Concentration in muscle (µg/g of dry weight)
Whitefish			
Hg	0.5	0.12	0.59
Ni	0.5	0.13	0.62
Cu	20	0.15	0.73
Cd	0.1	0.003	0.02
Pb	1	0.01	0.06
Perch			
Hg	0.5	0.28	1.32
Ni	0.5	0.12	0.57
Cu	20	0.16	0.75
Cd	0.1	0.003	0.02
Pb	1	0.01	0.06
Pike			
Hg	0.5	0.45	2.14
Ni	0.5	0.11	0.51
Cu	20	0.17	0.80
Cd	0.1	0.004	0.02
Pb	1	0.01	<0.05

* Source: Sanitary..., 1986.

Table 41.
The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Aittojärvi (in µg/g wet and dry weight).

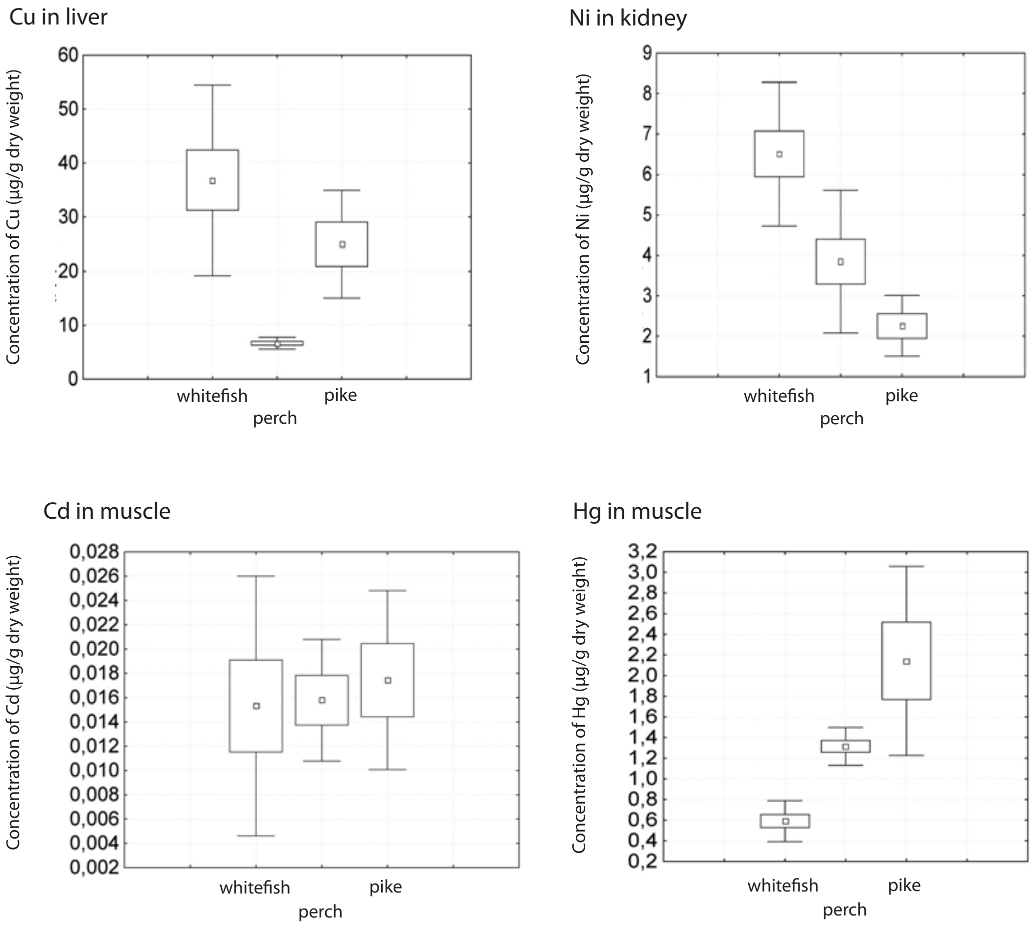


Fig. 62.
Accumulation of Cu (liver), Ni (kidneys), Cd and Hg (muscle) in fish from Lake Aittojärvi (µg/g dry weight).

3.2. LAKE KANTOJÄRVI

Lake Kantojärvi (watershed of the River Pechenga) is located 76.3 km to the south-west of the town of Nickel and 21.2 km to the north-east of the settlement of Nellim in Finland. It is a small (area of the lake 36.29 ha), shallow-water (maximum depth 5 m), elongated oval-shaped lake of glacial origin. The maximum length is 1.25 km and maximum width 0.52 km. The point of maximum depth is located in the central part of the lake. One river flows out of the lake.

The watershed area belongs to the forest zone. The lake shores are high and covered by shrubs and pine forests.

Physico-geographical characteristics	
Watershed	River Paz
Latitude	68°59.745′
Longitude	28°39.937′
Height above sea level, m	168.0
Maximum length, km	1.25
Maximum width, km	0.52
Maximum depth, m	5.0
Area, hectares	36.285
Watershed area, km^2	4.099
Study period	1988-2006

Hydrochemical properties	
pH	6.66 6.30-7.00
Electrical conductivity, mS/cm	30 22-46
Ca, mg/l	3.0 2.1-4.8
Mg, mg/l	0.8 0.6-1.2
Na, mg/l	1.7 1.4-1.9
K, mg/l	0.4 0.3-0.6
HCO_3, mg/l	10.8 7.0-18.8
SO_4, mg/l	1.9 1.7-2.4
Cl, mg/l	1.7 1.5-2.0
Total mineralization, mg/l	20.3 14.8-31.3
Alkalinity, μeq/l	176 115-308

Water colour, deg.	39 20-75
NH_4, μg/l	59 6-210
NO_3, μg/l	4 2-10
Total N, μg/l	298 230-420
Total P, μg/l	6 4-10
Fe, μg/l	450 53-1900

3.2.1. Hydrochemistry

The water of the lake is neutral with a low mean total mineralization (20.3 mg/l) and mean alkalinity of 176 μeq/l. During flood periods the pH of water drops, but acidification does not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 3.0 mg/l) and bicarbonate (average 10.8 mg/l) predominating.

The total P and total N concentrations in water are the main criteria used for assessing the development of water eutrophication. The concentrations and relationships between species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The concentrations of total P and total N during the vegetation period reach 10 μg/l and 420 μg/l, respectively.

According to the mineral nutrient concentrations, the lake is classified as mesotrophic. The lake also has colour values, and organic matter (up to 8.3 mg/l) and Fe concentrations (mean 450 μg/l) typical of small water bodies in the region. During high water periods in summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Although the watershed of Lake Kantojärvi is relatively remote from the Pechenganickel smelter (76.3 km), it is nevertheless subjected to anthropogenic impacts. The water system of the lake receives airborne pollutants derived from emissions from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Al, etc.) Despite the fact that emissions from the smelter have decreased to approximately one third of the maximum levels during the late 1970s, the deposition of pollutants still has an impact on the water body. The average Cu, Ni and Al concentrations 1.0 μg/l, 3.6 μg/l and 70 μg/l, respectively

Cu, μg/l	1.0 0.8-1.7
Ni, μg/l	3.6 0.5-13.0
Al, μg/l	70 49-89
Pb, μg/l	0.06 0.02-0.14

3.2.2. Lake bottom sediments

The sediments of Lake Kantojärvi have relatively high organic matter contents: the LOI value in the uppermost 1 cm layer is about 40% (Table 42). The lake is located at a distance of 78 km from the Pechenganickel smelter. However, airborne pollution from the smelter has had an effect on the lake: there is a clear decreasing gradient in the concentration of Ni and Cu (Fig. 63), and of Co and Zn in the uppermost 10 cm layer of the sediments (Table 42). The lake is subjected to a greater extent by pollution of chalcophile elements, such as Pb, As and Cd (Fig. 63). The maximum As concentration is located in the uppermost 1 cm layer. In contrast, there are slightly lower concentrations of Pb and Cd in the uppermost 1 cm layer, but maximum concentrations at depths of 1-3 and 2-3 cm, respectively. The contamination factor value for these elements range from 1.3 to 16.0 (Table 42), i.e. the values correspond to moderate and considerable contamination. The main heavy metals emitted by the smelter have moderate C_f values (from 1.3 to 2.0), and the chalcophile elements considerable and high values. The C_f value for Pb is the highest. The degree of contamination value (29.3) for this lake corresponds to high contamination (for 7 elements).

Table 42.
The organic matter contents (LOI, %) and heavy metal concnetrations (μg/g, dry weight) in the surface (0-1 cm) and pre-industrial (18-20 cm) sediment layers. C_f and C_d refer to the contamination factor and degree of contamination values, respectively.

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Kantojärvi	0-1	39.11	43	31	78	13.0	0.30	16.8	2.90	
	18-20	34.95	30	15	46	9.8	0.08	1.1	0.95	
C_f			**1.4**	**2.0**	**1.7**	**1.3**	**3.8**	**16.0**	**3.1**	**29.3**

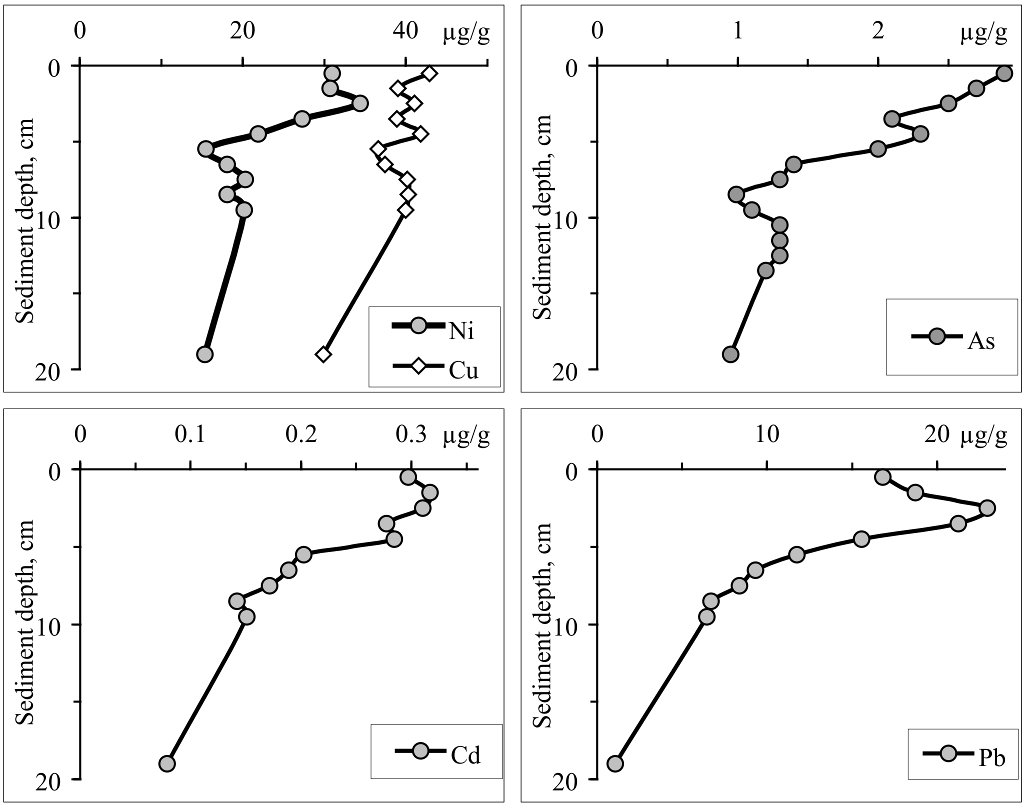


Fig. 63.
Vertical distribution of the concentrations of Ni, Cu, As, Pb and Cd (µg/g, dry weight) in the sediment core from Lake Kantojärvi.

3.2.3. Hydrobiological studies

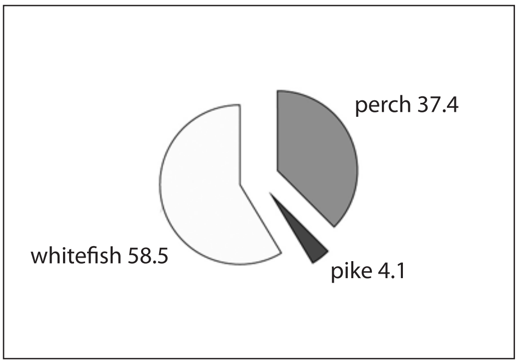


Fig. 64.
Distribution of fish species in Lake Kantojärvi.

Ichthyofauna. Studies on the fish community of Lake Kantojärvi were conducted in 2005.

The most common species in the lake are: whitefish (Coregonus lavaretus) and perch (*Perca fluviatilis*). Pike (*Esox lucius*) is caught occasionally (Fig. 64). Grayling (*Thymallus thymallus*), burbot (Lota lota), minnow (*Phoxinus phoxinus*), and nine-spine stickleback (*Pungitius pungitius*) obviously also inhabit the lake. The low fish population in the lake is probably concerned to the small size of the lake, and its proximity to settlements and subsequent risk of over-fishing.

Sparsely rakered whitefish inhabit the lake (up to 30 gill rakers). Due to the presence of large fish individuals (weight 1530 g and length 44.3 cm), the mean size and weight of whitefish are 24.3 cm and 271 g, respectively. The bulk of the whitefish population consists of fish with a length of 15-20 cm, and weight of less than 200 g (Fig. 65). The age distribution of the whitefish is dominated by 2-year old fish (more than 60%), and fish older than 7-8 years are occasionally caught (Fig. 66). In the sex distribution, females predominate over males (1.3:1).

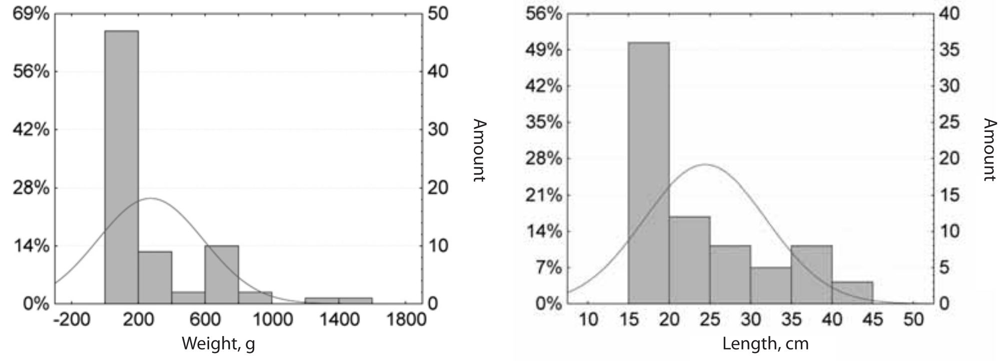


Fig. 65.
Size *and weight distribution of the sparsely rakered whitefish in Lake Kantojärvi.*

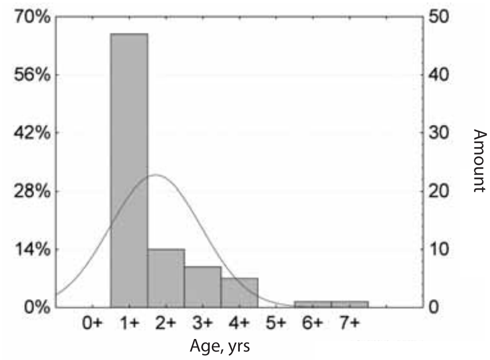


Fig. 66.
Age distribution of the sparsely rakered white-fish in Lake Kantojärvi.

The size of pike varies over a wide range: weight from 175 to 2535 g, and length from 31.2 to 70.0 cm. The mean values are 1010 g and 48.4 cm, respectively. The age limit of the pike is 8 years, but 2-year old specimens are predominant and fish older than 6 years are caught only occasionally. In the sex distribution, males predominate over females (1.5:1). The perch in the lake are small sized. The maximum weight and length do not exceed 194 g and 23.7 cm, with average values of 90 g and 18.2 cm, respectively. There is no dominating group in the size and weight distribution, which indicates irregular population recruitment. The age of the largest perch individuals do not exceed 4 years, and 3-year old fish are predominant. The sex distribution is characterized by a male to female ratio of about 1.

Fish pathology

The frequency of occurrence of pathologies of the liver of whitefish (pale liver and mosaic structure) is 54%. The development of connective tissue expansions in kidneys occurs in 29% of the fish. Changes in the reproductive system and gills are characteristic of 13% and 11% of the fish, respectively.

Heavy metals in fish

The heavy metal concnetrations (Cu, Ni, Pb and Cd) in fish muscle do not exceed the standard values. However, Hg concentrations in pike muscle exceed the maximum permissible concentration (Table 43). Metal concentrations (µg/g of wet weight) in liver, kidneys and gills are higher than in muscles, apart from Hg. The Cu concentrations in the liver of whitefish and pike are more than 20 µg/g, and the Ni concentrations in kidneys from 2.3 (pike) to 1.5 (whitefish) µg/g. Perch has higher accumulation of Ni (kidneys) and Cu (liver). The Cu concentrations in the liver of pike and whitefish are at least 3 times higher than those in perch liver. The Hg concentrations in pike muscle are higher than those in other fish species (Fig. 67).

Table 43. *The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Kantojärvi Lake (in µg/g wet and dry weight).*

	Standard value (µg/g wet weight)*	Concentration in muscle (µg/g wet weight)	Concentration in muscle (µg/g of dry weight)
Whitefish			
Hg	0.5	0.28	1.20
Ni	0.5	0.12	0.54
Cu	20	0.17	0.74
Cd	0.1	0.001	0.01
Pb	1	0.01	0.05
Perch			
Hg	0.5	0.21	0.98
Ni	0.5	0.12	0.59
Cu	20	0.15	0.71
Cd	0.1	0.002	0.01
Pb	1	0.01	0.05
Pike			
Hg	0.5	0.62	2.89
Ni	0.5	0.12	0.55
Cu	20	0.18	0.83
Cd	0.1	0.002	0.01
Pb	1	0.02	0.09

* Source: Sanitary..., 1986.

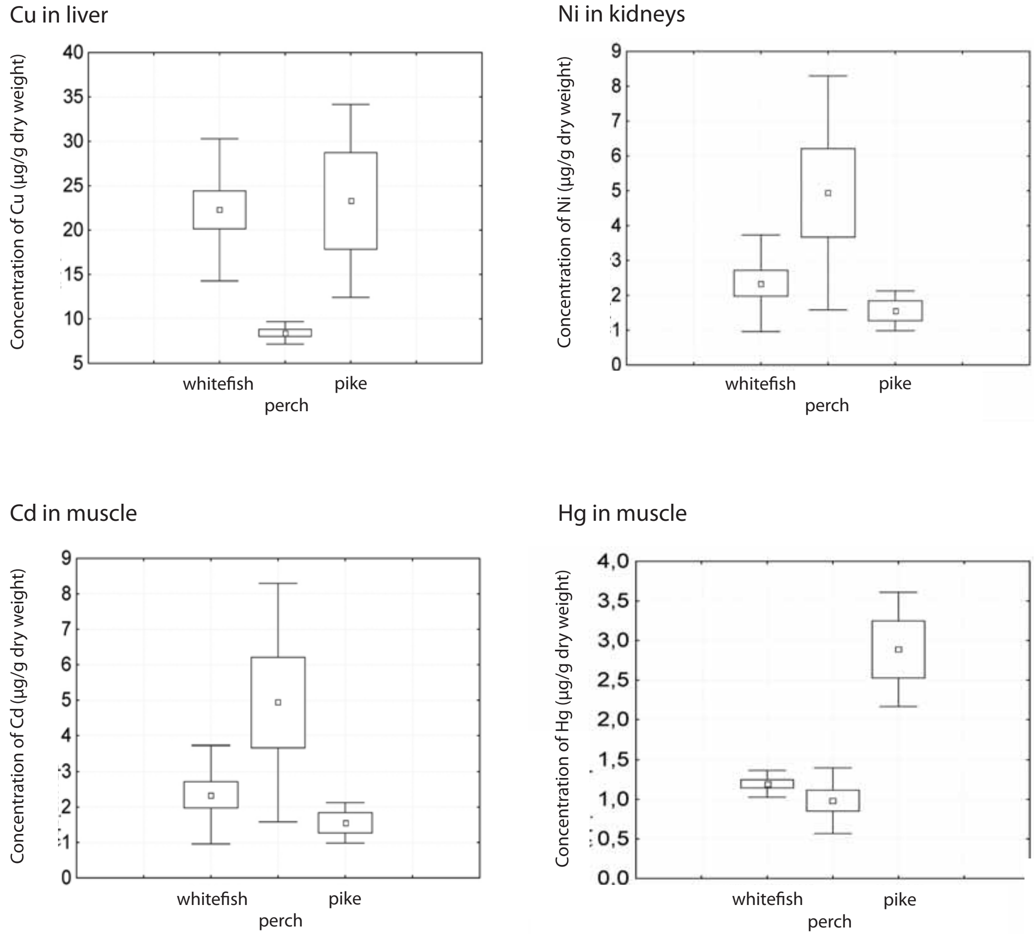


Fig. 67. *Accumulation of Cu (liver), Ni (kidneys), Cd and Hg (muscle) in fish from Lake Kantojärvi (µg/g dry weight).*

3.3. LAKE KIVIJÄRVI

Lake Kivijärvi (watershed of the River Kemijoki) is located at a distance of 305 km to the south-west of the town of Nickel and 29 km to the east of the settlement of Muonio in Finland. It is a small (area of the lake 186.92 ha), shallow-water (maximum depth 9.0 m) oval-shaped lake of glacial origin. The maximum length is 2.4 km and maximum width 1.1 km. The point of maximum depth is located in the central part of the lake.

According to the landscape type, the watershed area belongs to the forest zone with heights of upto 419 m (Korkea-Kivirova fell). The lake shores are high, and covered by shrubs and pine forest.

Physico-geographical characteristics	
Watershed	River Ounasjoki—River Kemijoki
Latitude	67°58.638′
Longitude	24°19.438′
Height above sea level, m	267.7
Height above sea level, m	2.4
Maximum length, km	1.1
Maximum width, km	9.0
Area, hectares	186.924
Watershed area, km^2	7.219
Study period	2005

Hydrochemical properties	
pH	6.98 6.97-6.99
Electrical conductivity, mS/cm	20 20-21
Ca, mg/l	2.5 2.5-2.5
Mg, mg/l	0.6 0.6-0.6
Na, mg/l	1.2 1.2-1.2
K, mg/l	0.2 0.2-0.3
HCO_3, mg/l	8.0 7.9-8.1
SO_4, mg/l	1.8 1.8-1.8
Cl, mg/l	0.5 0.5-0.5
Total mineralization, mg/l	14.8 14.7-15.0
Alkalinity, µeq/l	130 129-132

Color of water, deg.	65 65-65
NH_4, µg/l	6 5-8
NO_3, µg/l	2 2-2
N, µg/l	250 220-280
P, µg/l	12 11-13
Fe, µg/l	780 770-790

3.3.1. Hydrochemistry

The water of the lake is neutral with a low mean total mineralization (14.8 mg/l) and a low mean alkalinity (130 µeq/l). The lake has low concentrations of base cations and anions, with calcium (average 2.5 mg/l) and bicarbonate (average 8.0 mg/l) predominating.

The P and N concentrations of water are the main criteria used in assessing the development of water eutrophication. The concentrations and relationships between the species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. The concentrations of total P and total N during the vegetation period reach 13 µg/l and 250 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as mesotrophic. The lake also has colour values and organic matter (up to 7.4 mg/l) and Fe concentrations (mean 780 µg/l) typical of small water bodies in the region. During high water periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Although the watershed of Lake Kivijärvi is relatively remote from the Pechenganickel smelter (305 km), it is nevertheless subjected to its airborne pollution (primarily Ni and Cu) from the smelter. The average Cu, Ni and Al concentrations are 0.4 µg/l, 0.2 µg/l and 55 µg/l, respectively.

Cu, µg/l	0.4
Ni, µg/l	0.2
Al, µg/l	55
Pb, µg/l	0.1

3.3.2. Lake bottom sediments

There are no data available about the organic matter contents of the sediments in Lake Kivijärvi. The lake is located at a distance of 340 km from the Pechenganickel smelter. Owing to the considerable distance from the smelter, airborne pollution has almost no effect on the lake; the concentrations of e.g. heavy metals in the lake sediments are not elevated (Fig. 68). However, there are somewhat elevated concentrations of chalcophile elements (e.g. Pb, As and Cd) in the uppermost 10 cm layer of the sediments, which are presumably derived from long-range, trans-boundary air pollutants (Fig. 68). The maximum As concentration is in the uppermost 1 cm layer of the sediment core, and the highest concentrations of Pb and Cd at a depth of 3-5 cm. The contamination factor values of the chalcophile elements range from 1.6 to 8.4 (Table 44), i.e. the values correspond to moderate and high contamination. Pb has the highest C_f value. The degree of contamination value (19.9) for this lake corresponds to considerable contamination.

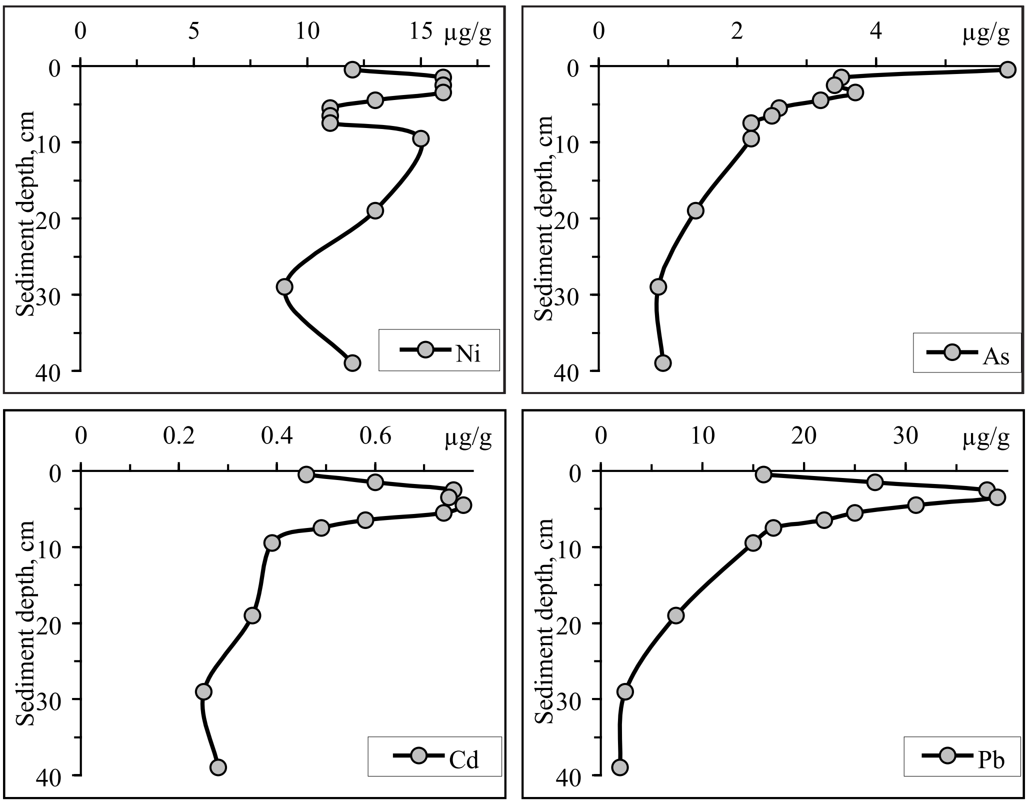


Fig. 68. *Vertical distribution of the concentrations of Ni, As, Cd and Pb (µg/g, dry weight) in the sediment core from Lake Kivijärvi.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Kivijärvi	0-1	–	17	12	87	14	0.46	16	5.90	
	38-40	–	27	12	84	16	0.28	1.9	0.93	
C_f			**0.6**	**1.0**	**1.0**	**0.9**	**1.6**	**8.4**	**6.3**	**19.9**

Table 44.
The organic matter contents (LOI, %) and heavy metal concnetrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (38-40 cm) sediment layers. C_f and C_d refer to the contamination factor and degree of contamination values, respectively.

3.3.3. Hydrobiological studies

Ichthyofauna. No direct hydrobiological investigations have been carried out in this lake. Lake Kivijärvi is a typical reservoir for such species as trout (*Salmo trutta*), whitefish (*Coregonus lavaretus*), grayling (*Thumallus thumallus*), pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*).

Fish samples obtained from the lake are not numerous. Whitefish is represented by individuals with an average length of 24.5 cm and weight 207 g. The size of the largest specimens is 32.6 cm and 580 g, respectively. The age limit of the whitefish is apparently 8 years, 3- to 6-year-old specimens constituting the bulk of the population. Males are predominant over females (1.9:1). The mean length and weight of the pike are 45.4 cm and 687 g, respectively, 7-year-old individuals have a weight of 900 g and length of 50.0 cm.

Heavy metals in fish

The heavy metals concentrations (Cu, Ni, Pb, Cd and Hg) in fish muscle do not exceed the standard values (Table. 45). The Cu concentrations in the liver of whitefish and pike (µg/g dry weight) are up to 37.4 and 9.6 µg/g, respectively, and Ni in the kidneys of whitefish up to 2.8 µg/g. Cd accumulation in fish kidneys is higher than that in muscle, while the corresponding Hg concentrations are double thay in muscle.

Analysis of the heavy metal accumulation in different fish species show that Ni (in kidneys) and Cu (in liver) accumulate the most strongly in whitefish (Fig. 69). There are no significant differences in Pb accumulation between the muscular tissue of whitefish and pike, whereas the Hg concentration in pike muscle is higher than that in perch (Fig. 69).

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g of dry weight)**
		Whitefish	
Hg	0.5	0.08	0.35
Ni	0.5	0.13	0.60
Cu	20	0.18	0.83
Cd	0.1	0.002	0.01
Pb	1	0.02	0.08
		Pike	
Hg	0.5	0.24	1.22
Ni	0.5	0.16	0.82
Cu	20	0.22	1.10
Cd	0.1	0.002	0.01
Pb	1	0.02	0.08

* Source: Sanitary..., 1986.

Table 45.
The standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Kivijärvi (in µg/g wet and dry weight).

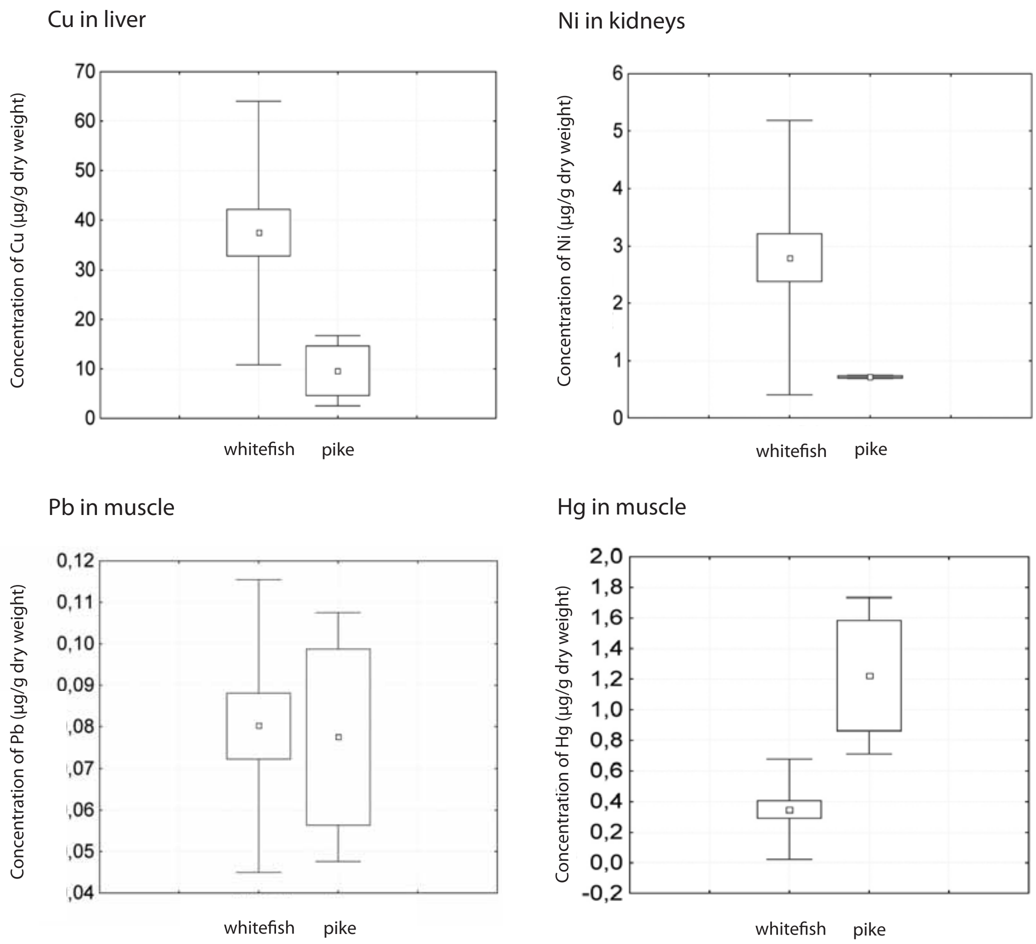


Fig. 69. *Accumulation of Cu (liver), Ni (kidneys), Pb and Hg (muscle) in fish from Lake Kivijärvi (µg/g dry weight).*

3.4. LAKE MELLALOMPOLO

Physico-geographical description	
Watershed	River Paz
Latitude	69°19.794′
Longitude	28°54.703′
Height above sea level, m	149.5
Maximum length, km	2.75
Maximum width, km	1.55
Maximum depth, m	12.5
Area, hectares	227.149
Watershed area, km^2	14.935
Study period	1983-2006

Lake Mellalompolo (watershed of the River Paz) is located 52.5 km to the west of the town of Nickel and 57.5 km to the north of the settlement of Nellim in Finland. It is a small (area of the lake 227.15 ha), shallow-water (maximum depth 12.5 m) lake, with an oval shape and indented shoreline, of glacial origin. The maximum length is 2.75 km and maximum width 1.55 km. The point of maximum depth is located in the central part of the lake.

According to the landscape type the watershed area belongs to the forest zone. The lake shores are high, and covered by shrubs and pine forests.

3.4.1. Hydrochemistry

The water of the lake is slightly acid and has a low mean total mineralization (14.6 mg/l) and low mean alkalinity (108 µeq/l). During flood periods the pH of the water drops, but acidification does not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 1.6 mg/l) and bicarbonate (average 6.6 mg/l) predominating.

Hydrochemical properties	
pH	6.51 6.02-6.82
Electrical conductivity, mS/cm	24 16-41
Ca, mg/l	1.6 1.2-2.2
Mg, mg/l	0.5 0.4-0.7
Na, mg/l	1.5 1.3-1.8
K, mg/l	0.3 0.3-0.4
HCO_3, mg/l	6.6 4.1-12.0
SO_4, mg/l	2.1 1.9-2.5
Cl, mg/l	1.7 1.5-2.1
Total mineralization, mg/l	14.6 10.7-18.8
Alkalinity, µeq/l	108 68-197

The total P and total N concentrations of water are the main criteria used in assessing the development of water eutrophication. The concentrations and relationships between the species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production and, consequently, the trophicity of the water body. During the vegetation period, the concentrations of total P reach 10 µg/l and of total N 253 µg/l.

According to the concentrations of mineral nutrients, the lake is classified as mesotrophic. The lake also has colour values and organic matter (up to 5.1 mg/l) and Fe concentrations (mean 335 µg/l) typical of small water bodies in the region. During high water periods in summer, the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Water colour, deg.	21 10-45
NH_4, µg/l	23 5-71
NO_3, µg/l	27 2-90
Total N, µg/l	253 190-390
Total P, µg/l	6 3-10
Fe, µg/l	335 39-1300

Although the watershed of Lake Mellalompolo is relatively remote from the "Pechenganickel" smelter (50 km), it is nevertheless subjected to anthropogenic impacts. The water system of the lake receives airborne pollutants emitted by the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Al, etc.) Despite the fact that emissions from the smelter have decreased to approximately one third of the maximum levels during the late 1970s, the deposition of pollutants still has an impact on the water body. The average Cu, Ni and Al concentrations are 1.2 µg/l, 1.2 µg/l and 42 µg/l, respectively.

Cu, µg/l	1.2 1.1-1.3
Ni, µg/l	1.2 0.9-2.1
Al, µg/l	42 25-61
Pb, µg/l	0.18 0.03-0.56

3.4.2. Lake bottom sediments

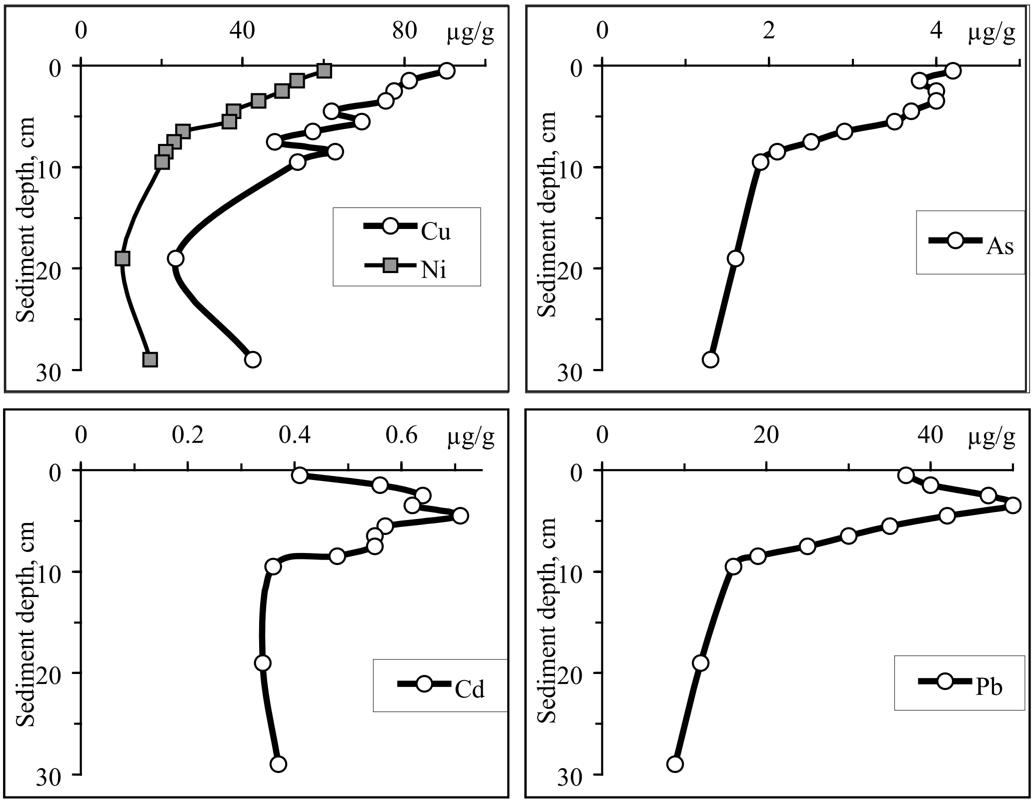


Fig. 70. *Vertical distribution of the concentrations of Ni, Cu, As, Cd and Pb (µg/g, dry weight) in the sediment core from Lake Mellalompolo.*

The sediments in Lake Mellalompolo are characterized by organic matter contents (LOI %) in the uppermost 1 cm layer of more than 36% (Table 46). Although the lake is located at a distance of 54 km from the "Pechenganickel" smelter, emissions from the smelter do have an effect on pollution in the lake; in the uppermost 10 cm sediment layer there is a clear gradient in the Ni and Cu concentrations (Fig. 70), as well as of Co and Zn (Table 46). The lake is also subjected to airborne pollution by chalcophile elements (Pb, As and Cd). The uppermost 10 cm sediment layer has elevated concentrations of these elements (Fig. 70): the maximum concentrations of Pb and Cd occur at depths of 3-4 and 4-5 cm, respectively. The contamination factor values for these elements range from 1.1 to 4.2 (Table 46), i.e. the values correspond to moderate and considerable contamination. Pb has the highest C_f value. The degree of contamination value (17.2) for this lake corresponds to considerable contamination.

Table 46. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (28-30 cm) sediment layers. C_f and C_d refer to the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Mellalompolo	0-1	36.68	90	60	140	7	0.41	37.0	4.2	
	28-30	31.31	43	17	86	5	0.37	8.9	1.3	
C_f			**2.1**	**3.5**	**1.6**	**1.4**	**1.1**	**4.2**	**3.2**	**17.2**

3.4.3. Hydrobiological studies

Ichthyofauna. Studies on the fish community in Lake Mellalompolo were conducted in 2005.

The ichthyofauna of the lake consists of seven species belonging to six fish families: trout (*Salmo trutta*), arctic char (*Salvelinus alpinus*), whitefish (*Coregonus lavaretus*), grayling (*Thymallus thymallus*), pike (*Esox lucius*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*). However the last two species were not found in our catches. Overall, whitefish predominates in Lake Mellalompolo. Grayling is also a common fish in this lake. Trout, arctic char and pike occur only occasionally (Fig. 71).

Sparsely rakered whitefish inhabits the lake (up to 30 gill rakers). The weight and length of the fish range from 7-888 g (average 329 g) and 9.3-40.5 cm (average 27.9 cm), respectively. There are two groups in the size and weight distributions: specimens with a weight of up to 100 g and length of 15-20 cm, and fish with a weight 400-600 g and length of 30-35 cm (Fig. 72).

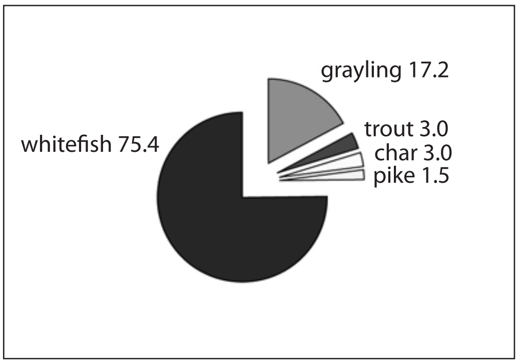


Fig. 71.
Distribution of fish species in Lake Mellalompolo.

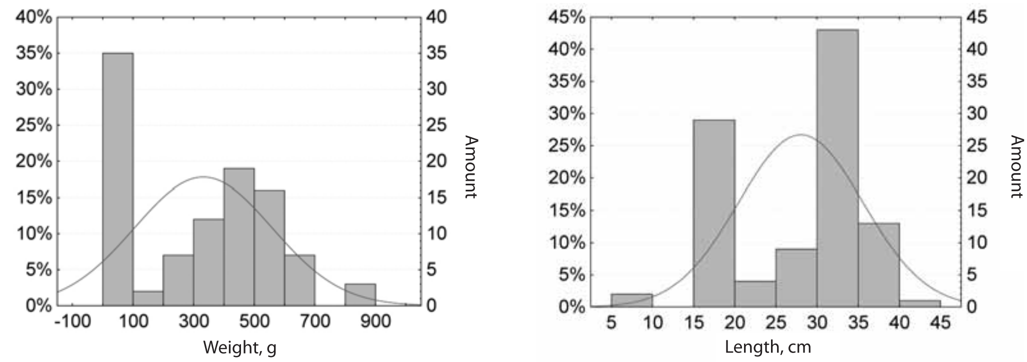


Fig. 72.
Size and weight distribution of the sparsely rakered whitefish in Lake Mellalompolo.

The age limit of whitefish is 8 years. 2-year-old (33%) and 5- to 6-year-old (40%) fish are the most numerous (Fig. 73). Some whitefish individuals appear to have very high growth rates. This is most probably due to the escape of mature fish from the fish farms into the water bodies. The ratio between females and males is 1.1:1.

The average size of the trout are weight 346 g and length 29.5 cm. The average weight of char is less than that of trout (293 g), but the length is 30.4 cm. The age limits of both species do not exceed 4 years. Some pikes at the age of 7 years have a weight over one kilogram (1205 g), and length up to 56.0 cm. The bulk of the grayling population consists of fish with a weight of 300-600 g and a length of 30-34 cm. The average weight is 261 g and 168.3 cm, respectively. There are no graylings older than 8 years. Females are predominant over males (1.4:1).

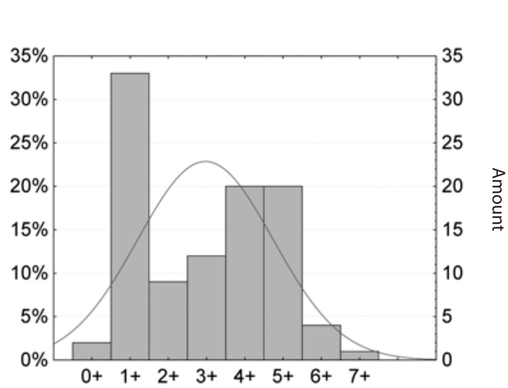


Fig. 73.
Age distribution of the sparsely rakered whitefish in Lake Mellalompolo.

Fish pathology
The initial stage of pathologies in whitefish organs and tissues have been ddocu-

mented in Lake Mellalompolo. The most frequently occurring pathologies of whitefish are pathologies of the liver (72%), kidneys (52%) and gills (27%). These pathologies are similar to those found in whitefish from lakes Kochejaur and Virtuovoshjavr.

Heavy metals in fish

The heavy metal concentrations (Cu, Ni, Pb and Hg) in fish muscle do not exceed the standard values (Table. 47). The metal concentrations (μg/g of dry weight) in other organs of whitefish are higher than those in muscles: Cu in liver (to 22.9 μg/g), Ni in kidneys (to 4.4 μg/g). The Cd concentrations in the kidneys of whitefish and char are much higher than those in muscular tissue (12.7 and 14.1 μg/g, respectively). The accumulation of Hg in the kidneys of whitefish, char, trout and grayling are 2-3 times higher than in the muscles.

There were no clear trends in metal accumulation between the different fish species. However, Cu had accumulated more strongly in trout liver, and the maximum Ni concentration is in whitefish kidneys and the maximum Hg concentration in pike muscle. Perch has the highest concentration of Cd in muscle (Fig. 74).

Table 47. *Standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Mellalompolo (in μg/g wet and dry weight).*

	Standard value (μg/g wet weight)*	Concentration in muscle (μg/g wet weight)	Concentration in muscle (μg/g of dry weight)
		Char	
Hg	0.5	0.20	0.84
Ni	0.5	0.16	0.71
Cu	20	0.28	1.19
Cd	0.1	0.004	0.02
Pb	1	0.04	0.17
		Whitefish	
Hg	0.5	0.11	0.53
Ni	0.5	0.14	0.65
Cu	20	0.16	0.72
Cd	0.1	0.004	0.02
Pb	1	0.03	0.13
		Trout	
Hg	0.5	0.23	1.01
Ni	0.5	0.16	0.69
Cu	20	0.27	1.15
Cd	0.1	0.003	0.01
Pb	1	0.02	0.07
		Pike	
Hg	0.5	0.28	1.37
Ni	0.5	0.12	0.57
Cu	20	0.14	0.68
Cd	0.1	0.002	0.01
Pb	1	-	<0.05
		Grayling	
Hg	0.5	0.20	0.93
Ni	0.5	0.15	0.69
Cu	20	0.19	0.92
Cd	0.1	0.003	0.02
Pb	1	0.02	0.08

* Source: Sanitary..., 1986.

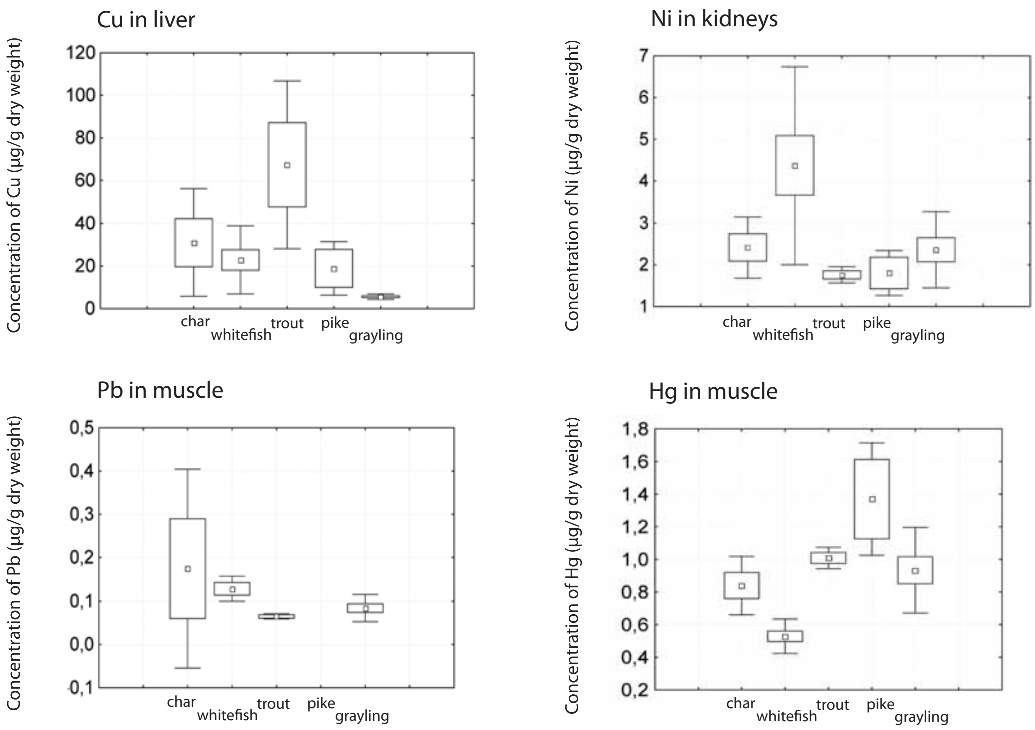


Fig. 74.
Accumulation of Cu (liver), Ni (kidneys), Pb and Hg (muscle) in fish from Lake Mellalompolo (µg/g dry weight).

3.5. LAKE SUOVASELKÄJÄRVI

Physico-geographical characteristics	
Watershed	River Paz
Latitude	68°57.176′
Longitude	28°27.514′
Height above sea level, m	168.0
Maximum length, km	1.12
Maximum width, km	0.62
Maximum depth, m	2.7
Area, hectares	43.512
Watershed area, km^2	5.098
Study period	1987-2006

Lake Suovaselkäjärvi (watershed of the River Paz) is located 86.2 km to the south-west of the town of Nickel and 13.2 km to the north-east of the settlement of in Finland. It is a small (area of the lake 43.51 ha), shallow-water (maximum depth 2.7 m) lake, with an elongated, oval shape, and of glacial origin. The maximum length is 1.12 km and maximum width 0.62 km. The point of maximum depth is located in the central part of the lake.

According to the landscape type the watershed area belongs to forest zone. The lake shores are high, and covered by shrubs and pine forests.

3.5.1. Hydrochemistry

The water of the lake is neutral with a low mean total mineralization (24.6 mg/l) and a low mean alkalinity (230 µeq/l). During flood periods the pH of the water drops, but acidification does not develop due to the buffering capacity of the water. The lake has low concentrations of base cations and anions, with calcium (average 3.8 mg/l) and bicarbonate (average 14.1 mg/l) predominating.

The P and N concentrations of water are the main criteria used for assessing the development of water eutrophication. The concentrations and relationships between the species of P and N vary according to the season, and the dynamics is to a greater extent determined by the level of production processes and, consequently, the trophicity of the water body. The concentrations of total P and total N during the vegetation period reach 10 µg/l and 350 µg/l, respectively.

According to the concentrations of mineral nutrients, the lake is classified as mesotrophic. The lake also has colour values and organic matter (up to 8.0 mg/l) and Fe concentrations (mean 431 µg/l) typical of small water bodies in the region. During high water periods in the summer the concentrations of PO_4^{3-} and NO_3^-, which determine the lake productivity, are low.

Although the watershed of Lake Suovaselkäjärvi is relatively remote from the Pechenganickel smelter (76.3 km), it is nevertheless subjected to anthropogenic impacts. The water system of the lake is exposed to the deposition of airborne pollutants derived from the smelter. The main pollutants are sulphur compounds and heavy metals (Ni, Cu, Al, etc.) Despite the fact that emissions from the smelter have decreased to approximately one third of the maximum levels during the late 1970s, the deposition of pollutants still has an impact on the water body. The average Cu, Ni and Al concentrations are 0.8 µg/l, 1.7 µg/l and 63 µg/l, respectively.

Hydrochemical properties	
pH	6.48 6.19-7.00
Electrical conductivity, mS/cm	35 21-53
Ca, mg/l	3.8 2.2-5.7
Mg, mg/l	0.8 0.5-1.2
Na, mg/l	1.5 1.2-2.0
K, mg/l	0.6 0.4-0.8
HCO_3, mg/l	14.1 6.5-22.0
SO_4, mg/l	2.2 1.8-2.9
Cl, mg/l	1.5 1.0-2.0
Total mineralization, mg/l	24.6 13.6-36.6
Alkalinity, µeq/l	230 107-360

Water colour water, deg.	30 20-35
NH_4, µg/l	74 6-140
NO_3, µg/l	5 4-7
Total N, µg/l	350 270-410
Total P, µg/l	6 4-10
Fe, µg/l	431 33-850

Cu, µg/l	0.8 0.5-1.1
Ni, µg/l	1.7 0.3-4.6
Al, µg/l	63 42-88
Pb, µg/l	0.08 0.04-0.14

3.5.2. Lake bottom sediments

The sediments of Lake Suovaselkäjärvi have high organic matter contents: the LOI value in the uppermost 1 cm sediment layer is about 60% (Table 48). The lake is located at a distance of 87 km from the Pechenganickel smelter. Airborne pollution from the smelter has slight effect on the lake: there is a gradual increase in Ni concentrations in the uppermost 6 cm layer of the sediments (Fig. 75). The uppermost 5-7 cm layer of the sediments has elevated concentrations of chalcophile elements (Pb, As and Cd)

(Fig. 75). The maximum concentrations of As, Pb and Cd occur at a depth of 1-3 cm, and the concentrations decrease on moving upwards into the uppermost 1-2 cm layer. The contamination factor values for these elements range from 1.9 to 10.8 (Table 48), i.e. the values correspond to moderate and high contamination. Pb has the highest C_f value. The degree of contamination value (20.7) for Lake Suovaselkäjärvi corresponds to considerable contamination.

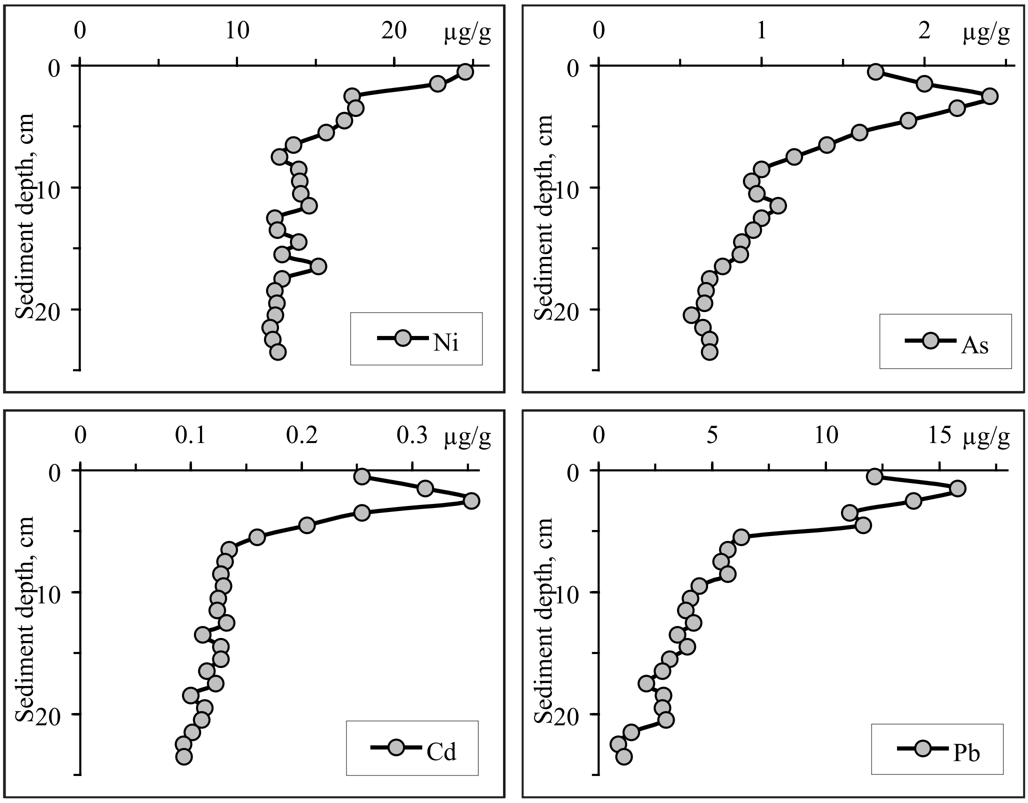


Fig. 75. *Vertical distribution of the concentrations of Ni, As, Cd and Pb (µg/g, dry weight) in the sediment core from Lake Suovaselkäjärvi.*

Table 48. *The organic matter contents (LOI, %) and heavy metal concentrations (µg/g, dry weight) in the surface (0-1 cm) and pre-industrial (23-24 cm) sediment layers. C_f and C_d refer to the contamination factor and degree of contamination values, respectively.*

Lake	Layer, cm	LOI	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Suovaselkajärvi	0-1	59.91	24	25	28	1.4	0.25	12.2	1.7	
	23-24	31.18	24	13	22	3.0	0.09	1.1	0.68	
C_f			**1.0**	**1.9**	**1.2**	**0.5**	**2.8**	**10.8**	**2.5**	**20.7**

3.5.3. Hydrobiological studies

Ichthyofauna. Studies on the fish community of Lake Suovaselkäjärvi were conducted in 2005.

The most common fish species in the lake are: whitefish (*Coregonus lavaretus*), pike (*Esox lucius*) and perch (*Perca fluviatilis*). Perch is the predominant species (90 %) (Fig. 76)., Grayling (*Thymallus thymallus*), burbot (*Lota lota*), minnow (*Phoxinus phoxinus*) and nine-spine stickleback (*Pungitius pungitius*) obviously also inhabit the lake.

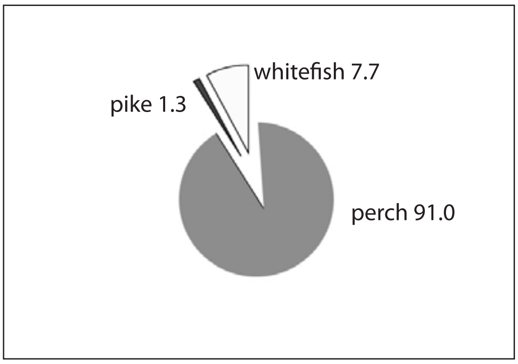


Fig. 76.
Distribution of fish species in Lake Suovaselkäjärvi.

Sparsely rakered whitefish occur in the lake (up to 30 gill rakers). Its mean length is 33.9 cm, and mean weight 563 g. Fish with a weight of 500-700 g and length of 34-36 cm are the most numerous (Fig. 77). The maximum weight and length of whitefish at the age of 5 years are 815 g and 38.5 cm, respectively. Specimens of younger age groups are occasionally caught. The bulk of the population consists of 5-year-old fish (Fig. 78). The low numbers of whitefish and their high growth rates suggest that they have been artificially introduced into the lake. The number of females is half that of males. (1:2). 2-year-old fish have mature gonads, and their weight and length is 110 g and 21.0 cm, respectively. This may also be due to their artificial origin.

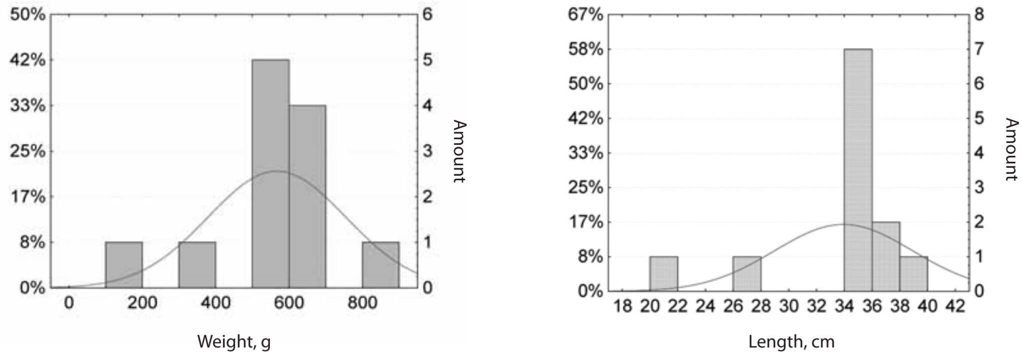


Fig. 77.
Size and weight distribution of the sparsely rakered whitefish in Lake Suovaselkäjärvi.

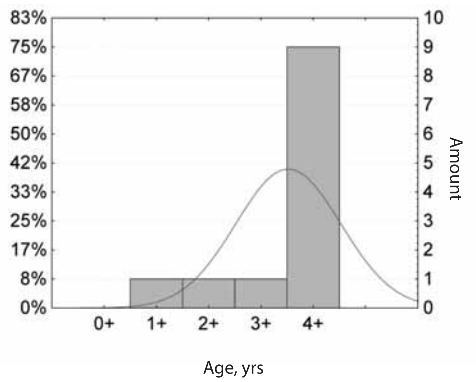


Fig. 78.
Age distribution of the sparsely rakered whitefish in Lake Suovaselkäjärvi.

Pike is represented by single specimens. The weight and length of 6-year-old fish can reach 598 g and 45.5 cm, respectively. Despite being the dominant fish species in the lake, the perch are relatively small: average weight 137 g and average length 21.4 cm. The bulk of the population consists of fish with a weight 100-150 g and length of 20-22 cm (Fig. 79). The maximum weight at the age of 8 years does not exceed 277 g, and the maximum length 26.8 cm. In the sex distribution males predominate (1:1.3).

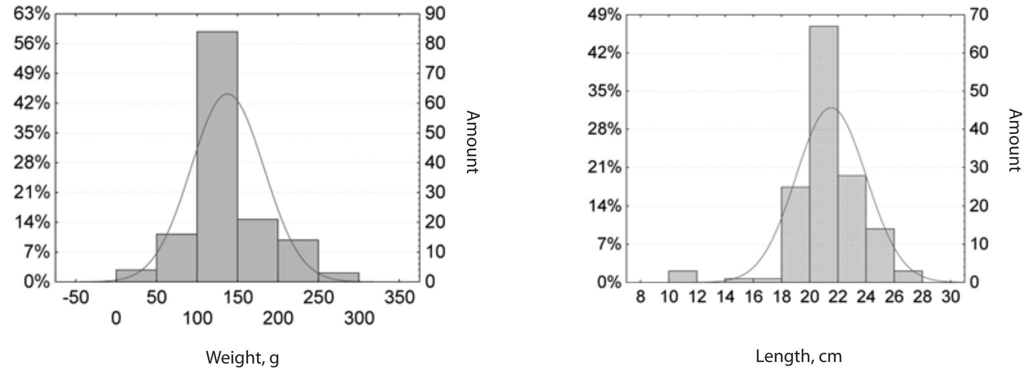


Fig. 79.
Size and weight distribution of perch in Lake Suovaselkäjärvi.

Fish pathology

The most frequently occurring pathologies of whitefish are liver disorders, primarily changes in colour, shape (oblong) and fatty degenerations (pale liver) (up to 83%). The development of connective tissue expansions in the kidneys occur in 59% of specimens. Changes in the gills and reproductive system are characteristic of 15% and 8% of the fish, respectively.

Heavy metals in fish

Heavy metal accumulation (Cu, Ni, Pb, Cd and Hg) in fish muscle of fish does not exceed the standard values (Table 49). The highest concnetrations of Cu (µg/g of dry weight) occur in fish liver (up to 38 µg/g in whitefish and up to 31 µg/g in perch). The Ni concentrations in fish kidneys (3.9 µg/g in perch) and skeleton (4.8 µg/g in whitefish, 4.2 µg/g in perch and 6.3 µg/g in pike) are very high. The Cd concentrations in fish kidneys are much higher than those in muscle.

Analysis of heavy metal accumulation in different fish species showed that the highest Cu concentrations occur in the liver, and of Pb, in the muscles of whitefish. Perch has maximum Ni concentrations in the kidneys, and pike has higher Hg concentrations in the muscle than the other fish species (Fig. 80).

	Standard value (µg/g wet weight)*	**Concentration in muscle (µg/g wet weight)**	**Concentration in muscle (µg/g of dry weight)**
		Whitefish	
Hg	0.5	0.23	1.02
Ni	0.5	0.11	0.48
Cu	20	0.17	0.74
Cd	0.1	0.003	0.01
Pb	1	0.03	0.11
		Perch	
Hg	0.5	0.15	0.74
Ni	0.5	0.10	0.51
Cu	20	0.12	0.56
Cd	0.1	0.002	0.01
Pb	1	0.02	0.07
		Pike	
Hg	0.5	0.27	1.32
Ni	0.5	0.10	0.50
Cu	20	0.16	0.77
Cd	0.1	0.002	0.01
Pb	1	0.01	-

* Source: Sanitary..., 1986.

Table 49.
Standard values for heavy metal concentrations in foodstuffs and in fish muscle in Lake Suovaselkäjärvi (in µg/g wet and dry weight).

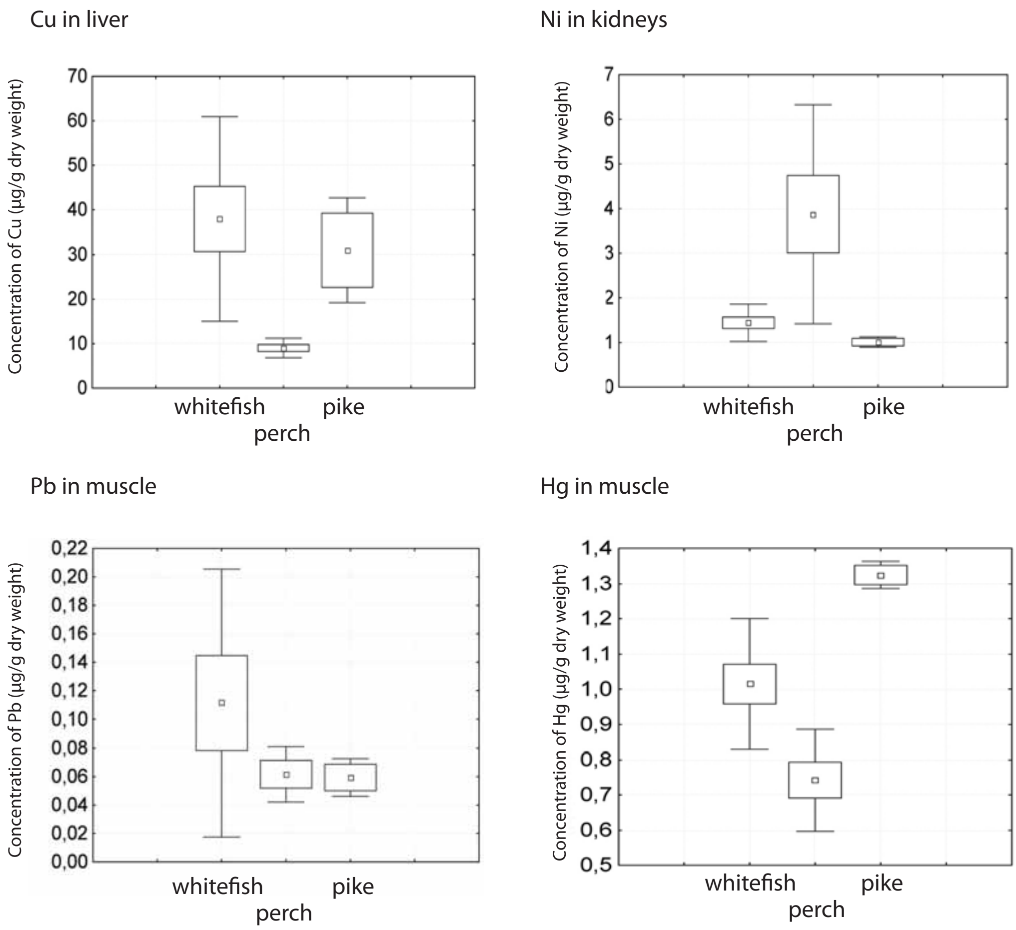


Fig. 80. *Accumulation of Cu (liver), Ni (kidneys), Pb and Hg (muscle) in fish from Lake Suovaselkäjärvi (µg/g dry weight).*

CONCLUSIONS

Hydrochemistry

Freshwater systems are sinks for pollution, because pollutants are transported from the surrounding landscape into the streams and lakes. The watercourses in the Russian, Norwegian and Finnish border area consist of two contrasting types of system: the large Inari-Paz watercourse and the numerous small lakes and streams. The Inari-Paz watercourse has important environmental properties, is rich in natural resources, and constitutes a sub-arctic system with high biodiversity and production of fish and other aquatic organisms. The area is, however, subjected to severe anthropogenic impacts, primarily from the Pechenganikel smelter complex. The main pollutants that influence the lakes and rivers are sulphur compounds and heavy metals (Ni, Cu, Cd, Cr, Zn, As, Hg etc.), polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs).

Sulphur dioxide (SO_2) emissions from the smelter can lead to the acidification of surface waters and the contamination of groundwater through the leaching of polluting elements from the surface soil. For example, data on the contribution of snowmelt to groundwater in the area indicate that Ni contamination is highly likely.

Joint investigations carried out in the early 1990's identified numerous acidified and heavy metal polluted lakes in the border area. The impact of pollution is the greatest at Russian and Norwegian sites in the vicinity of the smelters, although the effects are also seen on the Finnish side of the border. The area was classified as being moderately to very severely contaminated, primarily due to emission from the Ni-Cu smelting industry on the Kola Peninsula.

Some of the differences and changes in water quality reflect the influence of the Pechenganikel smelter. The strongest evidence for this are the high Cu (> 3 $\mu g\ l^{-1}$) and Ni (> 15 $\mu g\ l^{-1}$) concentrations in the lakes near the smelter. Water bodies with elevated Cu and Ni concentrations occur within a 30 km radius around the smelters. The Cu and Ni concentrations decrease with increasing distance from the smelter, although relatively elevated concentrations also occur near to the border on the Finnish side.

According to the Swedish water quality criteria, harmful biological effects may occur in sensitive waters if the Cu concentration exceeds 3 µg l-1 or the Ni concentration exceeds 15 $\mu g\ l^{-1}$. Moiseenko et al. (1995) presented critical levels for Ni and Cu concentrations in lake waters based on the occurrence of pathological conditions in fish. The critical levels in well-buffered waters (ANC > 200 $\mu eq\ l^{-1}$) were 8 $\mu g\ l^{-1}$ for Cu, and 20 $\mu g\ l^{-1}$ for Ni. The Cu concentrations in 8 lakes exceed these critical levels, and the Ni concentration in 12 lakes and 2 small rivers. There is also a weak, increasing trend in the Ni concentration in the lakes in the Raja-Jooseppi area, and a statistically non-significant increase in the TOC concentration. The catchments of the lakes in the Raja-Jooseppi area have a higher proportion of peatland than the other areas studied, resulting in higher humic concentrations.

Although SO_2 emissions from the Pechenganikel smelter have decreased to approximately one third of the maximum levels in the late 1970s, sulphur deposition still has a clear impact in the region. The sulphate concentrations in lakes and rivers in the vicinity of the Pechenganikel smelter are considerably higher than those in other areas. Despite the high sulphate concentrations, the lakes and rivers in the area are well-buffered and are not suffering from acidification. The bedrock in the Pechenganikel area contains relatively large amounts of alkaline material, thus ensuring a considerable supply of base cations. Thus, despite the high sulphur deposition, the soils in the catchment area contribute sufficient base cations to prevent acidification. This is clearly reflected in the water quality; lakes with relatively high sulphate concentrations also have high base cation concentrations and high alkalinity. The emission of alkaline dust from the smelter, power station and mining activities also undoubtedly contributes to the high base cation concentrations in the lakes.

The Jarfjord and Vätsäri areas have more weakly buffered lakes. This is also the case in Vätsäri and in Sør-Varanger, to the east of Vätsäri. Jarfjord and Sør-Varanger are situated relatively close to the smelter. and are therefore subjected to relatively high sulphur deposition. Strong signs of acidification have earlier been recorded in the lakes in the Jarfjord area but, since 1987, the mean pH has increased from below 5 to 5.4 in 2004. Similar signs of recovery from acidification have been reported in the Vätsäri lakes. However, the lakes in Vätsäri are in the early stage of recovery, and the increase in the buffering capacity is not yet very strongly reflected in the pH. The low alkalinity and low pH values in some lakes in the Raja-Jooseppi area, as well as in the reference area in Pallas, are caused by the naturally higher concentrations of organic acids in the lakes.

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

Lake bottom sediments

Lake sediment samples provide an excellent tool for assessing the ecological state of lakes and the impact of pollution from both local and global sources. Analysis of the distribution of heavy metals in the bottom sediments clearly demonstrates that lakes with high concentrations of highly correlated elements (e.g. Ni, Cu, Co and Hg) are located within a 50 km radius around the smelter complex. The increase in Pb concentrations follows a gradient running from east to west, and is related to the long-distance, trans-boundary transport of pollutants from central Europe. Cadmium, As and Hg are, in addition to Pb, also so-called global pollutants. The maximum Ni and Cu concentrations, which exceeded the background (pre-industrial) values by a factor of 10 to 130, occur within a distance of 10 km from the Pechenganikel smelter. At distances of 10 to 30 km from the emission source the concentrations are only 3–7 times higher than the corresponding background values. The concentrations of Co are 4–10 times higher than the background values within a distance of 15 km from the smelter, and up to 3 times higher at distances of more than 15 km. Lakes Kuetsjarvi, LN-2, LN-3, LN-4 receive the highest pollutant loads from the Pechenganikel smelter, and this is reflected in the fact that the maximum concentrations of Ni, Cu, Co, Zn, Cd, Hg and As occur in the uppermost sediment layers. Some lakes located at greater distances from the smelter have relatively high Cd, Pb, Hg and As concentrations in their sediments, and this is related to global pollution by these elements during the past few decades.

Hydrobiological studies

Hydrobiological indices

The phytoplankton communities in the lakes consist of cyanobacteria, diatoms, yellow-green algae and green algae. Cladocerae and Copepoda form the dominant zooplankton communities. The predominant species in the benthic communities are Chironomids, mayfly (*Ephemeroptera*) and stoneflies (*Plecoptera*). Despite the extremely high level of pollution, Lake Kuetsjarvi is the richest lake as regards the number of zooplankton species, and also has considerable species diversity in bottom organisms. The number of zoobenthos species is over 20, with Chironomids predominating (60-80%).

Ichthyofauna

According to the studies on fish communities in the Finnish, Norwegian and Russian border area, the ichtyofauna of the lakes comprises 14 fish species. The most common species are whitefish, perch and pike. The whitefish in forest lakes (Aittojärvi, Kantojärvi, Suovaselkäjärvi, Mellalompola, Kochejaur, and Virtuoshjaur) were represented by the sparsely rakered form only.

<u>Whitefish</u>. The densely rakered whitefish was caught only in Lake Kuetsjarvi. The sparsely rakered whitefish in this lake had the smallest length and weight. The largest whitefish occurred in lakes Suovaselkajärvi and Kochejaur (Fig. 81). The whitefish in Lake Stuorajavre also had high lengths and weights. The maximum age of the whitefish varied within broad limits. The maximum whitefish age was in Lake Kochejaur (18 years). Overall, the maximum age of whitefish in the small forest lakes in the region varied from 4+ (Suovaselkajärvi) to 11+ (Kochejaur).

Normally, whitefish reach maturity at the age of 5-8 years (Reshetnikov, 1980). However, as a result of long-term exposure to pollutants, the whitefish in some lakes reached maturity at the extremely early age of 0+-1+ and had a minimum weight of 6-14 g and length 8.9-12.1 cm (Lake Kuetsjarvi). The whitefish in Lake Stuorajavre reached maturity at the age of 5 years. Whitefish spawning for the first time at the age of 3 years were found in water bodies (Kochejaur, Virtuovoshjaur) located at considerable distances from the emission sources.

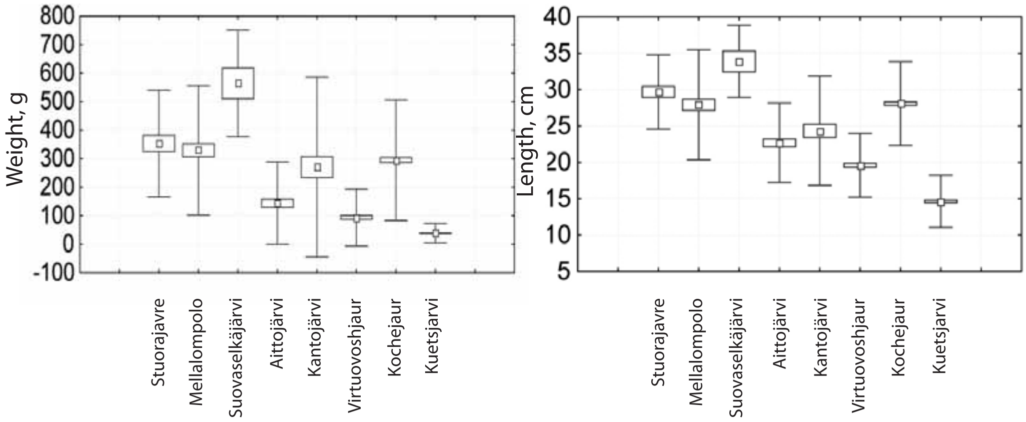


Fig. 81. Comparative length and weight of sparsely rakered whitefish.

Trout and arctic char. The length and weight of trout in Lake Stuorajavre were higher. The smallest weights and lengths occurred in Lake Shuonijarvi (Fig. 82).

Arctic char was the most common in Lake Shuonijarvi, and was only occasionally caught in Lake Mellalompola. Overall, the weight varied from 64 to 875 g (average 258 g) and length from 17.7 to 40.0 cm (average 27.3 cm).

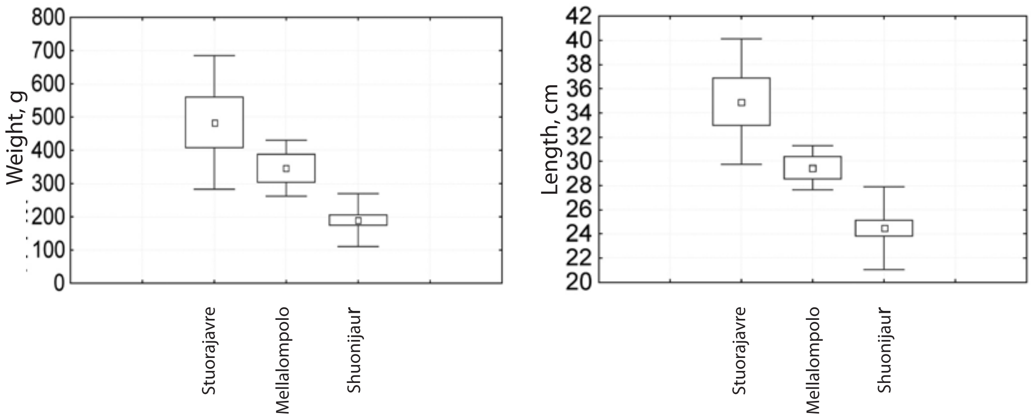


Fig. 82.
Comparative length and weight of trout.

Pike. The largest pike were caught in Lake Aittojärvi. The weight and length indices of pike in the other lakes varied to an insignificant extent (Fig. 83).

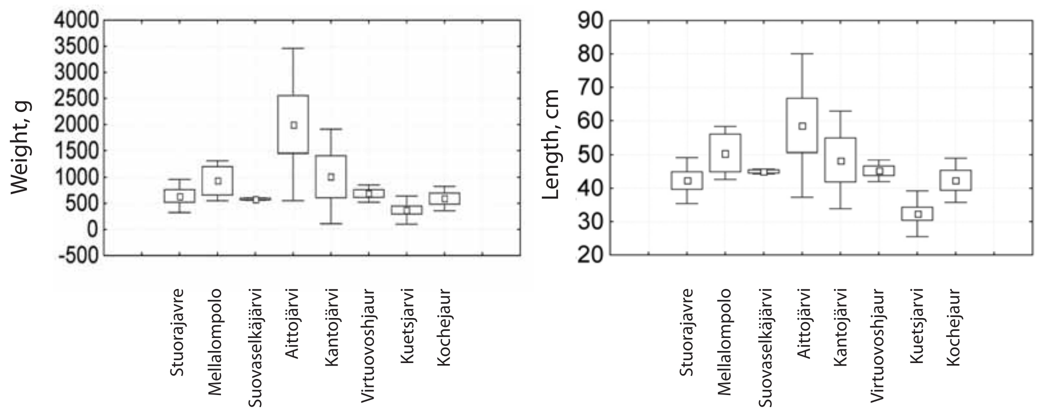


Fig. 83.
Comparative length and weight of pike.

Perch. The average size and age of this species were higher in Lake Virtuovoshjaur (16 years) and Lake Kochejaur (14 years) (Fig. 84). The fish in lakes Stuorajarvi and Kantojärvi had the smallest length and weight.

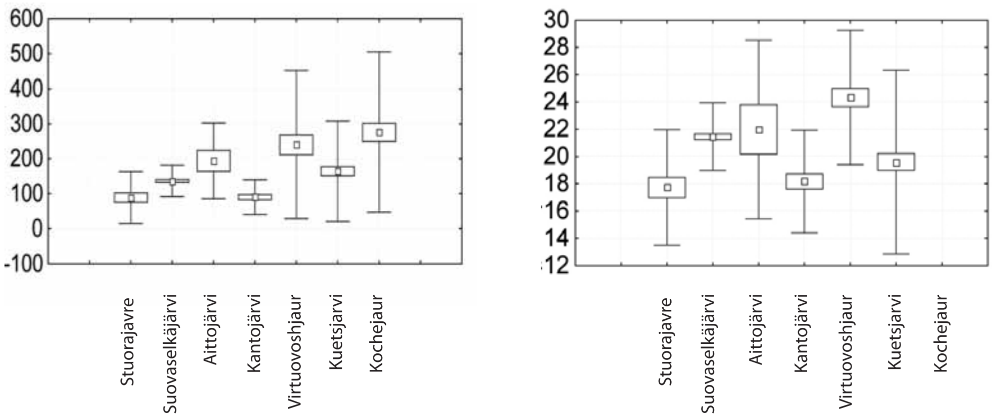


Fig. 84.
Comparative length and weight of perch.

Vendace. The vendace inhabiting the pelagic zone of Lake Kuetsjarvi were of small size (9.3 – 13.6 cm, 6-19 g). The mean values were 10 g and 11.0 cm.
Grayling. According to our data grayling was the most common in Lake Mellalompola. In the other water bodies it was caught only occasionally.
Burbot. There were only single catches of this fish.

Analysis of some population parameters in the water bodies at various distances from the smelter indicate changes in the fish populations. The decrease in the age, size and maturity ranges of the fish populations in the polluted water areas (Lake Kuetsjarvi) indicates poor water quality. The whitefish populations are characterized by a small number of age groups, rejuvenation of the populations, and maturation at an early age.

Fish pathology

According to the analysis of pathological changes in whitefish in the lakes, on the whole, disorders in the liver, kidney, gonads and gills were the most common. The frequency of pathologies of the liver and kidney tended to increase throughout the whole study period. Fish pathologies were frequently encountered in the water bodies located both in the vicinity and at greater distances from the pollution sources. The intensity and characteristics of the fish pathologies observed in the water bodies exposed to different levels of air borne pollution were similar. In the water bodies in the background region (Stuorajavri) and in small forest lakes (Kochejaur, Virtuovoshjavr, Aittojärvi, Kantojärvi, Mellalompola and Suovaselkäjärvi), of organ abnormalities was common, as was the case in the water bodies located in the vicinity of the pollution sources. The most frequently occurring disorders of whitefish were connective-tissue expansions. This may reflect the increasing load of Ni on the water bodies, which causes the development of this particular type of pathology.

Heavy metals in fish

Copper. Comparison of the Cu concentrations in whitefish liver in the different lakes showed that the mean Cu concentrations in liver in the strongly polluted water body (Lake Kuetsjarvi) were comparable to those in the small forest lakes, and sometimes even exceeded them (Lake Suovaselkäjärvi). The Cu concentration in liver was at its lowest in Lake Stuorajavre (Fig. 85).

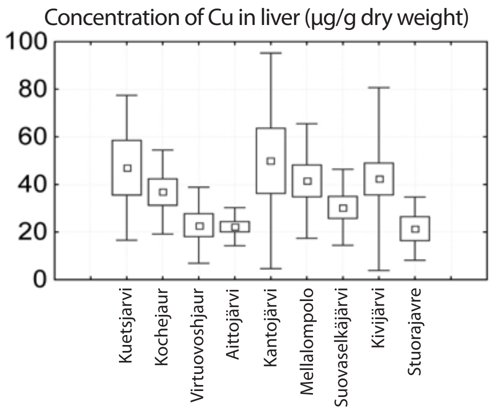


Fig. 85.
Copper concentrations in the liver of sparsely rakered whitefish in the studied lakes.

Nickel. The Ni concentrations in whitefish kidney from Lake Kuetsjarvi (average 22.72 µg/g dry wt) were higher than those in the other water bodies (Fig. 86). The whitefish in the small forest lakes (Virtuovoshjaur and Aittojärvi) had mean Ni concentrations of 6.50-6.60 µkg/g dry wt. In the other water bodies, including the background region (Stuorajavri), the Ni concentrations did not exceed 5 µg/g dry wt.

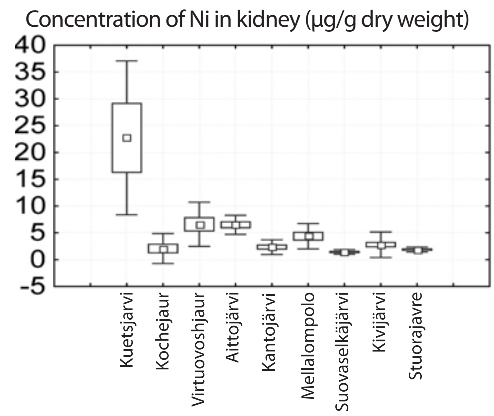


Fig. 86.
Nickel concentrations in the kidney of sparsely rakered whitefish in the studied lakes.

Mercury. The Hg concentrations in whitefish muscle in the Finnish lakes (Mellalompolo, Aittojärvi, Kantojärvi and Suovaselkäjärvi lakes) were the highest (Fig. 87).

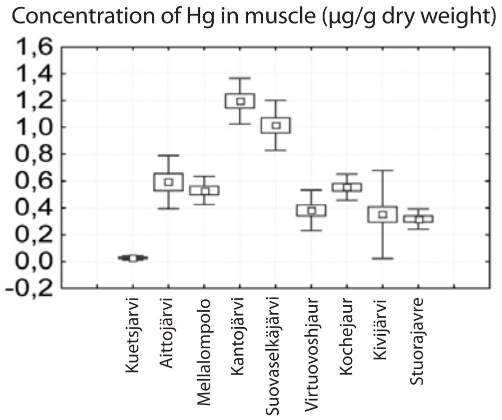


Fig. 87. *Mercury concentrations in the muscle of sparsely rakered whitefish in the studied lakes.*

The Cu, Ni, Cd and Pb concentrations in fish muscle do not exceed the established standard values. However, the Hg concentrations in perch (Lake Kochejaur) and pike (lakes Kochejaur, Aittojärvi and Kantojärvi) muscle are higher than the maximum permissible concentration. Overall, the metal concentrations of (µg/g dry weight) in other fish organs are much higher than those in the muscles.

Further assessment and monitoring of the small lake ecosystems in the region are required. This should primarily be based on the characteristics of the whitefish, perch and pike populations and on parameters of the phyto-, zooplankton and benthic communities. In some lakes populated by trout and char these species are more reliable as quality indicators of the aquatic ecosystems. Metal concentrations in fish reflect the level of anthropogenic pollution in the water bodies. These indices can therefore be employed in assessing the impact and extent of airborne industrial pollution. The permanent monitoring of ichthyofauna is needed to control the air borne pollution of water bodies.

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Catalogue of Lakes in the Russian, Finnish and Norwegian Border Area

The catalogue of lakes represents a collection of data on baseline conditions in the aquatic ecosystems of small lakes in the joint Russian, Finnish, Norwegian border area, which is subjected to considerable levels of anthropogenic pollution.

The present catalogue was compiled by researchers from the Institute of the North Industrial Ecology Problems, Kola Science Center RAS, in collaboration with the Lapland Regional Environment Center, Finland. This publication is based on the data, collected in connection with the Interreg IIIA Kolarctic project "Development and implementation of an environmental monitoring and assessment programme in the joint Finnish, Norwegian and Russian border area", carried out during 2003-2006, as well as data from earlier studies.

The catalogue is meant for a wide audience: the local population, people involved in economic activities in the border area, recreationists, students, environmental organizations and ecologists.

This report was prepared in Russian and translated into English.
The Russian version is appended to this publication as a CD appendix.

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