Zoobenthic study of biological state of small lakes in the joint Finnish, Norwegian and Russian border area

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Zoobenthos samplin in Vätsäri, Finnish Lapland. Photograph: Petri Liljaniemi

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LAPLAND REGIONAL ENVIRONMENT CENTRE

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Preface

Within the frame of the Interreg III A Kolarctic programme "Development and implementation of an environmental monitoring and assessment programme in the joint Finnish, Norwegian and Russian border area", Lapland Environment Centre (LEC) and the Institute of North Industrial Ecology Problems (INEP) performed a co-operative freshwater invertebrates study in August-September 2005. This report summaries the results of extended field inventories from 25 small lakes, located in the following regions: Nikel (Russia), Jarfjord (Norway), Vätsäri, Raja-Jooseppi and Pallas (Finland). The programme has been co-ordinated by Ilona Grekelä (LEC). Scientists Valery Yakovlev, Anna Yakovleva (INEP) and Petri Liljaniemi (LEC) were responsible for invertebrate sampling, laboratory analyses and report preparation. Martti Salminen (LEC) assisted in field inventories and carried out water sampling for chemical analysis in the Pallas Region.

Our sincere thanks to Odd Terje Sandlund and Trygve Hesthagen (Norsk Institut for Naturforskning, NINA) for their help with sampling and taking care of accommodation for the Russian participants in Jarfjord Region. We are grateful also to Lubov Kudravseva (INEP) for analyses of metal concentrations in invertebrates. Further, we thank Markku Örn, the Head of Hydrochemical Laboratory (LEC), and all staff at Lapland Environment Centre for their help in organisation of field inventories, chemical analyses and in preparing of this report.

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Abstract

Intensive invertebrate samplings were performed in border area between Finland, Norway and Russia in order to study the present state of the acidification-sensitive surface waters receiving airborne pollution from the industrial complexes of Kola Peninsula. Total of 25 small lakes were chosen for monitoring from five regions: Nikel (Russia), Jarfjord (Norway), Vätsäri, Raja-Jooseppi and Pallas (Finland). The study was conducted using methods and sites of an earlier inventories carried out in years 1993 - 1996. Along with the study of invertebrate community structure, accumulation of metals in tissues of Polycentropodidae caddisfly larvae was investigated. The analysis of the data included spatial comparison between the different regions, and temporal comparison between the earlier and present material.

Total number of species, relative abundance and biomass of acid- and pollution-sensitive species, Shannon Diversity Index, Kola Biotic Index Score (KolaBIS), Short Score Index (ShSI) and Acidic Score Index (AcSc) were used for the assessment of the ecological state and environmental quality of the monitored lakes.

Acid- and pollution-sensitive species found in 2005 included snails *Lymnaea peregra* and *Gyraulus albus*, amphipoda *Gammarus lacustris*, 13 mayflies (except Leptophlebidae) and 15 stoneflies (except Nemouridae). In comparison to years 1993 - 1996, number of acid- and pollution-sensitive species and their share of total number and biomass of benthic communities had decreased considerably. In 2005, they were lacking from Lake Otervatn in Jarfjord, three lakes in Raja-Jooseppi (Kalaton Kampajärvi, Peuranampumajärvi and Lampi D49), and from lakes Käyräjärvi, Sarvijärvi and Hietajärvi in Pallas. These lakes are mainly small, acidic lakes representing generally closed or headwater lake types. Sensitive species were also absent from three polluted lakes in Nikel Region of Russia. However, they frequently occurred and were abundant in Lake Shuonijavr, south-east of Nikel town.

According to the present material, thirteen of twenty (without Nikel Region) lakes monitored in 2005 had low Acidic Index values (< 0.5 for all of lake habitats). The lakes Store Skardvatn (Jarfjord Region), Harrijärvi, Pitkä-Surnujärvi, Lake 222 (Vätsäri Region), Takkireuhkajärvi, Pieni Arttajärvi (Raja-Jooseppi Region) and Keimiöjärvi (Pallas Region) showed no signs of acidification. Further, in Nikel Region lakes LN4 and LN5 were characterized as lakes undisturbed by pollution from Pechenganikel plants.

The comparison between the regions revealed that the highest values of ecological indexes were characteristic for regions Raja-Jooseppi and Pallas, and lowest for Nikel region (with the exception for lakes LN4 and LN5). However, ecological state had deteriorated in majority of studied lakes during the last decade. In comparison to the period of 1993 - 1996, only one Lake 222 had remained undamaged by 2005. Formerly circumneutral Lake Rautujärvi in Pallas had become moderately acidified by 2005. Lampi 3/88 in Vätsäri had turned into strongly acidified lake status.

Although a decreasing trend could be detected in the heavy metal concentrations of the tissues of caddisfly larvae sampled from two lakes of Nikel area, the state of invertebrate communities revealed no signs of recovery. The results therefore suggest that the improved air- and water protection measures carried out in the industry of Kola Peninsula have not improved the acidity and pollution status of the monitored lakes. It is possible that recent renovation of Pechenganikel industrial plant's air protection facilities have not yet taken effect on the benthic biota of small lakes. The negative processes in water ecosystems of the main part of Nikel lakes are still persist-

ing as a result of severe pollutant emissions and the accumulation of contaminants in lakes and their adjacent territory. Further, the long history of airborne loading has reduced acid-neutralizing capacity in remote regions on Norway and Finland. Only subsequent periodic monitorig of lakes can give the certain answers about the responses of biological communities to decrease of pollution from Pechenganikel plants and other sources.

The results obtained from this study provides grounds for further examination of the long-term changes in invertebrate communities in small lakes and their supplementary streams. Approaches for the development of the long-term monitoring program of lakes located in the Finland-Norway-Russia border area are proposed on the bases of the results.

1. Introduction

The Pechenganikel factories in the Murmansk region are the main sources of pollution affecting the environment of northern parts of Scandinavia and Russia. The emissions from the industry results to high concentration of pollutants in the atmosphere and surface waters, and the damage to the aquatic ecosystems is obvious. During the last 15 years severe impacts on freshwater communities have been documented, especially for the small lakes located near the Pechenganikel factories (Langeland et al., 1993).

Earlier studies have shown that as a result of long-term contamination, the small lakes and running waters in Nikel region are characterized by extremely high concentration Ni, Cu, Co, Cd and other heavy metals in water and bottom sediments (Langeland et al., 1993; Nøst et al., 1997).

Acidification of surface waters by acid atmospheric deposition is considered as an important ecological problem in northern Finland (Kämäri 1986, Kinnunen 1990, Tuovinen et al. 1990, Nenonen 1991) and Norway (Langeland et al. 1993, Nøst et al. 1997). The north-eastern Lapland also receives elevated sulphur acid loadings (Nenonen 1991). However, large number of acidic lakes in Finland are naturally acidic due to geological properties of their catchment area (e.g. Kortelainen 1993).

It has been shown that elevated depositions of SO_4 and relatively low buffering capacity of clear water lakes in north-eastern Lapland can led to loss of acid-sensitive fish (Lappalainen et al. 1995). In 1993 - 1994, extended field study of the state of zoobenthic invertebrate communities and water acidity revealed that many lakes located in different parts of Finnish Lapland (areas between Kittilä and Kolari, and around Enontekiö) were acidic and damage of invertebrate communities was evident (Yakovlev 1999).

This report presents results regarding invertebrate species composition, species richness, relative abundance and biomass of acid- and pollution-sensitive species, as well as biological assessment of water acidity and pollution using several hydrobiological indices. The trace and other metal concentrations in aquatic invertebrates were also examined. In order to reveal the possible improvement of the ecological state due to the renovation of Pechenganikel industrial complex, we compared results obtained from inventories in 1993 - 1994 and 2005.

Further aim of the present study was the development of national monitoring methods, and the creation the cross-border, long-term biological monitoring programme for the Inari-Pasvik international watershed.

2. Study area

The study area is located in the border area of Finland, Norway and Russia (latitude $67^0 55'$ - $69^0 45'$ North and in longitude $24^0 00'$ - $30^0 40'$) (Fig. 1). For the study, the area was divided into five regions: 1) Nikel (Russia), 2) Jarfjord (Norway), and 3) Vätsäri, 4) Raja-Jooseppi, 5) Pallas (Finland).

The coordinates and some physical and water-chemistry parameters of the lakes are presented in Table 1 and Appendix 1.

Figure. 1**.** Map of study regions with the investigated lakes in 2005.

According to maps, the monitored lakes are located at the height of 120 - 353 m above see level, in tundra and northern forest landscapes. The highest altitudes of lakes are characteristic for the Pallas region, and the lowest for Vätsäri region.

Table 1. Mean (± SE) values of lake altitudes (ALT, m a.s.l.), water surface area (LSA, km^2) and shoreline (ShL, km) of lakes sampled in five regions.

Region	ALT	LSA	ShL
Nikel	206 ± 29	2,6 ± 2,2	7,2 ± 4,4
Jarfiord	204 ± 25	0,3 ± 0,1	3,8 ± 0,5
Vätsäri	177 ± 21	0,5 ± 0,2	7,2 ± 1,7
Raja-Jooseppi	227 ± 7	0,13 ± 0,53	2,2 ± 0,5
Pallas	338 ± 5	0,3 ± 0,5	3,7 ± 0,3

The mean lake size parameters are lowest for Raja-Jooseppi region. Jarfjord and Vätsäri regions are characterized by well developed lake drainage areas and presence of many lakes in upper parts of catchments. Lake surface area (LSA) and shoreline (ShL) ranged from 0,06 km^2 (Lampi 3/88) to 12,5 km^2 (Shuonijärvi) and 1,6 km (Sarijärvi) to 26,8 km (Shuonijärvi), respectively.

According to maps, 56 % of lakes belong to drainage lake type and 28 % and 16 % represent headwater and closed (or seepage) lake types, respectively. However, field inventories revealed that drainage lakes Lampi 2/38 and Takkireuhkajärvi belonged to headwater type, and lakes LN2 and Sarvijärvi belonged to headwater lake type. Drainage lakes were the most common lake type

in Jarfjord and Vätsäri regions, while three out of five lakes of Raja-Jooseppi region belong to closed lake type.
In the studies conducted in 1993 - 1994 in Finnish Lapland, 53 %, 31 % and 17 % of 217 studied lakes belonged to drainage, headwater and closed (or seepage) lake types, respectively. However, due to extremely low precipitation in summer, the studied areas in Finnish Lapland were generally characterized by low lake water levels and drying out of streams, especially inlet streams. Therefore only 34 % of lakes represented drainage lake type during invertebrates sampling (Yakovlev 1999).

Based on water chemistry analyses in 1993 - 1994 and 2005, slight increase of pH can be detected in Jarfjord Region. However, most of the lakes seem still to be acidic with water pH < 6,5 (Table 2).

Table 2. Mean (min-max) values of water pH and total Al concentration in water of the sampled lakes (except for Nikel Region), 1993 - 1994, and 2005.

Lake	pH		Total Al (µg/l)	
	1993 - 1994	2004 - 2005	1993 - 1993	2004 - 2005
Jarfjord region				
Limgambergtjern**	5,4 (5,2 - 5,6)	-	-	-
Dalvatn**	5,7 (5,6 - 5,7)	6,2 (6,2 - 6,3)	-	-
Guoika Luobbalat **	6,2 (6,1 - 6,4)	6,4	-	-
Store Skardvatn**	6,4 (6,4 - 6,5)	6,7 (6,7 - 6,8)	-	-
Otervatn**	5,9 (5,4 - 6,5)	6,4 (6,1 - 6,6)	-	-
Vätsäri region				
Harrijärvi H62	6,4 (6,0 - 6,8)	6,8 (6,4 - 7,0)	8,0	6,5 (2,5 - 11)
Pitkä-Surnujärvi	6,7	6,8 (6,7 - 6,9)	8,0	24,0
Lampi 3/88	6,0 (5,9 - 6,0)	6,2 (6,1 - 6,2)	14,5 (14 - 15)	24,0
Lampi 222	6,5	6,6 (6,1 - 6,9)	26,7 (25 - 30)	23,5 (19 - 30)
Lampi V1 Joulujärvet	6,5	6,6	29,0 (25 - 33)	40,0
Raja-Jooseppi region				
Kalaton Kampajärvi	6,2 (6,0 - 6,3)	6,4 (6,3 - 6,5)	31,4 (21 - 51)	35,0
Peuranampumajärvi	5,8 (5,7 - 5,8)	5,6 (5,5 - 5,7)	83,5 (57 - 110)	74,0
Lampi D49	4,8 (4,8 - 4,9)	4,9 (4,8 - 4,9)	75,5 (74 - 77)	90,0
Takkireuhkajärvi	7,2	7,0	35,0	54,0
Pieni Arttajärvi D47	7,2	–	28,0	–
Pallas region				
Käyräjärvi 521	5,7 (5,6 - 5,8)	5,3 (5,2 - 5,4)	71,0	80,0
Keimiöjärvi	-	6,7 (6,2 - 7,1)	-	38,0 (19 - 52)
Sarvijärvi S4	6,4 (6,4 - 6,4)	6,4 (6,4 - 6,5)	28,5 (28 - 29)	27,0
Rautujärvi 56	6,8 (6,7 - 6,8)	6,5 (6,4 - 6.6)	34,0	18,0
Hietajärvi Z41*	6,4 (6,3 - 6,4)	6,4	10,5 (9 - 12)	13,0

- Here and in other tables, dash line means lacking of data.
* Data for one water analysis.
** Data are given for the years 1990 - 1996 (NINA database, Langeland et al. 1993) and for 2004 - 2005 (NIVA database).

In Finland, the comparison of water pH levels in the surveyed lakes in 1993 - 1994 and 2005 shows no essential changes in a degree of water acidity. By 2005, small decrease in pH levels was observed for some lakes located in regions of Pallas and Raja-Jooseppi. Conversely, mean water pH level increased slightly in lakes Harrijärvi, Kalaton Kampajärvi, and Lampi 3/88. More prominent change can be seen in increased concentrations of total aluminium. Except for lakes Peuranampumajärvi, Lampi 222 and Rautujärvi concentration of Al was higher in 2005 in comparison with the years 1993 - 1994.

In Nikel Region, the most polluted lakes were LN1 and LN2, located on a distance of 2 and 6 km from the Nikel plants. Concentration of Cu and Ni had decreased in lakes LN2 and LN3 in comparison with the years 1993 - 1994 years (Table 3). The rather high conductivity and concentrations of heavy metals indicate that the lakes in Nikel Region (except Schuonijarvi, LN5) are still strongly polluted.

Table 3. Mean (±SE) values of conductivity (C.20, µS/cm), metal concentrations (µg/l) and Na (mg/L) in water of the studied lakes of Nikel region in 1990 - 1996 and 2003 - 05 (Data base of INEP, Apatity).

Para-meter	LN1 (Velikjampjanjarvi)		LN2 (Sarijarvi)		LN3		LN5 (Schuonijarvi)	
	1993-1994	2003-2005	1993-1994	2003-2005	1993-1994	2003-2005	1993-1994	2003-2005
C.20	145 ± 17	127,0	361 ± 5	251 ± 5	55 ± 2	75 ± 21	31,4	-
Alk	282 ± 15	331	256 ± 16	181 ± 14	136 ± 29	151 ± 6	123	-
pH	6,87 ± 0,04	7,06	6,97 ± 0,07	6,99 ± 0,06	6,62 ± 0,06	6,97 ± 0,07	6,63	-
Cd	-	0,21	-	0,13 ± 0,03	-	0,03 ± 0,00	-	-
Cu	27,8 ± 2,8	43,8	13,8 ± 5,2	9,2 ± 0,5	19,5 ± 6,7	4,4 ± 0,04	2,5	-
Pb	-	1,13	-	0,58 ± 0,14	-	0,34 ± 0,01	-	-
Ni	273 ± 53	360	394 ± 12	245 ± 24	55 ± 2	26 ± 2	2,5	-
Zn	-	5,6	-	12,4 ± 1,6	-	3,4 ± 0,4	-	-
Na	3,6 ± 0,1	3,9	4,3 ± 0,4	3,7 ± 0,1	2,5 ± 0,2	2,2 ± 0,1	1,8	-

3. Material and methods

3.1. Invertebrate sampling

A total of 25 small lakes presenting the five regions (Nikel, Jarfjord, Vätsäri, Raja-Jooseppi, Pallas) were selected for the zoobenthos study. The data obtained during earlier studies (1990 - 1996) conducted in the border area was used as a base in selecting the small lakes for present study. Lakes from Pallas area (located in western Lapland) were included as reference lakes due to their pristine nature and low airborne loading of the area.

Each lake was sampled once in 2005, during the time period from 23 August to 10 September (Appendix 1). Number of invertebrate samples taken from a lake depended on a presence of available habitats suitable for invertebrate sampling. Sampled habitats included 1) lake littoral, 2) outlet area, 3) outlet stream (100 - 200 m below the lake), and 4) inlet stream (10 - 50 m above the lake) (Fig. 2).

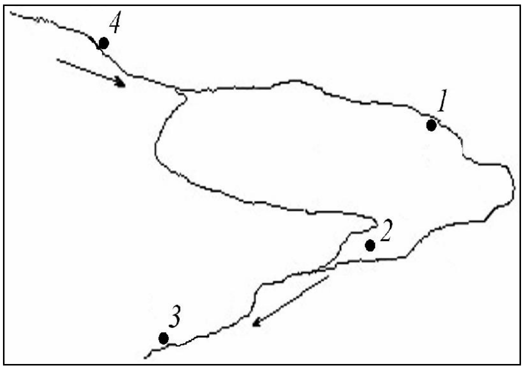

Figure. 2. Scheme of benthos sampling in lake the habitat. 1 - 4: sampled habitats.

Separate samples were taken from each habitat of a lake. Four samples were usually collected from a drainage-type lake, three from a headwater lake, and one from a closed lake. Total of 65 samples were collected from the all lakes monitored in 2005. 25 samples were taken from littoral habitats, 17 from outlet area, and 17 from outlet stream. Suitable inlet streams were hard to find, and only 6 lakes were sampled for that habitat.

The invertebrate sampling was performed as a kick-net sampling using the methods of earlier studies. The used methods were slightly modified from the instructions of Finnish standards for kick-net sampling in order to increase the faunistical scope of the samples (Suomen Standardiso-imisliitto 1989). The hand net (0.5 mm mesh size, 260 x 360 mm frame, 680 mm bag depth) with a 1.5 m handle was used for obtaining a qualitative sample. One approximately 3-minute kick sample was taken from each habitat. Care was taken to include all microhabitats from each sampled habitat. Samples were reserved in a plastic containers in the field. At the laboratory, all invertebrates were picked from the samples and fixed in 70 % alcohol.

3.2 Laboratory identifications

Except for Turbellaria, Hydrachnellae, Nematoda, and some Oligochaeta and Diptera families, animals were identified to a species or genus level. Taxonomy and species names followed the generally used nomenclature (Illies 1978, Catalogue of Palaearctic Diptera 1990). The accuracy of invertebrate species identification was ensured through participation in intercalibration conducted by UN ECE International Cooperative Program on Assessment and Monitoring of Acidification of Rivers and Lakes (Intercalibration 1996).

Biomass of animal groups was measured as wet weight. Invertebrates were carefully dried on high purity chemical filter papers for about 1 min, before weighing using a torsion weight with a scale of 0.1 - 100 mg.

3.3 Metal bioconcentrations

The decision to use Polycentropodidae caddisfly larvae as indicators for metal accumulation was based on our preliminary study of metal bioaccumulation in invertebrates in 1990 - 1996 (Yakovlev 2002 a, b). They are common in various habitats of northern Fennoscandia, and occur in both polluted and pristine waters. They were also frequently found in extremely contaminated lakes and streams close to "Pechenganikel" factories (Langeland et al. 1993).

However, collecting the larvae in order to gain enough tissue biomass for analyses proved to be rather difficult in 2005. Sufficient number of individuals could only be found from six lakes: LN1, LN4 (Nikel Region), Harrijärvi, Pitkä Surnujärvi (Vätsäri Region), Takkireuhkajärvi and Pieni Arttajärvi (Raja-Jooseppi). Invertebrates were generally collected from the outlet areas and outlet streams, and more rarely from littoral habitats.

Total of seven heavy metals (Cu, Ni, Co, Zn, Mn, Pb, Cd,), along with Al, Ca, Mg, Na and K concentrations were determined from Polycentropodidae caddisfy larvae. A sample for metal bioaccumulation study consisted of approximately 50 - 100 caddisly larvae. They were placed in plastic containers with clean water for about twelve hours in order to remove the intestine contents. After that, samples were washed with water, dried with high purity chemical filter papers and stored frozen in refrigerator. Before chemical analyses, samples were dried to constant weight at 105^{o} C. Organic matter was removed using concentrated nitric acid (HNO_3). Concentrations of metals were determined using the atomic absorption method at INEP (Apatity).

3.4 Statistical methods

The species number, relative abundance and biomass of acid-sensitive species and taxa (amphipoda, gastropoda, ephemeroptera (except Leptophlebidae) and plecoptera (except Nemouridae) were used in statistical analyses.

Total of twelve physical and nine chemical variables were used in the statistical analyses (Table 4). In accordance with hydrologic type, the studied lakes were classified by visual examination of topographic maps into four numerical categories (T1): 1 and 2: closed and seepage lakes (1: no inflow or outflow, 2: inflow exists, no outflow), 3: headwater (no inflow, outflow exists), and 4: drainage lakes (inflow and outflow exist). In addition, each lake was classified into the same four groups according to their real state during the field period (T2), depending on the presence and absence of inlet or outlet streams. The location of the lake within a lake chain (LO), presenting number of lakes above the lake in a lake chain, was obtained from maps with a scale of 1: 50,000. Lake altitude (ALT), lake surface area (LSA) and shoreline length (SHL) data were also obtained from maps.

Owing to non-parametric distributions of most variables, Wilcoxon test was used to test the temporal differences of individual variables. In order to study the relationships between invertebrate data, metal bioconcentrations and environmental variables, Spearman's non-parametric rank correlation analysis (r_s) was carried out.

3.5. Biological assessment of water quality and acidity

Biological indices are useful in the estimation of environmental quality and ecological state of the lakes subjected to different types of anthropogenic influence. Since the human impact on the studied lakes varied from strong heavy metal pollution to acidification caused by airborne loading, use of several indices was necessary. Used indices included Shannon Diversity Index, Kola Biotic Index Score (KolaBIS), Short Score Index (ShSI) and Acidic Score Index (AcSc).

Table 4. The environmental variables used in the statistical analyses, abbreviations and brief notes on data.

Environmental variable	Abbre-viation	Units of mea-surements, no. categories	Brief notes
Lake type from maps	T1	1-4	1: closed; no inflow, no outflow 2: closed; inflow, no outflow 3: headwater; no inflow, outflow 4: drainage; inflow and outflow
Lake type during field period[1]	T2	1-4	1: closed; no inflow, no outflow 2: closed; inflow, no outflow 3: headwater; no inflow, outflow 4: drainage; inflow and outflow
Altitude of lake	ALT	M	Obtained from 1 : 50 000 maps
Location within a lake chain (number lakes above a lake in a lake chain)	LO	0, 1, 2, 3, ...N	Obtained from 1 : 50 000 maps
Habitat type	HAB	1-4	1: lake littoral; 2: outlet area; 3: outlet stream; 4: inlet stream
Lake area	LSA	km^2	Obtained from 1 : 50 000 maps
Shoreline	LSHL	Km	Obtained from 1 : 50 000 maps
Dominant substratum type in sampling area[1]	DS	1-6	1: peat/silt; 2: silt/clay; 3: sand; 4: gravel; 5: > gravel; 6: > bedrock
Macrophyte cover of bottom in sampling area[1]	MAC	1-5	Percentage (%):1: <10; 2: <25; 3: <50; 4: <75; 5:>75
Mosses cover of bottom in sampling area[1]	MOS	1-5	Percentage (%): 1: <10; 2: <25; 3: <50; 4: <75; 5: >75
Water velocity in lake outlet and outlet stream[1]	WV	1-5	1: no flow; 2: very weak; 3: eak; 4: medium; 5: high velocity
Mean down stream channel	CHW	1-5	Width (m): 1: < 0.5; 2: < 1.0; 3: < width [1] 2.0; 4: < 4.0; 5: > 4.0
Alkalinity[2]	ALK	mmol l^{-1}	ALK_NTG [2]
pH	pH		PH_L25[2]
Al	Al	µq l^{-1}	AL_NG[2]
Cu	Cu	µq l^{-1}	
Ni	Ni	µq l^{-1}	
Pb	Pb	µq l^{-1}	
Zn	Zn	µq l^{-1}	
Hg	Hg	µq l^{-1}	
Na	Na	mg l^{-1}	NA_NF[2]

[1] The variables obtained for the sampling site during invertebrates sampling and based on visual estimation.

[2] Water quality data bank of the Lapland Environment Centre (Rovaniemi) and Institute of North Industrial Ecology Problems (INEP).

1. Information theory diversity index (Shannon 1948):

Shannon Diversity Index: $H = -\sum_{r=1}^{s} p_i \log_2 p_i)$, p_i - proportion of individuals in *r*th spp.

2. Quotient of similarity (Sorensen et al. 1948): $I = \frac{2c}{(a+b)}$, *a* – no. of spp. in community *A*, b – no. of spp. in community *B*, *c* – no. of spp. common to both communities.

3. Biological Scale for Assessment of Surface Water Acidity, Acid Score Index (AcSc) for the northern Fennoscandia.

Raddum index can be used for the biological assessment of acidity in Fennoscandian running waters (Raddum et al. 1988, Fjellheim and Raddum 1990). In this study, the species selection of Raddum's index was adapted to reflect also the state of lake littoral communities. For this purpose we added some species and groups, which occur in a coastal zone of lakes, especially in acidification-sensitive closed small lakes (Yakovlev 2005). The adapted index is suitable for the versatile conditions of lotic and lentic littoral habitats of northern Fennoscandia. (Table 5).

Degree of water acidity was based on occurrence of the most acid-sensitive species given in the table. For example, presence of gastropoda molluscs in samples from any lake indicated the scale 1 (low acidity).

Table 5. Scale for Assessment of Surface Water Acidity (AcSc) for the northern Fennoscandia.

Species, taxon	Scale	Acidity
Gastropoda, Margaritana margaritifera, Gammarus lacustris, Baetidae (except for B. rhodani), Ephemera, Metretopus, Arctopsyche ladogensis, Bereodes minutus, Notidobia ciliaris, Philopotamus montanus, Tinoedes waeneri, Wormaldia subnigra	1	Low acidity, pH is usually above 6,0, though it can drop down to 5,5 during snow melt or heavy rains
Hirudinea, Ameletus inopinatus, Baetis rhodani, Caenis horaria, Centroptilum luteolum, Ephemerella, Heptagenia (except for H. fuscogrisea), Siphlonurus, Capnia, Diura (except for D. nanseni), Isogenus, Isoperla, Leuctra fusca, Leuctra hippopus, Limnius wolckmari, Apatania, Hydropsyche, Lepidostoma hirtum, Oxyethira, Taenopteryx nebulosa	0,5	Moderately acidified water, pH between 5,5 and 6,0 and it can drop down to 5,0 episodically
Pisidium, Heptagenia fuscogrisea, Nemoura, Elmidae, Limnephilidae, Polycentropodidae, Phryganeidae, Rhyacophila	0.25	Strongly acidified, pH 4,8 – 5,5, and it can drop down to 4,5 episodically
No above mentioned taxa found	0.0	Very strongly acidified, pH < 4,7

4. Kola Biotic Index Score for Assessment of Water Quality for the Kola North region (Kola-BIS).

This index was also adapted for northern Fennoscandia (Table 6). Use of this index has shown that it can be applied for assessment of water quality with all types of anthropogenic influence, including impact of pollution with heavy metals (Yakovlev 2005). As for the previous index, index value is determined by counting the number of indicator families, starting with the most sensitive indicators.

Table 6. Kola Biotic Index Score for Assessment of Water Quality for the Kola North region (KolaBIS)

Group*	Number of groups		
	0 - 1	2 - 5	≥ 6
Acanthobdellidae Mysidacea Ephemerellidae Ephemeridae Heptageniidae Potamanthidae Siphlonuridae Capniidae Chloroperlidae Perlidae Perlodidae Beraeidae Brachycentridae Goeridae Lepidostomatidae Molannidae Odontoceridae Sericostomatidae	8	9	10
Lymnaeidae Margaritiferidae Physidae Planorbidae Valvatidae Piscicolidae Gammaridae Haustoriidae Baetidae Caenidae Leuctridae Taeniopterygidae Aeshnidae Corduliidae Gomphidae Lestidae Libellulidae Leptoceridae Philopotamidae Psychomyiidae	6	7	8
Sphaeridae Erpobdellidae Glossiphonidae Coenagrionidae Gerridae Chrysomelidae Dryopidae Elminthidae Gyrinidae Haliplidae Helodidae Hydrobiidae Hydrophilidae Hydropsychidae Hydroptilidae Limnephilidae Phryganeidae Polycentropodidae Rhyacophilidae Ceratopogonidae Limoniidae Simulidae Tipulidae	4	5	6
Lumbriculidae Asellidae Corixidae Dytiscidae Sialidae	2	3	4
Tubificidae Chironomidae	1	2	-

“Group” includes each family of annelids (except for Tubificidae), leeches, mollusks, crustaceans and insects (except for families Nemouridae, Leptophlebidae and genus *Chironomus*).

5. ISO’s Short Score Index (Aanes and Baekken 1989). This index offers an estimation of water quality and it is designed for European waters. Short Score Index is also based on the presence of the pollution-sensitive indicator groups. However, unlike previous indeces, this index is calculated from relative abundances of indicator groups.

4. Results

4.1. Species richness and composition

A total of 174 benthic invertebrate species and taxa of higher level were identified from the whole material (Appendix 2). Diptera, Trichoptera and Coleoptera were the most rich taxa groups. A share of these three groups summed up to about 60 % of all taxa found from the samples. Chironomid larvae were the most common group in all lake habitats. *Ablabesmyia*, *Psectrocladius* and *Microtendipes* chironomids occurred frequently in samples. Other common taxa were Oligochaeta *Lumbriculus variegatus*, small mussels (*Pisidium*), water mites (Hydrachnellae), water bugs (Corixidae), Ceratopogonidae, Simulidae (Diptera), water beetles (Coleoptera), Phryganeidae (*Phryganea bipunctata*), Limnephilidae and Polycentropodidae caddisflies (*Neureclepsis bimaculata, Polycentropus flavomaculatus*). Leptophlebidae mayflies, *Nemoura* and *Diura nanseni* stoneflies frequently occurred in running water as well as in lake littoral habitats. Species richness of dipterans was high in Nikel and Jarfjord regions, whereas Trichoptera, Ephemeroptera and Plecoptera groups were more diverse in Vätsäri Region.

The highest number of species was found from Vätsäri and Raja-Jooseppi regions. The lowest species number was observed from Jarfjord region (Table 7).

Table 7. Invertebrate species/taxa number in the lakes of different regions

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Gammaridae	0	1	0	0	0
Gastropoda	1	0	1	2	2
Ephemeroptera*	6	3	6	2	3
Ephemeroptera	6	5	9	4	6
Plecoptera*	2	4	6	3	1
Plecoptera	4	6	8	4	2
Odonata	0	0	3	3	0
Heteroptera	3	0	2	4	1
Coleoptera	4	5	6	14	10
Megaloptera	1	1	2	1	3
Trichoptera	13	15	18	14	14
Diptera	27	23	19	21	16
Other groups	6	4	10	10	9
Total	65	60	78	77	63

*Ephemeroptera without Leptophlebidae, Plecoptera are without *Nemoura* spp.

As a whole, approximately half of the species occurred in all regions. The greatest similarity in the composition of benthic communities was found between Nikel and Vätsäri regions, and minimum similarity was observed between Vätsäri, Raja-Jooseppi and Pallas and regions (Table 8).

Table 8. Quotients of Sorensen similarity for zoobenthos of the surveyed regions.

	Nikel	Jarfiord	Vätsäri	Raja-Jooseppi	Pallas
Nikel	-	0,47	0,51	0,42	0,43
Jarfiord	-	-	0,41	0,39	0,44
Vätsäri	-	-	-	0,37	0,38
Raja-Jooseppi	-	-	-	-	0,43

Number of species correlated positively ($P < 0,05$) with lake order (LO) and hydrological type (T1, T2). Increase of the species richness associated with the size of drainage lakes, high water velocity in streams and bottom moss cover. Number of species showed negative correlations with concentrations of heavy metals (Cu, Ni, Zn, Cd, Pb). Depending on the strength of the correlation, the examined variables settled down in the following order: WV*** >Ni** >Cu** >Zn** >MOS* >CHW* >T2* >LSA* >Pb* (***- $P < 0,001$, ** < 0,01,* < 0,05; negative correlations are underlined; for abbreviations see Table 4.

4.2. Acid- and pollution-sensitive species

Amphipod *Gammarus lacustris*, Valvatidae, Planorbidae and *Lymnaea* gastropods and Ephemeroptera mayflies, (except Leptophebidae) are among the invertebrate groups considered to be most sensitive to low pH (Engblom and Lingdell 1984, Raddum and Fjellheim 1984, Økland and Økland 1986). In the previous study conducted in 1993 - 1994, Gastropoda snails, stoneflies, mayflies and amphipod *G. lacustris* were lacking from waters with high concentrations of Ni and Cu and from waters with pH less than 6,9 (Yakovlev 1999).

The detrimental biological effects of the acidification were observed in earlier study of small mountain lakes in Jarfjord area, northern Norway (Langeland et al. 1993; Nøst et al., 1997). About 25 % of the monitored lakes in Finnish Lapland in 1993 - 1994 showed signs of evident stress and were lacking the acid-sensitive species (Yakovlev, 1999). Dramatic decline in species richness, especially among mentioned taxa, was characteristic for lakes near the Pechenganikel factories, with the exception of Lake Shuonijavr. Lake Schuonijavr (LN5) and its outlet stream Shuonijoki River, located south-east from Nikel, seemed to have the highest diversity of acid- and pollution-sensitive species in Nikel Region (Langeland et al. 1993; Nøst et al., 1997; Yakovlev 2005).

Mayfly *Baetis lapponicus* is regarded as one of the most acid-sensitive species among Ephemeroptera. In 1990 - 1992, the species was found in two localities, from outlet stream of Lake Otervatn and from Shuonijoki River, (Nøst et al. 1997). *B. lapponicus* was lacking from samples taken in 2005.

Numbers of acid- and heavy metal-pollution sensitive species found from the surveyed lakes in 1990 - 1996 and 2005 is shown in Appendix 3 and Table 9.

In general, all lakes with sensitive species were large and belonged to unpolluted drainage lakes with water pH above 6,5. Further, sensitive species were richer in steams covered with stone and gravel substratum. Number of acid- and pollution-sensitive species showed negative correlations with concentrations of heavy metals. Depending on the correlation coefficients, the examined variables settled down in the following order: T2***, T1*** >LSA*** >SHL*** >Zn*** > WV*** >LO** >CHW** >DS* >Cu* >Ni** >Hg*.

In 2005, amphipod *G. lacustris* was found only in one sample taken from Lake Store Skardvatn in Jarfjord region. In 1990 - 1996 this amphipod frequently occurred in Lake Store Skardvatn and Otervatn-Rundvatn area (Jarfjord region) and in localities of Raja-Jooseppi region (Yakovlev 1999, 2005).

Only two Gastropoda species (*Lymnaea peregra* and *Gyraulus albus*) were found from the studied lakes in both sampling occasions (1993 - 1994 and 2005). However, the two species seem to have more restricted distribution in 2005. In several lakes, one or the other of the two species found in 1993 - 1994 was not present in the samples taken in 2005 (Appendix 3).

The reduction of sensitive species number was characteristic also for mayflies (Ephemeroptera) and stoneflies (Plecoptera) between the two sampling periods. They were more species-rich and frequently occurred in localities of north-eastern Lapland in 1993 - 1994 in comparison with 2005. In 2005, the most acid-sensitive caddisfly species (*Arctopsyche ladogensis, Bereodes minutus, Notidobia ciliaris, Philopotamus montanus, Tinoedes waeneri* and *Wormaldia subnigra*) were lacking from the samples.

Among mayflies and stoneflies, only *Baetis rhodani* and the representatives of a *Nemoura* genus were more frequently found from the polluted streams in Nikel area in 1990 - 1996. These taxons also showed higher tolerance to low pH. Further, tolerant Leptophlebidae mayflies and *Nemoura* stoneflies occurred in high densities in both lentic and lotic environments. Leptophlebidae and

Nemoura species frequently inhabit moderately acidic humic and clear-water lakes and streams in Finland (Hämälainen and Huttunen 1990, Meriläinen and Hynynen 1990).

Table 9. The number of gastropoda, mayfly and stonefly species in samples collected from lakes in 1993 - 1994 and 2005.

Lake	Gastropoda		Ephemeroptera		Plecoptera	
	1993 - 1994	2005	1993 - 1993	2005	1993 - 1993	2005
Nikel region						
Ln1**	0	0	0	0	0	0
LN2**	0	0	1	0	3	0
LN3**	0	0	0	0	0	0
LN4	-	0	-	2	-	2
LN5**	2	1	8	4	6	1
Jarfjord region						
Limgambergtjern**	0	0	1	0	0	1
Dalvatn**	0	0	2	0	1	0
Guoika Luobbalat**	0	0	1	1	3	2
Store Skardvatn**	0	0	3	0	4	0
Otervatn**	1	0	10	0	5	0
Vätsäri region						
Harrijärvi H62	2	1	3	2	3	4
Pitkä-Surnujärvi	2	1	8	5	5	1
L. 3/88	1	0	0	0	0	1
L. 222	1	1	1	0	2	1
L. V1 Joulujärvet	0	1	1	0	1	2
Raja-Jooseppi						
Kalaton Kampajärvi	0	0	0	0	0	0
Peuranampumajärvi	0	0	0	0	0	0
L. D49	0	0	0	0	0	0
Takkireuhkajärvi	2	2	3	0	4	3
Pieni Arttajärvi D47	2	2	5	1	7	2
Pallas region						
Käyräjärvi 521	0	0	0	0	0	0
Keimiöjärvi	-	2	-	2	-	0
Sarvijärvi S4	0	0	0	0	0	0
Rautujärvi 56	2	0	0	1	0	1
Hietajärvi Z41	0	0	0	0	0	0

* Here and in other tables, Leptophlebidae (Mayflies) and Nemouridae (stoneflies) species are not included in the group of acid- and pollution tolerant species.

** Samplings in 1990 - 1996.

Acid- and pollution sensitive species were not found during the both study periods (1993 - 1994 and 2005) from the following Finnish lakes: Kalaton Kampajärvi, Peuranampumajärvi, Lampi D49, Käyräjärvi, Sarvijärvi, and Hietajärvi. Sensitive species had disappeared from lakes Dalvatn and Otervatn in Jarfjord Region by 2005. The reduction of the species is notable, since the largest numbers of mayfly and stonefly were recorded in small lakes and streams in Otervatn-Rundvatn and Store Skardvatn in 1990 - 1996.

Russian lakes LN1, LN2 and LN3 were characterised by the lowest species diversity and lack of the sensitive species. Frequency of occurrence and species richness of the sensitive mayfly and stonefly nymphs grew with increase of distance from pollution sources.

Reduction of species richness and occurrence of the acid- and pollution sensitive species in 2005 in comparison with the beginning of 1990'ies may indicate water quality deterioration and especially the increase of concentration of Al in most studied lakes (see Table 2).

4.3. Relative abundance and biomass of zoobenthos

The contribution of the most common invertebrate groups to a total zoobenthos abundance and biomass varied irregularly from one lake to another, as well as between lake habitats. Dipterans prevailed in lake littoral habitats (Table 10). But they were second to Trichoptera in outlet area and in outlet stream habitats in Finnish territories. The Sphaeridae mollusks were also numerous in the lake outlet and outlet stream habitats. The greatest relative abundances of gastropods, mayflies and stoneflies were found from the Raja-Jooseppi, Vätsäri and Pallas regions.

Table 10. Relative abundances (%) (mean per sample ±SE) of invertebrate groups in the different lake habitats in 2005.

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Lake littoral					
Gammaridae	0	1,0±0,9	0	0	0
Gastropoda	0	0	6,5±5,0	0,8±0,8	0,4±0,3
Ephemeroptera*	0	0	0	0	6,0±3,7
Ephemeroptera	0	3,4±2,0	1,7±1,5	4,4±2,4	10,3±7,0
Plecoptera*	0	1,2±1,1	0,9±0,8	0	0
Plecoptera	0	2,7±1,5	1,9±1,0	0	0,4±0,4
Heteroptera	12,1±8,7	0	0	1,4±0,5	4,4±4,0
Coleoptera	3,4±3,0	1,0±0,9	4,6±1,8	7,8±3,2	4,0±2,1
Trichoptera	12,2±7,2	4,9±2,7	21,2±6,6	10,2±4,5	20,7±6,6
Diptera	61,9±7,2	67,2±4,6	50,5±6,9	62,2±7,4	44,9±11,3
Other groups	10,4±7,9	20,8±13,5	13,6±9,9	13,2±11,2	14,9±11,5
Outlet area					
Gastropoda	0	0	1,4±1,0	5,3±1,1	1,3±0,9
Sphaeridae	0	16,0±12,1	3,4±1,6	23,4±15,0	22,5±12,6
Ephemeroptera*	1,3±1,2	0	0,3±0,3	0	2,6±1,5
Ephemeroptera	1,3±1,2	6,7±3,7	2,6±1,8	0,2±0,1	10,4±0,8
Plecoptera*	3,2±2,2	1,5±1,0	1,7±0,9	1,0±0,7	0
Plecoptera	3,8±2,2	4,4±2,2	2,1±0,9	2,4±1,7	0
Heteroptera	14,4±10,1	0	0,2±0,2	0	0
Coleoptera	12,5±10,8	1,2±0,8	0,3±0,2	1,0±0,04	0,4±0,3
Trichoptera	47,1±15,8	8,0±2,3	61,7±31,7	53,5±11,5	28,1±6,4
Diptera	15,3±4,9	61,1±12,3	25,8±13,7	10,8±2,4	27,8±14,0
Other groups	9,3±3,2	9,8±4.7	2,5±1,4	3,4±1,1	9,5±5,5
Outlet stream					
Gastropoda	0,4±0,3	0	4,9±1,6	8,4±4,0	1,4±0,9
Sphaeridae	0,4±0,3	31,2±14,1	18,2±5,8	5,1±0,6	18,4±13,0
Ephemeroptera*	5,6±2,9	2,0±1,7	8,0±7,0	1,0±0,7	0
Ephemeroptera	5,6±2,9	3,7±1,4	8,2±7,0	2,8±0,5	4,2±0,2
Plecoptera*	7,3±3,7	6,0±4,1	2,4±1,4	5,6±4,0	1,4±0,9
Plecoptera	8,9±4,4	7,8±3,7	2,6±1,5	5,6±4,0	1,4±0,9
Trichoptera	26,3±7,9	11,2±2,0	45,7±7,8	50,0±11,1	37,4±11.2
Diptera	54,2±13,7	37,9±11,5	18,3±0,6	18,8±10,8	22,6±8,4
Other groups	5,8±2,8	8,2±3,1	2,0±0,9	9,3±3,1	16,0±4,2

*Ephemeroptera without Leptophlebidae, Plecoptera without *Nemoura* spp.

In the strongly polluted lake littoral and outlet habitats of Nikel region, Corixidae water bugs and Chironomidae dipterans were abundant. They, like Dytiscidae water beetles, Polycentropodidae cadisflies and all dipterans are rather tolerant to pollution by heavy metals and low pH (Yakovlev, 2002 a). Chironomidae, water bugs and water beetles also dominated in lakes located between Nikel and Zapolyarny towns in 1990 - 1992 (Langeland et al., 1993).

4.4. Relative abundance and biomass of acid- and pollution-sensitive species

Earlier studies pointed out that relative abundance and biomass of acid sensitive species in the littoral habitats were significantly ($P < 0.01$) higher in drainage lakes than in closed lakes (Yakovlev, 1999). Among habitats sampled, outlet streams and lake outlets were distinguished by the highest acid-sensitive species richness, relative abundance and biomass. Acid-sensitive mayfly species were found in low densities in samples from littoral habitat, which is possibly caused by naturally unsuitable environmental conditions of the lentic littorals.

In general, relative abundance of acidification and pollution sensitive species correlated positively with lake parameters, such as a lake size (SHL, LSA), lake order (LO) and hydrological type (T1, T2). In lotic environments, relative abundance increased along with the stream size (SHW) and water velocity (WV). Concentrations of heavy metals had negative relationship with abundance of sensitive species. Depending on correlation coefficients, the examined variables settled down in the following order: T1*** >T2*** >SHL*** >LSA*** >Zn** >LO** >HAB** >WV*** >Ni** >DS*.

Among the lakes located in Nikel region, only two lakes (LN5 and LN4) were inhabited by acid- and pollution-sensitive species with high relative abundance and biomass (Tables 11 - 12). Their share also was high in lakes Guikka Luobbalat and Store Skardvatn in Jarfjord region.

Acid-sensitive species showed highest relative abundance and biomass in all habitats of Pitkä-Surnujärvi. In 1993 - 1994, no acid-sensitive species were found from Lake Joulujärvet, but in 2005 they occurred in outlet and outlet stream habitats. In 1993 - 1994, acid-sensitive species were found in low densities in all lakes of Jarfjord region. They were not found in the Lake Otervatn in 2005.

The sensitive species were lacking from the three Nikel lakes (LN1-LN3), as well as from Kalaton Kampajärvi, Peuranampumajärvi, Lampi D49 (Raja-Jooseppi Region), Käyräjärvi, Sarvijärvi and Hietajärvi (Pallas Region) during the both sampling periods in 1993 - 1994 and 2005. No significant differences in relative abundance and biomass of the sensitive groups were found between five regions in 2005.

4.5. Metal contents in caddisfly larvae

The metal concentrations of Polycentropodidae caddisfly larvae were measured from 6 lakes, situated in Nikel, Vätsäri and Raja-Jooseppi regions. The small amount of the collected samples complicates comparison between the surveyed lakes and regions. However, it was possible to compare metal concentrations measured in 1993 - 1994 and 2005 for four lakes: LN1, Harrijärvi, Pitkä Surnujärvi and Takkireuhkajärvi. The metal concentrations of the invertebrates varied widely (Table 13).

Table 11. Relative abundance (%) of acid- and pollution-sensitive species* in the different lake habitats in 1993 - 1994 and 2005.

Lake	1993 - 1994**			2005		
	Lake littoral	Outlet area	Outlet stream	Lake littoral	Outlet area	Outlet stream
Ln1 **	0	0	0	0	0	0
LN2**	0	-	-	0	-	-
LN3**	0	0	0	0	0	0
LN4	-	-	-	0	2,5	27,3
LN5**	0,5	12,8	30,2	0	15,8	25,8
Limgambergtjern**	0	0	0,2	6,3	0	4,0
Dalvatn**	0	0	5,2	0	4,8	0
Guoika Luobbalat **	1,6	27.1	4,4	0	1.1	28,0
Store Skardvatn**	17,1	-	-	4,8	-	-
Otervatn**	0	2,9	37,0	0	0	0
Harrijärvi H62	0	2,0	8,7	4,5	2,2	14,6
Pitkä-Surnujärvi	3,8	12,9	47,6	4,0	7,4	42,9
L. 3/88	0	0,9	-	0	0,9	0
L. 222	0	0	13,3	28,6	5,8	5,3
L. V1 Joulujärvet	0	0	0	0	0,9	13,8
Kalaton Kampajärvi	0	-	-	0	-	-
Peuranampumajärvi	0	-	-	0	-	-
Lampi D49	0	-	-	0	-	-
Takkireuhkajärvi	8,7	3,8	32,6	4,2	3,8	14,0
Pieni Arttajärvi	21,4	23,6	28,1	0	8,8	16,0
Käyräjärvi 521	0	-	-	0	-	-
Keimiöjärvi	-	-	-	23,1	3,0	2,7
Sarvijärvi S4	0	0	-	0	-	-
Rautujärvi 56	23,3	-	-	8,7	4,7	2,7
Hietajärvi Z41	0	0	-	0	-	-

The results of studies in 1990 - 1996 revealed that concentrations of heavy metals in invertebrates of unpolluted lakes depend from large number of abiotic and biotic factors, as well as from bio-geochemical properties of metals. Therefore it is very difficult to find out dependences between concentrations of metals in invertebrates and in water and bottom sediments (Yakovlev 2002 a, b). In small lakes of Finnish Lapland, the heavy metal concentrations in Polycentropodidae larvae ranged in the following order: Zn > Mn > Cu > Ni > Pb > Cd > Co.

Table 12. Relative biomass (%) of acid- and pollution-sensitive species* in the different lake habitats in 1993 - 1994 and 2005.

Lake	1993 - 1994**			2005		
	Lake littoral	Outlet area	Outlet stream	Lake littoral	Outlet area	Outlet stream
Ln1 **	0	0	0	0	0	0
LN2**	0	-	-	0		-
LN3**	0	0	0	0	0	0
LN4	-	-	-	0	0,9	12,7
LN5**	1,1	10,6	5,6	0	9,5	5,7
Limgambergtjern**	0,1	0	0,3	38,3	0	2,0
Dalvatn**	0	0	6,3	0	1,1	0
Guoika Luobbalat **	0,3	19,0	3,6	0	0,9	32,9
Store Skardvatn**	11,0	-	-	10,2	-	-
Otervatn**	0	2,1	29,7	0	0	0
Harrijärvi H62	0	0	18,4	1,7	1,1	7,4
Pitkä-Surnujärvi	29,5	12,8	67,9	15,2	18,3	28,9
L. 3/88	0	1,9	-	0	4,2	0,0
L. 222	0	0	13,0	63,3	5,3	5,4
L. V1 Joulujärvet	0	0	0	0	0,3	31,9
Kalaton Kampajärvi	0	-	-	0	-	-
Peuranampumajärvi	0	-	-	0	-	-
Lampi D49	0	-	-	0	-	-
Takkireuhkajärvi	8,3	7,2	14,3	4,5	21,5	18,8
Pieni Arttajärvi	8,2	68,6	36,1	0	35,5	37,4
Käyräjärvi 521	0	-	-	0	-	-
Keimiöjärvi	-	-	-	9,5	2,4	1,2
Sarvijärvi S4	0	0	-	0	-	-
Rautujärvi 56	28,5	-	-	7,8	2,4	0,6
Hietajärvi Z41	0	0	-	0	-	-

In 1990 - 1996, the contents of Ni and Cu in *Chironomus* larvae and Polycentropodidae caddisflies were measured from lakes and streams located in 30 km radius around of the Pechenganikel nonferrous smelters. The metal concentrations were approximately 10 - 70 times higher than in remote regions. In 1990 - 1992, mean heavy metal concentrations in Polycentropodidae caddisfly larvae in extremely polluted small Lake LN1 were considerably higher, when compared to larvae collected from Finnish Lapland in 1993 - 1994. For instance, concentrations of Co, Ni, Cu and Mn were 253, 72, 31 and 3 times higher, respectively. Only Zn showed lower concentrations in Nikel Lake LN1. The magnitude of concentrations of Ni and Cu in Chironomidae and Polycentropodidae larvae sampled from polluted lakes, depended mainly on the Ni and Cu concentrations of the water and sediment.

Table 13. Values of metal concentrations in Polycentropodidae caddisfly larvae. Heavy metals and Al in µg g^{-1} d.w.; K, Na, Ca and Mg in mg g^{-1} d.w.

Metal	Nikel			Vätsäri				Raja-Jooseppi		
	LN1		LN4	Harrijärvi		Pitkä-Surnujärvi		Takkireuhka-järvi		Pieni Arttajärvi
	1990-1992	2005	2005	1993	2005	1993	2005	1993	2005	2005
Cu	295	77.8	15.8	28.0	14.0	21.0	19.3	9.3	15.6	113.7
Ni	180	22.9	2.1	4.6	2.5	10.2	4.2	0.9	3.1	89.1
Cd	2.60	2.45	0.57	1.20	1.14	0.80	0.51	0.30	0.58	2.15
Co	10.3	-	-	3.8	-	0.9	-	0.8	-	-
Zn	200	171	166	150.0	137	130	320	150	150	126
Mn	145	55	89	47.0	30	86	167	10	64	30
Pb	5.90	0.54	0.90	1.20	1.16	1.05	0.59	0.20	0.43	1.63
Hg	-	0.07	0.23	-	0.14	-	0.12	-	0.22	0.06
Al	-	26	747	85	215	29	221	-	84	215
Sr	-	1.44	1.54	-	1.04	-	1.94	-	1.97	1.42
Fe	-	155	1247	-	363	-	718	-	193	718
K	-	12.0	11.3	-	11.3	-	11.6	-	11.3	6.3
Na	-	7.7	10.8	-	8.5	-	8.8	-	6.6	3.0
Ca	-	0.96	1.13	-	0.51	-	1.16	-	0.94	0.46
Mg	-	1.20	1.94	-	1.32	-	1.79	-	1.20	0.82

Elevated concentrations of Ni and Cu in *Phryganea* sp. (Trichoptera) were reported by Verta et al. (1990) in Finnish Lake Äälisjärvi, situated only 50 km west from the Pechenganickel smelters in Russia. The high concentrations of Ni, Cu and Cd in lichen *Hypogymnia physodes* in eastern Lapland also indicated long-distance transport of metals from the Kola Peninsula (Kubin 1990). In this study, mean concentrations of Ni, Cu and Co in Polycentropodidae caddisflies from lakes situated in north-eastern Lapland (between Inari and Äälisjärvi lakes) were higher than those observed from other parts of Lapland.

Contrary to our expectations, highest bioaccumulated metal concentrations were not observed from heavily polluted Lake LN1 in Nikel. Instead, maximum concentration of Ni, Cu and Pb in caddisfly larvae were found from Lake Pieni Arttajärvi in Raja-Jooseppi region. Further, the highest Zn and Mn concentrations in caddisfly larvae were found from Lake Pitkä-Surnujärvi in Vätsäri. Only concentration of Cd was higher in Lake LN1 in comparison with other lakes.

Lake LN4, situated between Nikel and Zapolyarny, showed very low heavy metal concentrations, except for Al, Hg and Mn. The reason for low contents of Ni and Cu in Lake LN4 still seems unclear. We can only suggest that low bioaccumulation may result from the lake's moderately high altitude, large lake- and drainage area, or peculiarities in the prevailing wind directions with relation to pollution sources.

In 1990 - 1992, the descending order for the heavy metal concentration in caddisfly larvae collected from contaminated Lake LN1 was as follows: Cu > Zn > Ni > Mn > Pb > Cd. In 2005, this rank had another order: Zn > Cu > Mn > Ni > Cd > Pb. The concentrations of Cu and Ni had decreased in relation to Zn and Mn.

All these facts lead to conclusion, that the load of priority heavy metals (Ni and Cu) on water ecosystems in the Nikel Region at present have decreased in comparison with the beginning of 1990's. Actually, same applies to concentrations of all heavy metals in Polycentropodidae larvae. The decrease between the years 1993 - 1994 and 2005 ranges from 2,6 times decrease in Mn to 17 times decrease in Pb. Only concentrations Cd and Zn had decreased insignificantly. Contrary to the fact that the concentrations of heavy metals in Polycentropodidae larvae of Nikel region were low, the contents of K, Na, Ca and other metals had increased.

The ranks of mean concentration of heavy metals for Nikel and Vätsäri region in 2005 were identical: Zn > Mn > Cu > Ni > Cd > Pb > Hg. The order was virtually same in Raja-Jooseppi region, with the exception of Co, which was in second place after Zn. No obvious differences were found in the ranks between 1993 - 1994 and 2005 for the regions of Vätsäri and Raja-Jooseppi. Comparisons of the mean concentrations of metals in Polycentropodidae larvae in 2005 show that the highest Cd, Al and Fe concentrations were observed in Nikel region, Zn and Mn in Vätsäri region and Cu, Ni and Pb in Raja-Jooseppi region (Table 14).

Table 14. Mean values (±SE) of metal concentration in Polycentropodidae caddisfly larvae in the different regions in 2005.

Metal	Nikel	Vätsäri	Raja-Jooseppi	Finnish Lapland*
Cu	46,8±21,9	16,7±1,9	64,6±34,7	17,8±2,0
Ni	12,5±7,3	3,4±0,6	46,1±30,4	3,9±0,7
Cd	1,51±0,66	0,82±0,22	1,36±0,56	1,32±0,16
Zn	168,3±1,6	228,4±64,9	138,2±8,4	160,5±6,0
Mn	71,9±12,1	120,9±32,3	47,0±11,9	94,1±15,3
Pb	0,72±0,13	0,87±0,20	1,03±0,42	1,18±0,20
Hg	0,15±0,05	0,13±0,01	0,14±0,06	-
Al	386,6±254,7	244,9±17,1	149,2±46,4	102,6±14,1
Sr	1,49±0,04	1,49±0,32	1,69±0,19	-
Fe	701,2±386,2	540,4±125,6	455,5±185,5	-
K	11,66±0,23	11,47±0,12	8,78±1,74	-
Na	9,25±1,09	8,65±0,09	4,80±1,26	-
Ca	1,05±0,06	0,84±0,23	0,70±0,17	0,43±0,04
Mg	1,57±0,26	1,55±0,16	1,01±0,13	1,57±0,04

* In 1993 - 1994 (58 samples from 56 lakes).

It is necessary to note, that the Pb concentrations in Polycentropodidae larvae sampled from all three regions are lower in comparison with the data obtained from all territories of Finnish Lapland in 1993 - 1994. Before the introduction of un-leaded gasoline, the magnitude of Pb bioaccumulation was most probably related to the consumption of automobile fuel.

Earlier studies concerning the concentrations of Ca and Mg in Polycentropodidae caddisfly larvae from monitored Finnish lakes showed weak positive correlations with Ca and Mg concentrations in water, pH and water colour (Yakovlev, 1999, 2003). However, in 2005 bioaccumulation factors (BCF) of Ca and Mg correlated negatively with concentration of these cations in water and with water pH ($P < 0.001$). The relatively high values of the Ca and Mg BCF's in the acidified waters may suggest that these cations have a special role in the normal functioning of living organisms, and that certain mechanisms exist, especially when their concentrations decrease in water with low pH values.

As a whole, the aluminium contents in both water and larvae tissues had increased by 2005. Concentration of Al in caddisfly larvae sampled in Finnish Lapland in 1993 - 1994 averaged 102,6 µg/g, which is on the average 1,5 - 2 times was lower than concentrations observed in 2005. Al concentration increased almost 10 fold in Finnish Lake Pitkä-Surnujärvi.

Apparently, despite on slightly increase of water pH in lakes monitored in 2005 (in comparison with 1993 - 1994), the elevated Al content in water seems to be one of the essential reasons for the further degradation of the benthos communities and reduction of acid-sensitive species. The labile form of Al is prevalent in acid water. Increase of water pH has been observed to decrease Al concentration in water (Campbell et all. 1983, Hall et all. 1988, Wren and Stephenson 1991). This contradicts with the increase of Al concentrations in Polycentropodidae larvae according to our data.

With the lack of data on forms of Al and water colour, and contents of organic matters, it is difficult to make conclusions about increase or reduction of negative effects of metal. Toxicity and bioaccumulation of Al are influenced by biotic and abiotic factors, for example morphological and physiological features of an animal, content of humic and other organic substances in water, thophic status, and so on. It was reported earlier (Yakovlev, 2001, 2005) that maximal accumulations Al in larvae were characteristic for the neutral-alkaline environment (water pH = 6.5 - 8.0). Al_{BCF} values were maximal in circumneutral water with higher concentration of Ca (P = 0.04 - 0.004). The humic and other organic substances, binding Al in the non-toxic particle form, can reduce harmful biological consequences in acid water by reducing potential Al toxicity and intensive accumulation of metal in invertebrates.

Thus, during for more than 10 years from 1993 - 1994, concentration Al in water, and especially in caddisfly larvae has increased, which apparently is one of the reasons of negative changes in benthic communities in 2005. The observed changes are possibly affected also by the changes in climate or other natural conditions. However, the confirmation of these hypotheses will need further monitoring studies.

4.6. Biological assessment of water quality and ecological state of lakes

Usually outlets, streams and heavily wind-exposed stony littorals are naturally characterized by the higher values of index in comparison with a commonly found, sheltered lake littoral habitat, because acid-sensitive mayfly and stonefly nymphs occur more frequently in running water. Therefore overall scores for habitat-poor closed lakes can be misleadingly low in comparison with more diverse sites. In the following, the biological indices are calculated separately for each habitat.

4.6.1. Shannon diversity index

Shannon Diversity Index is an informative tool for describing the species richness and the evenness of species abundance in the benthic communities (Alimov, 2002). Values of the Shannon Diversity Index are higher in the communities with the large number of species and without the obvious dominant species. Shannon diversity values are usually highest in pristine and minutely polluted environments.

According to the present material, the highest values of the index were often characteristic for outlet stream and outlet habitats (Table 15). The lowest values of the index were revealed for lakes LN1 - LN3 in Nikel Region. Low values were also observed for Lampi 3/88 in Vätsäri region, lakes Kalaton Kampajärvi, Peuranampumajärvi, Lake D49 in Raja-Jooseppi region and lakes Käyräjärvi, Sarvijärvi, Rautujärvi, Hietajärvi in Pallas region.

It is difficult to draw conclusions from the comparison between the two monitoring periods (1993 - 1994 and 2005). However, sampling in 2005 revealed higher values for the lakes LN1-2, Otervatn, and for majority of lakes located in Raja-Jooseppi and Pallas regions.

Table 15. Values of Shannon diversity index (H_N) for the different lake habitats in 1993 - 1994 and 2005.

Lake	1993 - 1994**			2005		
	Lake littoral	Outlet area	Outlet stream	Lake littoral	Outlet area	Outlet stream
Ln1 **	1,12	1,13	1,47	1,84	1,08	2,25
LN2**	1,80	1,68	-	2,77	-	-
LN3**	1,99	1,02	-	1,00	1,00	2,32
LN4	-	-	-	3,27	2,15	3,55
LN5**	3,45	3,48	3,51	2,45	3,24	3,31
Limgambergtjern**	1,88	1,55	2,09	2,24	1,94	2,46
Dalvatn**	1,96	1,98	2,60	2,00	3,05	1,46
Guoika Luobbalat **	3,23	3.74	2,57	2,10	2,16	3,05
Store Skardvatn**	2,40	-	-	2,95	-	-
Otervatn**	2,62	1,55	2,79	3,16	2,82	2,58
Harrijärvi H62	1,10	2,64	2,36	2,91	1,47	2,74
Pitkä-Surnujärvi	2,45	3,12	3,71	2,38	1,75	3,30
L. 3/88	2,46	0,85	-	1,03	2,32	2,12
L. 222	1,04	1,79	3,35	2,38	2,81	2,54
L. V1 Joulujärvet	1,95	2,12	2.92	2,93	0,73	2,00
Kalaton Kampajärvi	2,91	-	-	2,44	-	-
Peuranampumajärvi	3,08	-	-	3,12	-	-
Lampi D49	1,28	-	-	1,75	-	-
Takkireuhkajärvi	3,71	3,34	3,65	2,55	2,21	2,99
Pieni Arttajärvi	3,65	3,20	3,71	3,12	2,34	3,73
Käyräjärvi 521	2,88	-	-	2,44	-	-
Keimiöjärvi	-	-	-	3,43	3,01	2,89
Sarvijärvi S4	2,79	2,98	-	2,13	-	-
Rautujärvi 56	2,23	-	-	2,12	2,74	2,37
Hietajärvi Z41	3,15	3,25	-	2,81	-	-

Shannon index values were highest in large circumneutral and unpolluted lakes. The index exhibited significant positive correlations (P< 0,05) with lake area (LSA) and moss cover (MOS).

4.6.2. Kola Biotic Index Score

According to the present results, the highest values of the Kola Biotic Index Score were found from lake outlets and outlet streams. This is caused by the habitat requirements of the species sensitive to disturbance of habitats condition, most of them occur more frequently in running waters (Table 16). The comparison of regions revealed that the highest values of an index are characteristic for regions Raja-Jooseppi and Pallas, and lowest for Nikel Region, with the exception for lakes LN4 and LN5.

Table 16. Kola Biotic Index Score (KolaBIS) values for the different lake habitats in 1993 - 1994 and 2005.

Lake	1993 - 1994**			2005		
	Lake littoral	Outlet area	Outlet stream	Lake littoral	Outlet area	Outlet stream
Ln1 **	2,9	4,9	5,0	5	5	5
LN2**	2,8	-	-	5	-	-
LN3**	3,0	3.2	-	3	3	1
LN4	-	-	-	6	10	10
LN5**	8,0	10,0	9,4	6	10	10
Limgambergtjern**	5,0	5,3	5,7	9	9	10
Dalvatn**	3,0	3,5	6,8	1	9	5
Guoika Luobbalat **	5,5	8	6,0	9	10	10
Store Skardvatn**	7,2	-	-	8	-	-
Otervatn**	6,0	10,0	9,8	8	8	6
Harrijärvi H62	5	8	10	10	10	10
Pitkä-Surnujärvi	10	10	10	7	10	10
L. 3/88	5	7	-	6	10	5
L. 222	4	5	10	7	8	10
L. V1 Joulujärvet	5	5	6	6	10	10
Kalaton Kampajärvi	9	-	-	6	-	-
Peuranampumajärvi	8	-	-	6	-	-
Lampi D49	5	-	-	8	8	
Takkireuhkajärvi	8	10	10	8	10	10
Pieni Arttajärvi	10	9	10	6	10	10
Käyräjärvi 521	10	-	-	5	-	-
Keimiöjärvi	-	-	-	8	10	10
Sarvijärvi S4	7	5	-	5	-	-
Rautujärvi 56	8	-	-	10	8	10
Hietajärvi Z41	10	5	-	9	-	-

The lowest index values were observed in lakes Käyräjärvi, Sarvijärvi, Kalaton Kampajärvi and Peuranampumajärvi. In these lakes, the values observed in 2005 were also lower than those recorded in 1993 - 1994. In contrast, lakes Limgambergtjern, Guoika Luobbalat and Lake D4 were characterized by the increased index values in 2005. Other lakes showed the high values of KolaBIS index during the both samplings.

The highest KolaBIS values are associated with relatively large unpolluted and circumneutral drainage lakes. Correlation coefficients ranked in a following decreasing order: SHL*** >T2***, T1*** >Zn*** >LSA** >SHW** >LO** >HAB** >WV* >Cu*. However, KolaBIS has been shown to be quite insensitive to decrease of the water pH level.

4.6.3. Short Score Index

The results of the water quality assessment using the Short Score Index in 1993 - 1994 and 2005 are presented in Table 17. The minimum values of index were revealed for the polluted lakes LN3 and LN2, and for acidified lakes Peuranampumajärvi, Lampi D49, Käyräjärvi, and Hietajärvi.

Table 17. Short Score Index (ShSI) values for the different lake habitats in 1993 - 1994 and 2005.

Lake	1993 - 1994**			2005		
	Lake littoral	Outlet area	Outlet stream	Lake littoral	Outlet area	Outlet stream
LN1 **	2,1	5,5	6,0	8	9	8
LN2**	3,0	-	-	6	-	-
LN3**	2,5	4,2	-	1	1	1
LN4	-	-	-	7	8	8
LN5**	6,5	9,0	8,7	6	9	9
Limgambergtjern**	5,8	2,5	6,0	8	6	8
Dalvatn**	3,3	3,5	7,4	1	8	7
Guoika Luobbalat **	6,5	8,0	6,0	7	8	9
Store Skardvatn**	6,2	-	-	7	-	-
Otervatn**	6,0	8,0	8,8	6	7	7
Harrijärvi H62	6	8	8	8	9	8
Pitkä-Surnujärvi	10	9	10	6	8	6
L. 3/88	7	6	-	6	8	8
L. 222	6	7	8	5	8	8
L. V1 Joulujärvet	6	7	7	7	8	9
Kalaton Kampajärvi	6	-	-	7	-	
Peuranampumajärvi	8	-	-	6	-	
Lampi D49	7	-	-	6	-	
Takkireuhkajärvi	8	8	9	6	9	9
Pieni Arttajärvi	6	9	9	7	8	7
Käyräjärvi 521	7	-	-	6	-	
Keimiöjärvi	-	-	-	7	7	6
Sarvijärvi S4	4	4	-	5	-	
Rautujärvi 56	6	-	-	7	6	8
Hietajärvi Z41	6	3	-	6	-	-

The highest values were found in lakes Harrijärvi, LN1, LN5, Guoika Luobbalat, Joolujärvet, and Takkireuhkajärvi (>8.0). Unexpectedly high value for Lake LN1 can be explained by the occurrence of Polycentropodidae caddisflies, which are considered to be the indicators of respectively high water quality in the Short Score Index. This seems incorrect, since Polycentropodidae larvae are often a dominant group in extremely deteriorated invertebrate communities of polluted lake habitats.

However, the Short Score Index did not appear to be sensitive for the content of heavy metals in water and water acidity. Depending on the strength of the correlation with the index, environmental variables rank in a following order: DS*** >HAB** >T1** >ALT** >T2*. Apparently, this index is not suitable for the use in the biological monitoring of small northern lakes.

4.6.4. Acid Score Index

Acid Score Index was not calculated for Nikel area, because the lakes of the area are not suffering from acidification. On the contrary, the contamination by heavy metals and other substances has resulted to a unusually high pH levels and buffering capacity in these lakes.

Thirteen of twenty (Nikel Region was not included) lakes monitored in 2005 had low values of Acid Score Index (< 0.5 for all of lake habitats) (Table 18). Lakes Store Scardvatv (Jarfjord), Harrijärvi H62, Pitkä-Surnujärvi, Lampi 222 (Vätsäri), Takkireuhkajärvi, Pieni Arttajärvi (Raja-Jooseppi) and Keimiöjärvi (Pallas) showed no signs of acidification.

Table 18. Values of Acid Score Index (AcSc) in different habitats of the lakes monitored in 1993 - 1994** and 2005.

Lake	1993 - 1994			2005		
	Littoral	Outlet area	Outlet stream	Littoral	Outlet area	Outlet stream
Limgambergtjern **	0,25	0-0,25	1	0,5	0,25	0,5
Dalvatn**	0-0,25	0-0,25	0,25-0,5	0	0,5	0,25
Guoika Luobbalat**	0,25-0,5	0,5-1	0,25-0,5	0,25	0,5	0,5
St. Skardvatn**	0,5-1	-	-	1	-	-
Otervatn	0,25	0,5	0,5-1	0,25	0,25	1
Harrijärvi H62	0,25	0,25	1	0,5	1	1
Pitkä-Surnujärvi	0,5	1	1	1	1	1
L. 3/88	0,25	0,25	1	0,25	0,5	0,25
L. 222	0,25	0,25	1	1	1	1
L. V1 Joulujärvet	0,25	0,25	1	0,25	0,5	1
Kalaton Kampajärvi	0,25	-		0,25	-	
Peuranampumajärvi	0,25	-		0,25	-	
L. D49	0,25	-		0,25	-	
Takkireuhkajärvi	1	0,5	0,25	0,25	1	1
Pieni Arttajärvi	0,5	1	1	0,25	1	1
Käyräjärvi 521	0,25			0,25		
Keimiöjärvi	-	-	-	1	1	1
Sarvijärvi S4	0,25	0		0,25	-	
Rautujärvi 56	1	-	-	0,5	0.5	0,5
Hietajärvi Z41	0,25	0	-	0,25	-	-

Acid Score Index had significant positive correlation with water alkalinity (r_S = 0,45, P = 0,005) and water pH (r_S = 0,043, P = 0,008), as well as with several lake and habitat parameters: SHL*** >T2*** >LSA*** >T1*** >WV** >ALK** >pH** >DS*. However, negative correlation with concentration of Al in water was insignificant.

Based on results of acidity estimation is it possible to classify the monitored lakes into the following groups (Table 19).

Table 19. Acidic status of the lakes monitored in 1993 - 1994 and 2005.

Scale	Water pH	1993 - 1994**	2005
1	Low acidity, pH is usually above 6,0, though it can drop down to 5,5 during snow melt or heavy rains	Store Scardvatn Pitkä-Surnujärvi Takkireuhkajärvi Pieni Arttajärvi Rautujärvi	Store Skardvatn Pitkä-Surnujärvi Lake 222 Takkireuhkajärvi Pieni Arttajärvi Harrijarvi Lake 222 Keimiöjärvi
0,5	Moderately acidified water, pH between 5,5 and 6,0 and it can drop down to 5,0 episodically	Limgambergtjern Guoika Luobbalat Otervatn Harrijärvi Joolujärvet Lake 222 Lampi 3/88	Limgambergtjern Guoika Luobbalat Otervatn Joulujärvet Rautujärvi
0.25	Strongly acidified, pH 4,8 – 5,5, and it can drop down to 4,5 episodically	Dalvatn Kalaton Kampajärvi Peuranampumajärvi Lampi D49 Sarvijärvi Hietajärvi Käyräjärvi 521	Dalvatn Kalaton Kampajärvi Peuranampumajärvi Lampi D49 Sarvijärvi Hietajärvi Lampi 3/88 Käyräjärvi 521

In Jarfjord Region, the values characteristic for un-acidified lakes were observed only in Lake Store Skardvatn. Lakes Pitkä-Surnujärvi, Takkireuhkajärvi, and Pieni Arttajärvi remained not acidic by 2005. Lake Rautujärvi, not acidified in 1993, was estimated as moderately acidified in 2005. In contrast, Lake 222 was classified as undamaged in 2005, and seemed to be recovered between the two samplings.

As a whole, water chemistry data for monitored lakes also coincide with the results of biological assessment of water acidity status. Except for lakes Store Skardvat (Jarfjord Region), Pieni Arttajärvi, Takkireuhkajärvi (Raja-Jooseppi Region), Harrijärvi, Lake 222 and Pitkä-Surnujärvi (Vätsäri Region), other lakes were characterized by low water pH (< 6,5) in 2004 -2005.

5. Discussion

Three of five lakes located in Nikel Region clearly showed the lowest pollution sensitive species richness and values of biological indexes. Surprisingly, lakes Shuonijavr (LN5) and LN 4, located between Nikel and Zapoljarny towns, had favourable condition for invertebrates.

Allthough the relative abundance and biomass of acidification and pollution sensitive species had not changed significantly during the last decade, reduction of the number of acid- and pollution sensitive species was found in almost every region. In 2005, Lakes Takkireuhkajärvi and Pieni Arttajärvi (Raja-Jooseppi Region) and all lakes located in Pallas Region showed notable reduction of total species number in the littoral habitats in comparison with 1993 - 1994. In addition to three Nikel Region lakes, obvious negative changes in invertebrate communities, due to low water pH (4,8 - 5,5), were found in strongly acidified lakes Dalvatn (Jarfjord Region), Lampi 3/88 (Vätsäri Region), Kalaton Kampajärvi, Peuranampumajärvi, Lampi D49, (Raja-Jooseppi Region), Käyräjärvi Sarvijärvi, and Hietajärvi (Pallas Region). Lakes Limgambergtjern, Guoika Luobbalat, Otervatn (Jarfjord Region), Joulujärvet (Vätsäri Region) and Rautujärvi (Pallas Region) were characterized as moderately acidified.

65 % of Finnish and Norwegian lakes monitored in 2005 were acidic. Share of the strongly acidic lakes averaged in Finnish Lapland c. 47 %. In Jarfjord Region of Norway, only Lake Dalvatn was strongly acidic. It is necessary to note, that the pH values obtained from chemical analysis are somewhat higher than estimates based on biological assessment. Apparently the low values of acidification state indexes are connected with the influence of other harmful factors in waters, such as concentration of Al and other metals, deterioration of trophic interactions in ecosystem etc.

Chironomid larvae, *Lumbriculus variegatus*, Phryganeidae and Polycentropodidae caddisflies were the most common group in all lake habitats. Leptophlebidae mayflies, *Nemoura* and *Diura nanseni* stoneflies frequently occurred in running water as well as in lake littoral habitats.

The analyses of bioaccumulation of metals in the tissues of Polycentropodidae caddisfly larvae revealed some unexpected results. Most alarming were the elevated aluminium concentrations in Vätsäri and Raja-Jooseppi in Finnish Lapland. Although the concentrations were clearly lower than in Nikel Region, the increase during the last decade can not be overlooked. In the studied lakes of Vätsäri Region, the concentrations of Al were 2 - 8 times higher in 2005 compared to the earlier analyses conducted in 1993 - 1994. Concentrations Al in water, and especially in caddisfly larvae has increased, which most probably is one of the reasons of negative changes in benthic communities observed in 2005. The cause for the elevated concentrations is unclear. The changes in Al concentrations are possibly caused by the slight increase in pH and alkalinity, since the bioaccumulation has been observed to increase in circum-neutral conditions. Further, decrease of precipitation due to changes in climate can decrease the loading of organic substances, which bind the soluble Al into biologically inactive form. However, the confirmation of these hypotheses will need further monitoring studies.

Surprisingly high Cu and Ni concentrations in Polycentropodidae caddisfly larvae tissues were measured from lake Pieni-Arttajärvi in Raja-Jooseppi Region. The concentrations in the invertebrate tissues exceeded the concentrations measured from polluted Lake LN1 in Nikel region. In 1993 - 1994, heavy metal concentrations in Polycentropodidae caddisfly larvae collected in Finnish Lapland were considerable lower than in lakes situated near the metal smelters in Kola Peninsula.The reasons for the high concentrations in Pieni-Arttajärvi are unclear, but may depend on the soil characteristics of the drainage area. On the contrary, Lake LN4 situated between Nikel and Zapolyarny showed very low heavy metal concentrations, with the exception for Al, Hg and Mn. The low content of Ni and Cu in Lake LN4 can be explained as a result of altitude and location of the lake in the relation prevailing wind directions.

The results lead to a conclusion that the load of priority heavy metals (Ni and Cu) on water ecosystems in the Nikel Region seem to be reduced in comparison with the beginning of 90th. Other confirmation to our conclusion is that the concentration of all heavy metals in Polycentropodidae larvae of Nikel lakes had clearly decreased by 2005 (from 2,6 times for Mn up to 17 times for Pb). Only concentrations Cd and Zn have decreased insignificantly. Allthough many lakes in Nikel Region are still strongly polluted, the reduction of heavy metal concentrations in the localities near the pollution source indicates that the renovation of smelters may have had some positive effects on the aquatic environments.

The occurrence and abundance of acid-sensitive invertebrates showed obvious dependence from physical characteristics of lakes (like size, hydrological type, lake order) and habitats (water velocity, dominant substratum, vegetation type, size characteristics of streams). Several environmental factors influence to the differences between lakes, regions and years. Therefore the clear causal connection between the aerial pollution and changes in invertebrate communities is hard to authenticate. Impacts of pollution and acidification, as well as biotic interactions may influence the benthos communities. Therefore it is important to conduct the long-time monitoring of the changes in pollution rate and aquatic communities.

The present study provides bases for long-term monitoring of the changes in invertebrate communities in northern Fennoscandia. Approaches to the development of the long-term extensive and intensive monitoring and assessment of biological effects of acidification are proposed in a following chapter.

6. Recommendations for monitoring program

6.1. Creation of joint network of biological monitoring of the small lakes located in the border area between Finland, Norway and Russia

One of the aims of the present study was the produce a programme for monitoring of the changes in lake ecosystems following the modernization of the Pechenganikel complex.

The 25 lakes surveyed in 2005 are suitable for the monitoring of the acidification and pollution status of the northern cross-border areas. Long-term monitoring will provide the necessary information concerning the development of zooecological state of the different habitats of lakes. Further, the data set offers a possibility to track the temporal changes in water quality and environmental status in the lakes with varying pollution and acidification status. Monitored lakes represent several hydrological types and several acidification states (acidic, acidified and acidifying). However, the further monitoring of Pallas region as a reference area needs to be re-evaluated, since three of the five lakes in the area expressed signs of acidification in the zoobenthos communities. The amount of lakes offers a possibility for efficient statistical treatment of the data.

In order to make the monitoring cost-effective, we propose a program with separate "compulsory" and "expanded" sampling schemes. "Compulsory monitoring" aims in observation of short-term variation in ecological status, and it is conducted more frequently than "expanded monitoring", but the number of surveyed sites is smaller. "Expanded monitoring" is conducted once a decade, and it includes all lakes of the present survey. "Expanded monitoring" is more thorough inventory of the environmental state of the Norwegian-Russian-Finnish border area.

6.2. Quidelines for the implementation of the cross-border monitoring

In order to maintain the comparability of the results between the countries and sampling periods, it is obviously important to co-ordinate the sampling site selection, sampling methods, taxonomy analyses, statistical analyses, data storage and exchange of the data. Common meetings and training with sampling, processing of samples and indentification of animals would be very useful in order to ensure the reliability of acquired data. Identification guides and keys should also be introduced and exchanged between the operators in order to harmonize the species identification.

Sampling procedure

In order to secure the comparability between data sets, it is very important to use the sampling technique of the previous studies, especially in "expanded monitoring" occasions (Yakovlev 1999).

The invertebrate sampling should be done as a qualitative kick sampling (hand net, 0.5 mm mesh size). If possible, up to four habitats (lake littoral and outlet, outflow and inflow streams) shoul be sampled from each lake. 2 - 3 samples should be taken from the lake littoral of closed lakes lacking other suitable habitats. In total, 2 - 4 samples should be taken in each headwater or drainage lakes.

One approximately 3-min composite sample including all microhabitats should be taken from each habitat. If possible, the samples should be taken from stony substrate in order to restrain the natural and random in-habitat variability. Samples should be preserved in 70 % alcohol and sorted in the laboratory. If it possible, samples should contain no less than 100 - 200 individuals. Group biomass should identified as wet weight. Roughly estimated, original plan would therefore require total of c. 40 - 60 samples. Further, samples for the measurement of metal contents in the tissues of Polycentropodidae caddisfly larvae should be taken from the most representative lakes, if the resources of thr monitoring allow the needed analyses. The methods for caddis larvae sampling and storage are described in "material and methods"-section of this report.

Additionally, the lakes selected to "compulsory monitoring" should be sampled with the methods selected for the implementation of EU's Water Framework Directive (WFD). The official instructions for WFD's benthic monitoring in Finland are published during autumn 2006.

Sampling time and frequency

"Compulsory monitoring" should be conducted in early fall in every 5 years. "Expanded monitoring" should take place once a decade.

Taxonomy identification

Hirudinea, Gastropoda, Amphipoda, Ephemeroptera, Plecoptera and Trichoptera should be identified mainly on species level. Oligochaeta, Lamellibranchiata, Diptera and small groups should be identified in group level, with the exception of easily identified species with indicator value.

Biological assessment of ecological state

Following biological variables and indexes should be used in the analyses of the results of monitoring:

- total number of species
- number, relative abundance and biomass of pollution- and acid-sensitive species (malacostraca crustaceans, Gastropoda molluscs, mayflies (except Paraleptophlebidae) and stoneflies (except (Nemouridae)).
- metal accumulation in Polycentropodidae caddisfly larvae or other target taxa
- Diversity (Shannon-Weaver) Index
- Kola Biotic Index Score for Assessment of Water Quality for the Kola North region (KolaBIS) (See Table 6)
- Several scales for Assessment of Surface Water Acidity, including the offered Scale (AcSc) for the northern Fennoscandia (See Table 5)
- Indexes used in the implementation of WFD: Average Score Per Taxon (ASPT) etc. (List will be confirmed later, when the quidelines of EU are available).

Statistical analyses

Suitable analyses for the dataset could be one-way ANOVA (or non-parametric Kruskal-Wallis test) between study areas (reference vs. impacted areas) and between previous and recent data, and regressions between indicators of acidification, environmental variables and distance from emission source. Multivariable analysis (DCA, CCA, Multidimensional scaling) are also useful in the analysis of spatial and temporal differences in fauna. They are also valuable in describing the relationships between environmental variables and species composition.

Documentation and data base management

Biological data along with lake and sampling site information should be collected and stored as integral part of the National and trilateral database.

Proposition for monitoring sites

Table 20 presents the most representative sites for long-term benthic monitoring. Lakes selected for minimum compulsory monitoring are mainly sites with several sampling habitats and well-developed outlet stream. Further, they represent different stages of acidification. Expanded monitoring sites include all lakes of the present study.

Table 20. Proposition for monitoring sites.

Code	Lake	Coordinates		Compulsory Monitoring	Expanded monitoring
LN 1	Velikjampjanjarvi	69°25'364		30°18'228	+ +
LN 2	-	69°25'454	30°23'747	+	+
LN 3	Sarijarvi	69°24'590	30°37'484	+	+
LN 4	Keinojarvi	69°26'516	30°39'068		+
LN 5	Shuonijaur	69°14'035	30°08'423		+
Li	Limgambergtjern	69°41'373	30°20'415		+
Da	Dalvatn	69°41'495	30°21'369	+	+
GL	Guoika Luobbalat	69°41'554	30°46'010	+	+
SS	Store Skardvatn	69°37'092	30°46'185		+
Ot	Otervatn	69°33'294	30°46'361	+	+
H62	Harrijärvi H62	69°17'737	28°37'476		+
PS	Pitkä-Surnujärvi	69°15'480	28°42'990	+	+
388	L. 3/88	69°26'870	29°08'552	+	+
222	L. 222	69°26'775	29°06'478		+
LV1	L. V1 Joulujärvet	69°25'460	29°09'540	+	+
KK	Kalaton Kampajärvi	68°43'419	28°30'009	+	+
Pe	Peuranampumajärvi	68°43'175	28°35'401		+
D49	Lampi D49	68°39'371	28°17'255	+	+
Ta	Takkireuhkajärvi	68°35'462	28°18'401	+	+
PA	Pieni Arttajärvi	68°39'330	28°18'420		+

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Appendix

Appendix 1.Coordinates, environmental characteristics of lakes (ALT, LSA, ShL in km) and number of lake habitats sampled in Nickel (Russia), Jarfjord Rgion (Norway), Vätsäri, Raja-Jooseppi and Pallas regions (Finland), fall overturn 2005. (LO- lake order or location of lake within a lake chain; lake hydrological type: 2 - closed, 3 - headwater, 4 - drainage; 1-4- biotopes and number samplings: 1- lake shore, 2 - outlet area, 3 - down stream, 4 - inlet stream; see Table 4 and Fig. 2)

Code	Lake	Coordinate		Lake characteristics								Sapling
		X-coord.	Y-coord.	ALT	LO	T1	Type1	T2	Type2	LSA	ShL	
Nikel												
LN1	Velikjampjanjarvi	69º25'364	30º18'228	120	0	2	H	2	h	0,09	2,5	1-3
LN2	-	69°25'454	30°23'747	210	0	2	H	1	c	0,11	2,0	1
LN3	Sarijarvi	69°24'590	30°37'484	318	0	2	H	2	h	0,08	1,6	1
LN4	Keinojarvi	69º26'516	30º39'068	200	0	4	D	4	d	0,19	3,1	1-3
LN5	Shuonijarvi	69º14'035	30º08'423	180	2	4	D	4	d	12,48	26,8	1-3
Jarfiord												
Li	Limgambergtjern	69º41'373	30º20'415	172	5	4	D	4	d	0,13	4,3	1-3
Da	Dalvatn	69º41'495	30º21'369	132	8	4	D	4	d	0,24	3,5	1-3
Gu	Guoika Luobbalat	69º41'554	30º46'010	186	4	4	D	4	d	0,12	3,0	1-4
SS	Store Skardvatn	69º37'092	30º46'185	238	3	4	D	4	d	0,58	5,6	1, 4
Ot	Otervatn	69º33'294	30º46'361	293	0	2	H	2	h	0,17	2,5	1-3
Vätsäri												
H62	Harrijärvi H62	69º17'737	28º37'476	127	5	4	D	4	d	0,95	12,0	1-4
PS	Pitkä-Surnujärvi	69º15'480	28º42'990	127	18	4	D	4	d	0,75	10,8	1-3
388	Lampi 3/88	69º26'870	29º08'552	240	1	4	D	2	h	0,06	1,8	1-3
222	Lampi 222	69º26'775	29º06'478	222	3	4	D	4	d	0,25	4,1	1-4
LV1	L. V1 Joulujärvet	69º25'460	29º09'540	167	3	4	D	4	d	0,36	7,4	1-4
Raja-Jooseppi												
KK	Kalaton Kampjärvi	68º43'419	28º30'009	242	0	1	C	1	c	0,13	2,6	1
Pe	Peuranampumjärvi	68º43'175	28º35'401	205	0	1	C	1	c	0,08	1,5	1
D49	Lampi D49	68º39'371	28º17'255	228	0	1	C	1	c	0,02	0,8	1
Ta	Takkireuhka. D24B	68º35'462	28º18'401	247	0	4	D	3	h	0,22	2,1	1-3
PA	Pieni Arttajärvi D47	68º39'330	28º18'420	215	1	4	D	4	d	0,20	3,9	1-4
Pallas												
521	Käyräjärvi 521	68º14'936	24º16'315	353	0	1	C	1	c	0,13	3,0	1
Ke	Keimiöjärvi	67º57'163	24º09'801	333	0	4	D	4	d	0,61	3.2	1-4
S4	Sarvijärvi S4	68º05'604	24º06'050	326	0	3	H	1	c	0,36	3,3	1
56	Rautujärvi 56	68º20'640	23º36'700	336	0	2	H	2	h	0,35	4,2	1-3
Z41	Hietajärvi Z41	68º27'380	24º40'290	336	0	2	H	2	h	0,35	4,2	1

Appendix 2. The invertebrate species/taxa list for regions studied, fall overturn 2005 (x – rare; xx – common, xxx – abundant, xxxx – almost in each sample).

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Turbellaria spp.			x		x
Nematoda spp.	x				
OLIGOCHAETA					
Enchytraeidae		x			x
Lumbricidae	x			x	
Lumbriculidae	x			x	
Lumbriculus variegatus (Mull.)	xx		xx	x	xxx
Limnodrilus sp.			x		
Eiseniella tetraedra (Savigny)			x		
Spirosperma ferox (Eisen)	x	x			
Stylodrilus heringianus Clap.		x			
Tubificidae spp.				x	
HIRUDINEA					
Glossiphonia complanata (L.)			x	xx	x
GASTROPODA					
Lymnaea peregra Muller	x			xxx	x
Gyraulus albus Muller			xxx	xxx	xx
BIVALVIA					
Pisidium spp.	x	xxx	xx	xxx	xx
Sphaerium spp.					xx
CRUSTACEA					
Gammarus lacustris Sars.		x			
Asellus aquaticus Sars.					xx
ARANEINA					
Hydrachnellae spp.	xx	xxx	x	x	x
EPHEMEROPTERA					
Baetis fuscatus L.	x				
B. rhodani Pict.	x	x	x		
B. vernus Curt.	x				
Baetis spp.	x		x		
Caenis horaria L.					xx
Ephemerella mucronata Bgtss.					x
Heptagenia dalecarlica Bgtss.	x		x		
H. fuscogrisea Retz.	x				
H. sulphurea Mull.			x	x	
Leptophlebia vespertina L.		x			xx
Leptophlebidae spp.		x	x	x	
Metretopus borealis Etn.			x		
Paraleptophlebia cincta Retz.			x	x	x
P.strandii (Eaton)		x			
P. submarginata Steph.					x
Paraleptophlebia sp.		xx	x	xx	x
Siphlonurus alternatus Say.			x		
PLECOPTERA					
Diura nanseni Kmp.	xx	xx	xx	x	

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Isogenus nubecula Newm.			x	x	
Isogenus sp.		x			
Isoperla difformis Klp.		x			x
I. obscura Zett.			x		
Leuctra digitata Kmp.			x		
L. hippopus Kmp.			x	x	
Leuctra spp.	x				
Nemoura cinerea Retz.		x			
N. sahlbvergi Morton			x	x	
N. viki Lilleham.	x				
Nemoura spp.	x	x	x		x
Taeniopteryx nebulosa L.			x		
ODONATA					
Cordulia aenea L.			x		
Leucorrchinia dubia (Linden)				x	
Somatochlora arctica (Tett.)			x	x	
Somatochlora metallica (Linden)			x	x	
HETEROPTERA					
Arctocorisa carinata (Sahlb.)			x	xx	
Arctocorisa sp.	x				
Callicorixa wollastoni (Douglas&Scott)				x	
Callicorixa sp.					x
Corixinae sp.	xx			x	
Gerris sp.				x	
Gloenocorisa propungia (Fieb.)	x		x		
COLEOPTERA					
Agabus sp.		x	x		
Coelambus sp.					x
Colymbetes sp.			x		
Colymbetinae sp.					x
Dytiscidae sp.	x		x		
Elmis aenea	x	x		xx	x
Elmidae spp.				x	x
Esolus angustatus (Muller)					x
Gyrinus sp.				x	
Haliplus sp.	x	x			
Hydaticus sp.					x
Hydraena gracilis Germar				x	
Hydroporus sp.		x		x	x
Hygrotus sp.			x		x
Ilibius sp.			x	x	
Lacophilus sp.				x	
Laccornis sp.				x	
Limnius volckmari Panzer				x	
Oreodytes sp.				x	x
Oulimnius tuberculatus Ph. Muller				x	
Platambus maculatus L.		x	x		x

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Scarodytes sp.	**x**			**x**	
Stenelmis canaliculata (Gyllenhal)				**x**	
Rhantus sp.				**x**	
MEGALOPTERA					
Sialis fuliginosa Pictet				**x**	**x**
S. morio Klingst.					**x**
S. sibirica MacLachl.		**x**	**x**		
S. sordida Klingst.	**x**		**x**		
Sialis sp.					**x**
LEPIDOPTERA					
Nimphula stagnata (Donavan)		**x**			
TRICHOPTERA					
Agrypnia obsoleta (Hagen)			**x**		
Arctopsyche ladogensis (Kolenati)			**x**		
Cyrnus flavidus McL.	**x**		**x**	**xx**	**x**
C. insolutus McL.			**x**		
Cyrnus sp.			**x**	**x**	
Grammotaulius sp.					**x**
Halesus tesselatus Ramb.					**x**
Halesus sp.					**x**
Holocentropus dubius Rbr.				**x**	
H. picicornis Steph.			**x**	**x**	
H. stagnalis Albarda		**x**			
Holocentropus spp.		**x**			**x**
Hydropsyche angustipennis Curtis			**x**	**xx**	
H. pellucidula (Curtis)	**x**				
H. siltalai Dohler			**x**		
Hydropsyche spp.	**x**		**x**		
Hydroptila spp.		**x**			
Ithytrichia lamellaris Eaton			**x**		
Lepidostoma hirtum Fbr.	**x**		**x**		**x**
Limnephilus rhombicus L.			**x**		
Limnephilidae spp.	**x**	**x**		**xxx**	**xxx**
Micrasema spp.	**x**				
Molanna albicans Zett.	**x**				**x**
Molannodes tinctus Zett.	**x**	**x**			**x**
Mystacides azurea L.		**x**			
M. longicornis L.					**x**
M. nigra L.					**x**
Neureclepsis bimaculata L.	**xx**	**x**	**xxx**	**xx**	**xx**
Oxyethira spp.		**x**	**x**		
Phryganea sp.		**x**	**x**	**x**	
Phryganea bipunctata Retz.	**x**	**x**	**x**	**xx**	**xx**
Plectrocnemia conspersa Curtis	**x**	**x**	**xx**		
Plectrocnemia spp.		**x**		**x**	
Polycentropus flavomaculatus Pictet.	**xxx**	**xx**	**x**	**xx**	**x**
Potamophylax sp.		**x**			
Rhyacophila spp.	**x**	**x**	**xx**	**x**	

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Sericostoma personatum K.& Sp.				x	
DIPTERA					
Atherix ibis (Fabr.)				x	
Ceratopogonidae spp.	x	xx	x	xx	x
Chaoborus obscuripes (wan der Wulp)				x	
Dicranota sp.		xx			
Enophomyia sp.				x	
Gnophomyia sp.				x	
Hemerodromia sp.	x				
Limoniidae spp.	x	x	x		
Pedicidae sp.			x		
Simulidae spp.	xx	xx	x	xx	x
Tabanidae spp.	xx		x		
Tipulidae spp.	x	x	x	x	
CHIRONOMIDAE					
T a n y p o d i n a e					
Ablabesmyia spp.	xx	xx	x	x	xx
Arctopelopia spp.	x	x	x	x	x
Conchapelopia spp.	x		x	x	x
Procladius (Holotanypus) spp.	x	x	x	x	x
Rheopelopia spp.	x				
Tanypodinae spp.	xx	x	x	x	x
Thienemannimyia spp.				x	
Zavrelimyia spp.	x				
D i a m e s i i n a e					
Diamesini spp.	x	x	x	x	
Potthastia longimana (Kieff.)	x		x		x
Prodiamesa olivacea (Meig.)	x				
O r t h o c l a d i i n a e					
Cricotopus (Cricotopus) spp.	x	x	x	x	x
Eukiefferiella spp.	x	x			
Orthocladinae spp.			x		
Parakiefferiella spp.					
Psectrocladius. (Psectrocadius) spp.	x	xx	xx	x	x
P. (P.) limbatellus gr.			x		
P. (P.) psilopterus gr.				x	
P. septentrionalis Chern.					x
P. (P.) sordidellus gr.					x
C h i r o n o m i n a e					
Chironomini spp.		x	x	x	
Cryptochironomus spp.		x			
Demeijerea spp.	x			x	x
Demicryptochiron. vulneratus (Zett.)		x		x	
Endochironomus spp.	x	x			
Endochironomus albipennis					
Lauterborniella agrayloides (Kieffer)				x	
Micropsectra spp.	x		x	x	x

Taxa	Nikel	Jarfjord	Vätsäri	Raja-Jooseppi	Pallas
Microtendipes spp.	**x**	**xx**	**x**	**x**	**x**
Polypedilum sp.	**x**				
P. (Tripodura) scalaenum Kieffer	**x**	**x**			**x**
Paratanytarsus spp.		**x**		**x**	**x**
Rheotanytarsus spp.		**x**			
Tanytarsini spp.	**x**		**x**		
Tanytarsus spp.	**x**		**x**		

Appendix 3. Acid sensitive species* found in different lake habitats surveyed.

Lake	Gastropoda, Amphipoda		Ephemeroptera		Plecoptera	
	1993 - 1994	2005	1993 - 1993	2005	1993 - 1993	2005
LN1**	-	-	-	-	-	-
LN2**	-	-	*Baetis* spp.	-	*D. nanseni* *Isoperla* sp. *T. nebulosa*	-
LN3**	-	-	-	-	-	-
LN4	No samplings	-	No samplings	*B. vernus* *Baetis* spp.	No samplings	*D. nanseni* *Leuctra* sp.
LN5**	*G. albus* *L. peregra*	*L. peregra*	*B. lapponicus* *B. muticus* *B. rhodani* *C. luteolum* *E. aurivilli* *E. ignita* *H. dalecarlica* *H. sulphurea*	*B. fuscatus* *B. rhodani* *H. dalecarlica* *H. fuscogrisea*	*D. nanseni* *Diura sp.* *L. digitata* *L. fusca* *L. nigra* *T. nebulosa*	*D. nanseni*
Limgambergtjern**	-	-	*B. rhodani*	-	-	*D. nanseni*
Dalvatn**	-	-	*A. inopinatus E. aurivilli*	-	*L. fusca*	-
Guoika Lubbalat**	-	-	*B. fuscatus*	*B. rhodani*	*Capnia* sp. *D. nanseni* *L. fusca*	*D. nanseni* *I. difformis*
Store Skardvatn**	*G. lacustris*	*G. lacustris*	*Baetis* spp. *S. lacustris* *Siphlonurus* sp.	-	*A. compacta* *C. schilleri* *Diura sp.* *Leuctra sp.*	-
Otervatn**	*G. albus*	-	*A. inopinatus* *B. fuscatus* *B. lapponicus* *B. muticus* *B. rhodani* *C. luteolum*	-	*A. compacta* *Capnia* sp. *D. nanseni* *L. digitata* *L. fusca*	-

Lake	Gastropoda, Amphipoda		Ephemeroptera		Plecoptera	
	1993 - 1994	2005	1993 - 1993	2005	1993 - 1993	2005
			E. aurivilli *E. ignita* *H. dalecarlica* *H. sulphurea*			
Harrijärvi H62	*G. albus* *L. peregra*	*G. albus*	*B. rhodani Baetis* spp. *M. alter*	*B. rhodani* *M. borealis*	*D. nanseni* *L. fusca* *T. nebulosa*	*D. nanseni* *I. nubecula* *L. digitata* *L. hippopus* *T. nebulosa*
Pitkä-Surnujärvi	*G. albus* *L. peregra*	*G. albus*	*B. niger* *Baetis* spp. *B. subalpinus* *B. rhodani* *E. aurivilli* *H. dalecarlica* *H. sulphurea* *S. alternatus*	*Baetis* spp. *B. rhodani* *H. dalecarlica* *H. sulphurea* *S. alternatus*	*D. nanseni* *I. difformis* *I.grammatica* *Leuctra* sp. *T. nebulosa*	*I. obscura*
Lampi 3/88	*G. albus*	-	-	-	-	*D. nanseni*
Lampi 222	*G. albus*	*G. albus*	*B. rhodani*	-	*D. nanseni* *L. fusca*	*D. nanseni*
Lampi V1 Joulujärvet	-	*G. albus*	*B. subalpinus*	-	*D. nanseni*	*D. nanseni* *I. obscura*
Kalaton Kampajärvi	-	-	-	-	-	-
Peuranampumajärvi	-	-	-	-	-	-
Lampi D49	-	-	-	-	-	-
Takkireuhkajärvi	*G. albus* *L. peregra*	*G. albus* *L. peregra*	*Baetis* spp. *C. horaria* *C. luteolum*	-	*D. nanseni* *Isoperla* sp. *L. digitata* *Leuctra* sp.	*D. nanseni* *I. nubecula* *L. hippopus*
Pieni Arttajärvi D47	*G. albus* *L. peregra*	*G. albus* *L. peregra*	*B. rhodani* *C. horaria* *C. luteolum*	*H. sulphurea*	*D. nanseni* *I. hibecula* *I. obscura*	*D. nanseni* *I. nubecula*

Lake	Gastropoda, Amphipoda		Ephemeroptera		Plecoptera	
	1993 - 1994	2005	1993 - 1993	2005	1993 - 1993	2005
			H. fucogrisea *H. dalecarlica*		*Isoperla* sp. *Leuctra* sp. *L. nigra* *L. digitata* *T. nebulosa*	
Käyräjärvi 521	-	-	-	-	-	-
Keimiöjärvi	No samplings	*G. albus* *L. peregra*	No samplings	*C. horaria* *E. muronanta*	No samplings	-
Sarvijärvi S4	-	-	-	-	-	-
Rautujärvi 56	*G. albus* *L. peregra*	-	-	*C. horaria*	-	*I. difformis*
Hietajärvi Z41	-	-	-	-	-	-

* Acid sensitive species: gammarids, gastropods, mayflies (without Leptophlebidae) and stoneflies (without Nemouridae).
** Samplings in 1990 - 1996.

Appendix 4. Spearman rank order correlations for some tested biological variables (Correlations with p < 0,05 only are shown)

Variables	Valid	Spearman	*t*(N-2)	*p*-level
NSP & T2	65	0.27	2.27	0.0268
NSP & LSA	61	0.27	2.16	0.0349
NSP & MOS	65	0.31	2.59	0.0120
NSP & CHW	40	0.36	2.34	0.0245
NSP & WV	40	0.53	3.83	0.0005
NSP & Cd	40	-0.37	-2.44	0.0193
NSP & Cu	40	-0.47	-3.25	0.0024
NSP & Ni	40	-0.49	-3.42	0.0015
NSP & Pb	40	-0.32	-2.11	0.0418
NSP & Zn	40	-0.44	-3.03	0.0043
HN & LSA	61	0.27	2.14	0.0362
HN & MOS	65	0.37	3.12	0.0027
HN & Ni	40	-0.41	-2.73	0.0094
N_SP_SENS & LO	61	0.37	3.01	0.0038
N_SP_SENs & T1	65	0.53	4.98	0.0000
N_SP_SENs & T2	65	0.58	5.59	0.0000
N_SP_SENs & LSA	61	0.46	4.00	0.0002
N_SP_SENs & SHL	61	0.44	3.79	0.0004
N_SP_SENs & DS	65	0.30	2.53	0.0140
N_SP_SEN & CHW	40	0.41	2.80	0.0079
N_SP_SEN & WV	40	0.53	3.84	0.0005
N_SP_SEN & Cu	40	-0.38	-2.56	0.0144
N_SP_SEN & Ni	40	-0.38	-2.51	0.0163
N_SP_SEN & Zn	40	-0.53	-3.87	0.0004
N_SP_SEN & Hg	21	0.49	2.43	0.0254
AB_%SENS & LO	61	0.39	3.22	0.0021
AB_%SENS & T1	65	0.51	4.64	0.0000
AB_%SENS & T2	65	0.55	5.21	0.0000
AB_%SENS & LSA	61	0.47	4.09	0.0001
AB_%SENS & SHL	61	0.48	4.16	0.0001
AB_%SENS & DS	65	0.25	2.07	0.0427
AB_%SENS & WV	40	0.36	2.38	0.0226
AB_%SENS & Ni	40	-0.33	-2.13	0.0396
AB_%SENS & Zn	40	-0.47	-3.30	0.0021
AB_%SENS & Hg	21	0.38	1.77	0.0920
B%SENS & LO	61	0.38	3.18	0.0023
B%SENS & T1	65	0.52	4.88	0.0000

Variables	Valid	Spearman	*t*(N-2)	*p*-level
B%SENS & T2	65	0.56	5.36	0.0000
B%SENS & LSA	61	0.39	3.21	0.0022
B%SENS & SHL	61	0.41	3.41	0.0012
B%SENS & WV	40	0.32	2.08	0.0442
B%SENS & Zn	40	-0.43	-2.94	0.0056
KOLBIS & LO	61	0.35	2.85	0.0060
KOLBIS & T1	65	0.47	4.21	0.0001
KOLBIS & T2	65	0.50	4.61	0.0000
KOLBIS & LSA	61	0.41	3.43	0.0011
KOLBIS & SHL	61	0.49	4.29	0.0001
KOLBIS & MOS	65	0.26	2.13	0.0369
KOLBIS & CHW	40	0.49	3.43	0.0015
KOLBIS & WV	40	0.40	2.70	0.0102
KOLBIS & Cu	40	-0.54	-3.97	0.0003
KOLBIS & Ni	40	-0.43	-2.92	0.0058
KOLBIS & Zn	40	-0.65	-5.23	0.0000
AC_SC & T1	53	0.45	3.58	0.0008
AC_SC & T2	53	0.48	3.90	0.0003
AC_SC & LSA	49	0.49	3.87	0.0003
AC_SC & SHL	49	0.42	3.21	0.0024
AC_SC & DS	53	0.30	2.22	0.0310
AC_SC & WV	33	0.50	3.23	0.0029
AC_SC & ALK	33	0.60	4.14	0.0002
AC_SC & pH	33	0.61	4.32	0.0002
AC_SC & Hg	21	0.54	2.82	0.0110
AC_SC & Nf	37	0.42	2.76	0.0092

* Environment variables in Table 4.

Appendix 5. Results of the Wilcoxon Matched Pairs Test (Comparisons). Significant at p <0.05000 tests are shown.

	Valid	T	Z	p-level

No. of species_tot				
Nikel_ & Raja-Jooseppi	10	6.50000	2.140518	0.032314
Vätsäri & Raja-Jooseppi	10	8.00000	1.987624	0.046854
Raja-Jooseppi & Vätsäri	10	8.00000	1.987624	0.046854
Jarfjord & Raja-Jooseppi	10	0.00000	2.803060	0.005062
Jarfjord & Pallas	10	2.00000	2.240448	0.025063
KolaBIS				
Nikel & Raja-Jooseppi	10	5.50000	2.013986	0.044012
Nikel & Pallas	10	1.00000	2.380476	0.017291
AcSc				
Vätsäri & Jarfjord	15	6.000000	2.588733	0.009633