BOREAL ENVIRONMENT RESEARCH 8: 1–7 ISSN 1239-6095
Helsinki 25 March 2003

Water quality and fish populations of acid sensitive waters in the Vätsäri area, north-eastern Finland: responses to reduced sulphur emissions from the Kola Peninsula, Russia, in the 1990s

Jouni Tammi[1)4)], Antti Lappalainen[2)] and Tarja Bergman[3)]

[1)] *University of Helsinki, Department of Limnology and Environmental Protection, P.O. Box 65, FIN-00014 Helsinki, Finland (e-mail: jouni.tammi@helsinki.fi)*
[2)] *Finnish Game and Fisheries Research Institute, P.O. Box 6, FIN-00721 Helsinki, Finland*
[3)] *Lapland Regional Environment Centre, P.O. Box 8060, FIN-96101 Rovaniemi, Finland*
[4)] *Finnish Game and Fisheries Research Institute, Evo Fisheries Research Station, FIN-16970 Evo, Finland*

Tammi, J., Lappalainen, A. & Bergman, T. 2003: Water quality and fish populations of acid sensitive waters in the Vätsäri area, north-eastern Finland: responses to reduced sulphur emissions from the Kola Peninsula, Russia, in the 1990s. *Boreal Env. Res.* 8: 1–7. ISSN 1239-6095

Changes in fish population and water quality in response to the decline in sulphur deposition in small waterbodies in north-eastern Finland were studied by using data from two consecutive surveys of fish and water chemistry at 20 sampling sites in 1993 and in 2000. The study area consisted of three separate catchment basins near the Norwegian–Russian border area, 40–50 km west of the nearest large source of SO_2, the Nikel industrial complex in the Kola Peninsula. The most common fish species caught were minnow (*Phoxinus phoxinus*), burbot (*Lota lota*) and brown trout (*Salmo trutta*). Special attention was focused on minnow because of its sensitivity to acidification and its frequent occurrence in the study area. At all sampling sites, the alkalinity values of the sampled brooks and lakes were significantly higher and the sulphate concentrations significantly lower in 2000 than in 1993. The increased densities of minnow and changes in the length distribution of the sampled fish indicated that reproduction of the species was successful at most of the sampling sites in the late 1990s. The results suggest that the decrease in acid emissions from the Kola industrial centres has resulted in noticeable chemical and biological recovery of the most acid-sensitive surface waters in north-eastern Finnish Lapland.

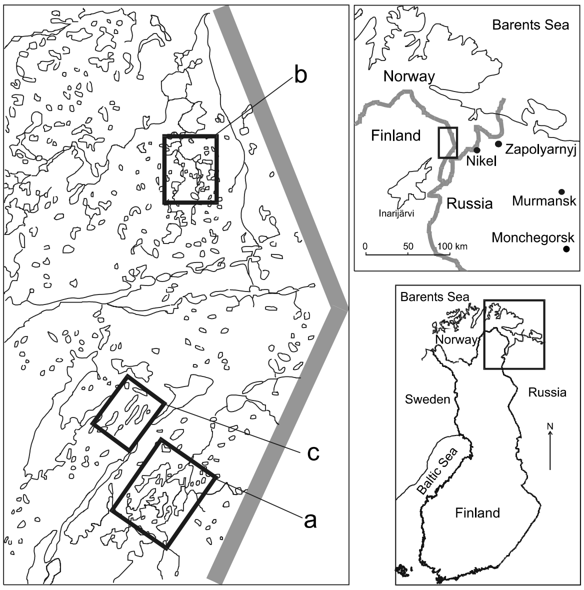

Fig. 1. Location of study areas. (a) Joulujärvi area, (b) Vuontisjärvi area, and (c) Äälisjärvi area in northern Finland.

Introduction

Sulphur emissions from the smelters of Nikel/Zapolyarnyj and Monchegorsk in the Kola Peninsula are known to cause surface water acidification in the nearby Norwegian–Russian border area (Nøst *et al*. 1991, Traaen *et al*. 1992, Moiseenko 1994, 1997, Hesthagen *et al*. 1998). Aquatic ecosystems have been affected by emissions from metal smelter also in North America (Keller *et al*. 1999, Gunn *et al*. 1995). The highest sulphur deposition in Finnish Lapland has been at Vätsäri, a remote wilderness area (Tuovinen *et al*. 1993) near the Finnish–Norwegian border, 40–50 km west of the Nikel smelter. A survey conducted in north-eastern Finnish Lapland in 1993 (Lappalainen *et al*. 1995) found that the buffer capacities of surface waters were lowest, mostly below 0.05 mmol l^{-1}, in the Vätsäri area. The first signs of acid-induced fish population damage in Finnish Lapland were found in local minnow (*Phoxinus phoxinus*) populations in the same area (Lappalainen *et al*. 1995). Damage to Arctic char (*Salvelinus alpinus*) and brown trout (*Salmo trutta*) populations have also been reported from Norwegian territory close to the Kola Peninsula (Hesthagen *et al*. 1998).

Annual SO_2 emissions from the Kola industrial area declined from an annual 600 000–700 000 t in the 1980s to about 400 000 t in the period 1992–1997 (Kashulina and Reimann 2000). The clearest decrease in sulphur deposition in north-eastern Finland and in the areas bordering Russia was recorded in the late 1980s and early 1990s (Leinonen *et al*. 2000, Finnish Meteorological Institute, unpublished data). The drop in sulphur deposition has decelerated during the 1990s, but was nevertheless still apparent in 2000. The decline in emissions in northern areas coincides with findings that the buffer capacity of large rivers in northern Finland has remained stable since the mid-1990s (AMAP 1998). The same pattern has been observed in the River Dalelva, NE Norway, and in the River Ura, Kola Peninsula (AMAP 1998), in which annual values of sulphate concentrations in the river water declined slightly and pH values rose in the mid-1990s. At the same time, data from the lake monitoring network showed reduced acidification during the 1990s (Mannio and Vuorenmaa 1995).

In the survey conducted in the Vätsäri area in 1993 (Lappalainen *et al*. 1995), 20 sites were electrofished and submitted to autumn water sampling. The same sites were re-sampled in 2000. This paper compares the results of the two consecutive survey efforts in order to discover potential changes in water quality and fish populations in the Vätsäri area. Although fish samples were taken in single years, the catches of electrofishing include several age-classes and thus the data on abundance and length distribution give combined information on the reproduction success of fish in former years. Special attention was focused on local minnow populations since the minnow is the most common fish species in the study area and is often the only species present in the smallest and most acid-sensitive watercourses (e.g. Bergquist 1991, Lappalainen *et al*. 1995).

Materials and methods

The study area is located in Vätsäri, an uninhabited area near the Finnish–Norwegian border (Fig. 1). The surface waters of the area are sensitive to acidification due to the geochemistry of the local soil (Kähkönen 1996). The distance to the nearest Russian industrial centre, the Nikel complex, is only 40–50 km. The 5-year average of annual sulphur (SO_4-S) deposition at Nellimö monitoring station, 70 km south of Vätsäri, was 329 mg m^{-2}, 238 mg m^{-2}, 180 mg m^{-2} and 160 mg m^{-2} in the periods 1981–1985, 1986–1990, 1991–1995 and 1996–2000, respectively (Finnish Environment Institute, unpublished data). The surface waters in the Vätsäri area consist of an exceptionally high number of small headwater lakes and brooks. Due to the relatively large differences in altitude over a short distance, natural obstacles to migration are common and the fish populations of many lakes and brooks are isolated from each other.

The sampling sites were located in three separate catchment basins of the following lakes: Joulujärvi, Vuontisjärvi and Äälisjärvi. In the Joulujärvi area, seven sites were located in brooks around a group of small lakes (Fig. 1). Five other sites were situated in brooks about 10 km to the north, running eventually into Vuontisjärvi. The brooks sampled in both areas were short, 50–400 m, between small (0.05–0.7 km^2) headwater lakes at 89–167 m asl. In the Äälisjärvi area, the sampling sites were in eight lakes (0.03–0.06 km^2), each site in a separate lake. These lakes were located at an elevation of more than 200 m a.s.l., above the local coniferous tree-line, and were entirely isolated from each other, even though the distances between them were only a few hundred metres.

Electrofishing was carried out in mid-September in both years, 1993 and 2000. Paulsen backpack with pulsed direct current was used. The brooks or stony shorelines of the lakes were fished only once during a sampling period and the length of fish caught was metered individually. At each site, the surface area was measured to give estimate of fish densities. Water level and water temperature, cloudiness and air temperature was measured. Water samples were taken at the same time as the electrofishing and were analysed at the laboratory of the Lapland Regional Environmental Centre according to SFS standards. The same water chemistry sample represented fish sampling sites 2–5 (Table 1 and 2).

Table 1. Some chemical properties of water samples (0 m) taken in mid-September 1993 and 2000.

Location	Alkalinity (mmol l^{-1})		Sulphate (mg l^{-1})		Cond. (mS m^{-1})		Al_{tot} (μg l^{-1})		TOC (mg l^{-1})	
	1993	2000	1993	2000	1993	2000	1993	2000	1993	2000
Joulujärvi area (brooks)										
Site 1	0.031	0.041	2.7	1.9	1.9	1.7	24	26	–	2.9
Sites 2, 3, 4 & 5	0.04	0.051	2.7	2.0	2.0	1.8	32	29	–	2.9
Site 6	–	0.066	–	2.1	–	1.9	–	31	–	2.4
Site 7	0.024	0.051	2.7	2.1	1.8	1.8	33	51	–	2.5
Vuontisjärvi area (brooks)										
Site 8	0.061	0.067	2.5	1.9	2.4	2.1	24	36	2.4	3.5
Site 9	–	0.074	–	2.2	–	2.2	–	30	–	2.9
Site 10	0.073	0.083	2.4	1.8	2.7	2.4	33	72	3.7	4.4
Site 11	0.058	0.075	2.2	1.7	2.5	2.3	35	62	4.0	5.2
Site 12	0.047	0.051	2.6	1.9	2.3	1.9	26	51	2.7	3.4
Äälisjärvi area (lakes)										
Site 13	0.012	0.022	2.6	2.0	1.5	1.2	13	19	–	2.3
Site 14	0.002	0.02	3.0	2.4	1.56	1.4	31	33	–	2.4
Site 15	0.02	0.029	2.7	2.3	1.7	1.5	26	26	–	2.6
Site 16	–0.002	0.016	2.7	2.2	1.44	1.2	39	28	–	2.1
Site 17	–0.004	0.013	2.7	1.9	1.42	1.1	15	15	–	1.8
Site 18	0.047	0.076	2.3	1.8	2.1	1.9	49	46	–	3.1
Site 19	–0.004	0.015	2.7	2.0	1.5	1.2	20	29	–	2.6
Site 20	0.019	0.026	2.8	2.2	1.7	1.5	22	24	–	2.9

Possible differences between sampling years for water quality parameters and fish densities were tested by paired *t*-tests and for fish length distribution by Mann-Whitney *U*-test.

Results

At all sampling sites, the alkalinity values of the sampled brooks and lakes were significantly higher and the sulphate concentrations significantly lower in 2000 than in 1993 ($P < 0.001$, paired *t*-test, Table 1). Conductivity values were also significantly lower in 2000 than in 1993 ($P < 0.001$, paired *t*-test), but total aluminium concentrations showed no significant differences. The total aluminium concentrations at the sites of Vuontisjärvi were even higher in 2000 as in 1993, but were still lower than 75 μg l^{-1}, which can be considered a moderate level in small Finnish lakes (Tuunainen *et al.* 1991). The higher total organic carbon, TOC (Table 1) and also higher Fe concentrations at Vuontisjärvi sites in the year 2000 suggested that aluminium was bound in humic substances and the rise in aluminium was connected to a rise in humic matter. Both the buffer capacity and the conductivity of water were highest in the Vuontisjärvi area. Water level at all sampling sites was at the same in both sampling years and water temperature at the sites varied from 6.3 to 9.0 °C in 1993 and from 7.5 to 9.4 °C in 2000.

The most common fish species caught were minnow, burbot (*Lota lota*) and brown trout. Less common species were grayling (*Thymallus thymallus*), perch (*Perca fluviatilis*), pike (*Esox lucius*), nine-spined stickleback (*Pungitius pungitius*) and Arctic char. Burbot and minnow occurred in all three studied areas, but brown trout was common only in the Joulujärvi area and the estimated densities were there generally lower than 10 ind. 100 m^{-2} (Table 2). No clear differences were found in the abundance of burbot and brown trout between 1993 and 2000 (paired *t*-test, Table 2). Neither were differences found in the length distributions of the fish (Mann-Whitney *U*-test). In the Joulujärvi area, the size range of brown trout was 50–250 mm in

Table 2. Densities (ind. 100 m^{-2}) of minnow, brown trout and burbot at electrofishing sites.

Location	Minnow		Brown trout		Burbot	
	1993	2000	1993	2000	1993	2000
Joulujärvi area						
Site 1	1.4	–	19.4	6.9	1.4	6.9
Site 2	5.0	3.9	3.3	0.6	1.1	3.9
Site 3	–	13.2	–	–	1.5	1.5
Site 4	15.2	1.4	6.5	8.7	–	5.1
Site 5	16.7	5.0	1.7	–	–	3.3
Site 6	4.5	57.5	0.5	–	1.5	0.5
Site 7	–	47.5	–	–	–	–
Vuontisjärvi area						
Site 8	15.6	13.3	8.9	2.2	–	–
Site 9	86.7	73.3	–	–	13.3	–
Site 10	422.0	755.0	–	–	–	–
Site 11	20.0	–	–	–	4.0	–
Site 12	45.8	79.2	–	–	12.5	4.2
Äälisjärvi area						
Site 13	5.9	4.9	–	–	–	–
Site 14	–	–	–	–	15.8	–
Site 15	16.7	–	–	–	–	10.0
Site 16	12.0	28.0	–	–	–	–
Site 17	–	0.6	–	–	–	–
Site 18	1.4	–	–	–	0.7	1.4
Site 19	–	–	–	–	2.2	2.2
Site 20	30	73.3	–	–	–	–

Table 3. Percentiles for the length (mm) distribution of minnow at electrofishing sites in 1993 and 2000 (mid September in both years). In a group comparison Mann-Whitney *U*-test was used.

Location	1993	2000	
Joulujärvi area	$n = 50$	$n = 155$	$P < 0.001$
1st quartile	33	20	
Median	56	21	
3rd quartile	70	42	
Vuontisjärvi area	$n = 55$	$n = 70$	$P < 0.2$
1st quartile	51	52	
Median	60	63	
3rd quartile	65	69	
Äälisjärvi area	$n = 33$	$n = 42$	$P < 0.058$
1st quartile	57	38	
Median	63	58	
3rd quartile	70	75	
Total	$n = 138$	$n = 267$	$P < 0.001$
1st quartile	49	20	
Median	60	42	
3rd quartile	68	65	

1993 and 67–263 mm in 2000. The length range of burbot in the same area was 90–170 mm in 1993 and 52–213 mm in 2000. In the two other areas, small (50–100 mm) burbot were found in both 1993 and 2000.

The densities of minnow were generally highest in the Vuontisjärvi area both years, 1993 and 2000 (Table 2). In that area, the buffer capacity of water samples in 1993 was not as low as at the other two sites. There were also no differences in the length distribution of minnow between 1993 and 2000 (Table 3). In the Joulujärvi area, however, the median length of the minnows caught was significantly lower and share of small individuals higher in 2000 than in 1993 (Table 3), indicating better reproduction success in years before 2000. The recruitment of small fish can be seen in the densities and length distributions of fish at sites 6 and 7 (Table 2 and Fig. 2). Small individuals (< 40 mm) were also found at site 3, which was previously empty.

In the Äälisjärvi area, no minnows were found in two lakes (sites 14 and 19) in either 1993 or 2000 (Table 2). The alkalinity values in these lakes were critically low in 1993 (Table 1), indicating that any existing minnow populations might be at risk of becoming extinct. At site 15, alkalinity was higher but the minnow population would appear to have become extinct in the 1990s, as no minnows were found by electrofishing in 2000 and the catch in 1993 consisted of only a few, rather large, 60–80 mm, individuals. Two other lakes (sites 17 and 18) also yielded only a few (1 and 2) large minnows despite surveys of all suitable parts of the shorelines. In contrast, in two lakes (sites 16 and 20), the density of minnows was higher in 2000 than in 1993 and the length distribution showed recruitment of smaller fish, especially at site 20 (Fig. 2).

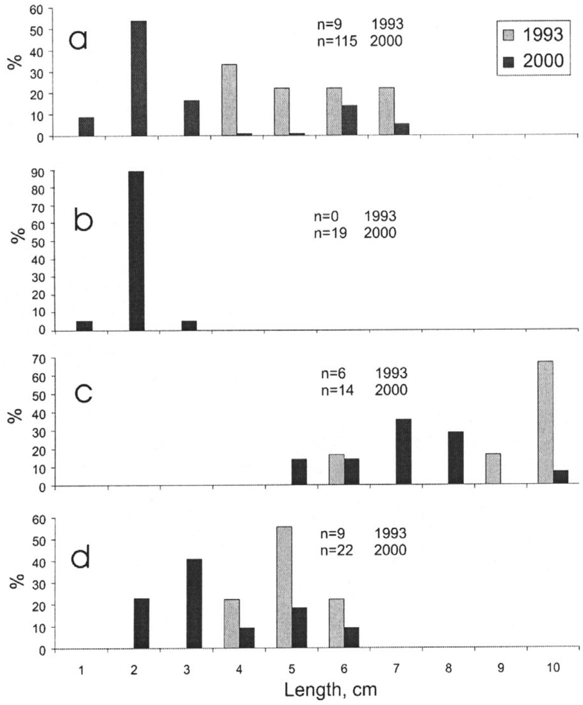

Fig. 2. Length distributions of minnow caught by electrofishing in the Joulujärvi area (**a**) site 6 and (**b**) site 7, and in the Äälisjärvi area (**c**) site 16 and (**d**) site 20, in 1993 and 2000.

Discussion

The consistent increase in alkalinity and decrease in sulphur concentrations at all sampling sites of this study indicate that the surface waters are recovering from acidification. The results are in line with observations that acid deposition in the area has decreased due to the decline in sulphur emissions from the Kola smelters (Kashulina and Reimann 2001). Alkalinity, however, was still below or near 0.05 mmol l^{-1} at many sites, indicating low buffer capacity. The observed sulphate levels were also higher than the median value, 1.7 mg l^{-1}, of 190 randomly sampled lakes in northern Finland (Forsius 1992).

On the Norwegian side of the border, closer to the smelters, acid-induced damage has been reported in Arctic char and brown trout populations (Hesthagen *et al.* 1998). Damaged and lost fish populations were identified in small lakes at relatively high elevations (172–349 m a.s.l.), and the damage is thought to have occurred during the 1970s and 1980s. Our findings in the Vätsäri area did not reveal any damage in populations of brown trout or other species subject to fishing. On the other hand, we have no data on our sites before 1993, and were thus unable to detect changes at those sites during earlier decades. An assessment of national monitoring data on river water chemistry from 1963 to 1989 has revealed trends indicating acidification in the rivers of northern Finland (Kinnunen 1990).

As suggested by Lappalainen *et al*. (1995), minnow is a good indicator of acid-induced damage in areas where the species is common. Hesthagen *et al*. (1998) used gill nets in their survey conducted on the Norwegian side of the border and due to too large mesh size of survey nets they did not obtained data on potential losses in minnow populations. Our results revealed that some minnow populations have become extinct at the most acid-sensitive sites in the Äälisjärvi area. On the other hand, signs of recovery during the late 1990s were found in other minnow populations in the Äälisjärvi area and in those in the Joulujärvi area, too. The increased densities of minnow and the frequent occurrence of small, 20–40 mm, fish indicated that reproduction has been successful at many sites in recent years. According to growth data on minnow in Finnish Lapland (Mills 1988), individuals reach a length of 40–50 mm at an age of 4 years and of 80 mm at 10 years. Alkalinity values have increased simultaneously and minnow is known to be sensitive to acidification (Magnuson *et al*. 1984, Muniz 1984, Bergquist 1991). Several age classes in the catch of minnow at many sampling sites in 2000 is more likely a result of continuous improving of water quality rather than some other, more irregular environmental factor. Comparability of the sampling years 1993 and 2000 is supported by the fact that water level and water temperature in both sampling periods were similar. Water samples taken in autumn gives more accurate information on average water quality at sampling sites compared to those taken during the spring flood and early summer. Although short term acid peaks in the springtime may be critical for fish, reproduction success of the minnow populations of this study showed that at many sites possible acid peaks have not prevented the recruitment of new age classes before year 2000.

To conclude, a comparison of data from 1993 and 2000 revealed that the decrease in acid emissions from the Kola industrial centres has resulted in noticeable chemical and biological recovery of the most acid-sensitive surface waters in north-eastern Finnish Lapland. The buffer capacity of many waters was still low in 2000, implying that the waters are in immediate danger of acidification should the emissions start to increase in the future.

References

AMAP 1998. Assessment Report: Arctic pollution issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. pp. 640–642.

Bergquist B.C. 1991. Extinction and natural recolonization of fish in acidified and limed lakes. *Nordic Journal of Freshwater Research* 66: 50–62.

Forsius M. 1992. Acidification of lakes in Finland: Regional estimates of lake chemistry and critical loads. National Board of Waters and the Environment, *Publications of the Water and Environment Research Institute* 10, 37 pp.

Gunn J., Keller W., Negusanti J., Potvin R., Beckett P. & Winterhalder K. 1995. Ecosystem recovery after emission reductions: Sudbury, Canada. Acid Reign '95. In: Proceedings from the 5th International Conference on Acid Deposition Göteborg, Sweden, 26–30 June 1995. *Water, Air and Soil Pollution* 85: 1783–1788.

Hesthagen T., Langeland A. & Berger H.-M. 1998. Effects of acidification due to emissions from the Kola Peninsula on fish populations in lakes near the Russian border in the northern Norway. *Water, Air and Soil Pollution* 102: 17–36.

Kashulina G. & Reimann C. 2001. Sulphur in the Arctic environment (1): results of a catchment-based multimedium study. *Environmental Pollution* 114: 3–19.

Keller W., Heneberry J.H. & Gunn J.M. 1999. Effects of emission reductions from the Sudbury smelters on the recovery of acid- and metal-damaged lakes. *J. Aquat. Ecosyst. Stress Recovery* 6: 189–198.

Kinnunen K. 1990. Acidification of waters in Finnish Lapland. In: Kinnunen K. & Varmola M. (eds.), *Effects of air pollutants and acidification in combination with climatic factors on forests, soils and waters in Northern Fennoscandia*, Report from a workshop held in Rovaniemi, Finland, 17–19 October, 1988. Nordic Council of Ministers, Copenhagen, Nord 1990:2, pp. 72–79.

Kähkönen A.-M. 1996. Geochemistry in relation to water chemistry and sensivity to acid deposition in Finnish Lapland. *Water, Air and Soil Pollution* 87: 311–327.

Lappalainen A., Mähönen O., Erkinaro J., Rask M. & Niemelä E. 1995. Acid deposition from the Russian Kola peninsula: are sensitive fish populations in north-eastern Finnish Lapland affected? *Water, Air and Soil Pollution* 85: 439–444.

Leinonen L. (ed.) 2000. *Air quality measurements 1999*. Finnish Meteorological Institute, Helsinki 2000. 254 pp.

Magnuson J.J., Baker J.P. & Rahel S.J. 1984. A critical assessment of effects of acidification on fisheries in North America. *Phil. Trans. R. Soc. Lond.* B 305: 501–516.

Mannio J. & Vuorenmaa J. 1995. Regional monitoring of lake acidification in Finland. *Water Air Soil Pollut*. 85: 571–576.

Mills C.A. 1988. The effect of extreme northerly climatic conditions on the life history of the minnow, *Phoxinus phoxinus* (L.). *J. Fish. Biol*. 33: 545–561.

Moiseenko T. 1994. Acidification and critical loads in surface waters: Kola, northern Russia. *Ambio* 23: 418–424.

Moiseenko T. 1997. Acidification and pollution by heavy metals of Kola surface waters. International Co-operative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes: 8th task force meeting, 1982. *Can. Tech. Rep. Fish. Aquat. Sci.* 1997: 23–33.

Muniz I.P. 1984. The effects of acidification on Scandinavian freshwater fish fauna. *Phil. Trans. R. Soc. Lond.* B 305: 517–528.

Nøst T., Yakovlev V., Berger H.M., Kashulin N., Langeland A., Lukin A. & Muladal H. 1991. *Impacts of pollution on freshwater communities in the border region between Russia and Norway. I. Preliminary study in 1990*. Norwegian Institute for Nature Research, Report 26, 41 pp.

Traaen T.S., Henriksen A., Moiseenko T. & Wright R.F. 1992. Lake monitoring, critical load of sulphur and modelling on future acidity for several sulphur reduction scenarios in the Norwegian-Russian border areas. In: Tikkanen E., Varmola M. & Katermaa T. (eds.), *The state of the environment and environmental monitoring in the northern Fennoscandia and the Kola Peninsula*, Extended Abstracts of the Symposium held October 6–8, 1992 in Rovaniemi Finland. Arctic Centre Publications 4: 161–164.

Tuovinen J.-P., Laurila T., Lättilä H., Ryaboshapko A., Brukhanov P. & Korolev S. 1993. Impact of the sulphur dioxide sources in the Kola Peninsula on air quality in northernmost Europe. *Atmospheric Environment* 27A: 1379–1395.

Tuunainen P., Vuorinen P.J., Rask M., Järvenpää T., Vuorinen M., Niemelä E., Lappalainen A., Peuranen S. & Raitaniemi J. 1991. Effects of acid deposition on fish and crayfish. Final report. *Suomen Kalatalous* 57: 1–44. [In Finnish with English summary].

Received 14 December 2001, accepted 10 September 2002