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WATER QUALITY CRITERIA FOR EUROPEAN FRESHWATER FISH

Report on the effect of zinc and copper pollution on the salmonid fisheries in a river and lake system in central Norway

with the cooperation of the
United Nations Environment Programme

EUROPEAN INLAND FISHERIES ADVISORY COMMISSION
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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REPORT ON

The Effect of Zinc and Copper Pollution on the Salmonid Fisheries in a River and Lake System in Central Norway

prepared by

the EIFAC Working Party on Biological Monitoring

UNITED NATIONS ENVIRONMENT PROGRAMME

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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1. INTRODUCTION

As part of a continuing programme of Sub-Commission III, of the European Inland Fisheries Advisory Commission (EIFAC), a Working Party was set up in 1964 to prepare water quality criteria for European freshwater fish, based on critical surveys of the literature on measured effects of the important pollutants known to cause harm to fisheries. A series of publications has been produced which contain a synthesis of information drawn from laboratory tests on lethal and sub-lethal effects of specific pollutants on fish, and on field observations. Although there are usually coherent and well-founded data on the response of fish to specific pollutants under closely defined laboratory conditions, there is generally a lack of comparable data from field observations. Such observations are essential for the validation of laboratory data and the preparation of accurate water quality objectives. This shortage of field data was emphasized in the Reports on the effects of zinc (EIFAC/T21; 1973) and copper (EIFAC/T27; 1976) on freshwater fish. Recognition was given to this need in 1970 and in 1973 a questionnaire was circulated to member countries of EIFAC in which information was sought on the existence of suitable sites where the interaction between the levels of pollution in water and the status of the fisheries there could be investigated, and where the pollution was caused by one or two pollutants of international importance. One such site which appeared to fulfil the requirements was in Norway, where two inter-connected lakes were fed by a polluted stream containing copper and zinc wastes from former mining operations.

Two of the major deficiencies in existing field studies have been the insufficient number of samples taken for analysis and in some cases the use of inappropriate methods of analysis. This latter factor is important in the case of copper, where under field conditions a large proportion of the metal can be bound to soluble organic compounds, in which state it is much less harmful to the fish than the free ionic form or copper carbonate. Current analytical methods usually measure total copper (dissolved and bound to suspended solids) and it is often not possible to assess the potential harmfulness to fish of such concentrations. Since UNEP has a strong interest in the development of pollution monitoring programmes which provide data relevant to the needs of environmental protection, this organization funded a one-year project to carry out an investigation of the polluted Norwegian lakes, in order to generate data of value to the planning of other monitoring programmes and to provide information in support (or otherwise) of the tentative water quality objectives for zinc and copper put forward in EIFAC/T21 and EIFAC/T27.

The programme was carried out by Mr. K.W. Jensen (Directorate for Wildlife and Freshwater Fish (DVF)) who was mainly responsible for the fisheries investigation, and Mr. M. Grande (Norwegian Institute for Water Research (NIVA)) who was mainly responsible for the sampling and chemical analysis. General supervision of the project was exercised by members of the Working Party on Water Quality Criteria for Freshwater Fish (Sub-Commission III, EIFAC), which included Mr. J.S. Alabaster (Convener), Dr. D. Calamari (FAO), and Mr. R. Lloyd (Rapporteur) together with Mr. K. Baalsrud and Mr. E. Snekvik.

2. DESCRIPTION OF THE SITE

Lake Ringvatnet (63°10'N, 9°33'E, altitude 199 m, surface area 1.9 km^2) is situated in Central Norway about 50 km southwest of Trondheim (Fig. 1). The water flows from Lake Ringvatnet to the slightly lower-lying Lake Hostovatnet (2.9 km^2). A small dam at the outlet of Lake Hostovatnet regulates the lake level which can be reduced by 1.5 m for hydro-electric power generation.

The catchment area measured at the outlet of Lake Ringvatnet is about 27.5 km^2 and at the outlet of Lake Hostovatnet about 40 km^2. The lakes are partly surrounded by farmland, but most of the catchment area is forested with conifers and some deciduous trees. The geology of the area consists of basic effusive rocks together with some green schists.

Both lakes are oligotrophic; Lake Hostovatnet is shallow with considerable areas less than 5 m deep, whereas Lake Ringvatnet is deeper with areas of at least 25 m deep. The mean retention time of the water in Lake Ringvatnet is about six months, and for Lake Hostovatnet about four months. The lakes are covered by ice from the end of November until mid-May.

The biggest of the inflowing streams is the River Bjøraa which begins at the small tarn Bjørtjönna and passes through two other tarns, the Gruvedammen and Malisetertjönna, before it enters Lake Ringvatnet. The Gruvedammen is divided into two parts by a small causeway; the lower part is heavily polluted with copper and zinc by drainage water from the abandoned Drogset Mines. The mining operations for copper began in 1867; previously, the River Bjøraa was the chief spawning stream for trout in Lake Ringvatnet. Mining continued until 1909, and according to local farmers all fish disappeared from the River Bjøraa and also from the southern part of Lake Ringvatnet. Some years after the cessation of mining, trout and char began to reappear in the southern part of Lake Ringvatnet.

3. THE FISH AND FISHERIES OF THE AREA

The upper reaches of the River Bjøraa, from Bjørtjönna to the upper Gruvedammen contains dense populations of small brown trout (*Salmo trutta* L.). The lower Gruvedammen, Malisetertjönna and the remaining length of the River Bjøraa are completely fishless. Both Lake Ringvatnet and Lake Hostovatnet have populations of brown trout, char (*Salvelinus alpinus* L.) and three-spined stickleback (*Gasterosteus aculeatus* L.).

It was not possible to carry out a quantitative survey of the fish population in the two lakes within the time available. However, an assessment of the status of the fish population as a fishery can be obtained from calculations of growth rates and condition factors of the species present, and an assessment of the angling potential.

3.1 Growth Rates and Condition Factors

3.1.1 Brown trout

Age and growth were calculated from an examination of the scales, without correction for allometry between scale growth and length. A summary of the results is given in Table 1. The scales were read with some difficulty, and the figures obtained cannot be assumed to be free from error. As usual with brown trout, the variation in growth rate between fish from a lake is considerable; much of this difference is caused probably by the variation in the number of years that small trout live in the nursery streams before they enter the lake.

In both lakes the growth of the trout is good, but not exceptionally fast, and the fish continue to grow well even after they are 10 years old; occasionally the trout in the lakes attain sizes of 2-3 kg or more. The growth rate was faster in 1976 than in 1968, and for both years the rate was faster in Lake Ringvatnet than in Lake Hostovatnet. In comparison with other trout lakes in this part of Norway, the growth rates are above average.

In Norwegian trout lakes the growth rate of trout is usually highly dependent on the population density. This density is again highly dependent upon recruitment and fishing mortality. For the two lakes in this study, the two potentially best spawning streams cannot be used; the River Bjøraa is heavily polluted with copper and zinc, and the outlet of Lake Hostovatnet into the River Vorma is barred by a dam. Trout recruitment is, therefore, too small to lead to overpopulation.

Examination of the trouts' stomachs showed that the main food was sticklebacks, and where these are abundant the growth rate of trout is usually good. However, sticklebacks are intermediary hosts for trout parasites; in both lakes the trout were heavily infested by a cestode (probably Diphyllobotrium dendriticum Nitsch) and the infestation is probably caused by the trout feeding on sticklebacks.

In Lake Hostovatnet, a six-year old female trout was found to have spawned in the previous autumn; this was the youngest and smallest (about 27 cm long at spawning) female found in the samples from the two lakes. It appears that female trout in these lakes do not usually reach sexual maturity until they have reached 30-35 cm or more.

Compared with many other trout populations in this part of Norway, the quality of the trout is good. In both lakes, trout larger than 23-24 cm had pink to red coloured flesh.

The condition of trout is usually classified by a factor k, which is equal to the weight divided by the inverse cube of the length. The k values for all fish examined were calculated from the formula:

$$k = \frac{100w}{l^3}$$

where w is the weight in grammes and l the total length in cm. The results are summarized in Table 2. If the shape and specific gravity of a trout do not change as the fish grows in size, the k value will be constant during its whole life. In overcrowded populations, the larger, older fish will frequently be lean or thin, and above a certain length the value will decrease as the fish length increases. In sparsely populated trout lakes with abundant food, the k value will usually increase with length. Since the lengths of the trout were not distributed normally, the association between k and l was tested for all three samples by the non-parametric Kendall's rank correlation test (Sokal and Rohlf, 1969). In the sample of trout from Lake Hostovatnet, no correlation was found between k and l. The trout samples from Lake Ringvatnet gave a positive correlation between k and l (t_s = 1.90, P = 0.057).

3.1.2 Char

The growth data for char are given in Table 3; the age was determined by reading both the otoliths and the scales from the same fish. Both were difficult to analyse, and the ages shown in the table are subject to error. However, there is no doubt that growth rate is good, and better than in many other Norwegian char lakes. The char also grow faster in Lake Ringvatnet than in Lake Hostovatnet. Parasite infestation is much less common in the char than in the trout from the two lakes, probably because the char did not feed on sticklebacks to the same extent; stomach analyses showed that most of the char had been feeding on planktonic crustaceans. The average condition factor of the char in Lake Hostovatnet is shown in Table 2; there was a highly significant negative correlation (t_s = -3.49, P = 0.0004) between k and l. This is not abnormal among char in Norwegian lakes.

The char spawn in the lakes; according to the local farmers and to our own observations, the spawning areas are in shallow water (1-2 m) along the shores, but the area around the outlet of the River Bjøraa into Lake Ringvatnet is avoided.

3.1.3 Summary

The condition and growth of trout and char did not appear to be abnormal in the two lakes; population density and parasites appeared to be the major factors of importance in controlling the growth rate.

3.2 Status of the Fishery

The fishing rights are held by the farmers who own the land around the lakes. Most, but not all, of the farmers are organized into an owners' association which sells sport fishing licences for the lakes; the price is N.Kr. 15 per day, N.Kr. 30 per week and N.Kr. 50 for the year. Two boats are hired out at N.Kr. 3 per hour, but many of the sport fishermen use their own boats. The total income from the sale of fishing licences and boat hire is around N.Kr. 3 000-5 000 per year. In 1976 the sale of licences produced N.Kr. 3 550 and the hiring of the two boats, N.Kr. 750.

When the ice melts in May, fishing with gillnets in shallow water is very good in both lakes, with both brown trout and char being taken. However, the good catches only last for a few days and rapidly diminish thereafter. In late spring and in the summer, sport fishing continues with rod and line (including use of otters and spinners) and two people fish for char with floating gillnets. In the autumn, gillnet fishing for trout and char is again good and continues on a small scale until the lakes freeze over in November. In the winter, there is considerable sport fishing through the ice with jiggers and baited hooks; most of the catch is char.

The total catch per year in the two lakes is unknown, but the data obtained indicate a total yield of between 3-4 kg per hectare per year for both lakes combined, which is quite good for Norwegian trout and char lakes. The best data for catch/effort were obtained from one of the farmers who had recorded daily catch from his fishing the Lake Hostovatnet since March 1969; the figures in Table 4 were calculated from this source.

In summary, although there are no quantitative data available on the size of the trout and the char population in these lakes, it appears that they are considered to be good sport-fisheries.

3.3 Other Aquatic Life in the River and Lake System

A general investigation of the general biology of the lakes and rivers in the system investigated was not one of the objects of the project. However, a few observations have been made in order to give a brief description of the general biological conditions. The dates and type of sampling are shown in Table 5.

3.3.1 River Bjøraa

At its lower end before entering the lake, the River Bjøraa consisted of small pools and riffles with clear water flowing over a bed consisting mainly of sand and stones of different sizes and which was partly covered with a thin layer of ferric hydroxide. The fauna was extremely poor and sampling with a handnet resulted in only 2 Chironomidae larvae, 2 Trichoptera larvae and 1 Ephemeroptera larva; these groups are more resistant than fish to zinc and copper pollution. Other aquatic animals were not found.

3.3.2 River Langbekken

At its lower end, this small stream contained clear water flowing through small pools and riffles; the stream bed consisted mostly of clean sand, small stones and gravel. The sample of the bottom fauna showed a normal population, containing 120 specimens of Plecoptera larvae, 65 Ephemeroptera larvae, 97 Chironomidae larvae, 24 Simulidae larvae and a small number of other aquatic animals. Fish were also seen.

3.3.3 Lakes Ringvatnet and Hostovatnet

In general there was very little difference between the two lakes, either from a morphometric or a biological viewpoint. The following description applies, therefore, to both the lakes.

The bed of the littoral zone in the lakes was mainly covered with stone and sand. Some places, however, also contained a thicker layer of organic material which was only partly mineralized. There was a relatively sparse growth along the shore of Equisetum fluviatile, Nymphea alba and Menyanthes trifoliata.

The samples of phytoplankton taken in June and August were relatively poor both quantitatively as well as in the number of species present. The most important groups were the blue-green alga, Oscillatoria sp., the green alga Gloeocystis gigas and the diatom Synedra cf tenera. The zooplankton was fairly rich and the dominating species was the copepod Cyclops scutifer. The phyllopod Bosmina longispina was also present, while the copepods Diaptomus denticorinis and Heterocope saliens were sparsely found. Of the rotatoria, Kellicottia longispina and Polyarthra vulgaris were abundant. Bottom samples taken at 1, 2 and 4 m depth in August showed that the fauna at this time was poor with mainly chironomids present; the greatest abundance was recorded in Lake Ringvatnet where 3 200 specimens were found per m square at 1 m depth. In addition, a few oligochaetes and Trichoptera larvae were found. The apparent absence of molluscs and crustacea may be an indication of heavy metal pollution, but insufficient samples were taken to form any definite conclusions.

4. WATER CHEMISTRY

4.1 Introduction

Initially it was decided to make routine analyses of pH value, conductivity, water hardness, organic carbon, copper, zinc and iron. Analysis of cadmium were also included later in the programme; in addition, analyses were made of some other water quality characteristics in order to obtain a measure of the general water quality.

4.2 Sampling and Analytical Procedures

4.2.1 Sampling stations

Figure 1 shows the position of the sampling stations; stations A, B, and C are situated upstream of the main mining area, and only the small stream at point A may be influenced occasionally by drainage from some deposits on the outskirts of the old workings.

Gruvedammen receives the water from most of the mining area; station D, therefore, reflects the most heavily polluted locality in the water system. At station E the water is diluted somewhat by a clean tributary and at station 1 the concentrations of the pollutants were measured just before the River Bjøraa enters Lake Ringvatnet. Station 2 on the River Langbekken was chosen to provide data on the background values for heavy metals in the area.

Stations R 1-9 and H 1-16 are situated in Lake Ringvatnet and Lake Hostovatnet respectively, as shown in Figure 1. The outlets of Lake Ringvatnet and Lake Hostovatnet are represented by stations 4 and 5 respectively.

4.2.2 Frequency of sampling

An overall survey was carried out on 18 July 1975; samples were taken from a large number of stations in the water system on this date, to obtain an indication of the extent and magnitude of the pollution at the different localities, and at different depths in the lakes.

The routine sampling programme began on 12 October 1975 and ended on 27 August 1976. It was planned that sampling should take place every 14 days, but because of extremely difficult weather conditions during the winter it was impossible to keep to this schedule and no samples were taken between 10 December and 30 January.

4.2.3 Sampling procedures and analytical methods

Samples for heavy metal analysis were collected in specially washed 25 ml vials and acidified with nitric acid. Samples for other analyses were taken in polyethylene bottles. Sampling in the lakes was carried out using a Ruttner water sampler.

A short description of the analytical methods used, the detection limits and the units used for the routine programme are outlined in Table 6. Analyses for heavy metals, other than zinc, were carried out using flameless atomic-absorption spectrophotometry (AAS); zinc was analysed by flame AAS. The sampling and analytical procedures used for heavy metals are those used and validated at NIVA (Henriksen and Balmer, 1977 (in press)) and reliable results are obtained at levels close to the detection limits. The 95 percent confidence interval for differences between the standard deviation of paired samples from 38 localities in Norway is shown in Table 7. Two samples were taken for analysis from each locality and stored in separate bottles (Henriksen, Balmer and Wright, 1976).

In this investigation the analytical results for the heavy metals have a lower limit of 1 µg/l for copper, 0.05 µg/l for cadmium and less than 10 µg/l for zinc.

4.2.4 Chemical state of copper

A sample of water was collected from Lake Ringvatnet on 6 July 1976 and subjected to ultra-filtration to determine the extent to which copper was bound to humic components in the water. An Amicon ultra-filtration cell with UM2 and UM10 filters was used for this purpose; these filters will retain substances with molecular weights greater than 1 000 and 10 000 respectively. From previous experience, less than 10 percent of the natural water-soluble humic matter will pass an UM10 filter (Gjessing, 1976). Copper ions bound to compounds of high molecular weight will thus be retained by the filter while the "available" copper ions (free ions or ions bound to small molecules) will pass through with the filtrate. In each experiment, a 500 ml sample was filtered under 4.5 atm N_2 pressure until 50 ml remained. Copper concentrations were measured by AAS. The concentration of "available" copper was determined directly in the filtrate, while the concentration of copper bound to humic substances was calculated from the copper concentration of the sample remaining in the cell, with corrections made for the presence of "available" copper.

4.3 Results

4.3.1 General chemistry

Data from the initial survey made on 18 July are shown in Tables 8 and 9; results of analyses not included in the routine programme are shown in Tables 10 and 11. Results of the analyses included in the routine programme are shown in Tables 1A-9A in the Appendix.

The water in the two lakes has a relatively low suspended solids content with mean turbidity values of 0.7 JTU. It is pale yellow-brown with colour values of 46 mg pt/l in Lake Ringvatnet and slightly lower in Lake Hostovatnet (39 mg pt/l)1/. The single determination of permanganate value in July 1975 was 2.8 mg O_2/l. The colour, the high colour-values and the low turbidity values indicate that most of the organic matter is probably present as humic components.

1/ The contents of organic matter measured as organic carbon were 5.4 and 4.3 mg C/l in the two lakes respectively

The lake waters have a mean value of about 7; only when the snow melts in the spring is a lower value (about 6) measured in the surface waters. The mineral content is rather low and conductivity values are about 60 µS/cm. Mean water hardness values were 19.0 and 17.4 mg $CaCO_3$/l for Lake Ringvatnet and Lake Hostovatnet respectively and the fluctuations appear to be relatively small. The content of other minerals such as sodium and potassium gave mean values of about 3.6 and 0.50 mg/l respectively for both lakes; the manganese content was about 23 µg/l. Concentrations of chloride and sulphate were 6.3 and 4.7 mg/l respectively.

Nitrate and total phosphorus was found in concentrations of about 50 and 11 µg/l N and P respectively, which indicates a slight nutrient enrichment from human and agricultural activity within the catchment area. An approximate estimate of the biomass of planktonic algae was obtained from chlorophyll a analysis; mean values were about 4.6 µg/l in the lakes during June-August 1976, indicating that algal production was rather low.

Measurements of dissolved oxygen were made in the two lakes on 17 March 1976 at which time the values are normally at their lowest in Norwegian lakes; data are shown in Table 12. The values found of 9.7 mg O_2/l in the upper 15 m indicates that the oxygen demand in winter is small.

4.3.2 Heavy metals

Results of analyses for heavy metals are shown in Tables 1A-9A in the Appendix. Figure 2 illustrates the zinc and copper content of the water from various sampling stations in the water system. In the region upstream of Gruvedammen, the content of zinc and copper is low, with the exception of some higher values from the stream at A which may be contaminated occasionally from drainage from mining deposits. The mean values of zinc and copper in the Bjørtjönna (B), <10 and 6.5 µg/l respectively, can be taken as background values. The concentrations found in the River Langbekken (2) were <10 and 4.3 µg/l for zinc and copper respectively, which are similar to those found in unpolluted streams elsewhere in Norway and can also be considered as background values.

The highest concentration of heavy metals occurs at the outlet of the Gruvedammen; in July 1975 the concentrations were 1 550 µg Zn/l and 1 040 µg Cu/l. Further down the system the concentrations decline as a result of precipitation and dilution; the mean concentration in the River Bjøraa before it enters Lake Ringvatnet were 294 and 169 ug/l for zinc and copper respectively.

The percentile distribution of concentrations of copper and zinc found in the River Bjøraa and Lake Ringvatnet are shown in Figure 3 and it appears that they conform to a normal distribution.

The mean values of zinc and copper in Lake Ringvatnet were 88 and 43 µg/l respectively, and were 77 and 38 µg/l respectively at the outlet. Lake Hostovatnet contained lower zinc and copper concentrations, mean values being 44 and 22 µg/l respectively in the lake but 51 and 24 µg/l respectively at the outlet. Analyses of cadmium gave near concentrations of 0.56 and 0.47 µg/l in Lake Ringvatnet and Lake Hostovatnet respectively; concentration of lead measured on a single occasion was 1 and 2 µg/l for the two lakes respectively.

The results of the analyses made on a single sample subjected to ultra-filtration, as described in Section 4.2.4, are given in Table 13. No significant difference was found between the results from the two grades of filter used.

Although the results indicate that about 86 percent of the copper was bound to humic substances and other micro-particles, the total copper concentration found was about 31 µg/l for the UM2 filtered samples, compared with 42 µg/l from an analysis in the original sample. It would appear that a substantial proportion of the copper was absorbed onto the filtration apparatus and the original state of that copper is not known. If it were all "available" copper, then the total percent "bound" would be 63 percent; if it were part "available" and part "bound", then the total "bound" would be between 63 and 86 percent.

5. HEAVY METAL CONTENT OF FISH

The copper and zinc contents of fish from River Bjørtjönna and the two lakes are shown in Table 14. The data show wide variations and are too few to allow a rigorous statistical analysis to be attempted. Such variations have also been found in other similar studies. In any monitoring programme, therefore, it may be necessary to analyse large numbers of fish in order to demonstrate the presence of concentrations significantly greater than background values.

6. DISCUSSION

The EIFAC Technical Reports T21 and T27 make tentative proposals for the maximum 95 percentile concentrations for zinc and copper respectively, above which fisheries will become harmed. Interpolated values for these maximum concentrations, taking into account the water hardness found in this survey are shown in Table 15, where they are compared with the corresponding concentrations of copper and zinc found in the polluted fishless River Bjøraa, and Lake Ringvatnet and Lake Hostovatnet.

EIFAC values for zinc are those for brown trout; EIFAC values for copper take into account the presence of soluble organic compounds.

It is clear that the levels of zinc and copper in the River Bjørra exceed the EIFAC values by a considerable margin; combined values are 8.6 times higher than the proposed standards if the toxicities of zinc and copper are assumed to be additive at these levels. The concentrations of copper and zinc in Lake Ringvatnet and Lake Hostovatnet, both of which contain equally good fisheries, also exceed the EIFAC standard in combination with copper concentrations, being 1.9 and 1.2 respectively greater than the proposed limits. The apparent over-prediction of toxicity when the values given in the EIFAC Reports are used can be caused by several factors.

It is assumed in EIFAC/T27 that in the presence of humic substances in soft waters, only one third of the copper may be in a form toxic to fish. Studies made in conjunction with this project indicate that up to 86 percent of the copper could be present as organo-metal complexes and it is possible that only 14 percent of copper present in the lakes was in a form toxic to fish. This would alter considerably the ratios given in Table 15, the ratio value for copper then being 2.3, 0.8 and 0.5 for the River Bjøraa, Lake Ringvatnet and Lake Hostovatnet respectively, and the combined total for zinc and copper being 5.4, 2.0 and 1.2 respectively. A second factor to consider is whether the fish in the lakes had become adapted to the concentrations of copper and zinc present. It is known that the brown trout spawn in unpolluted side streams and only migrate into the lake at a later stage; there is some evidence that this species can acclimatize to concentrations of zinc higher than those proposed in the EIFAC standard. However, brown trout spawn successfully in the River Vorma below the outlet of Lake Hostovatnet, where the metal content is similar to that found in the lake. Also, char which breed in the two lakes undergo their whole life cycle there. The possibility of acclimatization is not taken into account by the proposed EIFAC standards for pollutants, because such higher values could act as a barrier to migration.

A third factor to be taken into account is the percentile distribution of concentrations of copper and zinc about the mean value. Fish populations may be affected by average or mean concentrations of a pollutant, but they are more likely to be limited by sporadic high concentrations which may persist for a sufficient time to cause harm to the fish. Evidence from polluted rivers suggests that the distribution of pollutant concentrations may be log-normal with 95 percentile values being about four times higher than the 50 percentile; this is reflected in the limiting values for copper given for these percentile values in EIFAC/T27. This relation predicts that the 99 percentile value (obtained on a total of $3\frac{1}{2}$ days in a year) would be 1.75 times the 95 percentile value. In the River Bjøraa, Lake Ringvatnet and Lake Hostovatnet, however, the distribution of concentrations was normal, with the 95 percentile values of the River Bjøraa and Lake Ringvatnet being only about 1.38 times the 50 percentile value. With this distribution, the 99 percentile value was only 1.1 times the 95 percentile, implying that sporadic peaks would not be so high relative to the 95 percentile values as those obtained where a log-normal distribution occurs. It is possible that the small tarns on the River Bjøraa may have acted as a buffering system for sporadic peak concentrations; the major lakes Ringvatnet and Hostovatnet with their long retention period would certainly have acted in this way.

There are two further considerations to take into account. A complicating factor may be the presence of other pollutants. Recent studies have shown that freshly precipitated ferric hydroxide can be harmful to fish at concentrations above 3 mg/l. The mine drainage discharges to the River Bjøraa are acidic; the pH value at sampling station D was 4.7 on 18 July, rising to 6.5 at station E and 7.0 at station 1. Iron concentrations were 1.45, 0.77 and 0.45 mg/l respectively, and the stream bed was partly coated with a thin layer of precipitated ferric hydroxide. No such deposits were observed from the margin of either of the two lakes. However, the River Bjøraa was fishless down to the point of its entry into the lake, and in the lower regions the effect of precipitated iron hydroxide was likely to be small. Measurable concentrations of both cadmium and lead were also found in the lakes, but again the concentrations are probably considerably less than the limiting values for these metals.

A further complicating factor may be that the maximum 95 percentile values for zinc and copper given in EIFAC/T21 and T27 are levels of no effect, and it is possible that the combined toxicities of the metals at these levels are less than additive; in fact they may act independently. This is an area where more research is required.

Both acclimatization and concentration distribution could account for the presence of good fisheries in Lake Ringvatnet and Lake Hostovatnet at combined zinc and copper levels slightly higher than those based on EIFAC/T21 and T27. However, the standards must be close to the true limiting values since whereas the combined ratios (EIFAC 95 percentile/measured 95 percentile) was 2.0 and 1.2 for Lake Hostovatnet and Lake Ringvatnet respectively, the River Bjøraa was fishless with a total of 5.4 and spawning char were observed to avoid the outflow of this stream into the lake. This implies that levels of zinc and copper at which fisheries begin to be affected may only be slightly greater than those found in Lake Ringvatnet.

7. CONCLUSIONS

The result of these studies undertaken within this project have three main implications. They show that the proposed standards for zinc and copper in EIFAC/T21 and T27 are not seriously in error, and the apparent over-estimation of toxicity can be accounted for by the distribution of heavy metal concentrations, a higher-than-predicted combination of soluble organic material with copper, and acclimatization of fish. The studies re-enforce the importance of measuring those chemical states of polluting substances which are toxic to fish; control of copper pollution based on total copper analysis might be unnecessarily stringent if a major proportion of the copper was present as non-toxic soluble cupro-organic complexes. This underlines the need for relevant analytical techniques to be used in monitoring programmes linked with toxicity testing on appropriate species, so that accurate estimates can be made of the environmental impact of the levels of pollutant found. Finally, there is a need to identify accurately the form of the distribution of concentrations of pollutant found at a sampling site, and this has implications (see Montgomery and Hart, 1974) for the frequency with which the samples have to be taken over a period of time.

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Table 1

Back-calculated length of brown trout at each age year

Lake and year of capture	Age	No.	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}
L. Ringvatnet 1968	3+	2	3.6	9.9	14.7									
	4+	6	3.4	8.0	12.7	18.4								
	5+	19	4.0	8.7	14.2	19.4	24.9							
	6+	16	4.3	8.9	13.6	19.5	25.4	30.5						
	7+	3	3.9	9.3	14.3	18.4	22.6	28.3	33.0					
	8+	1	4.4	8.1	14.1	17.0	22.5	28.6	35.0	39.1				
L. Ringvatnet 1976	3+	2	4.3	11.2	25.2									
	4+	20	4.9	9.8	16.1	27.1								
	5+	17	4.6	9.4	14.2	21.2	29.6							
	6+	3	4.6	8.3	13.1	18.0	26.5	34.3						
	8+	1	3.1	7.2	12.8	19.9	27.4	32.4	36.1	39.2				
	12+	1	3.8	8.1	13.0	20.7	26.4	31.4	36.8	41.8	45.2	49.4	53.3	56.7
L. Hostovatnet 1968	3+	1	2.8	6.7	16.0									
	4+	8	3.9	8.2	13.3	19.3								
	5+	19	3.5	8.3	13.5	18.6	24.3							
	6+	17	3.3	8.3	12.7	17.7	22.5	27.4						
	7+	25	3.6	7.7	12.0	16.9	22.4	26.3	30.8					
	8+	4	3.7	8.1	12.1	17.7	22.2	27.1	31.3	34.4				
	9+	1	3.8	8.6	12.2	-	21.7	27.0	31.9	36.4	38.1			
L. Hostovatnet 1976	4+	3	4.8	9.7	13.8	24.4								
	5+	7	4.6	9.1	15.6	22.6	30.1							
	6+	5	3.6	7.0	11.6	17.1	23.0	29.4						
	7+	3	5.2	9.3	13.7	19.3	24.1	30.0	33.5					

Table 2

The "condition" of trout and char from the lakes

Lake	Species	Date	N	Length range	k			
					Range	Mean	Std. error of mean	CV
L. Ringvatnet	Trout	31.5-1.6 1976	45	23.6-56.7	0.80-1.09	0.902	0.0117	8.6
L. Hostovatnet	Trout	1.6.76	18	24.4-34.6	0.81-1.10	0.942	0.0164	7.4
L. Hostovatnet	Char	3-5.7.76	60	25.4-36.1	0.84-1.04	0.938	0.0066	5.4

Table 3

Mean lengths of char at different ages

Locality	Age	N	Length range	Mean length
L. Hostovatnet	4	12	25.4-28.6	26.9
	5	27	26.1-30.6	27.9
	6	10	27.6-30.2	28.8
	7	6	29.2-36.1	32.7
L. Ringvatnet	3	2	24.5-27.7	26.1
	4	7	27.8-30.8	29.2
	5	6	29.1-31.2	29.8
	6	2	34.1-37.0	35.6
	7	1		36.2
	8	1		35.2

Table 4

Catch/effort data for Lake Hostovatnet

Gillnets set on the bottom:

Period	Effort	No. char	No. trout	Total wt.	Wt./Effort
May-69	28	47	20	14.8	0.53
" -70	14	12	40	14.5	1.04
" -71	8	9	27	9.8	1.23
" -72	12	18	15	8.3	0.69
" -73	12	5	48	14.4	1.20
" -74	12	6	55	15.0	1.25
" -75	16	3	18	5.1	0.32
Total:	102	100	223	81.9	0.80
Autumn-69	4	3	24	6.7	1.68
" -70	12	4	26	8.6	0.72
" -71	4	9	3	2.9	0.73
" -72	16	5	61	18.9	1.18
" -73	10	1	23	6.3	0.63
" -74	12	1	23	6.0	0.50
Total:	58	23	160	49.4	0.85

Floating gillnets:

1969	50	368	10	74.9	1.50
1970	24	85	8	21.0	0.88
1971	82	449	4	97.3	1.19
1972	30	248	17	55.8	1.86
1973	53	417	21	99.9	1.88
1974	42	400	15	97.8	2.33
1975	22	80	8	35.0	1.59
Total:	303	2 047	83	481.7	1.59

Table 5

Biological sampling in the Ringvatnet water system, 1976

Type of sampling	Method used	Locality			
		Bjøraa (1)	Langbekken (2)	Ringvatnet	Hostovatnet
Phytoplankton	Hand net (25 µ mesh size) hauled in the surface			4 July 27 Aug.	4 July 27 Aug.
Littoral vegetation	Sampling by hand			27 Aug.	27 Aug.
Zooplankton	Hand net (95 µ) hauled from 8 m depth to surface			4 July 27 Aug.	4 July 27 Aug.
Bottom invertebrates	Hand net (250 µ) and bottom grab	17 June	17 June	27 Aug.	27 Aug.

Table 6

Chemical and biochemical methods used in the analysis of water samples
(Hardness is calculated from Ca and Mg and given as mg $CaCO_3$/l)

Parameter	Detection limits	Units	Method - analytical instrument
pH	-	-	Orion pH-meter. Model 701
Spec. el. conductivity	-	µS/cm	Philips PW 9501
Total organic carbon	0.2 mg/l	mg C/l	Oceanography International and oxidation with persulphate, analysis of CO_2 in IR spectrophotometer
$KMnO_4$-number	0.5 mg/l	mg O/l	Oxidation with permanganate. Titration by hand
Colour	5 mg/l	mg Pt/l	Filter photometer, filter 601. Hazen colour scale
Turbidity	-	JTU	Hach turbidimeter. Model 2100 A
Ortho-phosphate	2 µg/l	µg P/l	Auto Analyzer (1)
Total phosphorus	2 µg/l	µg P/l	" " Oxidation to ortho-phosphate
Nitrate	10 µg/l	µg N/l	" " (3)
Total nitrogen	10 µg/l	µg N/l	U.V. oxidized and analysed as NO_3
Sulphate	0.2 mg/l	mg SO_4/l	Auto Analyzer (4)
Silicate	0.2 mg/l	mg SiO_2/l	" " (2)
Chloride	0.2 mg/l	mg Cl/l	" " (2)
Calcium	0.01 mg/l	mg Ca/l	Atomic abs. Perkin-Elmer Model 306
Magnesium	0.001 mg/l	mg Mg/l	" "
Sodium	0.01 mg/l	mg Na/l	" "
Potassium	0.01 mg/l	mg K/l	" "
Zinc	10 µg/l	µg Zn/l	" "
Manganese	1 µg/l	µg Mn/l	Atomic abs. Perkin-Elmer Model 300 SG, graphite cell HGA 72
Copper	1 µg/l	µg Cu/l	" "
Cadmium	0.05 µg/l	µg Cd/l	" "
Lead	0.5 µg/l	µg Pb/l	" "
Iron	10 µg/l	µg Fe/l	Auto Analyzer. TPT2 method
Oxygen	0.1 mg/l	mg O_2/l	Modified Winkler method
Chlorophyll *a*	1 µg/l	µg C.A./l	Spectrophotometric. Trichromatic

1. Murphy and Riley (1958); 2. Henriksen (1966) 3. Henriksen and Selmer-Olsen (1970); 4. Henriksen and Bergmann-Paulsen (1974)

Table 7

95 percent confidence intervals for the standard deviation of the difference between values obtained for pairs of samples

95% confidence interval	Zn: 3.1-4.9	Cu: 1.6-2.4	Pb: 0.6-0.9	Cd: 0.10-0.16

Table 8

Chemical analysis of samples from Lake Ringvatnet
and Lake Hostovatnet and feeder streams, 18 July 1975
(Samples R1-9 and Hi-16 taken at 1 m depth except where shown otherwise)
/Station Nos: see Fig. 2/

Station No.	pH	Conductivity µS/cm	$KMnO_4$-no. mg O/l	Total organic carbon mg C/l	Ca mg/l	Mg mg/l	Cu µg/l	Zn µg/l	Fe µg/l
1	7.0	56	1.8	2.0	10.2	1.3	174	350	450
4	7.3	46	2.8	3.5	6.5	0.9	38	75	125
5	7.1	46	2.8	3.5	5.6	0.9	22	50	25
D	4.7	114	2.2	2.5	10.8	2.4	1040	1550	1450
C	6.9	47	4.0	6.0	8.1	0.7	19	25	650
E	6.5	53	0.6*	3.5	6.4	1.0	260	460	775
R1	7.0	48	3.6	5.0	6.4	0.8	38	70	125
2	7.2	50	3.0	5.5	6.4	0.9	38	70	125
3	7.2	47	2.2	4.5	6.7	0.8	38	70	125
4	7.2	48	2.5	4.0	6.4	0.9	41	70	125
5	7.2	48	2.8	4.0	6.4	0.9	46	95	125
5 (10 m)	7.2	48	1.6	3.5	6.4	0.8	42	90	75
6	6.9	49	3.1	5.0	6.5	0.9	51	90	125
6 (10 m)	6.8	48	3.2	3.5	6.4	0.8	38	80	100
7	6.9	48	3.6	5.0	6.5	0.9	42	75	125
8	7.2	47	2.0	4.5	6.7	0.9	232*	400*	125
9	7.2	48	2.4	4.0	6.4	0.9	43	85	125
H1	7.2	45	3.4	3.5	5.9	0.8	21	40	75
2	7.2	45	3.0	3.5	5.9	0.8	24	50	75
3	7.2	45	3.8	3.0	5.7	0.8	22	45	50
4	7.2	44	2.7	3.0	5.7	0.8	33	70	75
4(10 m)	6.9	43	2.8	3.0	5.7	0.8	23	60	25
5	7.2	45		3.5	5.9	0.8	22	60	75
7	7.1	45	2.3	4.0	5.9	0.8	40	80	75
8	7.2	44		3.5	5.9	0.8	39	75	75
8 (10 m)	6.8	45	3.0	3.0	5.7	0.8	32	70	25
9	7.2	45	3.3	3.5	5.7	0.8	31	60	75
10	7.1	45	2.9	4.5	5.9	0.8	33	75	75
11	7.2	45	2.8	3.5	5.9	0.8	22	50	25
12	7.0	46	3.2	3.5	5.9	0.8	22	50	50
12 (10 m)	6.8	44	3.6	3.0	5.9	0.8	28	65	50
13	7.2	45	2.9	3.5	5.9	0.8	35	80	75
14	7.1	45	2.3	4.0	6.0	0.8	27	60	50
15	7.1	45	2.6	3.5	5.9	0.8	21	50	75
16	7.3	46	2.4	3.5	5.7	0.8	27	80	75

*Abnormal values; not used in mean value calculations

Table 9

Summary of chemical analysis from Lake Ringvatnet and Lake Hostovatnet, 18 July 1975

Mean values, range standard deviation (SD) and number of analysis from 1 metre depth

Locality		pH	Conductivity µS/cm	$KMnO_4$-no. mg/Ol	Total org. carbon mg/Cl	Ca mg/l	Mg mg/l	Cu µg/l	Zn µg/l	Fe µg/l
Ringvatnet	Mean	7.1	48	2.8	4.6	6.5	0.88	42	78	125
	Range	6.9–7.2	47–49	2.0–3.6	4.0–5.5	6.4–6.7	0.8–0.9	38–43	70–95	125
	SD	0.13	0.9	0.57	0.54	0.1	0.04	4.6	10.3	0
	No. of analysis	9	9	9	9	9	9	8	8	9
Hostovatnet	Mean	7.2	45	2.9	3.6	5.9	0.8	28	62	67
	Range	7.0–7.3	45–46	2.3–3.8	3.0–4.5	5.7–6.0	0.8	21–40	40–80	25–75
	SD	0.07	0.7	0.44	0.37	0.1	0	6.7	14	15
	No. of analysis	15	15	13	15	15	15	15	15	15

Table 10

Results of analyses of water samples from Lake Ringvatnet (R5) and Lake Hostovatnet (H8), 1976 not included in the routine programme

A. Ringvatnet

Parameter		Apr.25	May 23	June 8	June 17	June 22	July 4	July 18	Aug. 1	Aug.15	Aug.27
Ortho-phosphate,	µg P/l	3.5	< 2	4	2	< 2	< 2	< 2	< 2	< 2	2
Total-phosphate,	µg P/l	16	7.5	12	8	10	18	11	7	8	
Nitrate,	µg N/l	70			100		60			10	10
Total-nitrogen,	µg N/l		260	900	255	255	310	280	180		
Chloride,	mg Cl/l				6.3		6.0				6.5
Sulphate,	mg SO_4/l				5.0		4.3				4.8
Silicate,	mg SiO_2/l				1.6		1.6				0.5
Colour,	mg Pt/l				57		46			33	49
Turbidity,	JTU						0.7				0.7
Sodium,	mg Na/l				3.5		4.0				3.4
Potassium,	mg K/l				0.44		0.51				0.51
Manganese,	µg Mn/l				32		24				13
Lead,	µg Pb/l									1	
Chlorophyll a	µg/l				11.2		3.4				3.6

Table 10

Results of analyses of water samples from Lake Ringvatnet (R5) and Lake Hostovatnet (H8), 1976 not included in the routine programme

B. Hostovatnet

Parameter		Apr. 25	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 27
Ortho-phosphate,	μg P/1	< 2	< 2	< 2	3	< 2	<2	<2	<2	<2
Total-phosphate,	μg P/1	21.5	12	8	8.5	25	16	7	5	
Nitrate,	μg N/1	60				50			10	10
Total-nitrogen,	μg N/1		230	215	255	530	250	260		
Chloride,	mg Cl/1					5.4				7.3
Sulphate,	mg SO_4/1					5.1				4.0
Silicate,	mg SiO_2/1					1.5				1.3
Colour,	mg Pt/1					51			31	36
Turbidity,	JTU					0.7				0.7
Sodium,	mg Na/1					3.5				3.7
Potassium,	mg K/1					0.49				0.52
Manganese,	μg Mn/1					30				14
Lead,	μg Pb/1								2	
Chlorophyll *a*,	μg/1					2.7			2.3	

Table 11

Summary of results of analyses of water samples from Lake Ringvatnet (R5) and Lake Hostovatnet (H8), 1976 not included in the routine programme

Mean values, range, standard deviation (SD) and number of analysis from 1 metre depth

Parameter \ Locality and date		Ringvatnet			No. of analysis	Hostovatnet			No. of analysis
		Mean	Range	SD		Mean	Range	SD	
Ortho-phosphate,	µg P/1	<2	<2-4	-	10	<2	<2-3	-	9
Total-phosphate,	µg P/1	10.8	7.18	3.9	9	12.9	5-25	7.3	8
Nitrate,	µg N/1	50	<10-100	39	5	33	<10-60	26	4
Total-nitrogen,	µg N/1	349	180-900	246	7	290	215-53	119	6
Chloride,	mg Cl/1	6.3	6.3-6.5	0.3	3	6.4	5.4-7.3	-	2
Sulphate,	mg SO_4/1	4.7	4.3-5.0	0.4	3	4.6	4.0-5.1	-	2
Silicate,	mg SiO_2/1	1.2	0.5-1.6	0.6	3	1.4	1.3-1.5	-	2
Colour,	mg Pt/1	46.3	33-57	10	4	39.3	31-51	10.4	3
Turbidity,	JTU	0.7	0.7	-	2	0.7	0.7	-	2
Sodium,	mg Na/1	3.6	3.4-4.0	0.3	3	3.6	3.5-3.7	-	2
Potassium,	mg K/1	0.49	0.44-0.51	4.0	3	0.51	0.49-0.52	-	2
Manganese,	µg Mn/1	23	13-32	9.5	3	22	14-30	-	2
Lead	µg Pb/1	1			1	2			1
Chlorophyll a,	µg/1	2.7	1.2-3.6	1.3	3	2.5	2.3-2.7	-	2

Table 12

Dissolved oxygen concentrations in Lake Ringvatnet (R6) and Lake Hostovatnet (H4) 17 March 1976

Locality	Depth m	Temperature °C	Oxygen mg/l
R 6	2.5		11.0
	15		9.7
	25		4.9
H 4	2.5	2.1	10.9
	9	2.8	10.4
	15	3.2	9.7

Table 13

Copper analyses on a sample of water taken from Lake Ringvatnet

Filter	"Available" Cu	"Bound" Cu	% "Bound"
	µg/l		
UM10	3.5	24.3	88
Duplicate test (UM2	4.3	26.6	86
Duplicate test (UM2	4.3	26.6	86

Table 14

Metal contents in fish samples

Locality	Date	Species	Length	Weight	Sex	Organ	% Dry wt.	Cu	Zn
L. Ringvatnet	17.6.76	Char	40.0	830	♀	Muscle	25.6	2.3	13
						Liver	30.6	32	103
						Kidney	22.3	26	88
	17.6.76	Char	31.5	360	♀	Muscle	23.0	3.5	17
						Liver	23.9	60	147
						Kidney	18.7	30	99
	17.6.76	Trout	27.5	220	♀	Muscle	23.2	6.9	28
						Liver	22.8	925	305
						Kidney	21.3	32	376
	17.6.76	Trout	31.5	330	♀	Muscle	22.3	4.9	33
						Liver	22.6	827	315
						Kidney	23.5	24	992
L. Hostovatnet	8.7.76	Char	23.5	150	♂	Muscle	22.0	4.1	30
						Liver	34.2	41	124
						Kidney	21.7	38	117
	8.7.76	Char	27.0	210	♀	Muscle	27.1	3.1	26
						Liver	35.5	43	137
						Kidney	21.7	21	78
R. Bjørtjønna (unpolluted)	6.7.76	Trout	19.5	75	♂	Muscle	21.3	8.2	32
						Liver	27.2	88	333
						Kidney	23.4	79	237
	6.7.76	Trout	19.0	60	♀	Muscle	22.2	7.0	38
						Liver	28.6	61	231
						Kidney	21.7	338	434
	6.7.76	Trout	Mixed sample			Muscle	21.8	5.5	38
						Liver	25.8	161	276
						Kidney	22.8	27	499

Table 15

Comparison between EIFAC standards for zinc and copper and concentrations found in the R. Bjøraa, L. Ringvatnet and L. Hostovatnet

Sampling site	Hardness mg/l as $CaCO_3$	Zinc µg/l			Cu µg/l		
		EIFAC 95% ile	Site 95% ile	Ratio	EIFAC 95% ile	Site 95% ile	Ratio
R. Bjøraa (1)	30	130	405	3.1	42	230	5.5
L. Ringvatnet (5)	18	100	118	1.2	30	58	1.9
L. Hostovatnet (8)	18	100	72	0.7	30	37	1.2

Appendix Table 1A

Chemical analysis from stream A (A), 12 October 1975 – 28 August 1976

x = Probable analytical error, and not calculated in mean values
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct.12	Oct.27	Nov.11	Nov.25	Dec.10	Jan.30	Feb.11	Feb.24	Mar. 9	Mar.17	Apr. 4	Apr.25
pH		5.3	7.2		6.3	6.4	7.6	5.0	4.7	7.1	7.4	7.4	7.5
Electrolytical conductivity µS/cm		57	60	63	60	993	118	102	109	93	87	83	99
Hardness mg $CaCO_3$/l		17	27	22	24	33	47	31	35	32	32	30	26
Organic carbon, mg C/l		7.5	2.5	14	14	12	4	4	3.5		3	3	4.5
Cu, µg/l		265	4	390	205	510	445	660	845	5	6	3	3
Zn, µg/l		440	20	640	350	830	635	1 000	1 100	35	45	40	25
Fe, µg/l		1 050	50	1 250	650	10 600	2 450	3 200	4 200	40	60	70	50
Cd, µg/l										0.15	0.45	0.30	0.20

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug.15	Aug.28	Mean	Range	SD	N
pH	6.7	6.5	6.4	7.2	7.4	7.3	7.7	7.1	7.1	6.8	4.7–7.7	0.86	20
Electrolytical conductivity µS/cm	70	28	22	29	60	70	36	59	80	113	22–993	203–34	21
Hardness mg $CaCO_3$/l	19	9.2	6.4	10	25	28	14	25	33	25	6.4–47	9.8	21
Organic carbon, mg C/l		3.9	4.2	4.2	3.4	4.0	9.5	5.4	3.5	5.8	2.5–14	3.7	19
Cu, µg/l	5	4	3	4	3	2	5	6	3	161	2.0–8 450	258	21
Zn, µg/l	<10	<10	<10	<10	20	15	15	20	20	252	<10–1 100	368	21
Fe, µg/l	85	55	80	50	40	40	140			1 272	40–10 600	2 568	19
Cd, µg/l	–	0.4	0.2	0.65	0.2	0.1	0.5			0.31	0.10–0.65	0.17	10

Appendix Table 2A

Chemical analysis from outlet of Bjørtjönna (B), 12 October 1975 - 28 August 1976

SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct. 12	Oct. 27	Nov. 11	Nov. 25	Dec. 10	Jan. 30	Feb. 11	Feb. 24	Mar. 9	Mar. 17	Apr. 4	Apr. 25
pH		6.5	6.7		6.8	6.8	7.1	6.6	6.7	7.0	6.9	6.9	6.8
Electrolytical conductivity µS/cm		34	36	33	43	434	60	59	62	80	77	77	87
Hardness mg $CaCO_3$/l		13	15	14	17	19	19	20	21	24	25	23	23
Organic carbon, mg C/l		5.6	7	21	10	44	4.5	4.0	4.0		4.5	4.0	4.5
Cu, µg/l		4	17	7	10	5	5	4	8	4	25	3	3
Zn, µg/l		10	<10	10	<10	10	<10	<10	30	<10	23	10	<10
Fe, µg/l		170	200	250	375	300	125	130	80	130	180	150	90
Cd, µg/l										0.1	0.8	0.2	0.35

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 28	Mean	Range	SD	N
pH	6.6	6.3	6.4	7.0	7.2	7.1	7.3	7.1	7.0	6.8	6.3-7.3	0.27	20
Electrolytical conductivity µS/cm	70	25	22	28	44	45	37	43	49	69	22-434	86	21
Hardness mg $CaCO_3$/l	19	8.6	6.4	9.6	17	16	14	16	20	17.1	6.4-25	5.0	21
Organic carbon, mg C/l		3.9	4.0	5.7	6.2	6.2	7.4	7.8	7.4	6.1	3.9-21	4.1	19
Cu, µg/l	4	4	5	5	5	2	5	8	3	6.5	2.0-25	5.3	21
Zn, µg/l	<10	<10	<10	<10	15	<10	<10	10	<10	<10	<10-30	-	21
Fe, µg/l	80	70	70	90	130	130	170	-	-	154	70-375	81	19
Cd, µg/l	-	0.15	0.2	0.45	0.45	0.05	0.2	-	-	0.29	0.05-0.8	0.22	10

Appendix Table 3A

Chemical analysis from Gruvedammen (C), 12 October 1975 - 28 August 1976

x = Probable analytical error, and not calculated in mean values
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct. 12	Oct. 27	Nov. 11	Nov. 25	Dec. 10	Jan. 30	Feb. 11	Feb. 24	Mar. 9	Mar. 17	Apr. 4	Apr. 25
pH		8.2	6.9		7.1	6.8	6.6	6.8	6.8	6.6	6.7	6.6	6.8
Electrolytical conductivity µS/cm		65	60	36	53	579	72	70	71	114	91	133	85
Hardness mg $CaCO_3$/l		35	23	15	22	25	13	25	26	18	22	20	22
Organic carbon, mg C/l		4.5	6	13	22	22	2.5		6.0		3.5	2.5	4.5
Cu, µg/l		5	6	31	9	11	7	55	31	7	8	7	16
Zn, µg/l		95	20	65	30	30	10	60	70	20	30	35	60
Fe, µg/l		225	200	250	225	500	75	785	90	110	300	90	120
Cd µg/l										0.2	0.2	0.7	3.0[x]

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 28	Mean	Range	SD	N
pH	6.6	6.1	6.4	6.9	7.3	8.0	7.2	6.9	7.0	6.9	6.1–8.2	0.48	20
Electrolytical conductivity µS/cm	72	26	23	29	47	52	42	49	61	87	23–579	116	21
Hardness mg $CaCO_3$/l	20	8.4	6.7	9.3	20	20	18	19	25	19.6	6.7–35	6.6	21
Organic carbon, mg C/l		4.0	4.9	4.9	5.4	6.5	6.5	7.3	6.0	7.3	2.5–22	5.8	18
Cu, µg/l	29	23	6	16	11	13	14	14	12	16	5.0–55	12.1	21
Zn, µg/l	55	30	10	14	15	20	25	20	20	35	10–95	23.2	21
Fe, µg/l	90	95	55	175	360	1 000	230			262	75–1 000	252	19
Cd, µg/l		0.3	0.25	0.35	0.4	0.1	0.2			0.30	0.1–0.7	0.17	9

Appendix Table 4A

Chemical analysis from River Bjøraa (1), 18 July 1975 - 27 August 1976

x = Probable analytical error, and not calculated in the mean
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct. 12	Oct. 27	Nov. 11	Nov. 25	Dec. 10	Jan. 30	Feb. 11	Feb. 24	Mar. 9	Mar. 17	Apr. 4	Apr. 25
pH	7.0												
Electrolytical conductivity µS/cm	56												
Hardness mg $CaCO_3$/l	31												
Organic carbon, mg C/l	2.0												
Cu, µg/l	174	213	258	205	165	170	140	150	115	150	125	175	180
Zn, µg/l	350	440	370	370	315	240	220	310	375	345	355	320	290
Fe, µg/l	450	570	650	635	550	590	325	305	65	100			
Cd, µg/l										0.95	0.85	0.8	0.8

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 27	Mean	Range	SD	N
pH										7.0			1
Electrolytical conductivity µS/cm										56			1
Hardness mg $CaCO_3$/l										31			1
Organic carbon, mg C/l										2.0			1
Cu, µg/l	225	170	230	135	115	120	175	165	165	169	115–258	39	22
Zn, µg/l	315	185	180	150	19x	200	40x	275	270	294	150–440	78	20
Fe, µg/l				450	340					420	65–650	197	12
Cd, µg/l		0.5	0.5	0.7	0.75	0.55	0.7	0.7		0.70	0.50–0.95	0.14	11

Appendix Table 5A

Chemical analysis from Lake Langbekken (2), 27 October 1975 - 27 August 1976

x = Probable analytical error, and not calculated in the mean
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct. 12	Oct. 27	Nov. 11	Nov. 25	Dec. 10	Jan. 30	Feb. 11	Feb. 24	Mar. 9	Mar. 17	Apr. 4	Apr. 25
pH													
Electrolytical conductivity µS/cm													
Hardness mg $CaCO_3$/l													
Organic carbon, mg C/l													
Cu, µg/l			6	5	3	2	14	3	10	10	1	1	3
Zn, µg/l			<10	10	<10	<10	<10	10	20	15	11	<10	<10
Fe, µg/l			100	100	150	175	100	395	100	50			
Cd, µg/l										0.4	0.2	0.55	0.1

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 27	Mean	Range	SD	N
pH													
Electrolytical conductivity µS/cm													
Hardness mg $CaCO_3$/l													
Organic carbon mg C/l													
Cu, µg/l	3	3	10	2	1	3	3	5	2	4.3	1–14	3.6	20
Zn, µg/l	15	<10	35	<10	<10	15	<10	<10	<10	<10	<10–35		20
Fe, µg/l				90	100					136	50–395	97	10
Cd, µg/l		0.25	0.5	0.2	0.1	0.1	0.3	0.3		0.27	0.1–0.55	0.15	11

Appendix Table 6A

Chemical analysis from Lake Ringvatnet (R5), 18 July 1975 - 27 August 1976

x = Probable analytical error, and not calculated in the mean

SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct.12	Oct.27	Nov.11	Nov.25	Dec.10	Jan.30	Feb.11	Feb.24	Mar. 9	Mar.17	Apr. 4	Apr.25
pH	7.2	7.1	6.9		7.2				6.3	6.7	7.0	6.8	6.3
Electrolytical conductivity µS/cm	48	51	55	53	52				72	61	60	78	119
Hardness mg $CaCO_3$/l	20	20	21	20	19				15	22	21	16	17
Organic carbon, mg C/l	4.0	4.0	3.5	15	11				6.5		4.0	3.0	10
Cu, µg/l	46	45	37	45	36				55	60	50	25	80^x
Zn, µg/l	95	75	85	105	80				155	100	100	75	155^x
Fe, µg/l	125	120	100	150	150				120	80	120	120	240
Cd, µg/l										0.4	0.6	0.8	1.3

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug.15	Aug.27	Mean	Range	SD	N
pH	6.6	5.7^x	6.5	7.0	7.4	7.2	7.3	7.2	7.1	6.9	6.3-7.4	0.34	17
Electrolytical conductivity µS/cm	85	28^x	62	48	49	53	53	55	54	62	48-119	17.7	18
Hardness mg $CaCO_3$/l	26	6^x	22	16	16	18	18	17	18	19.0	15-26	2.9	18
Organic carbon, mg C/l		2.3^x	4.3	3.5	4.3	4.3	3.6	3.1	2.9	5.4	2.9-15	3.4	16
Cu, µg/l	57	21^x	41	50	42	37	36	31	34	43	31-57	9.6	17
Zn, µg/l	125	15^x	80	80	70	20^x	65	60	55	88	55-155	25.4	16
Fe, µg/l	150	95^x	195	150	120	100	110			134	80-240	39	16
Cd, µg/l		0.45	0.45	0.6	0.9	0.1	0.3	0.3		0.56	0.1-1.3	0.34	11

Appendix Table 7A

Chemical analysis from outlet of Lake Ringvatnet (4), 18 July 1975 - 27 August 1976

x = Probable analytical error, and not calculated in mean values
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct.12	Oct.27	Nov.11	Nov.25	Dec.10	Jan.30	Feb.11	Feb.24	Mar. 9	Mar.17	Apr. 4	Apr.25
pH	7.3												
Electrolytical conductivity µS/cm	46												
Hardness mg $CaCO_3$/l	20												
Organic carbon mg C/l	3.5												
Cu, µg/l	38	26	35	42	37	38		55	250^x	60	50	38	36
Zn, µg/l	75	70	85	85	85	70		110	515^x	100	110	100	80
Fe, µg/l	125	95	150	100	75	150		220	120	140			
Cd, µg/l										0.3	0.45	0.6	0.35

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug. 15	Aug. 27	Mean	Range	SD	N
pH										7.3			1
Electrolytical conductivity µS/cm										46			1
Hardness mg $CaCO_3$/l										20			1
Organic carbon mg C/l										3.5			1
Cu, µg/l	37	35	37	40	29	29	32	32	34	38	26-60	8.4	20
Zn, µg/l	95	50	80	65	45	55	65	47	65	77	45-110	19.8	20
Fe, µg/l	-			150	75					127	75-220	42	11
Cd, µg/l		0.3	0.3	0.35	0.2	0.1	0.3	0.4		0.33	0.1-0.6	0.12	11

Appendix Table 8A

Chemical analysis from Lake Hostovatnet (H8), 18 July 1975 - 27 August 1976

x = Probable analytical error, and not calculated in mean values
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct.12	Oct.27	Nov.11	Nov.25	Dec.10	Jan.30	Feb.11	Feb.24	Mar. 9	Mar.17	Apr. 4	Apr.25
pH	7.2	7.2	7.1	-	7.2				6.8	6.9	6.9	6.4	6.1
Electrolytical conductivity µS/cm	45	43	50	49	49				59	56	56	169	12
Hardness mg $CaCO_3$/l	18	16	19	17	18				19	19	19	20	1.4^x
Organic carbon, mg C/l	3.5	3.5	2.5	15	10				3.5		4	4	2.5
Cu, µg/l	39	12	19	22	18				210^x	30	31	13	11
Zn, µg/l	75	20	35	45	35				375^x	65	65	55	25
Fe, µg/l	75	35	50	50	50				55	60	80	50	20
Cd, µg/l										0.25	0.30	1.1	9.5^x

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug.15	Aug.27	Mean	Range	SD	N
pH	6.7	5.9^x	6.7	7.1	7.4	7.4	7.4	7.3	7.2	7.0	6.1-7.4	0.36	18
Electrolytical conductivity µS/cm	57	5^x	54	51	52	223^x	53	54	52	57	12-169	31	17
Hardness mg $CaCO_3$/l	17	3.2^x	16	16	16	15	18	16	17	17.4	15-19	1.5	17
Organic carbon, mg C/l		1.2	3.8	2.7	4.6	2.4	3.4	3.2	2.5	4.3	1.2-4.6	3.2	17
Cu, µg/l	12	5^x	25	25	22	38	17	18	24	22	11-39	8.6	17
Zn, µg/l	25	$<10^x$	55	50	45	50	25	44	35	44	20-75	16.1	17
Fe, µg/l	60	30	100	90	60	40	70			57	20-100	21	17
Cd, µg/l		0.25	0.30	0.95	0.6	0.25	0.2	0.5		0.47	0.2-1.1	0.3	10

Appendix Table 9A

Chemical analysis from outlet of Lake Hostovatnet (5), 18 July 1975 - 27 August 1976

x = Probable analytical error, and not calculated in mean values
SD = Standard deviation, N = Number of analysis used for calculations

Parameter	July 18	Oct.12	Oct.27	Nov.11	Nov.25	Dec.10	Jan.30	Feb.11	Feb.24	Mar. 9	Mar.17	Apr. 4	Apr.25
pH	7.1												
Electrolytical conductivity µS/cm	46												
Hardness mg $CaCO_3$/l	18												
Organic carbon, mg C/l	3.5												
Cu, µg/l	22	16	18	18	25			20	27	26	30	30	25
Zn, µg/l	50	30	30	40	35			35	70	65	70	70	70
Fe, µg/l	25	35	50	50	50			130	40	90			
Cd, µg/l										0.4	5.5[x]	0.45	0.3

Parameter	May 9	May 23	June 8	June 22	July 4	July 18	Aug. 1	Aug.15	Aug.27	Mean	Range	SD	N
pH										7.1			1
Electrolytical conductivity µS/cm										46			1
Hardness mg $CaCO_3$/l										18			1
Organic carbon, mg C/l										3.7			1
Cu, µg/l	29	24	30	23	26	17	25	22	21	24	16-30	4.4	20
Zn, µg/l	60	40	70	50	30	40	80	40	45	51	30-80	16.7	20
Fe, µg/l				50	75					60	25-130	31	10
Cd, µg/l		0.3	0.3	0.3	0.3	0.15	0.3	0.45		0.32	0.3-0.45	0.08	10

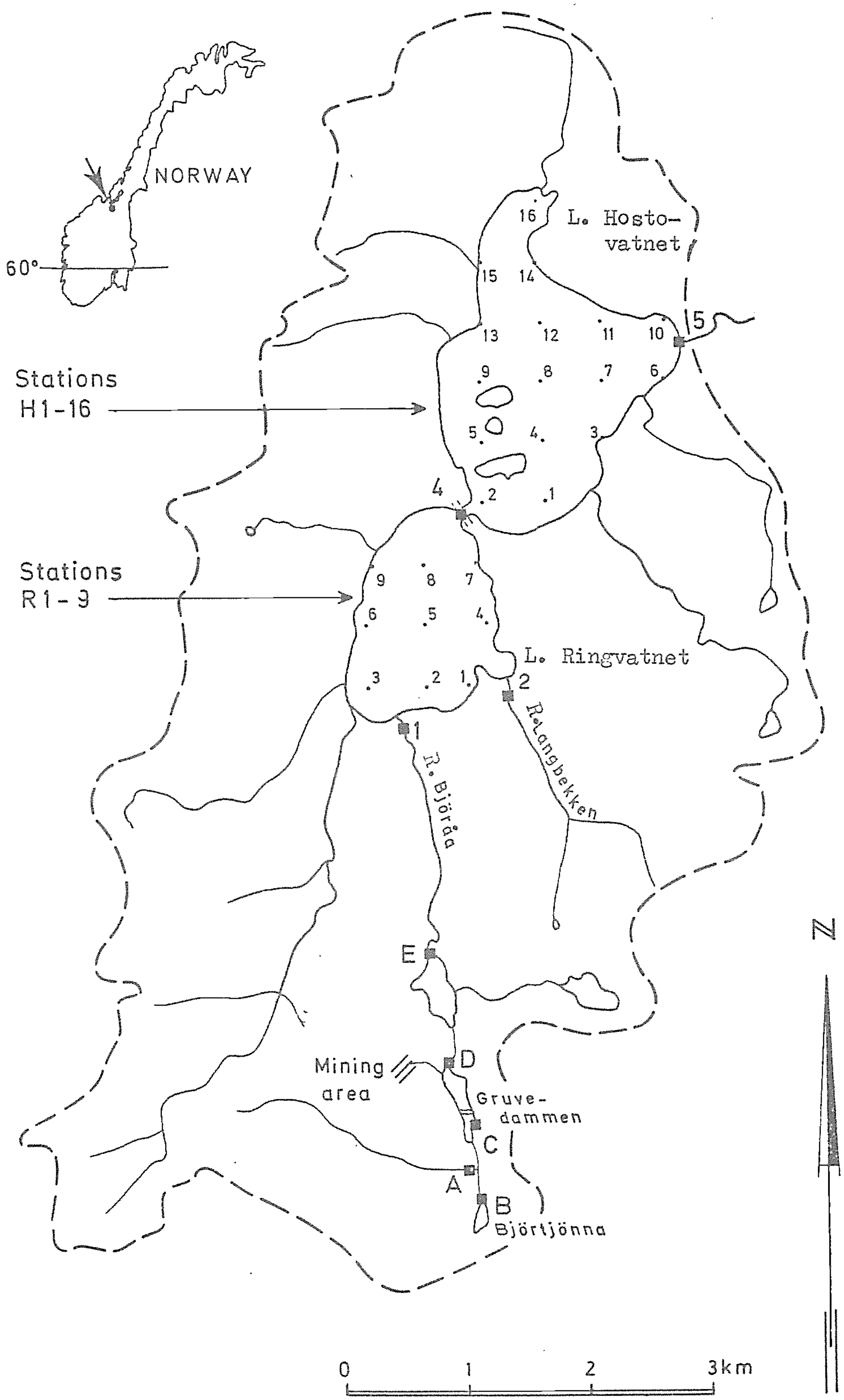

Fig. 1 L. Ringvatnet and L. Hostovatnet with catchment area and sampling stations (• ■)

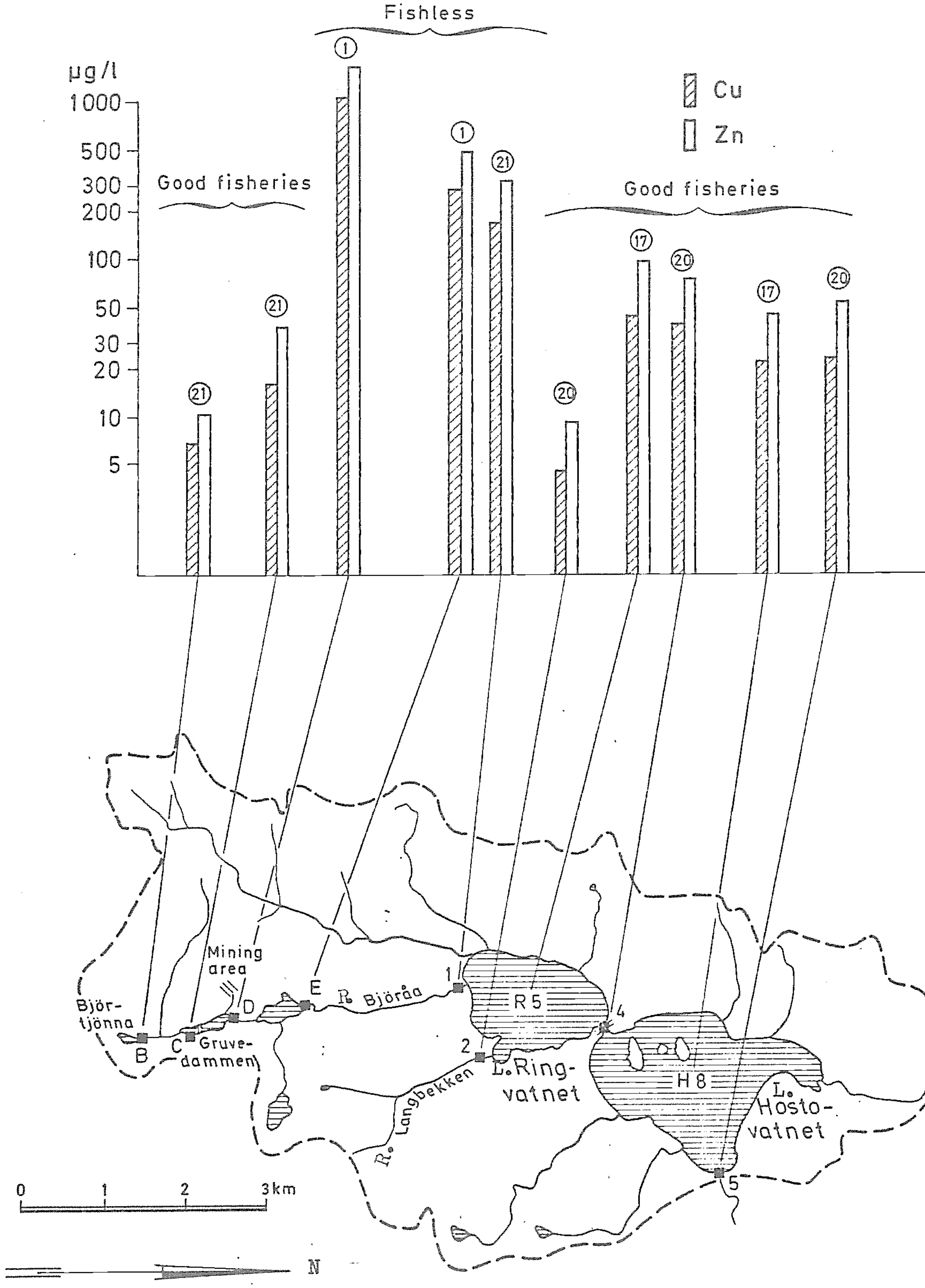

Fig. 2 Copper and zinc concentrations in the lake and river system
Annual mean values
(1) = Number of analysis

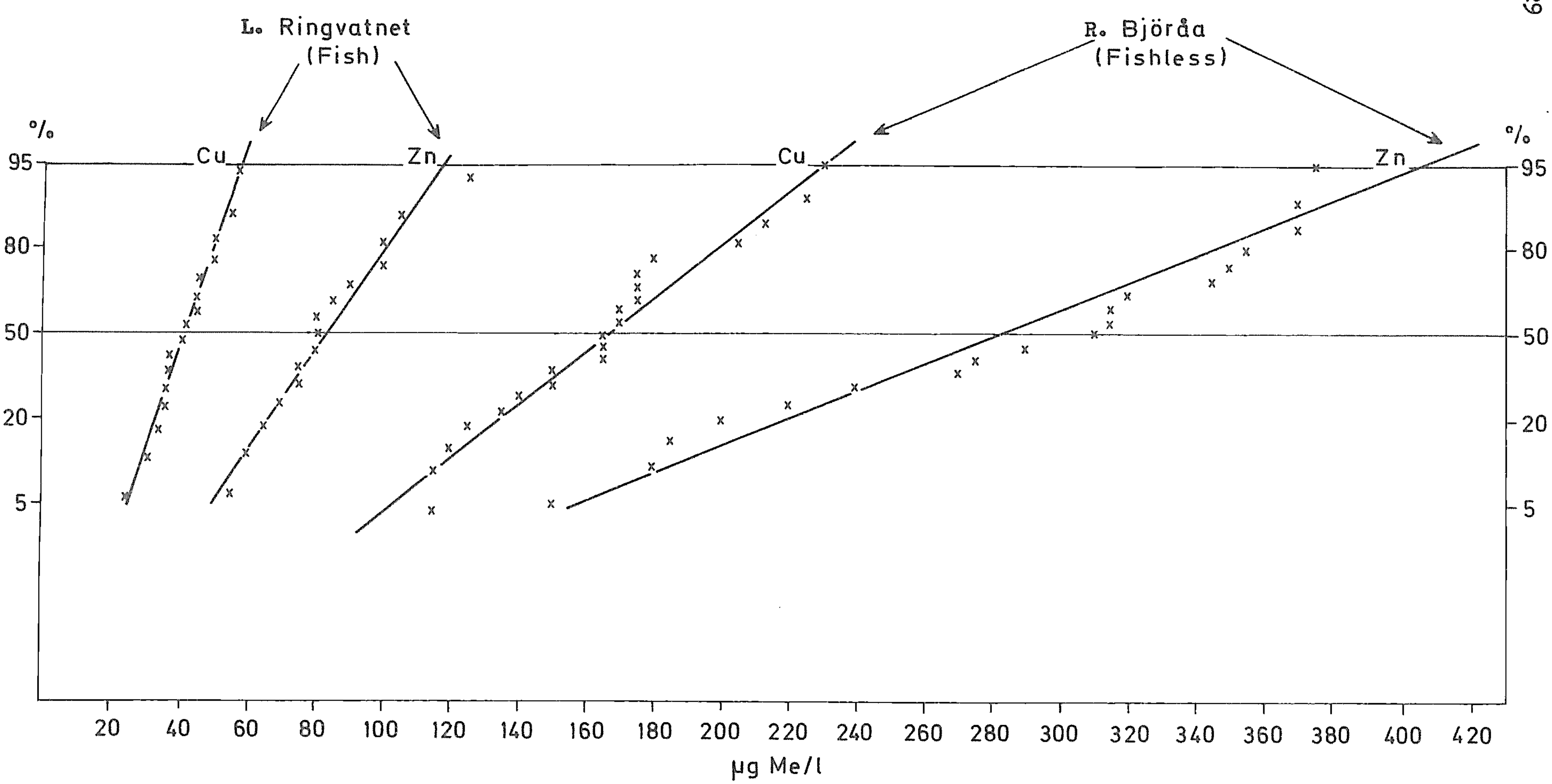

Fig. 3 Percentile distribution of the values of copper and zinc concentrations analyzed approximately twice monthly throughout a year in L. Ringvatnet and R. Bjøråa

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