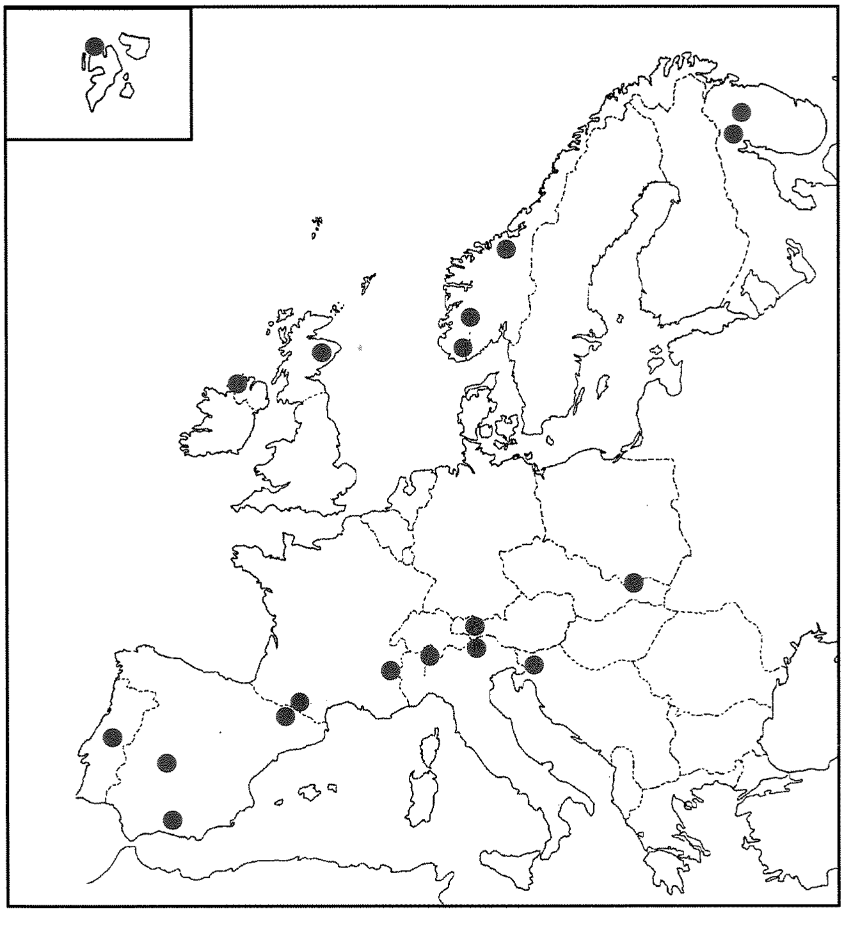
Acidification of Mountain Lakes:
Palaeolimnology and Ecology

AL:PE

AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology

Part 2 - Remote Mountain Lakes as Indicators of Air Pollution and Climate Change



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Abstract

AL:PE, funded by the European Commission, is a multi-disciplinary, multi-national project coordinated by research groups in London and Oslo. It represents the first comprehensive study of remote mountain lakes at a European scale. The AL:PE project is concerned with remote mountain lake ecosystems throughout the arctic and alpine regions of Europe that, despite their remoteness are threatened by acid deposition, toxic air pollutants and by climate change. Whilst the study is directly concerned primarily with the lakes themselves, the results of the study have much greater significance as these lake ecosystems, together with their sediment records, act as environmental sensors for the wider arctic and alpine environments. The AL:PE results illustrate two over-arching issues: (i) the importance of these remote and sensitive ecosystems as sensors of long-range transported pollutants and as providers of early warning signals for more widespread environmental change; and (ii) the importance and urgency of understanding the present and future impacts of pollutants, both singly and in combination, on aquatic ecosystems. Although acid deposition is currently thought to be the most potent threat, disentangling the interactions between the effects of changing deposition patterns of acids, nutrients, trace metals and trace organics in the context of global warming presents an immense scientific challenge. The AL:PE programme has begun to address this challenge and its successor EU project, MOLAR, is designed to tackle the issues more specifically by focussing on in-depth studies of key sites.

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Executive Summary

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1. Background and project aims

1.1 The AL:PE project, funded by the European Commission, is a multi-disciplinary, multi-national project coordinated by research groups in London and Oslo. It represents the first comprehensive study of remote mountain lakes at a European scale. The project is funded by the European Commission Environment Programme (contracts STEP-CT90-0079, EV5V-CT92-0205) with assistance from PECO (contract CIPD-CT93-0021). Additional funding was provided by the Norwegian Research Council (108046/720) and the Austrian Research Foundation (FWF P9199-BIO).

1.2 A major report of the first phase of this project (AL:PE 1) has been published in the EU series of Ecosystems Research Reports. This report describes the results of AL:PE 2, the second phase of the project (1993-1995).

1.3 The AL:PE project is concerned with remote mountain lake ecosystems throughout the arctic and alpine regions of Europe that, despite their remoteness are threatened by acid deposition, toxic air pollutants and by climate change.

1.4 The lakes are especially vulnerable because (i) most have little capacity to neutralise acid deposition; (ii) their catchments have only thin soils and sparse vegetation cover that do not effectively prevent pollutants from reaching surface waters; (iii) toxic trace metals and trace organics accumulate in the food chain more easily in low alkalinity waters; (iv) some pollutants (e.g. mercury, volatile organics) accumulate preferentially in cold regions; and (v) future climatic warming in Europe is predicted to be greatest in arctic and alpine regions.

1.5 Whilst the study is directly concerned primarily with the lakes themselves, the results of the study have much greater significance as these lake ecosystems, together with their sediment records, act as environmental sensors for the wider arctic and alpine environments.

2. Sites

2.1 Sites in the AL:PE programme were chosen from the European mountain ranges on the basis of the following criteria, (i) sites must be above (altitude) or beyond (latitude) the local natural timberline, so that water chemistry could not be influenced by forests and forest management; (ii) lake catchments should be undisturbed by human activity such as animal grazing or human recreation, so that any changes in lake water quality could only be due to atmospheric pollution or to natural environmental variability, and (iii) sites to be studied for the effects of acid deposition should have low base cation concentrations, with calcium preferably less than 50 meq l^{-1}, and always below 100 meq l^{-1}, so that sites were sensitive to the deposition of acidity.

2.2 In the AL:PE 2 programme some relaxation of this last criterion was allowed to include some sites with base rich bedrock, e.g. in Slovenia and southern Spain.

2.3 Sites in the project include control or reference sites in clean or relatively clean regions of Europe (Central Norway, Svalbard, Ireland, Spain and Portugal) as well as potentially more polluted sites (in Scotland, Austria, Italy, Slovakia and Poland).

2.4 Additional sites included a very base rich site in the Triglav National Park in Slovenia, and sites in the Kola Peninsula, Northern Russia and in the Gredos Mountains of Central Spain.

3. Organisation and methods

3.1 AL:PE is a large complex project. Project organisation involved the designation of lead laboratories to act as coordinators for each of the key scientific areas involved in the study.

3.2 The range of field and laboratory methods employed included water chemistry (cations, anions, nutrients, trace metals etc.), biology (epilithic diatoms, zooplankton, macroinvertebrates, test fishing) and sediment core analysis (dating, trace metals, persistent trace organics, carbonaceous particles, diatoms, chironomids).

3.3 Wherever possible analyses were undertaken at local laboratories and harmonisation of analytical and data reporting procedures was assured by analytical quality control (AQC) programmes as follows, (i) for water chemistry AQC involving both a standard programme of internal laboratory data control emphasising outlier detection, ionic balance determination and seeking continuity where time series were available, and annual intercalibration exercises involving all the AL:PE and several external laboratories, and (ii) for biological material AQC was assured by inter-laboratory exchange of samples (e.g. fish scales, diatom slides, zooplankton or invertebrate samples), taxonomic workshops (e.g. diatoms), or where locally-based analysis was difficult, centralised analysis by expert laboratories.

3.4 All the analytical results from the combined AL:PE programme are being transferred to the AL:PE database located at the Botanical Institute at the University of Bergen, Norway.

4. Water chemistry results

4.1 With the exception of some continuing difficulty with alkalinity determinations the AQC programme showed that all laboratories achieved acceptable standards of water chemistry analysis. Where variation occurred the use of Youden plots indicated the prevalence of systematic over random errors. Overall laboratory performances improved during the period of the project.

4.2 The majority of sites are acidic with pH between 4.5 and 6.5 and sensitive to acidification with calcium concentrations below 100 meq l^{-1}. La Caldera in southern Spain and Zgornje Krisko Jezero in Slovenia, included primarily for their geographic location, are outliers with much higher pH and mean calcium concentrations than other AL:PE sites.

4.3 Sulphate values for the main control site, Øvre Neådalsvatn, in Norway, are very low, and represent the expected background concentration (< 15 meq l^{-1}) for this compound. Similar low values also occur in the Pyreneean sites, Etang d'Aube and Lago Aguilo and L. Redo, whilst high values (40-80 meq l^{-1}) occur at most other sites, reflecting their geographical location in areas of high sulphur deposition and their catchment geology.

4.4 As in the case of sulphate, nitrate values at the control lake Ovre Neådalsvatn represent background concentrations (< 5 meq l^{-1}). All other sites show concentrations above background, with the highest values in the Tatra Mountain lakes.

4.5 Lakes in the Tatra Mountains and the Alps have both high nitrate and high sulphate levels and the relative importance of nitrogen in contributing to the acidity of lakes in Central Europe is much greater than at other sites.

4.6 The Iberian sites have very low values for both sulphate and nitrate indicating that their chemistry is relatively little affected by acid deposition, whilst some sites at the most northerly (Chuna and Chibini in the Kola peninsula, and Arresjøen on Svalbard) and westerly (L. Maam, Ireland) parts of Europe show levels which, although moderate, are above background.

4.7 Chloride concentration varies significantly between sites, but this is clearly a result of natural variation with those sites most influenced by the sea (Arresjoen, Lough Maam and Scottish sites) having the highest values. Lakes in the Central Alps have some of the lowest values.

4.8 Almost all sites have very low (< 10 mg l^{-1}) total phosphorus values indicating oligotrophic and ultra-oligotrophic conditions and the absence of local disturbance.

4.9 Trace metal results are based on only one sample. Although there are some high values, most notably lead (Pb) in Lochnagar, and mercury (Hg) in Escura and Dlugi Staw, all values are acceptable with respect to European Community drinking water standards.

4.10 Statistical analysis of the whole datasets using PCA confirms that the main pattern of variation is associated with the difference between the oceanic areas of northern and western Europe where sea-salts are important and lakes in southern, central and eastern Europe where nitrate and sulphate concentrations are above average.

4.11 Critical loads and critical load exceedance calculations for the AL:PE lakes show exceedances for several sites with nitrogen making an important contribution to the exceedances in the Tatra mountain sites. However, these exceedance calculations are provisional as reliable sulphur and nitrogen deposition data for many sites are not yet available.

5. Biology: epilithic diatoms

5.1 Replicate samples of the diatom epilithon were taken at all sites, and the results show small within site variation in species composition.

5.2 Species richness was high, often more than 50 taxa being present in a sample.

5.3 Comparison of the epilithic assemblages with the surface sediment assemblages, that integrate diatoms from all habitats in the lake, show substantial differences both in relative abundance and taxa present. This indicates that habitats other than the epilithon, such as the epipelon and epipsammon may also support important communities at many sites.

5.4 In many cases groups of samples from the same region cluster together, principally as a result of similar geologies and/or the influence of similar levels of atmospheric deposition.

5.5 The use of the statistical technique Detrended Correspondence Analysis (DCA) shows that the main environmental variable explaining differences between sites is pH, although other lake catchment and water chemistry variables also have significant influence.

5.6 The diatom epilithon can be used to estimate water pH accurately by applying the new surface sediment diatom - water chemistry calibration data set (see below, 13.1) to epilithic samples with a root mean square error (RMSE) of prediction of 0.23 pH units.

6. Biology: zooplankton

6.1 Zooplankton were not studied during the AL:PE 1 programme. They were introduced to the AL:PE 2 programme following the finding from the High Tatra Mountains of Slovakia that acidified lakes had lost their planktonic populations. The AL:PE 2 programme provided the opportunity to compare zooplankton fauna of alpine lakes across Europe.

6.2 The results show two main groups, a "northern lake" group from the Kola Peninsula, Norway and the British Isles, and a "southern lake" group from the Tatras, Alps, Pyrenees and Iberia.

6.3 The continental, high altitude lakes in the Tatras and the Alps have simple zooplankton communities sensitive to the additional stress caused by air pollutants. Lakes at lower altitudes with a more maritime climate in north-west Europe are less vulnerable.

6.4 The non-pelagic, ubiquitous species *Chydorus sphaericus* and *Acanthocyclops vernalis* are the only taxa to be found in the acidified Tatra lakes. Better evidence for changes in the recent status of cladoceran populations in alpine lakes can be obtained from sediment core records (see below 14.1).

6.5 The taxonomic status of some zooplankton populations remains to be clarified.

7. Biology: benthic invertebrates

7.1 All sites in the AL:PE programme were ranked according to the number of acid sensitive species present. The principal reference site, Ovre Neådalsvatn in Norway, had the greatest number (17) of sensitive taxa.

7.2 Although there is great diversity between sites the results indicate higher numbers of sensitive species present in Spain, Portugal and central Norway compared to lakes in the Alps and the Tatras.

7.3 The impact of acidification is registered mainly through the progressive loss of gastropods, mayflies, stoneflies, caddisflies, and crustaceans

7.4 However, impoverished faunas at some sites where water chemistry is suitable for survival may be due to other factors such as high altitude, short duration of the ice-free period and low rates of colonisation.

7.5 Faunal differences across Europe are also due to differences in the biogeographic ranges of species and groups of species as well as to environmental factors. In particular many taxa have distinct northern or southern distributions within Europe and some have very restricted ranges e.g. three of the plecopteran species encountered are endemic to the Pyrenees.

7.6 Chironomids with 154 taxa identified were the most diverse group of invertebrates present in the samples. Most are normal inhabitants of mountainous lakes and rivers throughout Europe, and no clear pattern in their distribution was observed. Canonical Correspondence Analysis (CCA) highlights major differences in the chironomid assemblages at Arresjoen and Chibini, and some differences between Hovvatn, Maam and Lochnagar and the rest of the lakes.

8. Biology: fish populations

8.1 All the lakes with fish (17) have been test-fished to asses population structure and to take samples for the analysis of trace metals (Hg, Cd, Pb) and trace organic pollutants in fish muscle and/or liver.

8.2 Differential spawning conditions and the practice of re-stocking makes an assessment of the relationship between fish population and water acidity difficult. Although many of the AL:PE lakes suffer from acidification (based on evidence from water chemistry (see above 4.11) and diatom analysis (see below 13.4) only at Stavsvatn and Lille Hovvatn in Norway can an impact on fish be inferred with confidence.

8.3 Although some of the differences in trace metal concentration between fish were related to size (length, age, weight) Partial Principal Components Analysis (PPCA) showed that the major variations are related to differences between sites and regions. Hg has highest concentrations in western localities (Arresjoen, Lagoa Escura, Lough Maam) close to the Atlantic Ocean whereas Pb and Cd showed low concentrations in the northern sites and highest levels in central and eastern Europe.

8.4 On the whole concentrations of Hg and Pb were below unacceptably high levels for human consumption, although an exception is Schwarzsee ob Solden in Austria where Pb exceeded the threshold. Threshold levels for Cd, on the other hand, are exceeded at many sites, especially those in the Alps and Tatra mountains.

8.5 Ovre Neådalsvatn showed the lowest or second lowest values for all three metals, confirming its suitability as a reference site.

8.6 Fish muscle tissue from 14 AL:PE sites were analysed for a range of organochlorinated compounds: hexachlorobenzene (HCB), total polychlorobiphenyls (PCBs), DDT derivatives (DDTs), and hexachlorocyclohexanes (HCHs).

8.7 The results show a difference in geographic pattern across Europe between the organochlorinated compounds from industrial sources (PCBs and HCB) and those used as pesticides (DDTs and HCH). The former show only low variation in values between sites, whilst the latter show variations in values between two and three orders of magnitude with the highest values in Schwarzsee ob Solden in the Austrian Tyrol.

8.8 Lake Redo in the Pyrenees also has high concentrations of all compounds and lakes in the Tatras have high concentrations of PCBs and DDTs but low levels of HCHs and HCBs. Most other areas, e.g. the Kola, British Isles, Norway and Iberia have low values, that can be considered to represent background atmospheric pollution.

8.9 Overall a good relationship exists between the levels of pollutants found in fish tissues and the concentrations found in surface sediments (see below 12).

9.0 The values for fish are of the same order as those found in other aquatic systems in Europe not receiving direct discharges of organochlorinated compounds, indicating that these compounds are easily transferred between ecosystems and that the atmosphere is an important transport medium.

9. Sediments: background

9.1 The sediment records of all primary AL:PE sites have been studied in detail to derive an understanding of the extent to which the lakes have been historically contaminated by atmospheric pollutants and the extent to which such contamination has had an impact on the lake biology in recent decades.

9.2 Although sediments in high altitude lakes are often characterised by low organic content and slow accumulation rates, the sediment cores from the AL:PE sites have all been successfully dated using radio-isotopic techniques (^{210}Pb, ^{137}Cs, and ^{241}Am).

9.3 Sediment accumulation rates in the cores vary from 0.2 mm yr^{-1} at Arresjøen on Svalbard to 1.3 mm yr^{-1} at L. Aguilo (Spanish Pyrenees) and L. Maam (Ireland).

9.4 Inter-comparisons of the fly-ash, trace metal and trace organic data within cores and between sites have been facilitated by standardising the data against the unsupported ^{210}Pb inventories at each site.

10. Sediments: fly-ash (carbonaceous particle) contamination

10.1 Considering the range of depositional regimes and meteorology experienced by the AL:PE sites, the temporal pattern of spheroidal carbonaceous particle (SCP) distribution is remarkably consistent. There are similarities in the profiles from Svalbard to the Sierra Nevada and from the Tatra Mountains to the west of Ireland. The three main features of the SCP profile are the start of the record, the rapid increase in concentration and the near surface concentration maximum, and all three are present at nearly all the sites.

10.2 The start of the SCP record is pre-1940 except at those sites where concentrations are very low (Arresjøen on Svalbard and La Caldera in southern Spain). The record starts early (mid-nineteenth century) in areas which are heavily impacted (e.g. Lochnagar in Scotland, Dlugi Staw and Starolesnianske Pleso in the Tatra Mountains). The remainder of sites show the start of the record to be 1900s - 1920s considerably later than the rise in the trace metal record (see below 11.3). Similarly consistent is the rapid rise in SCP concentration which at every site is post-1945 but varies between the 1950s and 1980s.

10.3 Spatial patterns of SCP deposition reflect a broad range of depositional regimes. The highest deposition is found in central Europe (e.g. Paione Superiore) and other areas of high deposition exist where there is a direct influence of 'regional' pollution (e.g Lochnagar in Scotland, and Stavsvatn and Lille Hovvatn in southern Norway). SCP deposition decreases from these areas to the north, west and south.

10.4 There is a particularly noticeable gradient in Norway with lowest surface concentrations found at Arresjøen on Svalbard (c. 1000 particles gDM^{-1}), which are similar to levels at the AL:PE reference site, Øvre Neådalsvatn. However, at Stavsvatn to the south, surface concentrations reach 4,000 gDM^{-1} in the mid-1980s, and further south still, at Lille Hovvatn peak concentrations reach 50,000 gDM^{-1}.

10.5 The SCP data clearly indicate the extent to which remote regions have been contaminated by emissions from fossil fuel combustion. Even the most remote sites e.g. Arresjoen, have significantly high concentrations, indicating that the entire northern hemisphere now experiences an easily detectable background level of atmospheric contamination.

11. Sediments: trace metal contamination

11.1 Trace metal records from the sediment cores show variations associated with both catchment geology and atmospheric contamination.

11.2 At some sites the profiles are difficult to interpret because of the influence of changes in sediment accumulation rate. However, most sites show evidence for increasing contamination by Pb, Cu, Cd and Zn. The Tatra sites show the most marked changes whilst Laguna Cimera (Central Spain) and Arresjoen show least contamination.

11.3 Overall the trace metal data show patterns similar to those for SCPs with atmospheric contamination increasing from both southern and northern Europe towards central and eastern regions. However, in most cases trace metal contamination commences between 1810 and 1860, generally well before the observed onset of SCP accumulation.

12. Sediments: trace organic contamination

12.1 The sediment records of trace organic pollutants show very consistent results. The n-alkanes mostly show little temporal change suggesting that catchment vegetation has remained fairly constant throughout the period covered by the cores. Most depth profiles suggest a significant increase of PAH at the beginning of the century with maxima generally occurring in the 1970s.

12.2 With the exception of Schwarzsee ob Solden (where the increase does not start until the 1960s) the record of chlorinated compounds (PCBs, DDE, HCB) in the sediments begins about 100 years ago. This is surprising as PCBs were not synthesised industrially until 1929 (in the USA) and 1954 (in Europe). These early increases may be due to downward migration in the sediment, contamination, or possibly due to the by-product of industrial combustion processes.

12.3 The area of highest contamination by PAH and chlorinated compounds is the Tatra Mountains and the central Alps. Concentrations generally decrease significantly away from this area and in more peripheral areas (e.g. Iberian Peninsula) the profiles of retene suggests that PAHs are more probably derived from regional forest fire sources rather than from industrial sources.

13. Sediments: diatom analysis

13.1 A diatom-pH training set consisting of surface sediment diatom assemblages and associated pH data from 118 alpine and arctic lakes was assembled from the AL:PE programme and associated projects. The pH-diatom transfer function has been developed using Weighted Averaging Partial Least Squares (WA-PLS).

13.2 The training set closely predicts the present-day lake water pH from the AL:PE lakes and significantly improves upon earlier attempts at pH reconstruction for mountain lakes used in the AL:PE 1 programme. The root mean square error (RMSE) of prediction is 0.33 pH units.

13.3 Diatom-based pH reconstructions have been made for 20 sites. The results show a range of responses depending mainly on site sensitivity to acidification in relation to acid deposition.

13.4 At sensitive sites with relatively low acid deposition, e.g. L. Cimera in central Spain, E. Aubé in the French Pyrenees, Ovre Neådalsvatn in Central Norway, there are no changes in diatom-inferred pH. At other sites e.g. Lochnagar in Scotland, Lough Maam in Ireland, Paione Superiore in Italy, Dlugi Staw in Poland and Stavsvatn in southern Norway, there are significant pH decreases in response to high sulphur and, in some cases, nitrogen deposition.

13.5 Although most of the diatom-inferred pH changes are consistent with pollution levels and catchment sensitivity, other factors, especially the potential impact of climate change, need to be taken into account at some sites. In particular the timescale, and therefore the cause, of the significant pH decline (pH 6.6 - 5.9) observed at Arresjøen on Svalbard is uncertain, and further work is required to clarify the apparent acidification at L. Escura in Portugal and the extent of post-1850 acidification (pH 6.7 - 5.9) at L. Redo in the Spanish Pyrenees. At some sites acidification may be partially compensated by Sahran dust depositions and by climate warming over recent decades, as increased temperature tends to increase pH in low alkalinity lakes.

14. Sediments: cladocera

14.1 Cores from Starolesnianske and Terianske Pleso in the Tatras and from Zgornje Krisko Jezero in Slovenia were analysed for cladoceran remains. The reduced diversity of the fauna in Starolesnianske is consistent with the acidification of that site. However, there is no clear explanation for the loss of *Daphnia pulicaria* in the non-acidified Teriankse Pleso. No recent changes were recorded at Zgornje Krisko Jezero.

15. Sediments: chironomids

15.1 Chironomid analysis was carried out on cores from 5 of the AL:PE lakes. In three cases there were significant recent changes in the relative abundances of the dominant taxa. However, at two sites (Schwarzsee ob Solden and Paione Superiore) These changes are probably due to a combination of a slight nutrient enrichment, possibly from atmospheric sources, and an early stage of acidification. The results agree with the fact that nitrogen may act both as a nutrient and an acidifying agent. The cause of change at the third site (Lagoa Escura) is not known.

16. Principal conclusions

16.1 The results strongly confirm the initial supposition that remote alpine lakes, that occur throughout Europe, are excellent sensors of air pollution. The data from the programme allow for the first time patterns of air pollution and its effect to be identified at a pan-European scale.

16.2 One of the clearest results is the evidence for the impact of potentially acidifying sulphur and nitrogen deposition on lakewater chemistry. Lakes in the more industrialised regions of Europe have high levels of sulphate and nitrate compared to the control sites on the oceanic fringes of Europe. Nitrate is relatively more important at sites in central and eastern Europe than at other sites.

16.3 The biological effects of sulphur and nitrogen deposition are seen at many sites where acidification has accounted for changes in diatom communities and for the impoverishment of zooplankton, benthic invertebrate and fish populations.

16.4 Fly-ash, trace metal and trace organic pollutants also show striking time and space patterns, broadly similar to the patterns for sulphate and nitrate, with notably high levels being found in the Tatras and the Alps (especially the Tyrol). Despite the remoteness of the sites some of the trace metal levels in fish in these regions are higher than acceptable for human consumption. This is especially so in the case of Cd.

16.5 Although the highest levels of atmospheric contamination occur in southern and eastern Europe, the data show that no site in Europe, however remote, is completely free from contamination by potentially toxic trace organics and trace metals. Indeed, relatively high levels of PAHs and PCBs occur in both fish and sediment samples from Arresjoen (Svalbard), the most remote lake in the AL:PE programme.

16.6 As the only medium of pollutant transport to AL:PE sites is by the atmosphere, these data demonstrate the ease with which all types of air pollutants are transported over long distances across Europe and enter remote high latitude and high altitude ecosystems. So far there is no evidence of any significant impact of these substances on populations in such ecosystems, but their presence is of concern as both metals and organics can be taken up by biota and concentrated through biomagnification.

16.7 Although contamination by air pollutants occurs at all sites, the results of the AL:PE programme allow areas of Europe with the least contamination to be identified. Within such areas unpolluted sites can be selected to serve as reference sites for studies of climate change. Their sediment records can also be used to provide evidence for past climate variability, an understanding of which is essential in order to place processes associated with greenhouse forcing in perspective.

16.8 The AL:PE programme now represents a large active consortium of researchers within Europe, and maintains a substantial and growing high quality environmental database (with AQC procedures cementing cooperation between laboratories) that can be used (i) to build further research e.g. the MOLAR project; (ii) as a baseline to assess future environmental responses to changes in European air quality; and (iii) as a secure basis for research activities using standard methods and protocols for water chemistry and biology.

16.9 Overall, the results illustrate two over-arching issues:

(i) the importance of these remote and sensitive ecosystems as sensors of long-range transported pollutants and as providers of early warning signals for more widespread environmental change; and (ii) the importance and urgency of understanding the present and future impacts of pollutants, both singly and in combination, on aquatic ecosystems. Although acid deposition is currently thought to be the most potent threat, disentangling the interactions between the effects of changing deposition patterns of acids, nutrients, trace metals and trace organics in the context of global warming presents an immense scientific challenge. The AL:PE programme has begun to address this challenge and its successor EU project, MOLAR, is designed to tackle the issues more specifically by focussing on in-depth studies of key sites.

17. Acknowledgements

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AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Chapter 1.

Introduction

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Introduction

The AL:PE ("Acidification of Mountain Lakes: Palaeolimnology and Ecology") project is designed to study remote mountain lakes as indicators of air pollution and climate change. It is a multi-national cooperative project which in its second phase (AL:PE 2) has grown in size and number of participants during the working period to involve institutions in 11 countries; (Norway, United Kingdom, Italy, France, Spain, Austria, Czech Republic, Slovak Republic, Slovenia, Russia and Poland). The project is funded by the European Commission Environment Programme (contracts STEP-CT90-0079, EV5V-CT92-0205) with assistance from PECO (contract CIPD-CT93-0021). Additional funding is provided by the Research Council of Norway (108046/720) and the Austrian Research Foundation (FWF P9199-BIO).

Alpine and arctic regions represent the most remote and least disturbed areas of Europe, but they are still threatened by acid deposition, and toxic air pollutants. These areas and their lakes represent especially vulnerable ecosystems because (i) most have little capacity to neutralise acid deposition; (ii) their catchments have only thin soils and sparse vegetation cover that do not effectively prevent pollutants from reaching surface waters; (iii) the ice free period is short. Their high vulnerability makes them good indicators of pollution and possible changes in environment and climate.

In this project alpine and arctic lakes are defined as lakes above (altitude) or beyond (latitude) the local natural timberline, so that water chemistry is not influenced by forests or forest management. All the lakes selected for study in the AL:PE project have catchments that are undisturbed by human activity such as animal grazing or human recreation, so that any changes in lake water quality can only be attributed to atmospheric pollution or to natural environmental variability.

AL:PE aims to evaluate the contemporary status of alpine and arctic lakes, chemically and biologically, and provides historical context through analyses of sediment cores. The sites are located across Europe to include areas that experience different loads of air pollution, and the data generated are used to evaluate the speed, direction and biological effects of environmental change. The AL:PE project also represents the first comprehensive study of remote lakes at a European scale.

The first part of the project, AL:PE 1 was launched in April 1991, and ran until April 1993. The results have been published in the EU series of Ecosystems Research Reports, Vol. 9. The second part. AL:PE 2, was launched in 1993, and formally completed in June 1995. AL:PE 2 develops upon the results from AL:PE 1 and represents en extension of the fist part both geographically and scientifically.

The principal aims and objectives of AL:PE 2 may be summarised:

Aims

- Continue AL:PE 1 to understand the structure and ecosystems of remote mountain lakes and the response of these lakes to varying levels of acid deposition.
- Enlarge the project to assess a wider range of long-range transported pollution components in addition to acidity.
- Identify unpolluted lake regions in Europe that can be used as reference sites for studies of climate change.

Objectives

- Identify critical sulphur and nitrogen loads and recommend target loads for remote mountain areas.
- Use biological data to establish guidelines for good monitoring and guidance practices.
- Develop and refine statistical methods for analysing biological data in relation to environmental data to provide a basis for predicting future biological responses to modelled chemical changes.
- Establish baseline conditions for the long-term evaluation of climatic change and its effects.
- Establish links between existing lake databases in EC countries, Austria, Switzerland, Czech Republic, Slovak Republic, Poland and Norway.
- Establish links with other scientists in this field in the world, especially the developing world, aiming at future co-operation and exchange of knowledge.

Oranagization and Programme Coordination

United Kingdom took on the administrative responsibility, while the scientific coordinating country has been Norway. For each of six subject areas there have been a coordinating country and person forming the steering committe for the project, as shown in the following text. This steering committe has been responsable for quality assurance and nessecary intercalibrations between participants.

Administrative Programme Centre:	UCL-ECRC/ Simon T. Patrick and Richard W. Battarbee
Scientific Programme Centre:	NIVA/ Bente M. Wathne and Merete Johannessen
<u>Subject area</u>	<u>Co-ordinated by</u>
- Lake sediments and diatoms	UCL-ECRC/ Nigel Cameron and Richard W. Battarbee
- Fish	NIVA/ Bjørn Olav Rosseland
- Invertebrates	UIB-ZM/ Gunnar Raddum
- Zooplankton	CU-DH/ Jan Fott
- Water Chemistry	CNR-III and NIVA/ Rosario Mosello and Bente M. Wathne
-Statistical analysis and modelling	UIB-BI/ John Birks

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Chapter 2.

Water Chemistry and Critical Loads Calculations for the AL:PE 2 Lakes

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2.1. Introduction - Water sampling and analysis

Water chemistry from earlier sampling was one of the criteria for the first selection of the remote mountain lakes for the AL:PE 1 project. There were also a criterion set with regard to acid sensitivity, and to fulfil that criterion, sites with lakewater calcium of 50 µeq/l (1 mg/l) or less, were required. For AL:PE 2 this criterion was somewhat modified, due to a wish of working sites with a broader biological spectrum combined with the wish to identify unpolluted sites in Europe suited for studies of climate change. The selection of lakes took place after careful consideration of all known information about them. A detailed description of each of the sites is given in Appendix 1.

Sampling and analysis for water chemistry was also required in the monitoring programme of the lakes, and planning of the field work was done at an early stage each year before the sampling season. The purpose of the joint planning was to combine the water chemistry sampling programme with the other sampling programmes of AL:PE in an optimal way, and to assure the comparability of chemical data obtained from the different laboratories.

2.2. Methods

2.2.1 Analytical methods

Water sampling followed the protocol agreed under the AL:PE 1 project (Wathne *et al.* 1995). The samples were taken from the outlet of the lake, and one water sample was taken at the same time as the samples for benthic invertebrates were collected. The minimum number of samples required was one yearly sample in the late autumn (at the turnover time for the lake), taken as a representative annual mean sample for the physical-chemical parameters in the lake (Henriksen *et al.* 1988). Most of the lakes were sampled more frequently than the minimum.

The samples were analysed by standard procedures for analysis of low ionic strength waters. The analytical programme includes the following components: pH, conductivity, calcium (Ca^{2+}), magnesium (Mg^{+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), nitrate (NO_3-N), fluoride (F), alkalinity, total organic carbon (TOC), reactive aluminium (RAL) and non-labile aluminium (ILAL), all the same as for ALPE 1. In addition, and new for AL:PE 2, was analysis of total phosphorus (Tot P) and the trace metals lead (Pb), mercury (Hg), and cadmium (Cd). The trace metals are the same as analysed for fish.

The analytical work for the most of the components was done at national laboratories in co-operation with the chemical centres in Italy (CNR-III) and Norway (NIVA), but one autumn sample was sent to NIVA for analysis of Al-speciation, Hg, Cd and Pb from all sites. The sample bottles were mailed from NIVA to the different participants on agreed and due time before the autumn sampling. The following bottles were sent:

- For Hg	250 ml glass bottle specially washed, preserving agent added (NaCl)
- For Cd + Pb	60 ml plastic bottle specially washed for heavy metal analysis
- For RAL, ILAL	500 ml plastic bottle specially washed samples of very low total ionic strength

The procedure was adopted to secure that all results of these low metal concentrations should be comparable.

Table 2.1. Major analytical methods used in Italy and Norway.

	Italy	Norway
pH, electrometry	X	X
Conductivity, electrometry	X	X
Alkalinity, electrometry	X	X
Gran. titration		
Nitrate, ion chromatography	X	
photom. autoanalyser		X
Ammonium, photom. autoanal.	X	X
Total nitrogen, photom. autoanal.	X	X
Chloride, ion chromatography	X	X
photom. autoanalyse		
Sulphate, ion chromatography	X	X
autoanalyser		
Calcium, ICP-OES		X
ion chromatography	X	
Magnesium, ICP-OES		X
ion chromatography	X	
Sodium, ICP-OES		
atomic emiss. spectr.		X
ion chromatography	X	
Potassium, FAAS		X
ICP-OES		
ion chromatography	X	
Fluoride, ion selec. electrode		X
Aluminium, GFAAS	X	X
Aluminium speciation		X
Total/Dissolved organic carbon $Na_2S_2O_8$/UV oxidation		X
Total phosphorus, UV/$Na_2S_2O_8$ digestion and photom. autoanal.	X	X
Lead, GFAAS		X
Cadmium, GFAAS		X
Mercury, Cold vapour AAS		X

The analytical methods used in co-ordinating countries for chemistry, Norway and Italy, are summarised in Table 2.1

All the analytical results have been processed using databases in Italy and Norway.

2.2.2 Analytical quality control

The analytical quality and the comparability of the chemical results obtained by the laboratories involved in the research were tested by yearly intercomparison exercises, carried out in 1991 and 1992 for AL:PE 1 and followed in 1993 and 1994 for AL:PE 2. The quality control programme of two exercises in AL:PE 1 and two exercises in AL:PE 2, was carried out by the CNR Istituto Italiano di Idrobiologia, Pallanza, Italy (CNR-III), and the Environment Institute of the European Joint Research Center, Ispra, Italy. The results are described in more details in Appendix 3 by Mosello, Marchetto, Muntau and Serrini.

Also NIVA has been running annual laboratory intercalibration exercises, in the framework of the International Cooperative Programme on Assessment and Monitoring of Rivers and Lakes (ICP Waters) under the UN Convention on Long-Range Transboundary Air Pollution. This has become a routine control of normal laboratory practice in the participating laboratories. The Youden method (two sample approach) is used to assess laboratory performance. Annual reports show how target accuracies are met for most ions in natural waters (Hovind, 1991 1992, 1993, 1994). The following analytical variables have been tested in the last four exercises:

9105 - pH, conductivity, alkalinity, nitrate + nitrite, chloride, sulphate, calcium, magnesium, sodium, potassium, and total organic carbon
9206 - pH, conductivity, alkalinity, nitrate + nitrite, chloride, sulphate, calcium, magnesium, sodium, potassium, aluminium, and dissolved organic carbon
9307 - pH, conductivity, alkalinity, nitrate + nitrite, chloride, sulphate, calcium, magnesium, sodium, potassium, total aluminium, reactive and non-labile aluminium, dissolved organic carbon, and chemical oxygen demand
9408 - pH, conductivity, alkalinity, nitrate + nitrite, chloride, sulphate, calcium, magnesium, sodium, potassium, total aluminium, dissolved organic carbon, and chemical oxygen demand

The participant AL:PE laboratories in the exercises carried out by the CNR-III and the Environment Institute of the European Joint Research Center, and /or NIVA were:

Norwegian Institute for Water Research, Oslo, (NO)
Laboratorio Biologico Provinciale, Laives, (IT)
CNR Istituto Italiano di Idrobiologia, Pallanza, (IT)
Freshwater Fisheries Laboratory, Faskally, Scotland (GB)
Department of Hydrobiology, Charles University, Praha (CS)
Czech Geological Survey, Praha (CS)
Hydrobiological Institute, Academy Sciences, Ceské Budějovice (CS)
Institute of Zoology, University of Innsbruck (A)
Department of Ecology, University of Barcelona (ES)
Department of Ecology, Universidad Autonoma Madrid (ES)
Instituto del Agua, University of Granada (ES)
Institute of Biology, Department of Freshwater Ecology, Ljubljana (SLO)
Institute of Ecology Problems, Kola Science Centre, Apatity (SU)
Institute of Ecology Industrial Areas, Katowice (PL)
Centro Ciencias Medioambientales, Madrid (ES)
Centre National de la Recherche Scientifique, Arcachon (FR)

2.2.3 Validation of results

Data validation was given special interest. Confidence in comparability between sites and countries was a basis for our work, and all participants needed to feel secure about the data presented, and relay completely on the reported results from others. In addition to the subjective check of the results thorugh looking for outliers and continuity where there are time series, the control was performed according to the following:

1. ionic balance
2. comparison between measured and calculated conducitvity

In particular the ionic balance is performed by a data programme made in two versions, the first including all ions, the second also including Al, NH_4 and TOC. The first set of equations are the following:

Sum anions : $SAN = ECl + ENO_3 + ESO_4 + ALK\text{-}E$

Sum cations : $SKAT = ECa + EMg + ENa + EK + EH+$

Difference cations/anions : $DIFF = SKAT - SAN$

Difference in % : $D\text{-}PRO = DIFF*100/SKAT$

E combined with the chemical component means that the component is given on an equivalent basis. For samples where analysis of Al, NH_4 and TOC are present, the second set of equations is used:

Sum anions : $SAN2 = SAN + AN-$

Sum cations : $SKAT\ 2 = SKAT2 + ELAL + ENH_4$

Difference cations/anions : $DIFF2 = SKAT2 - SAN2$

Difference in % : $D\text{-}PRO2 = DIFF2*100/SKAT2$

AN- is calculated from the TOC value taking into account week organic acids. The equation used is:

$AN- = 4.7 - 6.87 * \exp(-.332* TOC)$

The equation is based on empirical data from Norwegian sites. Tests have shown good agreement with analytical results. Other equations (Oliver *et al.* 1983) taking into consideration the pH-dependent dissociation of organic matter might also be used with minor differences.

In order to check the ionic balance, all of the necessary variables for calculating the sums of cations and anions must be analysed. For good analytical results, the difference in % between sum cations and anions should be <= 10%. To present the results from the ionic balance cheque in a clearly set out way, the sum of anions and cations are plotted against each other. For a perfect balance all results should be placed along the 1:1 line.

A further check of the ionic balance is made by comparing the measured conductivity to the conductivity calculated from the measured ions. Also a check of non marine Na (Na*) may indicate possible problems in Cl-analysis.

2.2.4 Calculating method for critical load of acidity to surface waters

Critical loads are used to express how much loading of a given pollutant natural environments can stand without being significantly harmed or changed.

Critical loads of airborne sulphur and nitrogen are a function of the amount of strong acid loading that result in changes of the chemical conditions of surface waters. These chemical changes may cause damage to biological indicators like freshwater fish and invertebrates. The chemical changes of surface waters are described as ANC (Acid Neutralising Capacity). ANC is used here as the difference in the sum of concentrations of base cations (calcium, magnesium, sodium and potassium) and the sum of anions of strong acids (sulphate, nitrate and chloride). Empirical links have been worked out between ANC and biological indicators. The critical value for biological damage is termed ANC_{limit}, and for freshwater organisms in Scandinavia the ANC_{limit} is set to 20 µeq/l (Lien *et al.* 1996).

Critical load (CL) and exceedance of critical load for sulphur (CL_{exS}), and sulphur plus nitrogen (CL_{exS+N}) are calculated according to the formulas:

$$CL = ([BC]^*_0 - [ANC_{limit}])\, Q - BC^*_d$$

$$CL_{exS} = SO_4{}^*_d - BC^*_d - CL$$

$$CL_{exS+N} = SO_4{}^*_d + NO_{3\ le} - BC^*_d - CL$$

$[BC]^*_0$ is the pre-acidification concentration of non - marine base cations in the surface water.
ANC_{limit} is the critical biological value (limit) for acid neutralising capacity of the water. 20 µeq/l is an acceptable ANC_{limit} for fish and invertebrates.
Q is the run-off from the catchment.
BC^*_d is the annual non - marine deposition of base cations.
$SO_4{}^*_d$ is the annual non - marine deposition of sulphate in the catchment.
$NO_{3\ le}$ is the annual leaching of nitrate from the catchment into the surface water.

For the AL:PE lakes critical load was estimated using an ANC_{limit} = 20 µeq/l. The deposition of base cations (BC^*_d) was set to 30 keq/km^2/year. The exceedance of critical loads was calculated for sulphur separately (CL_{exS}) and for sulphur plus nitrate together (CL_{exS+N}). Deposition of sulphur was used according to informations given from each AL:PE sites. Where no information was available, data from EMEP (Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe) was used.

2.3. Results

All the analytical results for the water samples taken within the AL:PE 2 project (during 1993 and 1994) are listed in Appendix 2. In table 2.2 mean values for each of the lakes are listed and grouped together after regions. In the following part of the report the water chemistry results are described in more detail for each of the lakes, again grouped after regions in Europe.

Svalbard

Arresjøen (9)

Arresjøen at Svalbard (Spitsbergen), is new in AL:PE 2. Arresjøen is situated beyond the timberline (79^O 40' N, 10^O 45'E), and is the northernmost site in the project. This arctic area has an extremely sensitive environment, and was especially chosen with the intention to prepare for studies of possible climate change. The calcium concentrations is low (Ca^{2+} 35 µeq/l), with seasalt ions being the main ions in the lake water, as the lake is situated close to the sea. In 1993 the mean pH of two samples was 5.81. SO_4^{2-} (32 µeq/l) and NO_3-N (close to 0) concentrations are low, and on the same level as for the AL:PE reference lake Øvre Neådalsvatn. Hg concentrations are elevated, again compared to the reference lake. Due to extraordinary weather conditions the sampling trip to Arresjøen, was impossible to carry through in the short ice free periode 1994, and the water chemistry results unfortunately are non-existing.

Kola, Russia

Chuna (17)

Chuna has pH values between 6.2 and 6.7 for 1993 and 1994, and the Ca^{2+} concentration is low (60 - 61 µeq/l). The geology of the Chuna tundra is gabbro with very low content of alkaline elements and not easily mobilised Ca^{2+} and Mg^{+}, resulting in low buffering capacity. Ni (< 1 µg/l) and SO_4^{2-} (42 - 47 µeq/l) concentrations reflect the negligible local effect to the atmospheric pollution of the local smelter. NO_3-N concentrations are fairly low (4 - 12 µeq/l). A small elevation of Hg, Pb, and Cd compared to the reference lake concentrations is found.

Chibini (18)

In Chibiny there are alkaline granites characterised by Na, K and Al geochemical association that favours reasonably quick neutralisation of acid precipitation. Chibini has followlingly a higher buffer capacity than Chuna, and pH values of 7.1 - 7.4. SO_4^{2-} concentrations are 55 - 58 µeq/l and representative for the area (Moiseenko, 1991, Moiseenko et al. 1994, 1995). NO_3-N concentrations are on the same level as central Europe (9 - 17 µeq/l).

Region summary - Kola

The results show that despite being close to the Severonickel smelter, local emissions affect only slightly the high mountain sites in Kola. Heavily polluted air masses do not raise high enough in the atmosphere to affect these lakes in the same way as registered for the lakes situated less than 200 m a.s.l. (Moiseenko, 1991). The water quality of the lakes are consistent with the average value for the region (SO_4^{2-} < 80 µeq/l). Thus the Chuna and Chibini reflects a real situation representative for airborne emissions for the whole Kola region which show higher concentrations of air-borne pollutants than the reference site. The acid sensitive Chuna mountains show sings of proceeding lake acidification. In Chibini the good buffer capacity protects the area against acidification (Moiseenko, 1994).

Norway

Øvre Neådalsvatn (1)

Øvre Neådalsvatn, situated in the part of Norway least affected by long-range transported air pollution, is chosen as the reference lake for the AL:PE project. Øvre Neådalsvatn is a large lake, with an area of 50 ha, lying above the tree line and remote from human activity. The underlying geology is of gneiss and the lakewater has a low Ca^{2+} concentration (Ca^{2+} 8-57 µeq/l). The area is naturally pristine, with little influence of acid rain and long-range transported air pollution. It fulfils the strongest AL:PE acid sensitivity criteria (criteria from AL:PE 1, see chapter 2.1), and is susceptible to acid deposition. The impression of a pristine and sensitive area is also reflected in the water chemistry, characterised by extremely low ionic strength. The main ions in the water are the seasalt ions, and all measured pH values lie between 5.9 and 6.45. Due to an other project in the same area, Øvre Neådalsvatn was sampled regularly through 1993 (n=10) and 1994 (n=28) for most of the parameters of interest also for this project. The mean pH for the 1993 samples was 6.16, and for 1994 the mean pH was 6.17. SO_4^{2-} and NO_3-N values are low. Mean values for 1993 and 1994 are 14 µeq/l and 18 µeq/l for SO_4^{2-} and ~1 µeq/l (10 - 21µg/l) for NO_3-N respectively. Background SO_4^{2-} values are estimated to 14 µeq/l (Henriksen *et al.*, 1988), while background nitrate should be close to 0 or 5 µeq/l as a maximum (Grennfelt & Thörnelöf, 1992). So the measured values confirms our reference site as pristine. In the area surrounding Øvre Nådalvatn is also a background station for the Norwegian Montoring Programme for Long-Range Transported Air Pollution (SFT 1994). Acid episodes in this area have been reported due to the influence of seasalts (SFT 1990).

Stavsvatn (2)

The second Norwegian site, Stavsvatn, is a large lake with an area of 40 ha, lying just above the tree line and with little human disturbance in the catchment. The underlying geology is of granite and the lakewater has a low Ca^{2+} concentration (40-50 µeq/l). Stavsvatn fulfils the strongest sensitivity AL:PE project criteria for a main site, and is susceptible to acid deposition. The lake is affected by acid rain, and the influence of acid deposition is seen from the relatively high contribution of SO_4^{2-} (concentrations of 37 and 33 µeq/l for 1993 and 1994) to the total amount of ions in the water samples. NO_3-N concentrations are ~3 µeq/l. The pH values for 1993 and 1994 respectively was 5.94 and 6.00.

Lille Hovvatn (3)

The third and southernmost Norwegian site, Lille Hovvatn, is an additional site and has a reduced total investigation programme. The lake is situated just below the tree line, and open forest of spruce, pine and birch is interspersed with peaty areas in the catchment. The granitic geology results in low lakewater Ca^{2+} (17-26 µeq/l). The water chemistry for Lille Hovvatn shows that the lake is strongly acidified, with all measured pH values for the years 1993 and 1994 below 5. The mean pH for 1993 and 1994 respectively, was 4.65 and 4.69. SO_4^{2-} makes a large contribution to the total amount of major ions. (SO_4*^{2-} concentrations of 58 µeq/l and 64 µeq/l for 1993 and 1994). Nitrate concentrations are high to be a Norwegian site, but not high compared to central Europe (NO_3-N concentrations of 11 µeq/l and 12 µeq/l for 1993 and 1994). The short distance to the sea is reflected in the seasalt concentrations, which also have a large contribution to the major ion total. Heavy metal analysis show an elevated Pb value compared to the reference site.

Region summary - Norway

In Norway the three sites studied in the AL:PE 2 project, are to a different extent affected by long-range transported air pollution and acid deposition. The northernmost, Øvre Neådalsvatn serves as a reference lake for the whole AL:PE study, is naturally pristine and acid sensitive. The water chemistry is characterised by extremely low ionic strength. Moving along the "pollution gradient", the next

Norwegian lake Stavsvatn, is also sensitive and susceptible to acid deposition. This lake is affected by long-range transported air pollution, and the influence of acid deposition is seen from the relatively high contribution of SO_4^{2-}. The southernmost Norwegian lake Lille Hovvatn is an additional site in the AL:PE programme and is strongly acidified. Buffering capacity in the area is low, and all measured pH values for the years 1993 and 1994 are below 5. Both SO_4^{2-} and NO_3-N concentrations are higher than the values measured in Stavsvatn. Also the measured Pb concentration is elevated compared to the reference site.

British Isles

Lochnagar (4.1)

Three of the AL:PE lakes in the United Kingdom are located within a small area in Aberdeenshire, N. E. Scotland. The primary site in the area is Lochnagar, a corrie lake lying above the tree line, having a small catchment with minimal anthropogenic disturbance. The granitic geology and resulting low lakewater Ca^{2+} concentration (Ca^{2+} 25-48 μeq/l) indicate that this lake is susceptible to acid deposition, a sensitive site fulfilling the strongest AL:PE project sensitivity criteria. Mean pH values for 1993 and 1994 respectively was 5.32 and 5.25. Due to the relatively short distance to the sea, the seasalts are dominant ions, but there is a marked contribution from SO_4^{2-} (mean values for 1993 and 1994 are 58 μeq/l and 57 μeq/l). NO_3-N concentrations are 18 μeq/l and 22 μeq/l as mean values for 1993 and 1994. Heavy metal analysis show an especially high Pb value, but also Cd is high compared to the reference site.

Sandy Loch (4.2)

Sandy Loch is one of the two additional lakes in the same region as Lochnagar. It is also a corrie lake lying above the tree line. The granitic geology and resulting low lakewater Ca^{2+} concentration (Ca^{2+} 30-51 μeq/l) indicate that this lake is susceptible to acid deposition, a sensitive site fulfilling the strongest AL:PE project sensitivity criteria. Mean pH value for 1993 was 6.09 and in 1994 the registered value was 5.05. Seasalts and SO_4 (54 μeq/l and 53 μeq/l as mean values for 1993 and 1994) are dominant ions. NO_3-N concentration is 8 μeq/l as mean value both for 1993 and 1994. The sample analysed for heavy metals show a concentration of Hg higher than the at the reference site.

Loch Nan Eun (4.2)

The third lake in the Lochnagar region is Loch Nan Eun. This lake, lies above the tree line, is susceptible to acid deposition and has low Ca^{2+} values (20 μeq/l). Loch Nan Eun is acidified, and all pH values were below 5.5. Mean pH value for the 1993 samples was 5.40, and the 1994 value was 5.05. Seasalts and SO_4^{2-} (48 μeq/l and 49 μeq/l as mean values for 1993 and 1994) were dominant ions. NO_3-N concentrations are 9 μeq/l and 19 μeq/l as mean values for 1993 and 1994. Both Pb and Cd show elevated values compared to the reference lake values.

Lough Maam (10)

Lough Maam is situated in Donegal, north-west Ireland at an altitude of 436 m. The catchment is granite and is mainly covered by blanket peat. Like the Svalbard site, Lough Maam was especially chosen bearing in mind the future studies of possible climate change. The lake is acidified, with mean pH value for 1993 of 4.96. Also here the seasalt are dominating ions due to the short distance to the sea. Marine influence is also seen on the sulphate concentrations. The SO_4^{2-} concentration is 61 μeq/l, but the seasalt corrected sulphate ($SO_4{}^{*2-}$) concentration of 20 μeq/l is low, and of the same magnitude as in the reference site. The water chemistry results for 1994 from Lough Maam unfortunately was lost due to EDB problems at the local laboratory where some data were destroyed. The sample analysed for Hg show a small elevation compared to the reference site.

Region summary - British Isles

The AL:PE lakes in Scotland, situated in the same watershed, are all sensitive to acidification with water of low buffering capacity. In all three lakes there is a marked contribution from SO_4^{2-}, but also seasalt concentrations are high, as the distance to the sea is relatively short. The NO_3-N concentrations are on the medium level compared to central Europe. Heavy metal analysis show elevated values for Pb, Cd and Hg in the area compared to the reference site.

The site in north-west Ireland is also acidified, but here the SO_4^{*2-} (seasalt corrected SO_4^{2-}) is as low as for the reference site, and Na^+ and Cl^- are the dominating ions. The sample analysed for Hg show a small elevation compared to the reference site.

Iberia

La Caldera (13)

La Caldera in Sierra Nevada shows high values for Ca^{2+}, (and alkalinity) and pH. The lake has a high buffering capacity protecting against acidificaiton. Also total nitrogen (and the relation TN/TP) is high, but SO_4^{2-} is relatively low (19 µeq/l and 27 µeq/l as mean values for 1993 and 1994). The observed decrease of pH and nitrate along the ice-free period is a dominant (and persistent) feature of the lake (Carrillo, 1989) and the increase in the concentration for most of the other parameters, linked to the seasonal variation, are probably related to the total mineral concentration due to an extreme water volume reduction by infiltration processes. Pb and Cd values are elevated, and also a small elevation of Hg is registered when results are compared to the reference lake.

Lagoa Escura (14)

Lagoa Escura in Sierra de Estrela is an acidified lake (pH 5.3, alkalinity 16 µeq/l). The lake has a higher content of Mg^+ (18 µeq/l and 23 µeq/l) than Ca^{2+} (12µeq/l) and SO_4^{2-} (22 µeq/l and 14 µeq/l) when comparing mean values for 1993 and 1994. This suggests that the acidity can come from natural oxidation of minerals containing sulphides. Also the SO_4^{2-} concentration is of the same magnitude as for the reference site. The water chemistry results for Lagoa Escura in 1994 were consistent with data gathered in 1993, with only minor differences that can be attributed either to analytical accuracy or to a slightly low interannual variability. Lagoa Escura was at the border of acidification, showing null acid neutralising capacity and pH according to that value (pH 5.3-5.5). Nitrate concentration was below detection levels. Lagoa Escura was slightly more productive than the Pyreneen lakes, as was shown by its consistently higher total phosphorus value. Lower altitude and more frequented catchment are probably sufficient to explain this fact. Marine influence was highly apparent in L. Escura with Cl^- being 5-fold higher than in the Spanish Pyrenean lakes. According to those levels of Cl^-, it can be assumed that practically all Na^+ was from marine origin, and that catchment provided scarce concentrations of Ca^{2+}, Mg^+ and SO_4^{2-}, in proportions that did not lead to a positive alkalinity. Therefore, L. Escura, and lakes in Serra d'Estrela in general are highly sensitive to acidification. A slightly acid deposition can lead to a net acidification of their waters. The highest Hg value recorded in the project was found in Escura, when the heavy metal sample was analysed.

Laguna Cimera (16)

Laguna Cimera is situated in Central Spain, in Gredos Mountains, and was not originally in the AL:PE project. The results from this lake was brought into the project through cooperation, and financed through a Spanish national programme. The catchment is granitic and has rocks and debris with small alpine meadows. The water shows low buffering capacity with low Ca^{2+} concentrations (mean values for Ca^{2+} for 1993 and 1994 were 14 µeq/l and 9 µeq/l). Mean pH values for 1993 and 1994 were 5,97 and 5,69 respectively. SO_4^{2-} (11 µeq/l and- 17 µeq/l as mean values for 1993 and 1994) concentrations are very low and about the same as in the reference lake Øvre Neådalsvatn.

Region summary - Iberia

The three lakes scattered over the Iberia peninsula show some differences in their water chemistry, but seems generally less affected by long-range transported air pollution than central Europe. Both SO_4^{2-} and NO_3^- concentrations are low compared to more central mountain sites. La Caldera has high buffering capacity and are not expected to suffer from acidification problems. Laguna Cimera seems to be almost as unaffected and pristine as the reference lake with respect to pollution. Lagoa Escura is an acidified lake but the water chemistry suggests that the acidity can come from natural oxidation of minerals containing sulphides. With respect to heavy metals, La Caldera show elevated values for all three measured components, Pb, Cd, and Hg, and Escura show an especially high Hg concentration.

Pyrenees

Étang d'Aubé (8)

Étang d'Aubé is a corrie lake lying well above the tree line, and with minimal anthropogenic disturbance in the catchment. The granitic geology and resulting low lakewater Ca^{2+} concentration (24 - 32 µeq/l) would suggest that this lake is susceptible to acid depostion. The pH values for the yearly samples in 1993 and 1994 were 6.06 and 6.11 respectively. SO_4^{2-} concentrations are low, and almost at the same level as the reference lake Ø. Neådalsvatn. NO_3-N concentrations are more close to a medium range. (Values for 1993 and 1994 are 26 µeq/l and 17 µeq/l for SO_4^{2-} and 9 µeq/l and 16 µeq/l for NO_3-N.) The Hg value is elevated compared to the reference lake.

Lago Aguiló (12.1)

Aguiló is located in the Bassiers batholith in the Spanish Pyrenees. Aguiló is acid sensitive but not acidified (1993 and 1994 show pH 5.8 - 6.10, Ca^{2+} 22 µeq/l - 18 µeq/l and alkalinity 11 µeq/l - 18 µeq/l). The lake water concentrations are generally low for all compounds, as Cl^-, SO_4^{2-} and NO_3-N^- (SO_4^{2-} concentrations are 15 µeq/l and 13 µeq/l and NO_3-N 3 µeq/l and 2 µeq/l). Total phosphorus (TP) in Aguiló is 5 µg/l, and TOC is 0.59 mgC/l. The the acidity loading through deposition is higher in the Pyrenees than in Iberia, as reflected in the higher nitrogen content in those lakes. Higher nitrate levels in Pyrenean lakes may suggest an on-going acidification process that until now have been compensated by catchment and in-lake alkalinity production, and dust deposition. Its future evolution is difficult to foresee, and merits a more detailed study including direct deposition measurement and catchment and lake chemical modelling. The Hg value for Aguiló is elevated compared to the reference lake.

Estany Redó (12.2)

Redó has pH of 6.3 and 6.69 for 1993 and 1994 respectively. Redó is located on Maladeta batholith, which has a higher weathering rate and contains the largest number of lakes in the Pyrenees. SO_4^{2-} and NO_3-N concentrations are in the low to medium range.Yyearly mean values for 1993 and 1994 are 31 and 23 µeq/l for SO_4^{2-} and 14 and 11 µeq/l for NO_3-N. Total phosphorus (TP) is 9 µg/l, and TOC is 0.63 mg/l.

Region summary - Pyrenees

None of the Pyreneen lakes are acidified. On the Spanish side Lago Aguiló and Estany Redó show some differences in the chemical composition. In this sense, they are representative of the lakes of the two different granodiorite batholiths where they are located, as it was shown in a previous extensive study on the chemistry of the Pyrenean lakes. Maladeta batholith, where Redó is located and which contains the larger number of lakes in the Pyrenees, has a higher weathering rate than Bassiers batholith where Aguiló is located. Water in this latter lake is also more diluted, even in compounds not related with rock weathering, such as Cl^- and NO_3-N^-. Compared to Lagoa Escura in Sierra da Estrela, central Iberia, which was at the border of acidification, the differences are likely to result from weathering properties of the basin bedrock rather than from differences in the acidity loading through deposition. The latter seem to be higher in the Pyrenees as reflected in the higher nitrogen content in those lakes. Higher NO_3-N levels in Pyrenean lakes compared to the Iberian may suggest an on-going acidification process that until now have been compensated by catchment and in-lake alkalinity production, and dust deposition. Its future evolution is difficult to foresee, and merits a more detailed study including direct deposition measurement and catchment and lake chemical modelling. The Hg values both for Étang d'Aubé and Aguiló (French and Spanish side) is elevated compared to the reference lake.

Alps

Lago Paione Superiore (5.1)

Paione Superiore is a small lake (86 ha), lying above the tree line in the Western Italian Alps, with no human disturbance in the catchment. The underlying geology is of gneiss and the lakewater has a low Ca^{2+} concentration (36-51 µeq/l). The alkalinity is close to zero, and the lake has a mean 1993 and 1994 pH of 5.64 and 5.84 respectively. Paione Superiore fulfils the strongest AL:PE 1 project sensitivity criteria and is susceptible to acid deposition. The dominant anions are SO_4^{2-} and NO_3-N. (Mean values for 1993 and 1994 are 46 µeq/l and 36 µeq/l for SO_4^{2-} and 25 µeq/l and 21 µeq/l for NO_3-N.) The heavy metal analysis show elevated concentrations for Pb, Cd and Hg.

Lago Paione Inferiore (5.2)

Close to the Paione Superiore, in the same watershed, Paione Inferiore is situated at a lower altitude. The water chemistry shows relatively high Ca^{2+} values (67-88 µeq/l), higher than Paione Superiore, resulting in higher buffering capacity and resistance to acidification. This is also reflected in the higher pH values for Paione Inferiore, mean values for 1993 and 1994 were 6.43 and 6.53 respectively (alkalinity values of 25 - 27 µeq/l). The dominating anions are SO_4^{2-} and NO_3-N (mean values for 1993 and 1994 are 53 µeq/l and 49 µeq/l for SO_4^{2-} and 27 µeq/l and 26 µeq/l for NO_3-N.) Cd and Hg concentrations are elevated compared to the reference lake values.

Lago Lungo (6.1)

Lago Lungo is a medium sized lake (20 ha) in the group of AL:PE lakes with underlying geology of gneiss. It is located in the Eastern Italian Alps. The lakewater has a rather higher Ca^{2+} concentration (65 - 108 µeq/l) compared to the other AL:PE primary sites. The mean 1993 and 1994 pH values were 6.43 and 6.17 respectively (alkalinity values 27 - 30 µeq/l). The dominant anions in the lakewater were SO_4^{2-} and NO_3-N (mean values for 1993 and 1994 are 70 µeq/l and 60 µeq/l for SO_4^{2-} and 14 µeq/l and 16 µeq/l for NO_3-N). The chemistry of Lago Lungo indicates that the site has a some, but low buffering capacity giving resistance to acidification. Cd concentration is elevated compared to the reference lake.

Lago di Latte (6.2)

Lago di Latte (Milchsee) is a small corrie lake, lying above the tree line in the Eastern Italian Alps, with minimal human disturbance in the catchment. The underlying geology is of gneiss and the lakewater has a higher Ca^{2+} concentration (Ca^{2+} 92 - 108 µeq/l) than the main group of AL:PE 1 primary sites investigated. The 1993 and 1994 mean pH values were 6.60 - 6.35 (alkalinity values 51-53 µeq/l). Lago di Latte fulfils some AL:PE project criteria in that it is a remote and undisturbed site, however lakewater chemistry suggests that the site has some buffering capacity and would be unlikely to show the most marked response to acid deposition. (Mean values for 1993 and 1994 are 23 µeq/l and 22 µeq/l for SO_4^{2-} and 59 µeq/l and 56 µeq/l for NO_3-N.) Also for Lago di Latte was the Cd value elevated compared to the reference lake.

Lac Blanc (7.3)

Lac Blanc is a small lake situated above the tree line in the French Alps. The Ca^{2+} concentration of the lake is 75 - 150 µeq/l, indicating that the lake water has some buffering capacity and not likely to give the most marked response to acid deposition. Mean pH for 1993 was 6.88, and one sample from 1994 gave as result pH of 7.02. SO_4^{2-} and NO_3-N concentrations are in the medium range compared to the other AL:PE lakes (mean values for 1993 and 1994 are 15 µeq/l and 27 µeq/l for SO_4^{2-} and 10 µeq/l and 14 µeq/l for NO_3-N).

Lac Noir (7.4)

Lac Noir is a small lake situated above the tree line in the same area as Lac Blanc. Compared to the other AL:PE sites, the Ca^{2+} concentration of the lake is 125 - 170 µeq/l, indicating as for Lac Blanc, that the lake water has good buffering capacity. Mean pH for 1993 was 7.08, and one sample from 1994 gave as result pH of 7.09. (Mean values for 1993 and 1994 are 24 and 67 µeq/l for SO_4^{2-} and 9 µeq/l and 11 µeq/l for NO_3-N.) Tot P (31 µg/l) is high compared to the other AL:PE lakes, and also high compared to Lac Blanc (3 - 6 µg/l) in the same area. The Tot-P values are indicating some local influence. The Pb value is elevated compared to the reference lake.

Schwarzsee ob Sölden (11)

Schwarzsee ob Sölden (SOS), a new lake in AL:PE 2, is situated at 2799 m a.s.l. in the Austrian Oetztaler Alps, is a softwater lake with low alkalinity (<10 meq/l) in surface waters. However, it has considerable acid neutralising capacity in the hypolimnion which generally becomes anoxic during winter stratification. SOS is, according to our knowledge, the highest fish-bearing lake in the Alps with information on the fish status for several decades. The Ca^{2+} concentration is low (42 - 75 µeq/l), and mean pH values for 1993 and 1994 are 5.56 and 5.60 respectively. Water chemistry samples have been taken monthly for SOS. The SO_4^{2-} concentrations (mean values for 1993 and 1994 of 70 µeq/l and 86 µeq/l) are among the highest registered in the AL:PE project, and also the Hg concentration seem high (68 ng/l) compared to the reference lake.). NO_3-N concentrations are 13 µeq/l and 11 µeq/l as mean values for 1993 and 1994.

Zgornje Krisko Jezero (19)

Zgornje Krisko Jezero is situated in Triglav National Park in the Julian Alps (NW Slovenia) at an altitude of 2150 m a.s.l. In the AL:PE group this lake is special because it is situated in limestone deposits and therefore also has high Ca^{2+} values (660 - 744 µeq/l), and it was included into the AL:PE 2 project through the PECO programme as a reference lake for the study of effects of climate change. pH values are naturally high (7.66 - 7.86), and also SO_4^{2-} concentrations show high values (146 µeq/l and 100 µeq/l as mean values for 1993 and 1994). NO_3-N (8 µeq/l and 10 µeq/l as mean values for 1993 and 1994) concentrations are in the lower area compared to central Europe. A small elevation of Hg compared to the reference lake concentration is found.

Region summary - Alps

The Alps, being centrally placed in Europe, are markedly exposed to long-range transported air pollution, but differences are registered within the area. When comparing the lakes analysed in this project, the acid sensitivity is highest in the western Italian Alps and the Austrian lake Schwarzsee ob Sölden (SOS). SO_4^{2-} concentrations are highest in the eastern part of the Italian Alps together with Schwarzsee ob Sölden. The Slovenian site is rather special in the AL:PE group, because of the high Ca^{2+} and SO_4^{2-} concentrations due to the bedrock in the area. NO_3-N concentrations in the Italian Alps area are among the highest measured in the project, in fact the values measured in the western Italian Alps are the 2nd highest after the lakes in the Tatra Mountains. The Tot-P values are generally low for the whole area, except for Lac

Noir where the high Tot-P values are indicating some local influence. The heavy metals concentration in the area as a whole show higher values than those of the reference site.

Tatra Mountains

Starolesnianske pleso (15.1)

Starolesnianske pleso is a strongly acidified lake situated at 2000 m a.s.l. in High Tatra Mountains. The vegetation cover is alpine meadow and bare rocks. Ca^{2+} concentrations are low (39 - 29 µeq/l), resulting in low buffer capacity. Mean pH vales for 1993 and 1994 were 4.80 and 4.69 respectively. SO_4^{2-} concentrations are high (74 µeq/l and 52 µeq/l mean values for 1993 and 1994). NO_3-N concentrations are in the medium range compared to the other European lakes, but low compared to the other Tatra lakes (mean values for 1993 and 1994 of 12 µeq/l and 11 µeq/l). Especially Pb and Hg, but also Cd show high concentrations in Starolesnianske pleso.

Terianske pleso (15.2)

Terianske pleso is situated close to the Starolesnianske pleso in the Slovak Tatra Mountains. Ca^{2+} concentrations are higher than for Starolesnianske pleso (159 µeq/l - 143 µeq/l), resulting in some buffer capacity and higher pH values. Mean pH vales for 1993 and 1994 were 6.86 and 6.40 respectively. Also here the SO_4^{2-} concentrations are high (68 µeq/l and 55 µeq/l as mean values for 1993 and 1994). NO_3-N concentrations (mean vales for 1993 and 1994 of 39 µeq/l and 31 µeq/l) are especially high and in the same range as the Polish Tatra lakes. A small elevation of Cd is registered when the value is compared to the reference lake.

Dlugi Staw (15.3)

Dlugi Staw is situated at 1783 m a.s.l. on granitic bedrock. The Ca^{2+} concentration is 73 - 173 µeq/l. Despite the following buffering capacity, the lake is acidified. Mean pH values for 1993 and 1994 were 5.96 and 5.95. Both for 1993 and 1994 the two Polish lakes have been sampled biweekly through the year due to other project work in a Polish Norwegian cooperative programme. Both SO_4^{2-} and NO_3-N concentration in this area are high. Mean values for 1993 and 1994 are 77 and 74 µeq/l for SO_4^{2-} and 56 and 51 µeq/l for NO_3-N, respectively. Cd is somewhat elevated and Hg show a very high value in the one sample taken for the heavy metal analysis from Dlugi Staw.

Zielony Staw (15.4)

Zielony Staw Gasienicowy, is situated at 1617 m a.s.l. in the same watershed as Dlugi Staw, and also on granitic bedrock. The vegetation cover is slide rock, dwarf pine and alpine meadows. The Ca^{2+} values are higher than for Dlugi Staw (125 µeq/l - 197 µeq/l), giving buffering acpacity, and the mean pH is also higher. For 1993 and 1994 the mean pH values are 6.61 and 6.57 respectively. The nitrate values are high with mean values for 1993 and 1994 of 35 and 51 µeq/l. SO_4^{2-} concentrations are 76 µeq/l and 72 µeq/l as mean values for 1993 and 1994. Also for Zielony Staw high concentrations of Hg and Cd compared to the reference lake, were found.

Region summary - Tatra Mountains

The Tatra Mountains seem to be the region most heavily exposed to air pollution of all the regions in the project. The four lakes in the Tatra Mountains all show high SO_4^{2-} concentrations, and with the exception of Starolesnianske pleso they also show very high NO_3^- concentrations. In fact they show the highest NO_3^-concentrations measured in the project. The area as a total shows elevated values also for the heavy metals Hg, Cd and Pb. The Polsih side of the mountains seem to be highest exposed for air pollution, with the highest concentration of SO_4^{2-}, NO_3^- and Total nitrogen (TN).

Table 2.2. Water chemistry mean values for the AL:PE 2 lakes grouped together after regions.

Lake n°	Site/lake	Mean period	pH	Cond µS/cm 20°C	Cond mS/m 25°C	NH4 (µgN/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Alk (µeq /l)	SO4 (mg/l)	SO4* (mg/l)	NO3 (µgN/l)	Cl (mg/l)	F (µg/l)	TN (µgN/l)
9	Arresjøen	1993	5,81	37,55	3,76	5	0,71	0,59	4,76	0,24	24	1,55	0,40	<1	8,25	<0.1	94
17	Chuna	93-94	6,50	16,05	1,61	19	1,32	0,23	0,78	0,13	49	2,13	1,99	110	1,03		245
18	Chibini	93-94	7,18	29,60	2,96	5	0,88	0,10	4,52	1,15	183	2,72	2,61	177	0,76		190
1	Ø. Neådalsvatn	91-94	6,26	8,30	0,83	5	0,46	0,11	0,80	0,14	23	0,72	0,58	10	0,99	<0,1	64
2	Stavsvatn	91-94	5,96	9,94	0,99	11	0,86	0,12	0,53	0,09	21	1,81	1,72	40	0,68	0,74	111
3	L. Hovvatn	91-94	4,63	27,22	2,72	51	0,45	0,19	1,56	0,11		2,98	2,36	140	2,70	<0,1	110
4.1	Lochnagar	91-94	5,38	22,32	2,23	56	0,65	0,39	2,12	0,23	9	2,86	2,42	229	3,13	20,00	400
4.2	Sandy Loch	91-94	5,77	18,80	1,96	60	0,87	0,32	2,06	0,19	26	2,64	2,30	122	2,41	<0,1	390
4.3	L. Nan Eun	91-94	5,23	14,54	11,33		0,63	0,34	2,49	0,17	5	2,35	1,80	213	3,95		
10	L. Maam	1993	4,96	59,50	5,95		0,81	0,76	7,84	0,37	7	2,93	0,98	46	13,89	<0,1	285
13	La Caldera	93-94	7,69	29,18	2,92	62	4,77	0,47	0,35	0,14	114	1,20	1,06	45	0,95		263
14	L. Escura	93-94	5,36	12,15	1,22	7	0,25	0,25	0,69	0,14	1	0,86	0,69	1	1,20		
16	Laguna Cimera	93-94	5,83	5,85	0,59		0,44	0,14	0,59	0,04	21	0,68	0,64	141	0,33		116
8	Etang d'Aube	91-94	6,10	8,51	0,85	44	0,65	0,07	0,48	0,21	22	1,16	1,09	154	0,49		415
12.1	L. Aguilo	93-94	5,95	5,90	0,59	7	0,41	0,14	0,20	0,07	15	0,68	0,65	36	0,21		
12.2	L. Redo	93-94	6,51	12,05	1,21	11	1,46	0,16	0,22	0,08	43	1,30	1,27	175	0,23		
5.1	L.Paione S.	91-94	5,67	9,81	0,98	46	0,89	0,09	0,21	0,26	3	1,96	1,94	326	0,13		402
5.2	L.Paione Inf.	91-94	6,45	13,03	1,30	8	1,55	0,15	0,31	0,34	27	2,50	2,48	378	0,14		417
6.1	Lago Lungo	91-94	6,34	13,49	1,38	38	1,58	0,18	0,35	0,27	32	3,17	3,15	239	0,16		346
6.2	Lago di Latte	92-94	6,47	14,65	1,51	33	1,83	0,15	0,36	0,35	49	2,76	2,74	332	0,13		415
7.3	L.Blanc	92-94	7,15	15,79	1,58	15	2,39	0,22	0,29	0,35	138	1,16	1,14	175	0,10	135,00	227
7.4	L.Noir	92-94	7,17	21,14	2,12	4	2,90	0,42	0,32	0,19	113	2,93	2,92	139	0,15	44,00	183
11	Schwarzsee ob S.	93-94	5,58	14,47	1,45	17	1,19	0,25	0,33	0,13	4	3,75	3,73	166	0,10	4,79	
19	Krisko jezero	93-94	7,73	93,03	9,30	17	14,95	0,80	0,83	0,29	647	5,90	5,90	126	0,20	0,10	483
15.1	Starolesnianske pl.	93-94	4,74	14,75	1,46	27	0,68	0,08	0,09	0,09		3,04	3,02	412	0,14	0,01	372
15.2	Terianske pleso	93-94	6,63	19,98	2,01	7	3,03	0,10	0,33	0,14	65	2,96	2,93	488	0,18	0,02	556
15.3	Dlugi Staw	93-94	5,97	20,17	2,02	14	2,38	0,13	0,37	0,14	8	3,65	3,65	746	0,27	<0,1	794
15.4	Zieloni Staw	93-94	6,60	12,61	1,16	27	2,86	0,18	0,43	0,17	62	3,59	3,54	541	0,27	<0,1	619

2.4. Overall comparison between sites and discussions

2.4.1 Quality control

All the AL:PE lakes have been sampled at least once a year for water chemistry. Most of the lakes have been sampled more often than annually, although they are not easily reachable. Results of the analytical quality controls (AQC), as described in section 2.2.3, are shown in figure 2.1a and 2.1b, where the sum of anions and cations are plotted in comparison with the 1:1 line.

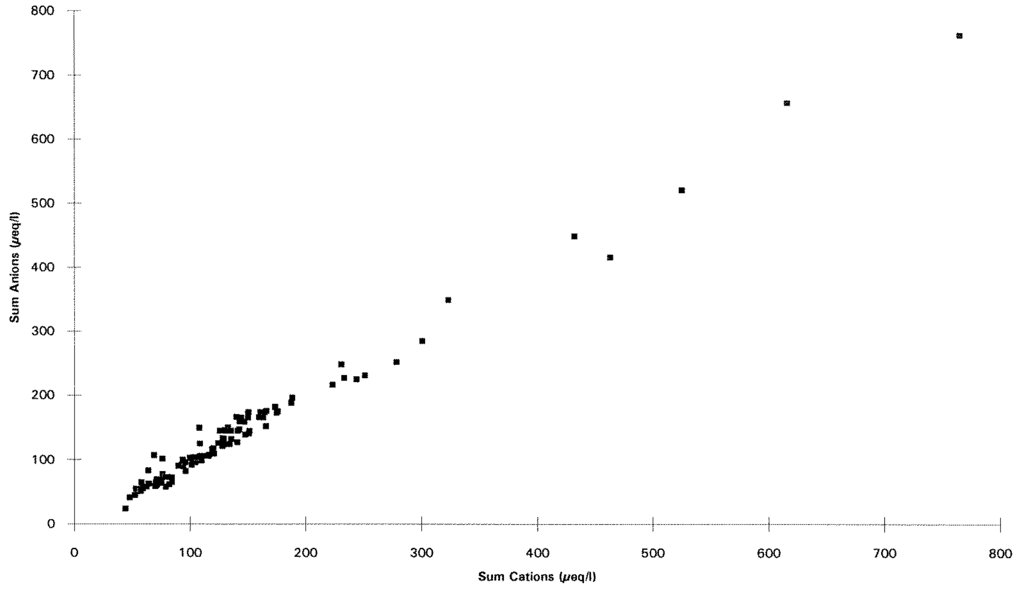


Figure 2.1a. Sum of cations plotted against anions for the 1993 data.

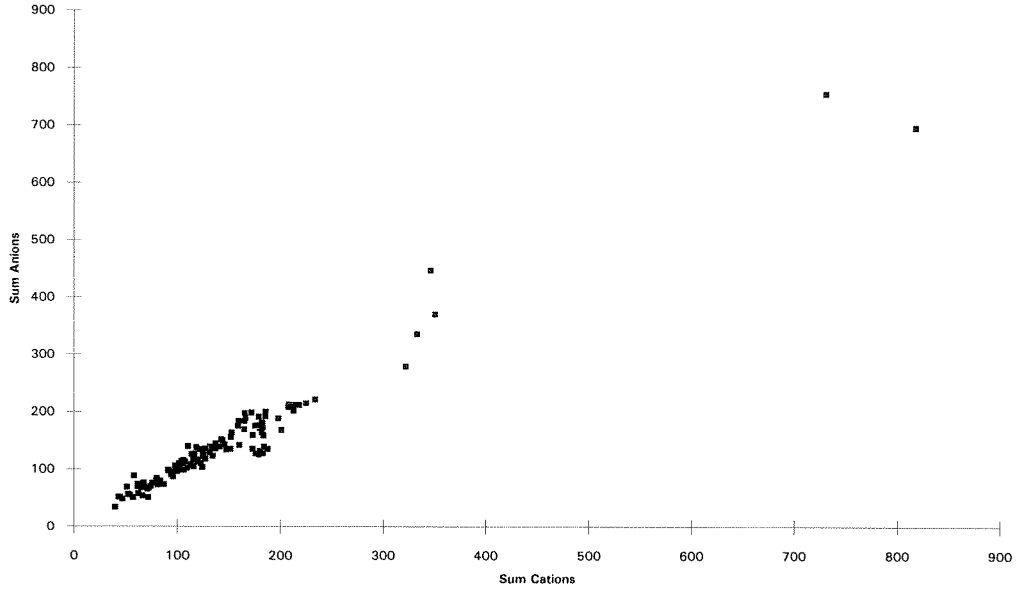


Figure 2.1b. Sum of cations plotted against anions for the 1994 data.

Also the AQC based on the comparison of measured and calculated conductivity (Fig. 2.2a and b) gives satisfactory results.

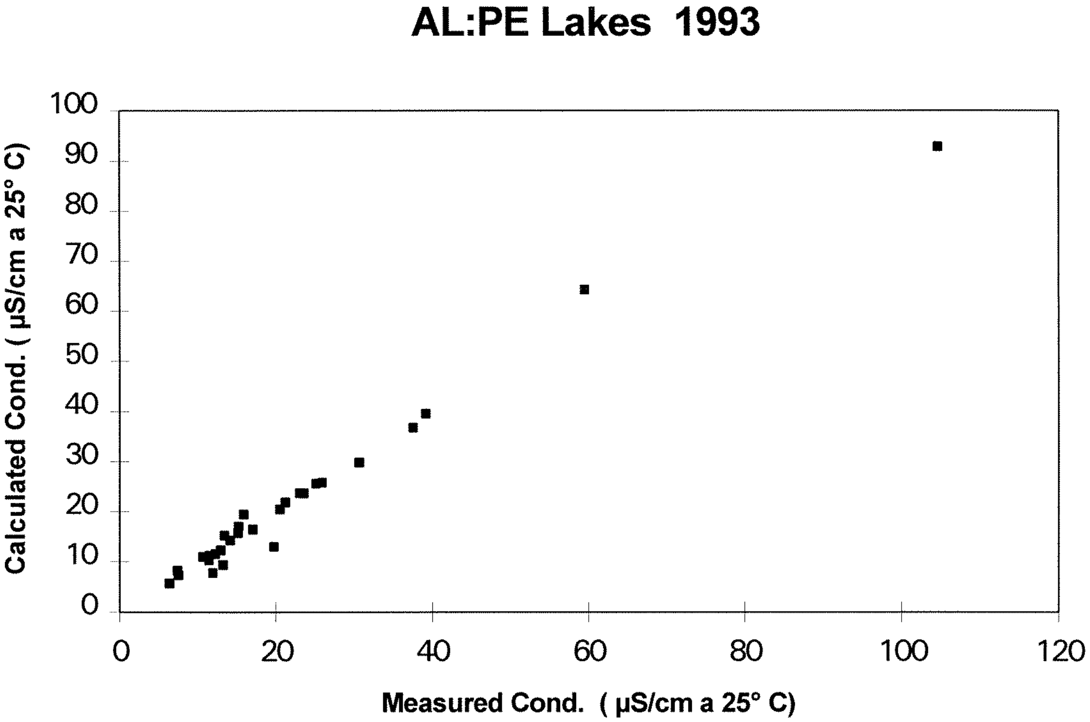


Figure 2.2a. Comparison between measured and calculated conductivity for the 1993 mean values.

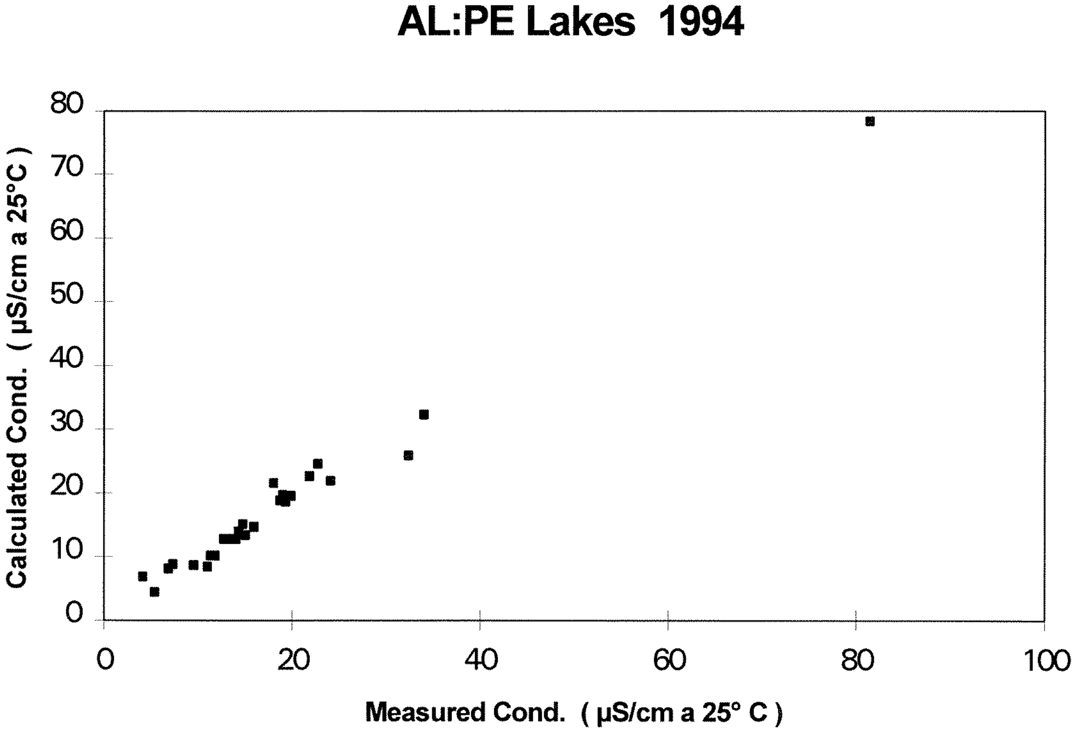


Figure 2.2b. Comparison between measured and calculated conductivity for the 1994 mean values.

2.4.2 Water chemistry

To give an impression of the pollution status of the different lakes and a comparison between the sites with regard to the water chemistry results, the yearly mean lakewater values for pH, SO_4^{2-}, Ca^{2+}, base cations and NO_3-N for 1993 and 1994 are shown in Figures 2.3 - 2.12. Also the heavy metal concentrations are shown in Figures 2.13 - 2.16. All the detailed water chemistry data are shown in Appendix 2.

The yearly mean pH values (Fig. 2.3) range from 4.65 and 4.69 (1993 and 1994) in the most acid Lille Hovvatn to 8.05 and 7,33 (1993 and 1994) in Caldera in the Spanish Sierra Nevada and 7.76 (1994) in Zgornje Krisko Jezero in Slovenia. The results also show the acid gradient in Norway from the unpolluted Øvre Neådalsvatn with pH values 6.37 and 6.32 (1993 and 1994) via the moderately exposed Stavsvatn (pH 5.94 and 6.00) to Lille Hovvatn (pH 4.65 and 4.69), the site in the area most heavily exposed to acid rain. The high pH values in La Caldera and Z. Krisko Jezero result from high base cation concentrations in the lakewater, especially high Ca^{2+} concentrations, as shown in Figures 2.4 and 2.5.

In AL:PE 1 the strongest criteria with respect to acid sensitivity would require sites with lakewater Ca^{2+} concentrations of 50 μeq/l (1 mg/l) or less, and these sites were selected as primary AL:PE sites. For AL:PE 2 this criterion was somewhat modified, due to a wish of working sites with a broader biological spectrum combined with the wish to identify unpolluted sites in Europe suited for studies of climate change. The Ca^{2+} concentrations in the AL:PE lakes are still of great interest and are shown in Figures 2.5 and 2.6. Because of the high Ca^{2+}concentrations in Zgornje Krisko Jezero, a Figure (2.6) was made, which excludes this lake.

In Figure 2.7 the SO_4^{2-} concentrations for the AL:PE lakes are shown. Again the acid gradient in Norway from Øvre Neådalsvatn to Lille Hovvatn is clear. It is also seen that high SO_4^{2-} values may be found in high mountain lakes in all the countries represented in the AL:PE project. The SO_4^{2-} concentrations in Zgornje Krisko Jezero, the Polish Tatras (Dlugi Staw and Zielony Staw) and Italian/Austrian Alps show the highest values registered (mean values from 1993 and 1994 in the area 70 - 100 μeq/l or 3.35 - 4.80 mg/l). Likely in the case of the Zgornje Krisko Jezero there is a contribution of sulphate from the weathering of the watershed, mainly composed by calcareous rocks.

Lac Noir in the French Alps also shows high SO_4^{2-} values in 1994 (as in 1992 which is reported in the AL:PE 1 report), while the nearby lake Lac Blanc show lower values (see Fig. 2.7). It is reported from the French group that sampled the lakes, that Noir has tributaries from springs and small brooks, while Blanc mostly receive its inputs from melting ice and snow. This suggests that the high SO_4^{2-} values in Lac Noir are results from parts of the geology in the watershed or geological bands where the springs have their origin, while the concentrations of Lac Blanc are more representative for the atmospheric deposition in the area.

The lowest SO_4^{2-} values are found as expected, in the reference site Øvre Neådalsvatn, but apart from the reference site, the French and Spanish Pyréneé sites (Étang d'Aubé, lakes Aguilo and Redo) show the lowest values, with the Lac Blanc in the French Alps almost at the same low level.

SO_4^{2-} and Cl^- are shown together in Figure 2.8a and b. The Cl^- concentrations indicate the distance from the sea and the seasalt influence at the different sites, and it is clearly seen that Arresjøen and Lough Maam are situated close to the sea. Also Nan Eun seems to have high mean Cl^- concentration for 1993, due to one sample from May which shows high values both for Na^+ and Cl^-.

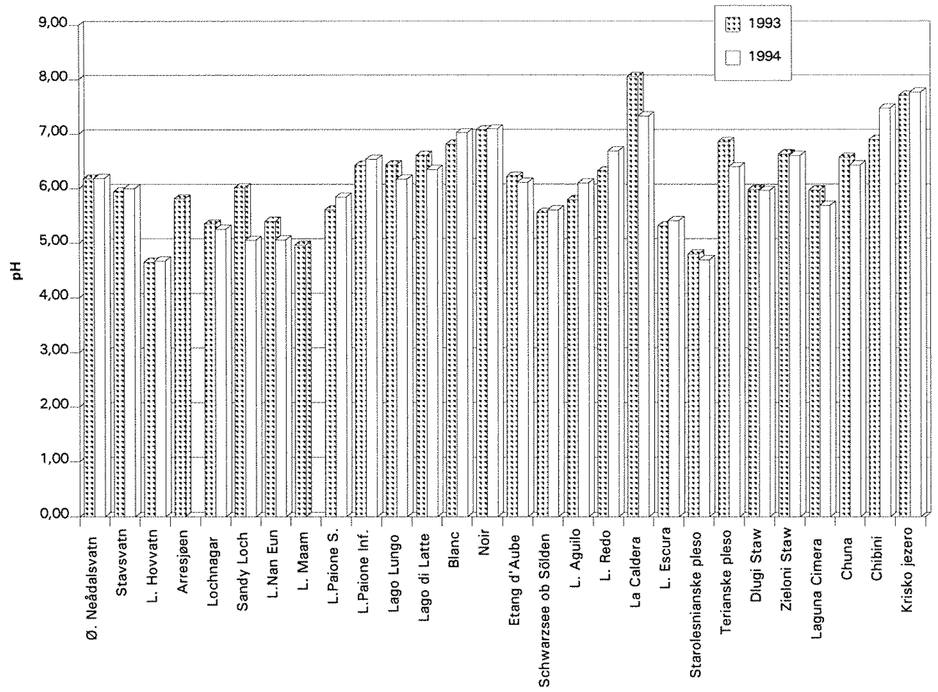


Figure 2.3. Yearly mean pH values for the AL:PE lakes in 1993 and 1994.

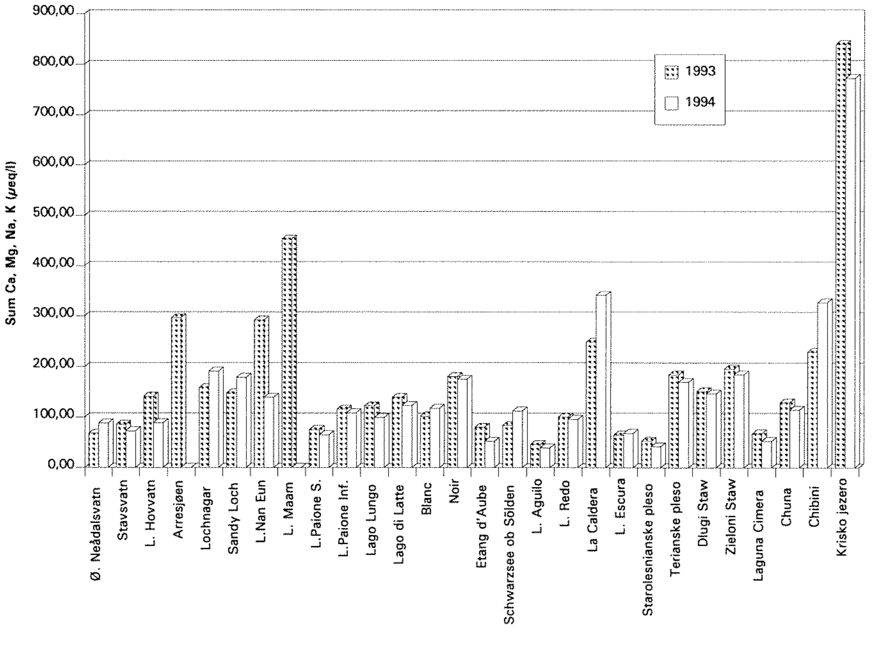


Figure 2.4. Yearly mean values for the sum of the cations Ca^{2+}, Mg^{+}, Na^{+} and K^{+} for the AL:PE lakes in 1993 and 1994.

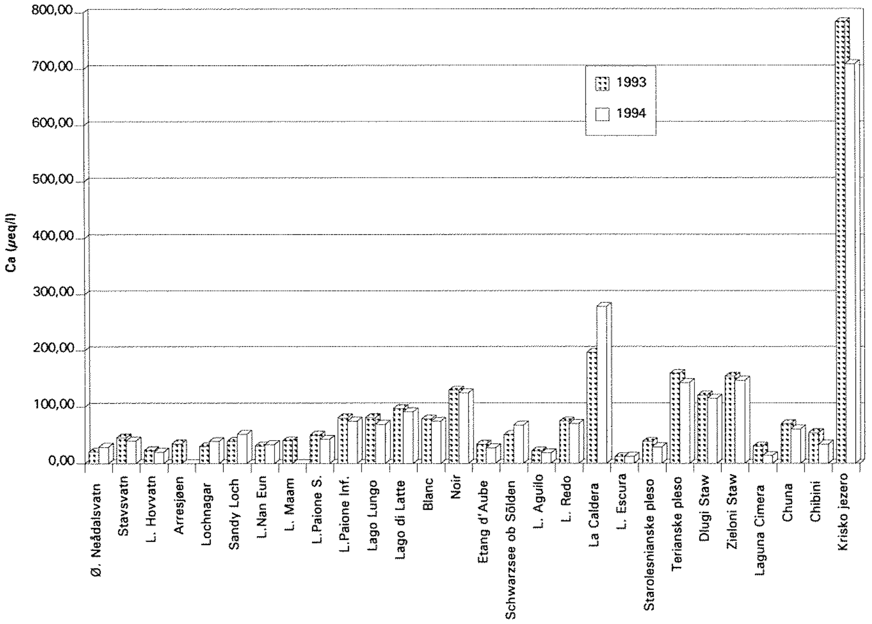


Figure 2.5. Yearly mean Ca^{2+} values for the AL:PE lakes in 1993 and 1994.

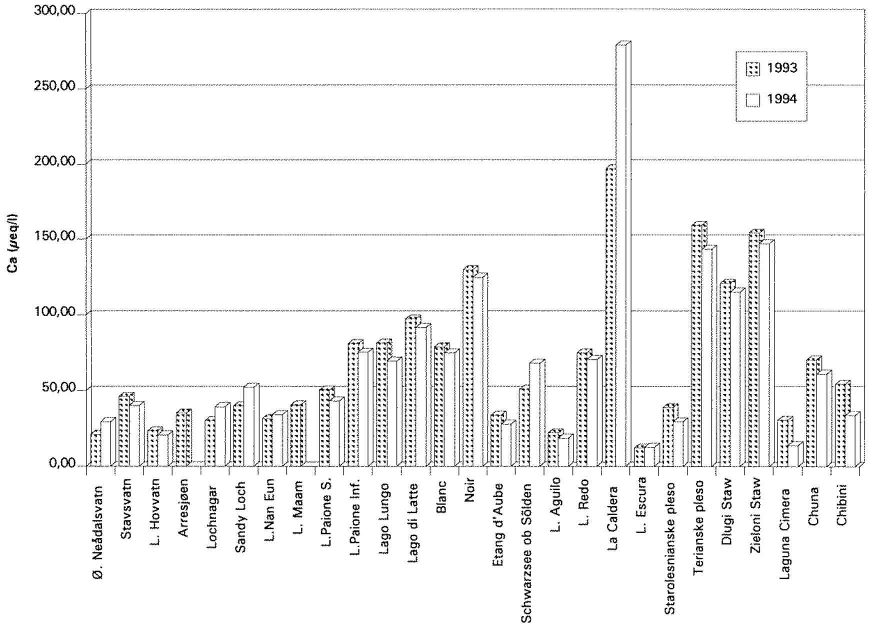


Figure 2.6. Yearly mean Ca^{2+} values for the AL:PE lakes in 1993 and 1994, (without Zgornje Krisko Jezero).

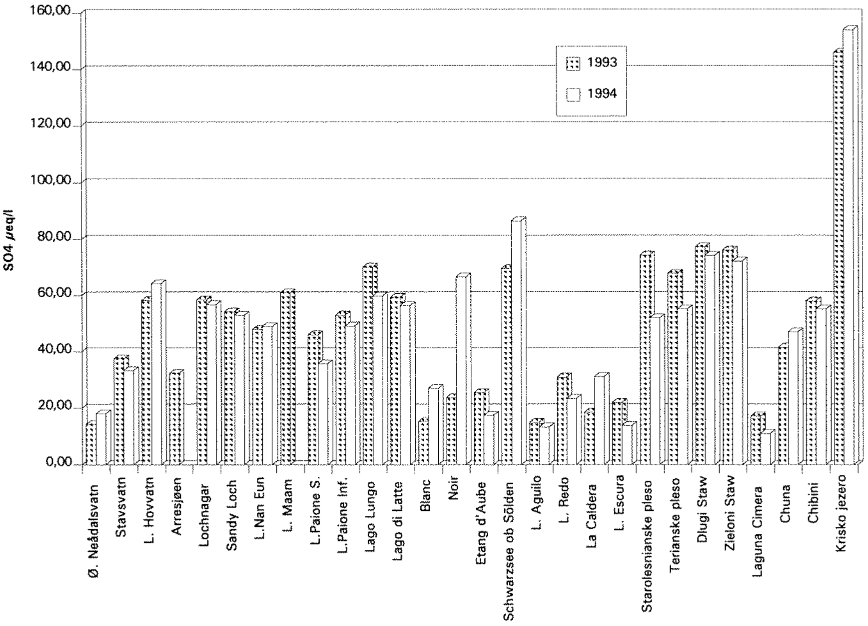


Figure 2.7. Yearly mean SO_4^{2-} values for the AL:PE lakes in 1993 and 1994.

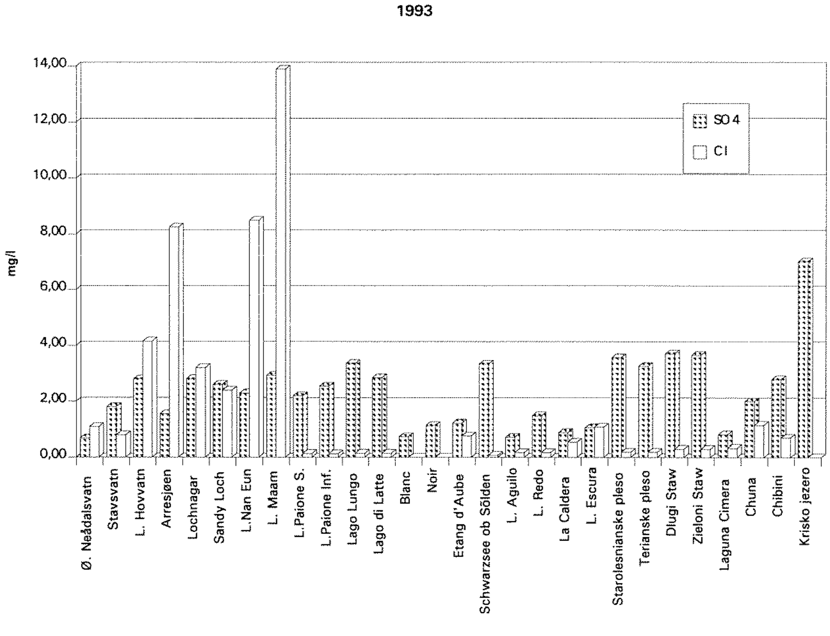


Figure 2.8 a. Yearly mean Cl^- and SO_4^{2-} values for the AL:PE lakes in 1993.

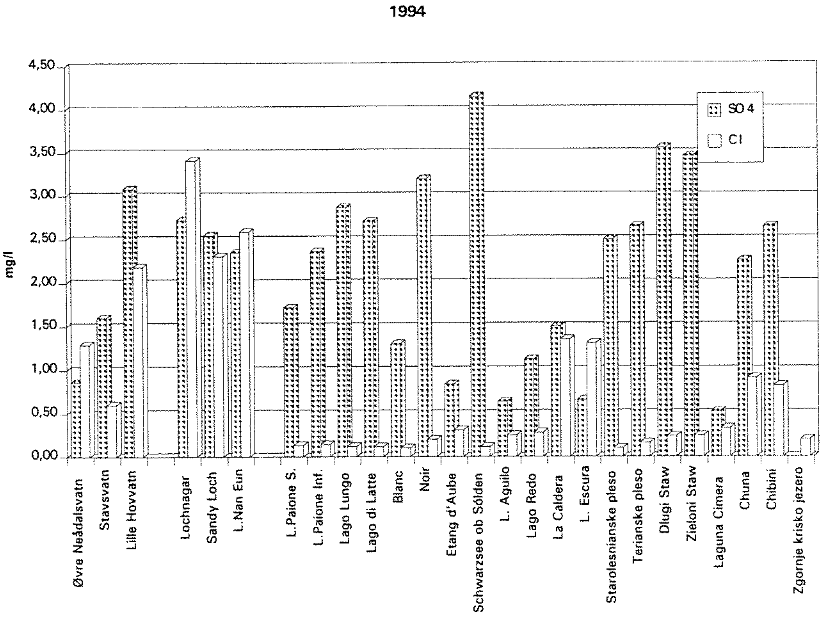


Figure 2.8 b. Yearly mean Cl^- and SO_4^{2-} values for the AL:PE lakes in 1994.

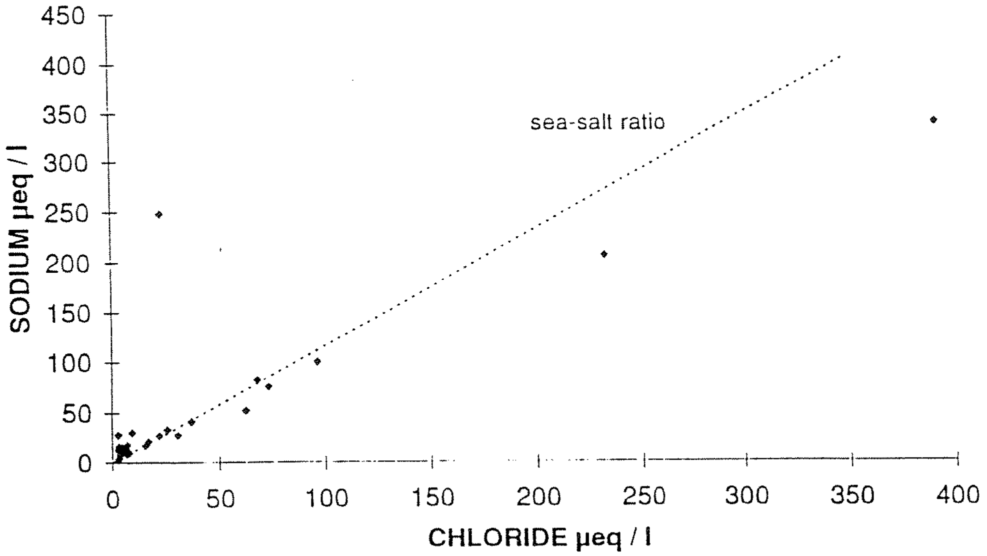


Figure 2.9. Yearly mean Na^+ values plotted against Cl^- for the AL:PE lakes for 1993 and 1994.

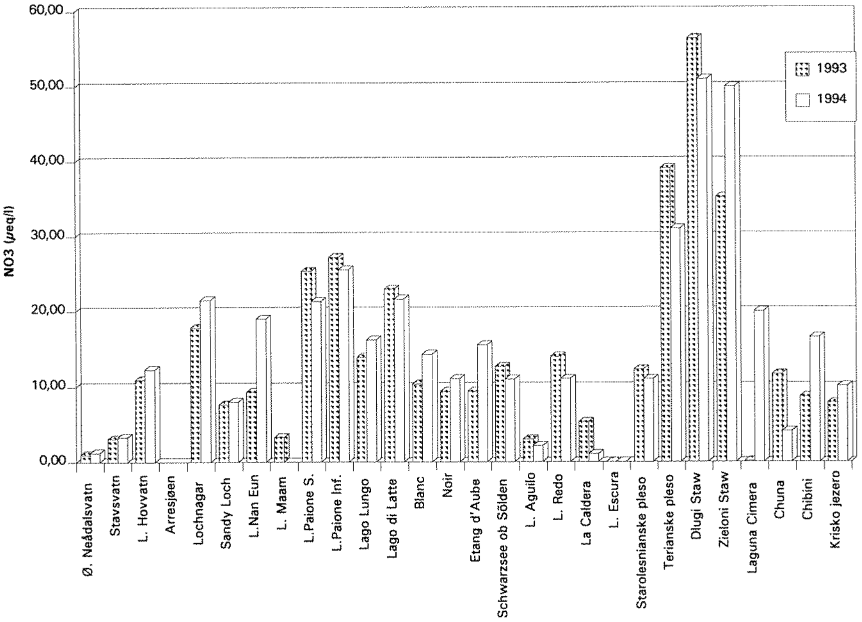


Figure 2.10. Yearly mean NO_3-N values for the AL:PE lakes in 1993 and 1994.

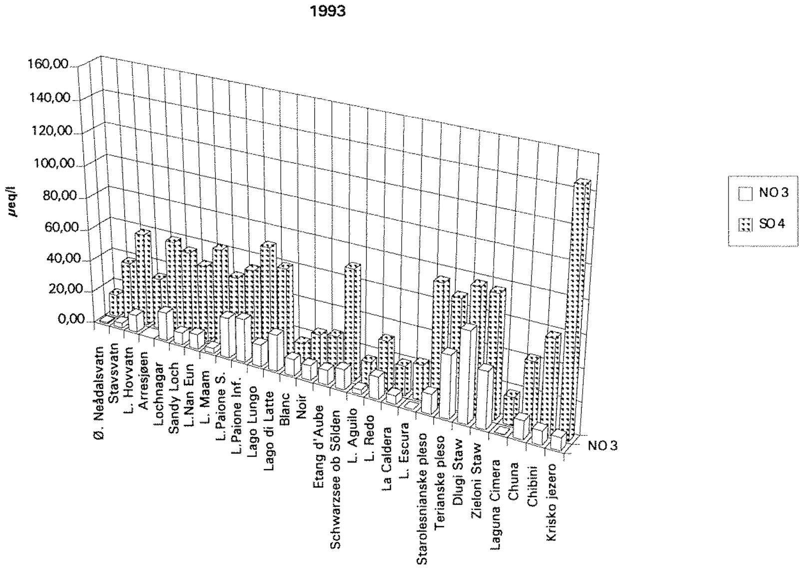


Figure 2.11.Yearly mean SO_4^{2-} and NO_3-N values for the AL:PE lakes in 1993.

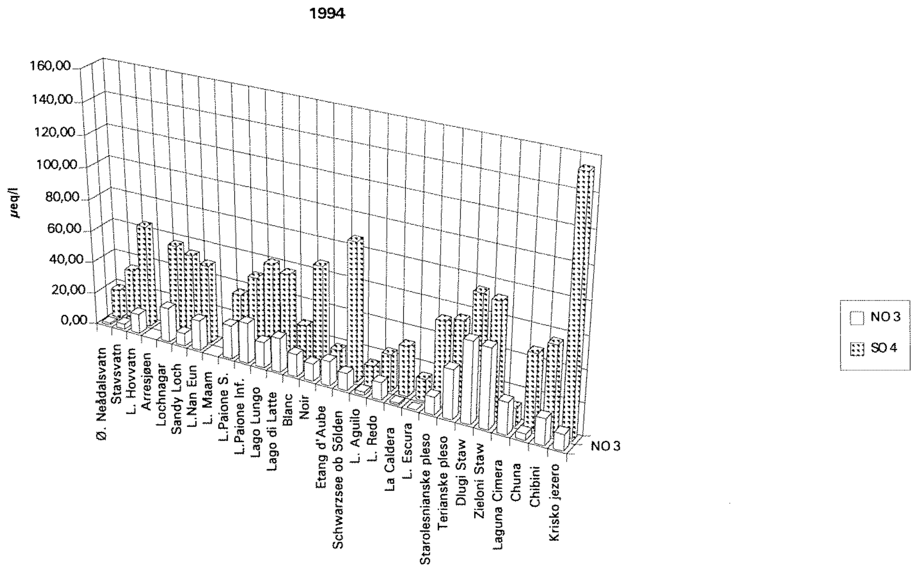


Figure 2.12. Yearly mean SO_4^{2-} and NO_3-N values for the AL:PE lakes in 1994.

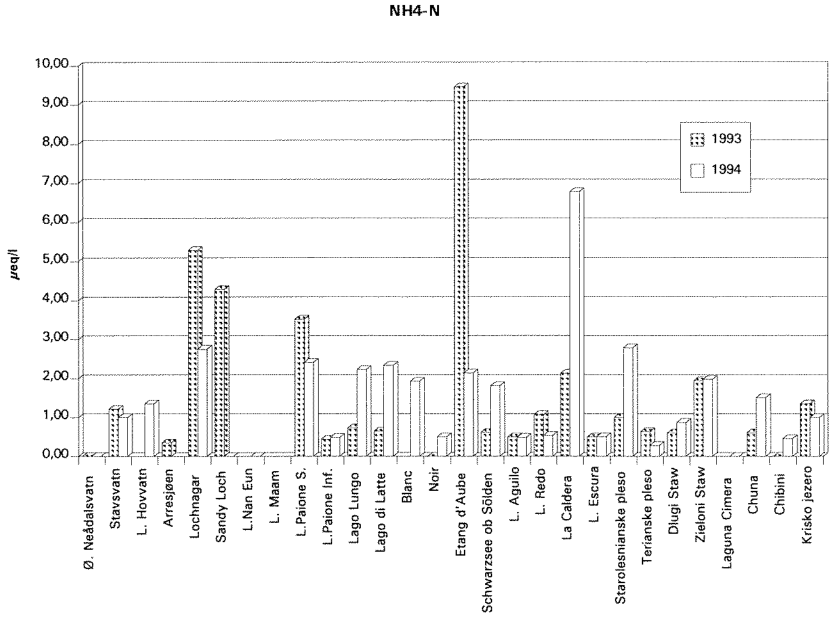


Figure 2.13. Yearly mean NH_4-N values for the AL:PE lakes in 1993 and 1994

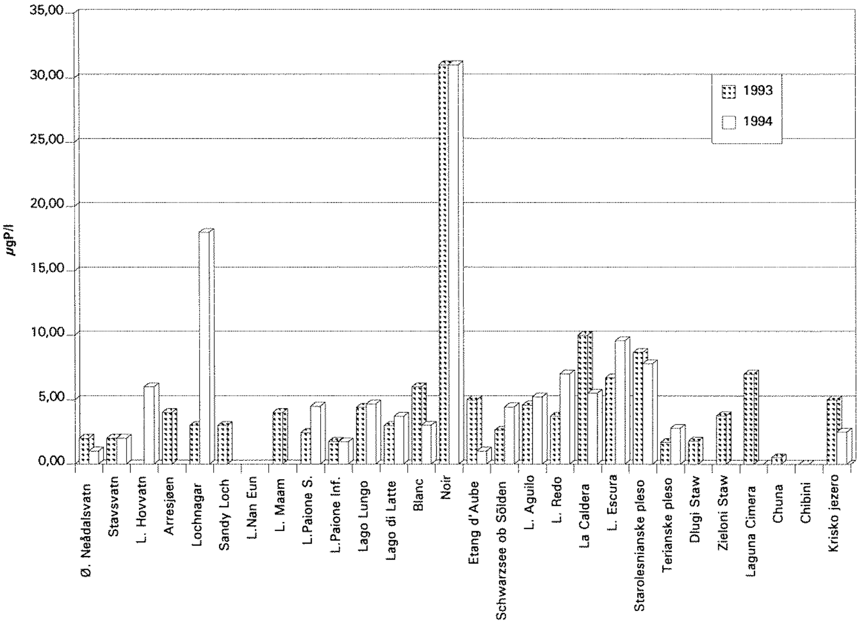


Figure 2.14. Yearly mean TotP values for the AL:PE lakes in 1993 and 1994

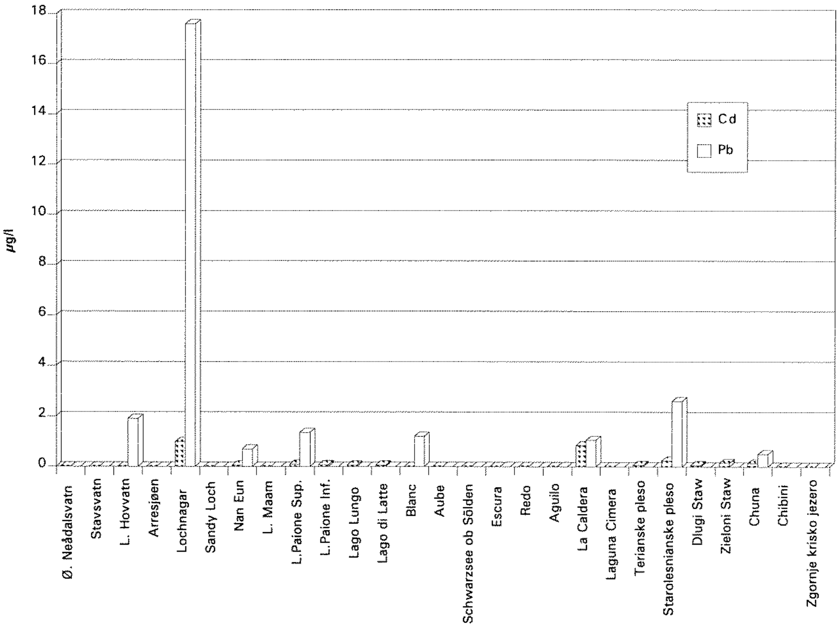


Figure 2.15. Cd and Pb values for the AL:PE lakes in 1993/1994.

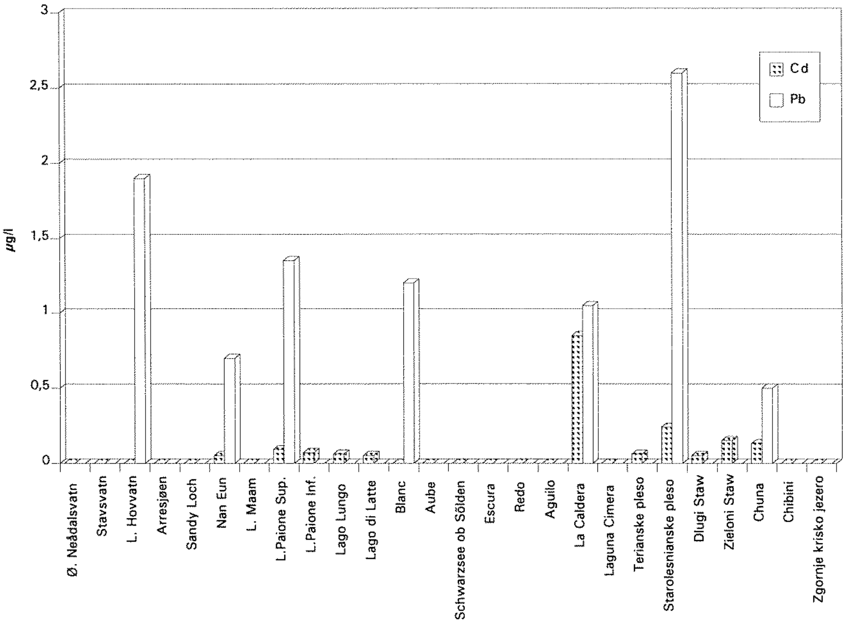


Figure 2.16. Cd and Pb values for the AL:PE lakes in 1993/1994 (without Lochnagar).

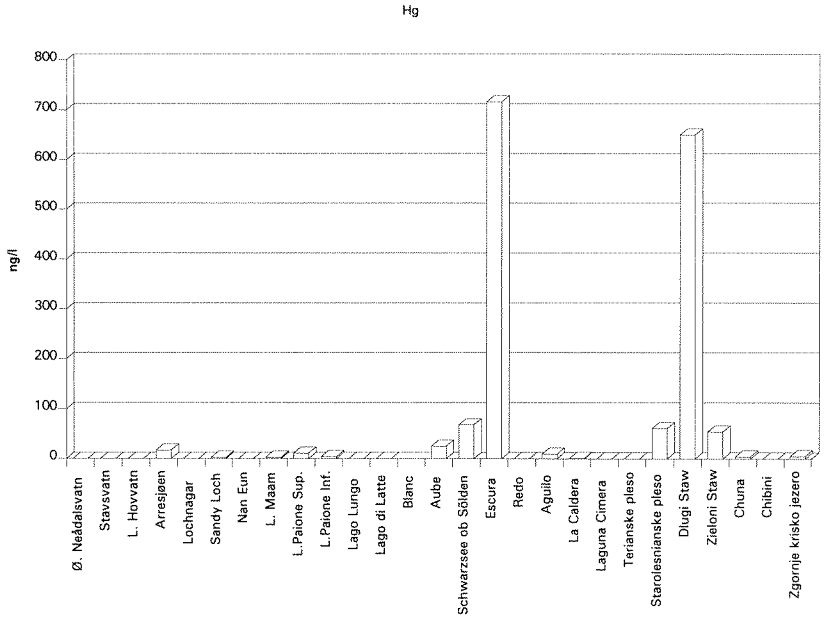


Figure 2.17. Hg values for the AL:PE lakes in 1993/1994.

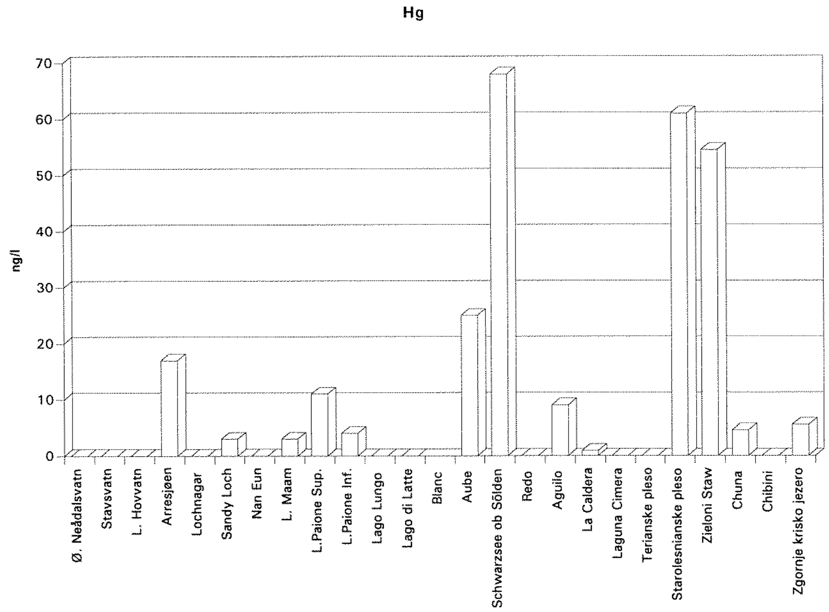


Figure 2.18.Hg values for the AL:PE lakes in 1993/1994 (without Escura and Dlugi Staw).

Cl^- are in most of the cases related to Na^+ concentration, indicating that they are mainly deriving from atmospheric deposition (Fig. 2.9). Only in the case of Lake Chibini, located in a minerary area in the Kola Peninsula, there is a strong excess of Na^+ in relation to Cl^-, indicating a relevant contribution of weathering processes for Na^+. Of course also in the case of the other lakes part of the Na^+ derive from silicate weathering.

In Figure 2.10 the results for NO_3-N are shown. The distribution pattern of the NO_3-N concentrations between the sites is somewhat different from that of SO_4^{2-}. The NO_3-N concentrations in the Tatras are the highest, and there seems to be also a gradient from the north (Svalbard and Norway) to Central Europe (via U.K. to Italy and the Tatras). In Central Europe a gradient also appears from West to East, from low values in Portugal through Spain and then the Italian Alps to the absolutely highest values in the Tatras. Even the relatively clean site in the French Pyrénées, Étang d'Aubé shows higher values than the highest values in Norway and Spain. Inside Norway the gradient from the reference lake to the most affected lake is clearly seen, but, as noted above, the values are lower than for the other European areas.

In Figure 2.11 and 2.12 the results for SO_4^{2-} and NO_3-N in 1993 and 1994 are shown together. The different distribution for the two components is clearly seen with the higher NO_3-N concentrations in the Italian Alpine region compared to the Northern and Western zones.

These results follow and strengthen the conclusions drawn in the first part of the AL:PE project and described in the AL:PE 1 report (Wathne *et al.* 1995). They are also in agreement with earlier results from a comparison of the chemical characteristics of mountain lakes in Norway and Italy (Wathne *et al.* 1990), where it was concluded that NO_3-N plays a more important role in acidification processes in the Alpine lakes than in Norwegian mountain lakes, and that the mobility in the Ossola Valley in the Alps was twice the value found in Skreådalen in Norway, an area not far from Stavsvatn. To follow these results in more detail, atmospheric deposition data for the sites need to be more thoroughly considered.

Ammonium concentrations (Fig. 2.13) are in most cases lower than 5 μeq/l, and lower than the nitrate concentrations (Fig. 2.10). Altogether inorganic nitrogen (ammonium + nitrate) is lower than 30μeq/l (400 μgN/l) in most of the AL:PE lakes, with the exception of the Tatras.

Also the total phosphorus TotP (Fig. 2.14) are very low, mainly below 5 μg P/l, with the exception of Lac Noir, which shows the highest values of 30 μg P/l. These values, considered together with those of inorganic nitrogen, indicate oligotrophic or ultra-oligotrophic conditions for the AL:PE lakes.

For most of the lakes only one sample is taken the heavy metal analysis. All samples are analysed the the laboratory of NIVA. One sample can only give an indication of a possible pollution problem, but in the fish bearing lakes the heavy metal analysis of the fish fillet and organs might strengthen the indications given from the water chemsitry results. The results from the heavy metal analysis of Cd, Pb and Hg are presented in Figures 2.15- 2.18. The results show that Loch Nagar has high Pb concentrations compared to the other lakes. Also Starolesnianske Pleso, Paione Superiore, Lille Hovvatn, Lac Blanc and La Caldera show elevated values for Pb. The results from La Caldera indicates higher values also for Cd. For Hg, Escura and Dlugi Staw show the highest values. Also Schwarssee, Starolesnianske and Zielony Staw show elevated values, and the otherwise relatively unpolluted arctic lake Arresjøen show a noticable value. All measured values for all three heavy metals are below the drinking water standards for the European Community (Council Directive of 15 July, 80/778/EEC).

2.5 Statistical analysis

2.5.1 Numerical analysis of water chemistry data

A large amount of primary data has been collected during the AL:PE 1 and 2 projects, including i.a. data on lake-water chemistry. Multivariate numerical methods of data analysis have been applied to these data in an attempt to detect the major patterns of variation within the data-sets. Such patterns highlight the principal gradients of variation, help to generate hypotheses about the underlying causal processes, and define new research questions.

Data

Determinations for 9 determinands (pH, conductivity, Ca, Mg, Na, NO_3N, K, Cl, SO_4) that meet the quality control criteria within the AL:PE project are available from 30 lakes in 13 countries or areas (Norway (3 lakes), United Kingdom (3), Italy (4), France (5), Spitsbergen (1), Ireland (1), Austria (1), Spain (4), Portugal (1), Slovenia (1), Slovakia (2), Poland (2), and Kola Peninsula (2)). For some lakes, data are available for four years (1991, 1992, 1993, 1994), whereas for other lakes data are only available for one or two years.

All the data have been analysed as annual means for each lake, giving a total of 77 individual samples from 30 lakes.

Numerical analyses

The data have been analysed by principal components analysis (PCA) (ter Braak, 1987), using a correlation matrix between variables. The results are presented as correlation biplots (ter Braak, 1983), in which the correlations between variables can be inferred from the angles between arrows representing the individual variables. Variables with arrows with a sharp angle are positively correlated, and the longer the arrows, the greater the correlation. In contrast, obtuse angles reflect negative correlations, and arrows at right angles to each reflect an absence of correlation.

Results

The first principal component represents 29.7% of the total variance in the data, whereas the second component captures 25.2% of the total variance. Together the two axes represent 55% of the total variance in the chemical data. This is a relatively large amount for such a large data (n=77).

Axis 1 clearly reflects the contrast within the data (Figure 2.19) between lakes with relatively high, above-average Ca, Mg, and SO_4 concentrations and high pH and conductivity values and lakes dilute in Ca, Mg, and SO_4 and with below average pH and conductivity values. Axis 2 contrasts lakes with above-average Na and Cl concentrations from lakes with above-average NO_3N concentrations.

The scatter of the individual 77 samples on PCA axes 1 and 2 is considerable (Figure 2.20), but with a dense concentration of samples with below-average pH, NO_3N, conductivity, Na, and Cl values.

In an attempt to display the differences between lakes and the annual variation in water chemistry within a lake, the annual means for each lake are plotted on PCA axes 1 and 2 of the correlation biplot of Figure 2.19. In general there is little between-year, within-lake variation, in contrast to the considerable between-lake variation in chemical composition. On the basis of the PCA results (Figures 3-32 shown in Appendix 2), the 30 AL:PE lakes can be grouped into the following four general types.

The first group contains lakes with high, above-average Na and Cl concentrations and low pH, Ca, and NO_3N values. All lakes in this group are positioned in the top-left quadrant of the PCA space of axes 1 and 2. The group includes Lough Maam (Ireland - Appendix 2 Figure 3), Arresjøen (Spitsbergen - Appendix 2 Figure 4), Lochnagar (Scotland - Appendix 2 Figure 5), Sandy Loch (Scotland - Annex 2 Figure 6), Loch Nan Eun (Scotland - Appendix 2 Figure 7), Lille Hovvatn (Norway - Appendix 2 Figure 8), and Lake Chibini (Kola - Appendix 2 Figure 9).

The second group is characterised by low, below-average Mg, SO_4, Ca, Na, Cl, and K concentrations and low conductivity values, and are all positioned in the lower-left quadrant of the PCA plot (Figure 2.20). The lakes in this group are Lago Escura (Portugal - Appendix 2 Figure 10), Laguna Cimera (Spain - Appendix 2 Figure 11), Estany Redo (Spain - Figure Appendix 2 12), Estany Aguiló (Spain - Appendix 2 Figure 13), Étang d'Aubé (France - Appendix 2 Figure 14), Øvre Neådalsvatn (Norway - Appendix 2 Figure 15), Stavsvatn (Norway - Appendix 2 Figure 16), Lago Paione Superiore (Italy - Figure Appendix 2 17), Lake Chuna (Kola - Appendix 2 Figure 18), and Starolesnianske Pleso (Slovakia - Appendix 2 Figure 19).

The third group occurs in the lower-right quadrant of the PCA plot (Figure 2.20) and is characterised by above-average NO_3N, Ca, and SO_4 concentrations and above-average pH and conductivity values. The group contains Terianske Pleso (Slovakia - Appendix 2 Figure 20), Zieloni Staw (Poland - Appendix 2 Figure 21), Dlugi Staw (Poland - Appendix 2 Figure 22), Le Caldera (Spain - Appendix 2 Figure 23), Combeynod (France - Appendix 2 Figure 24), Lac Noir (France - Appendix 2 Figure 25), Lago di Latte (France - Annex 2 Figure 26), Lago Paione Inferiore (Italy - Appendix 2 Figure 27), and Lago Lungo (Italy - Appendix 2 Figure 28).

The fourth small group contains two lakes only that are characterised by high Ca, SO_4, pH, and conductivity values. The lakes are positioned in the top-right quadrant of the PCA plot (Figure 2.20) and are Lac Rond (France - Appendix 2 Figure 29) and Zgornje krisko jezero (Slovenia - Appendix 2 Figure 30).

There are two lakes whose individual annual means fall within two of the PCA quadrants. These are Lac Blanc (France - Appendix 2 Figure 31) and Schwarzsee ob Sölden (Austria - Appendix 2 Figure 32). They are both characterised by slightly above-average pH and NO_3N values but appear to show a slightly larger between-year variation in chemical composition than the other AL:PE lakes.

Conclusions

The PCA results summarise the major patterns of variation in lake-water chemistry in the 30 AL:PE lakes. They highlight the contrast in composition between lakes in oceanic areas of northern and western Europe where sea-salts are important (e.g. Appendix 2 Figures 3-9) and between lakes in southern, central, and eastern Europe where Na and Cl values are below average but where NO_3N, Ca, and SO_4 concentrations are above average (e.g. Appendix 2 Figures 20-28). There are 10 lakes (Portugal, Spain (including the Pyrenees), the French Pyrenees, central Norway, northern Italy, Kola, and Slovakia (Appendix 2 Figures 10-19) with below-average values for all chemical determinands.

Figure 2.19. Principal components correlation biplot showing the biplot arrows for the nine determinands including in the analysis on principal components analysis (PCA) axis 1 and 2. The variable scores are variance adjusted.

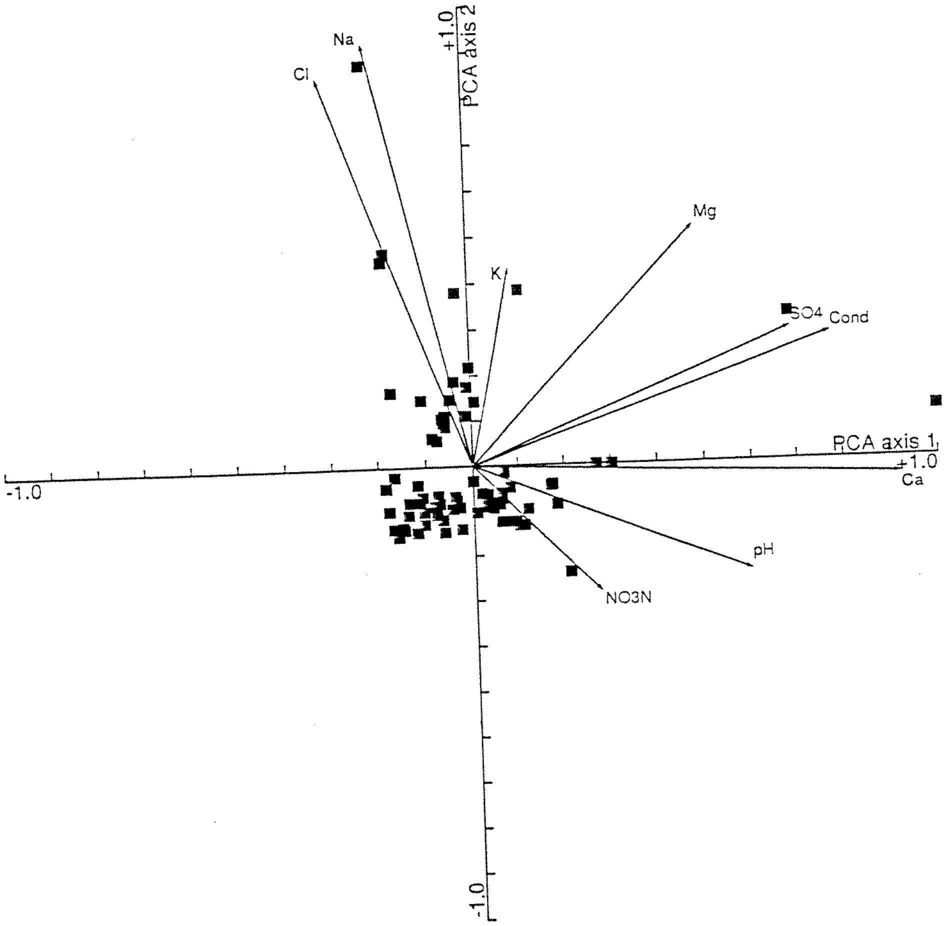
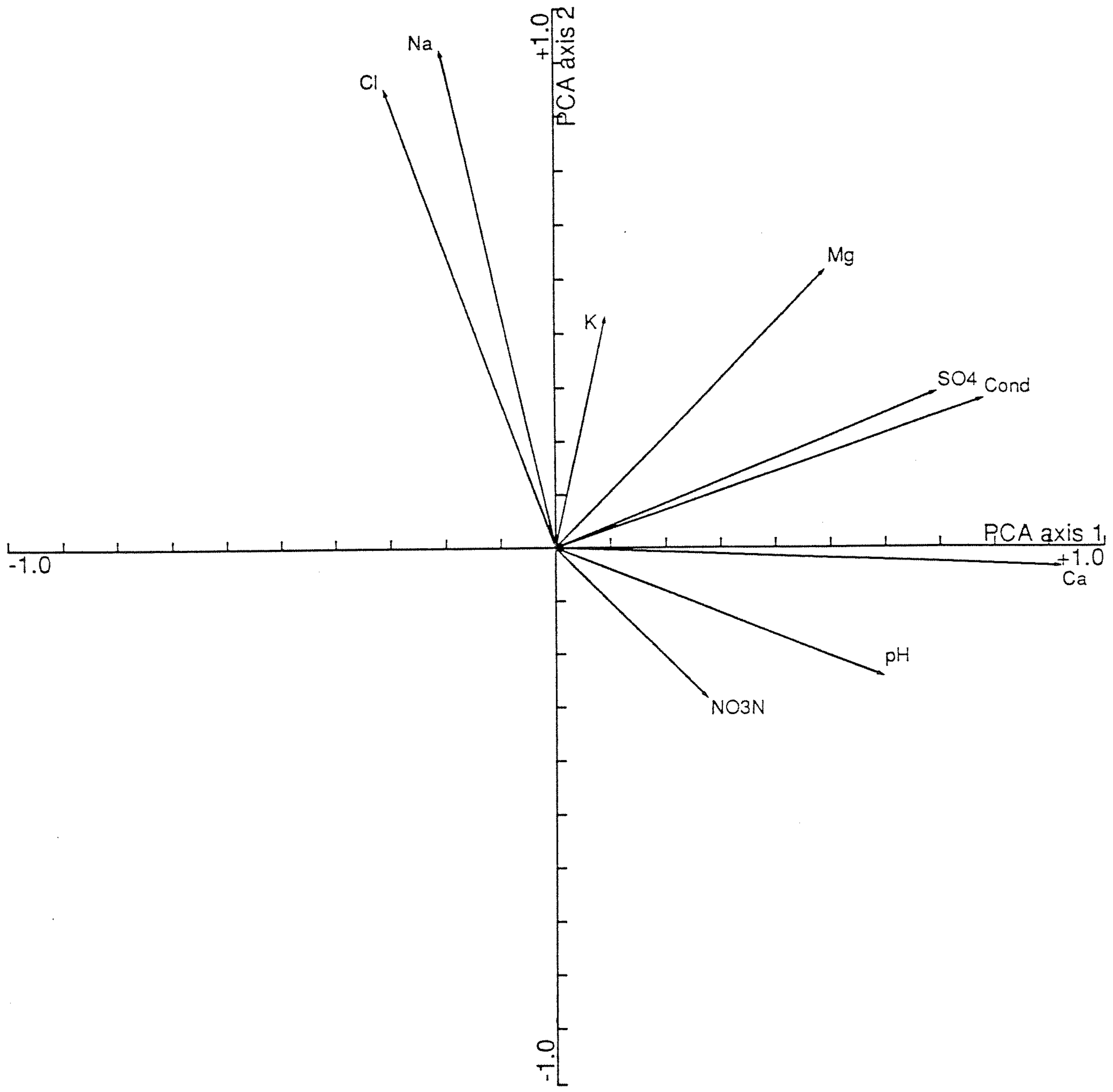


Figure 2.20 Position of the 77 annual means from 30 AL:PE lakes on PCA axes 1 and 2, along with the nine determinands. The plot is the correlation biplot of Figure 2.19.



2.5.2 Clustering of the AL:PE lakes

A further comparison of the lakes on the basis of main ion concentrations may be made using cluster analysis (Fig. 2.21 and Tab. 2.3). The data used are a mean of the 1993-94 values. If a linkage distance of 200 is arbitrarily assumed as significant, seven different categories of lakes are identified. Two of them (groups 1 and 3 of Tab. 2.3) are composed of single lakes showing peculiar chemical characteristics due to the lithology of the watersheds. Zgornje Krisko Jezero (Slovenia), draining a calcareous watershed, shows the highest alkalinity, sulphate and calcium concentrations, while Lake Chibini (Kola Peninsula) shows high sodium and alkalinity, due to the presence in the watershed of alkaline rocks (apatite, nepheline syenites) (Moiseenko 1994). A further type of chemical composition (group 2 of Tab. 2.3) emerges in lakes Arresjøen and Maam, characterised by a high sea-salt contribution. The mean Na/Cl ratio of these lakes is 0.88, very close to the value for sea water (0.86).

Group four (lakes Caldera, Zieloni, Terianski, Noir) is formed by lakes with relatively high alkalinity (mean 107, range 68-195 μeq/l), although lower than the values of lakes Zgornje and Chibini (212 and 557 μeq/l, respectively). Group five (Lochnagar, Nan Eun, Sandy Loch and Hovvatn) shows relatively high sodium and chloride concentrations, although lower than group two. However, the Na/Cl mean ratio is 1.04, higher than the value of cluster 2 and of the sea water ratio, indicating a contribution of sodium due to silicate weathering. Groups six and seven contain the highest number of lakes (7 and 9 respectively), which are characterised by low solute concentrations, with the prevalence of calcium, alkalinity and sulphate. The main differences are in the concentrations of sulphate and nitrate, which are higher in group 6 than in group 7 (Tab. 2.3).

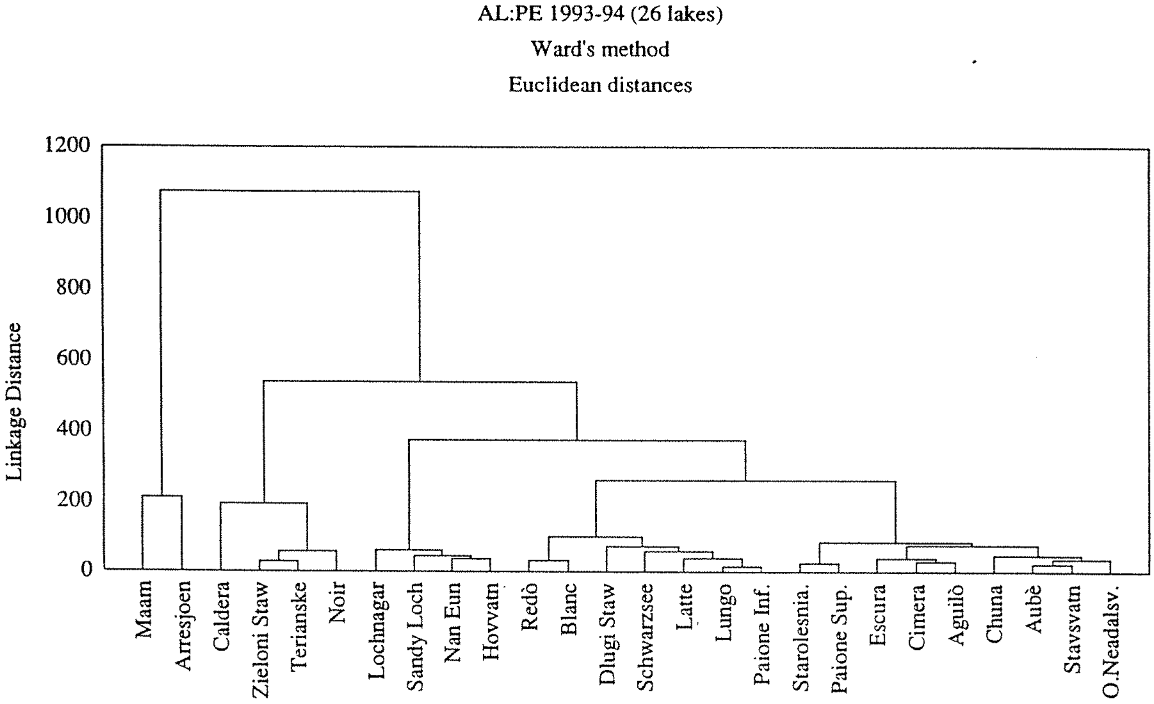
Another analysis of the chemistry of the AL:PE lakes may be made considering the clusters among the main ion concentrations (Fig. 2.21). The analysis was made excluding lakes Zgornje and Chibini, because of the peculiarity of their chemical composition. The results underline the close relationship between sodium and chloride, and their importance in determining conductivity. Furthermore, sodium and chloride are related both with magnesium, a significant quantity of which derive from sea salt, and, to a lower extent, with potassium. Closely related are also the two acid anions sulphate and nitrate and, in a different cluster, pH, alkalinity and calcium.

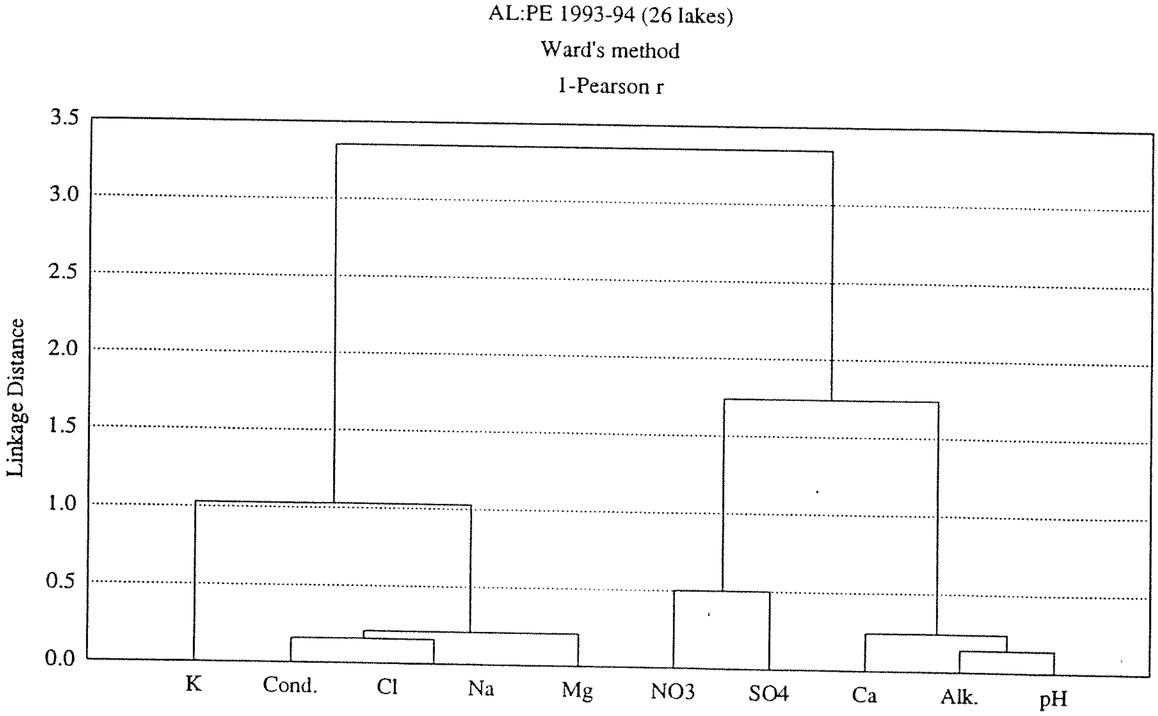
Table 2.3. Clustering of AL:PE lakes

CLUSTERING OF AL:PE LAKES (1993-94). CONCENTRATIONS IN μeq l^{-1},
CONDUCTIVITY IN mS m-1 AT 25° C

CLUSTER	pH	H+	NH4	Ca	Mg	Na	K	Alk	SO4	SO4NM	NO3	Cl	COND	S.AN	S.CAT	Na/Cl
1°																
Zgornje krisko jezero	7.76	0	1	709	33	28	3	557	154	154	10	3	8.15	724	774	10.099
2°																
Arresjøen	5.81	2	0	35	49	207	6	24	32	9	0	233	3.76	288	299	0.889
L. Maam	4.96	20	0	40	63	341	9	7	61	22	3	392	5.95	463	473	0.870
Mean	**5.38**	**11**	**0**	**38**	**56**	**274**	**8**	**15**	**47**	**15**	**1.62**	**312**	**4.85**	**376**	**386**	**0.879**
3°																
L. Chibini	7.47	0	0	34	6	248	39	212	55	53	17	23	3.40	307	327	10.746
4°																
L. Noir	7.09	0	0	125	33	13	5	92	67	66	11	6	1.99	175	176	2.313
La Caldera	8.05	0	2	197	31	17	3	195	19	17	5	15	2.60	234	251	1.137
Terianske pleso	6.40	0	0	143	7	16	4	68	55	55	31	5	1.87	159	170	3.469
Zieloni Staw	6.60	0	2	147	14	19	4	75	72	71	50	7	2.19	204	186	2.709
Mean	**7.04**	**0**	**1**	**153**	**21**	**16**	**4**	**107**	**53**	**52**	**24**	**8**	**2.16**	**193**	**196**	**2.407**
5°																
Lille Hovvatn	4.67	22	1	21	13	53	2	0	64	58	12	62	2.41	139	112	0.845
Lochnagar	5.25	6	3	39	43	101	8	7	57	47	22	96	2.28	181	199	1.049
Sandy Loch	6.01	1	4	40	21	82	4	26	54	47	8	68	1.91	156	153	1.217
L.Nan Eun	5.06	9	0	34	25	76	4	-7	49	42	19	73	1.90	134	148	1.041
Mean	**5.25**	**10**	**2**	**33**	**25**	**78**	**5**	**6**	**56**	**49**	**15**	**75**	**2.13**	**152**	**153**	**1.038**
6°																
L.Paione Inf.	6.53	0	0	75	12	14	8	26	49	49	26	4	1.35	104	109	3.426
Lago Lungo	6.17	1	2	69	13	12	5	27	60	59	16	3	1.40	106	102	3.630
Lago di Latte	6.35	1	2	92	11	13	7	51	56	56	22	3	1.62	132	126	4.099
L. Blanc	7.02	0	2	75	19	13	10	72	27	27	14	3	1.40	116	119	4.626
Schwarzsee	5.60	2	2	68	24	16	4	7	86	86	11	3	1.59	108	116	5.007
Lago Redo	6.69	0	1	71	13	10	2	44	23	23	11	8	1.18	86	96	1.237
Dlugi Staw	5.96	2	1	115	10	17	4	17	74	74	51	7	1.93	149	148	2.551
Mean	**6.33**	**1**	**1**	**81**	**14**	**14**	**6**	**35**	**54**	**53**	**22**	**4**	**1.50**	**115**	**117**	**3.511**
7°																
Ø. Neådalsvatn	6.19	1	0	29	12	42	5	32	18	14	1	37	1.14	88	89	1.126
Stavsvatn	6.00	1	1	40	9	21	2	16	33	32	3	17	0.73	70	74	1.259
L.Paione S.	5.84	2	2	43	7	8	6	1	36	35	21	4	0.95	62	69	2.211
Etang d'Aube	6.22	1	9	34	6	27	13	29	26	23	9	22	1.08	85	90	1.253
L. Aguilo	6.10	1	0	18	10	9	2	11	13	13	2	7	0.54	33	40	1.273
L. Escura	5.31	5	0	12	23	28	2	6	22	19	0	31	1.33	59	70	0.915
Starolesnianske pleso	4.69	20	3	29	6	3	3	0	52	52	11	3	1.43	66	65	1.233
Laguna Cimera	5.69	2	0	14	9	30	2	17	11	10	20	9	0.42	57	57	3.271
L. Chuna	6.43	0	2	61	16	33	4	37	47	44	4	26	1.50	114	116	1.304
Mean	**5.83**	**4**	**2**	**31**	**11**	**23**	**4**	**17**	**29**	**27**	**8**	**17**	**1.01**	**70**	**74**	**1.538**

Figur 2.21. Clustring of the AL:PE lakes after Ward's method.





2.6 Critical load of acidity to surface waters.

Critical loads and exceedance of critical loads were calculated for all the AL:PE sites where sufficient informations were available. The calculation of both critical load and exceedance were performed on the annual mean value of water analysis for each locality for 1993 or 1994. The figures representing each lake were selected according to an acceptable ion balance, and representativity of the analyses compared to the other data sets from each lake.

Critical loads of acidity for 23 of the AL:PE lakes are shown in Figure 2.22. Øvre Neådalsvatn has a critical load of 0. It means that the lake can not tolerate any load of acidity without causing harm to biological indicators. It also means the original concentration of non-marine base cations was less than 20 µeq/l (compare the ANC_{limit} = 20 µeq/l in the formula). The lakes Lille Hovvatn, Arresjøen, Estany Aguilo, and Laguna Cimera are in the same category.

Many of the AL:PE lakes have a critical load less than 50 keq/km^2/yr: Stavsvatn, Lochnagar, Sandy Loch, Loch Nan Eun, Lago Paione Superiore, Lago Lungo, Schwarzsee ob Sölden, Estany Redo, Starolesnianske Pleso, and Lake Chuna, while the critical loads of Zgornje Krisko Jezero is the only extremely high; 989 keq/km^2/yr.

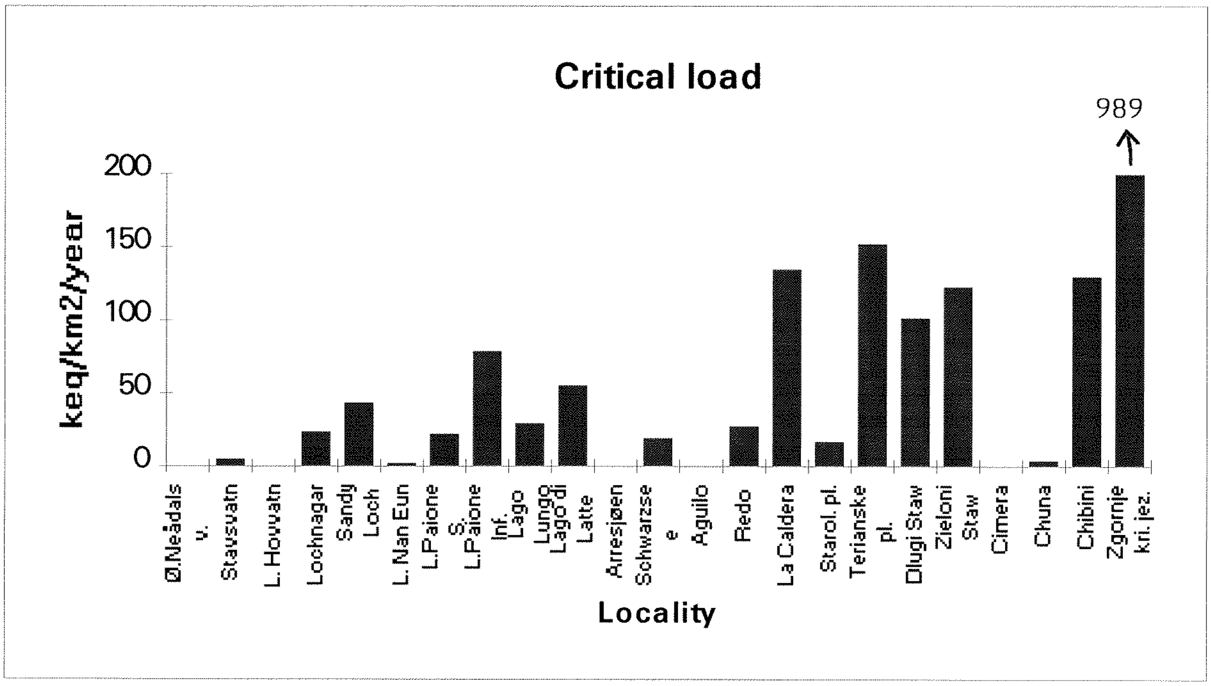


Figure 2.22. Critical load of acidity to AL:PE lakes 1993/94.

Fig. 2.22. shows the exceedance of critical loads of acidity for 23 AL:PE lakes. The exceedance of critical loads are estimated according to deposition of sulphur (CLexS, white bars), and according to deposition of sulphur plus leaching of nitrate from the catchment (CLex S+N, black bars). Negative exceedance

means that critical load is not exceeded, and the higher negative values of exceedance, the more acid can be received before the critical level is reached.

The six lakes Lille Hovvatn, Estany Aguilo, Estany Redo, Starolesnianske Pleso, Dlugi Staw, and Zielony Staw show exceedance of critical loads for sulphur. The critical loads of other five lakes: Stavsvatn, Loch Nan Eun, Lago Paione Superiore, Schwarzsee ob Sölden, and Nizne Terianske Pleso are also exceeded, when both sulphur and nitrogen were taken into account. These lakes showed no exceedance of critical load when only the sulphur was estimated. No exceedance of critical load was observed for half of the examined AL:PE lakes.

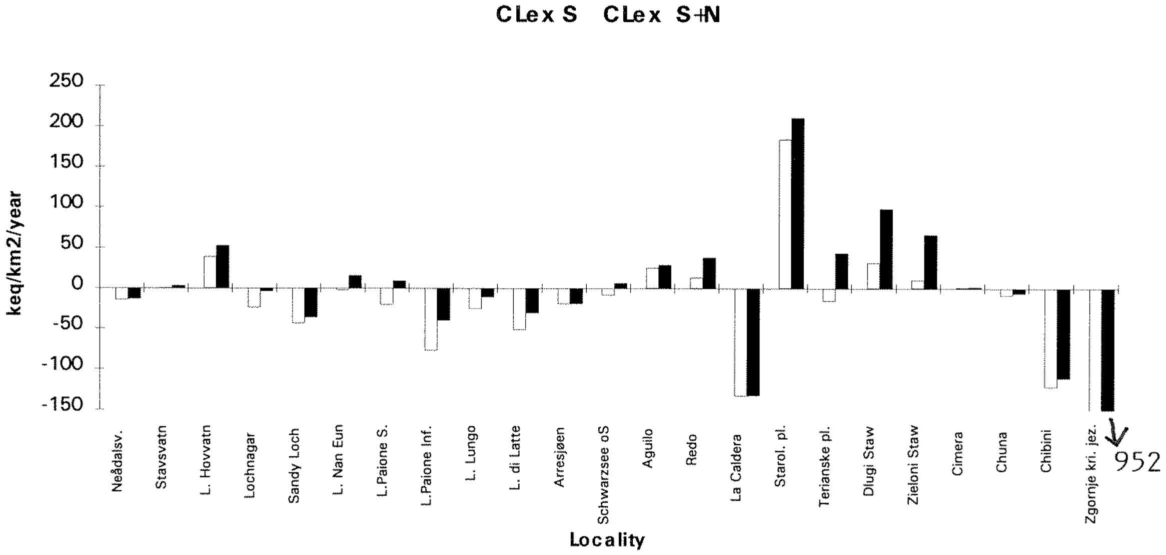


Figure 2.23. Exceedance of critical load of acidity for AL:PE lakes 1993/94.

The importance of nitrogen to the exceedance of the lakes can also be seen in Fig. 2.23. The contribution of nitrogen are highest in the central south-east Europe (Tatra Mts.), decreasing towards west (The Alps), and further reduction to south-west (The Pyrenees) and to southern Spain. A pronounced and gradually reduction is also observed towards north-west from central south-east Europe. None of the lakes was exceeded due to nitrogen only.

2.7 Overall summary and conclusions

Water sampling followed the protocol agreed under the AL:PE 1 project, and the samples were taken from the outlet of the lake. The minimum number of samples required was one yearly sample in the late autumn (at the turnover time for the lake), taken as a representative annual mean sample for the physical-chemical parameters in the lake. Most of the lakes were sampled more frequently than the minimum.

The analytical quality and the comparability of the chemical results were tested by yearly intercomparison exercises, and data validation was given special interest. Confidence in comparability between sites and countries was a basis for our work, and all participants needed to feel secure about the data presented, and relay completely on the reported results from others. The AQC shows satisfactory results for the AL:PE laboratories.

To give an impression of the pollution status of the different lakes and a comparison between the sites, the water chemistry results are compared. The yearly mean pH values range from as low as 4.65 in the most acid Lille Hovvatn to 8.05 in Caldera in the Spanish Sierra Nevada and 7.76 in Zgornje Krisko Jezero in Slovenia. The results also show the acid gradient in Norway from the unpolluted reference lake Øvre Neådalsvatn with annual mean pH values 6.37 and 6.32 via the moderately exposed Stavsvatn (pH close to 6) to Lille Hovvatn, the site in the area most heavily exposed to acid rain. The same gradient is seen for SO_4^{2-}. The high pH values in La Caldera and Z. Krisko Jezero result from high base cation concentrations in the lakewater, especially high Ca^{2+} concentrations. It is also seen that high SO_4^{2-} values may be found in high mountain lakes in all the countries represented in the AL:PE project. The SO_4^{2-} concentrations in Zgornje Krisko Jezero, the Polish Tatras (Dlugi Staw and Zielony Staw) and Italian/Austrian Alps show the highest values registered (yearly mean values of 70 - 100 μeq/l or 3.35 - 4.80 mg/l). Likely in the case of the Zgornje Krisko Jezero there is a contribution of sulphate from the weathering of the watershed, mainly composed by calcareous rocks. Also in the French Alps there are indications that high SO_4^{2-} values in one of the lakes (Lac Noir), are due to impact from geological bands in the watershed, while the concentrations of another nearby lake (Lac Blanc) show lower values, and are more representative for the atmospheric deposition in the area. The lowest SO_4^{2-} values are found as expected, in the reference site Øvre Neådalsvatn, but apart from the reference site, the French and Spanish Pyréneé sites (Étang d'Aubé, lakes Aguilo and Redo) show the lowest values, with the Lac Blanc in the French Alps almost at the same low level.

The Cl^- concentrations indicate the distance from the sea and the seasalt influence at the different sites, and it is clearly seen that Arresjøen and Lough Maam are situated close to the sea. Cl^- are in most of the cases related to Na^+ concentration, indicating that they are mainly deriving from atmospheric deposition. Only in the case of Chibini, located in a minerary area in the Kola Peninsula, there is a strong excess of Na^+ in relation to Cl^-, indicating a relevant contribution of weathering processes for Na^+. Of course also in the case of the other lakes part of the Na^+ derive from silicate weathering.

When comparing the distribution pattern of the NO_3-N concentrations between the sites we find that it is somewhat different from that of SO_4^{2-}. The NO_3-N concentrations in the Tatras are the highest, and there seems to be also a gradient from the north (Svalbard and Norway) to Central Europe (via UK to Italy and the Tatras). In Central Europe a gradient also appears from West to East, from low values in Portugal through Spain and then the Italian Alps to the absolutely highest values in the Tatras. Even the relatively clean site in the French Pyrénées, Étang d'Aubé shows higher values than the highest values in Norway and Spain. Inside Norway the gradient from the reference lake to the most affected lake is clearly seen, but, as noted above, the values are lower than for the other European areas.

For most of the lakes only one sample is taken for the heavy metal analysis. The data then may only indicate possible pollution problems. The results show that Loch Nagar has high Pb concentrations compared to the other lakes. Also Starolesnianske Pleso, Paione Superiore, Lille Hovvatn, Lac Blanc and La Caldera show elevated values for Pb. The results from La Caldera indicates higher values also for Cd. For Hg, Escura and Dlugi Staw show the highest values. Also Schwarssee, Starolesnianske and Zielony Staw show elevated values. All measured values are below the drinking water standards for the European Community

Statistical analysis results summarise the major patterns of variation in lake-water chemistry in the 30 AL:PE lakes. They highlight the contrast in composition between lakes in oceanic areas of northern and western Europe where sea-salts are important and between lakes in southern, central, and eastern Europe where Na and Cl values are below average but where NO_3-N, Ca^{2+}, and SO_4^{2-} concentrationsare above average. There are 10 lakes (Portugal, Spain (including the Pyrenees), the French Pyrenees, central Norway, northern Italy, Kola, and Slovakia with below-average values for all chemical determinands.

Critical loads and exceedance of critical loads were calculated for all the AL:PE sites where sufficient informations were available. The calculation of both critical load and exceedance were performed on the annual mean value of water analysis for each locality for 1993 or 1994. The figures representing each lake were selected according to an acceptable ion balance, and representativity of the analyses compared to the other data sets from each lake. The six lakes Lille Hovvatn, Estany Aguilo, Estany Redo, Starolesnianske Pleso, Dlugi Staw, and Zielony Staw show exceedance of critical loads for sulphur. The critical loads of other five lakes: Stavsvatn, Loch Nan Eun, Lago Paione Superiore, Schwarzsee ob Sölden, and Nizne Terianske Pleso are also exceeded, when both sulphur and nitrogen were taken into account. These lakes showed no exceedance of critical load when only the sulphur was estimated. No exceedance of critical load was observed for half of the examined AL:PE lakes. The importance of nitrogen to the exceedance of critical the loads are highest in the central south-east Europe (Tatra Mts.), decreasing towards west (The Alps), and further reduction to south-west (The Pyrenees) and to southern Spain. A pronounced and gradually reduction is also observed towards north-west from central south-east Europe. None of the lakes was exceeded due to nitrogen only

2.8. References

Carrillo, P. 1989. Analisis de las interacciones troficas en el plancton de un sistema oligotrofico. PhD Thesis. Universidad de Granada. Granada. 181 pp.Carrillo, P. 1989

Grennfelt, P. and Thönelöf, E. (Eds.) 1992. Critical Loads for Nitrogen - report from a workshop held in Lökeberg, Sweden 6-10 April 1992. Nord 1992:41. Århus 1992.

Henriksen, A., Lien, L., Traaen, T.S., Sevaldrud, I. and Brakke, D.F. 1988. Lake Acidification in Norway - Present and Predicted Chemical Status. *Ambio* 17, 259-266.

Henriksen, A., Kamari, J., Posch, M., and Wilander, M. 1992. Critical loads of acidity: Nordic surface waters. *Ambio*, 21, 356-363.

Hovind, H., 1991. Convention of Long-range Transboundary Air Pollution. International Cooperative Programme on Assessment and Monitoring of Acidification in Rivers and Lakes. Intercalibration 9105. pH, κ_{25}, HCO_3, NO_3+NO_2, SO_4, Cl, Ca, Mg, Na, K, and TOC. July 1991.

Hovind, H., 1992. Convention of Long-range Transboundary Air Pollution. International Cooperative Programme on Assessment and Monitoring of Acidification in Rivers and Lakes. Intercalibration 9206. pH, κ_{25}, HCO_3, NO_3+NO_2, SO_4, Cl, Ca, Mg, Na, K, aluminium, and DOC. September 1992.

Hovind, H., 1993. Convention of Long-range Transboundary Air Pollution. International Cooperative Programme on Assessment and Monitoring of Acidification in Rivers and Lakes. Intercalibration 9307. pH, κ_{25}, HCO_3, NO_3+NO_2, SO_4, Cl, Ca, Mg, Na, K, total aluminium, reactive and non-labile aluminium, DOC and COD-Mn. September 1993.

Hovind, H., 1994. Convention of Long-range Transboundary Air Pollution. International Cooperative Programme on Assessment and Monitoring of Acidification in Rivers and Lakes. Intercalibration 9408. pH, κ_{25}, HCO_3, NO_3+NO_2, SO_4, Cl, Ca, Mg, Na, K, total aluminium, DOC and COD-Mn. October 1994.

Moiseenko, T., 1991. Acidification and pollution of the Kola North Surface Waters by Heavy Metals. Preprint issued by the Kola Science Centre, Russian Academy of Science. 33 p (in Russian).

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

Moiseenko, T., Dauvalter, V., Kagan, L., Vandysh, O., Yakovlev, V. Lukin, A., Kashulin, N., Kudravceva,L. 1994. AL:PE 2. The Ecosystem of Kola Mountain Lakes. Early response indicators of atmospheric pollution. INEP Report 1994.

Moiseenko, T., Dauvalter, V., Kagan, L., Sharov, A., Landysh, O., Kashulin, N., Yakovlev, V. 1995. AL:PE 2. Air pollution effects on the Mountain lakes of Northern Russia. INEP Report 1995.

Lien, L., Raddum, G.G., Fjellheim, A., and Henriksen, A., 1996. A critical limit for acid neutralizing capacity in Norwegian surface watres, based on new analysis of fish and invertebrate response. *Sci. Total Environ. 177*: 173-193.

Oliver, B.G., Thurman, E.M., and Malcolm, R.L. 1983. The contribution of humic substances to the acidity of natural waters. *Geochim. Cosmochim. Acta.* 47:2031-2035.

Wathne, B.M., Mosello, R., Henriksen, A. and Marchetto A. 1990. In: Johannessen, M., Mosello, R. and Barth, H. (Eds.). Acidification processes in remote mountain lakes. *Air Pollut. Res. Rep. 20,* Guyot, Brussels: 41-58.

Wathne, B.M. Partick, S.T., Monteith, D., and Barth, H. (Eds.): AL:PE PROJECT PART 1: AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology. AL:PE 1 Report for the periode April 1991 - April 1993. Ecosystems Research Report Vol. 9. European Commission Brussels. 1995

SFT (The Norwegian State Pollution Control Authority) 1990. Statlig program for forurensningsovervåking. Overvåking av langtransportert luft og nedbør. Årsrapport 1989. Rapport 375/89.

SFT (The Norwegian State Pollution Control Authority) 1994. Statlig program for forurensningsovervåking. Overvåking av langtransportert luft og nedbør. Årsrapport 1993. Rapport 583/94.

ter Braak,C.J.F. (1983) Principal components biplots and alpha and beta diversity. *Ecology* 64, 454-462.

ter Braak, C.J.F. (1987) Ordination. In *Data analysis in community and landscape ecology* (eds. R.H.G. Jongman, C.J.F. ter Braak and O.F.R. van Tongeren), pp. 91-173. Pudoc, Wageningen.

ter Braak, C.J.F. (1990) Update notes: CANOCO version 3.10. Agricultural Mathematics Group, Wageningen, 35 pp.

ter Braak, C.J.F. (1994) Canonical community ordination. Part I: Basic theory and linear methods. *Écoscience* 1, 127-140.

ter Braak, C.J.F. and Prentice, I.C. (1988) A theory of gradient analysis. *Advances in Ecological Research* 18, 271-317.

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Appendix 1

Site Information Data

Leif Lien

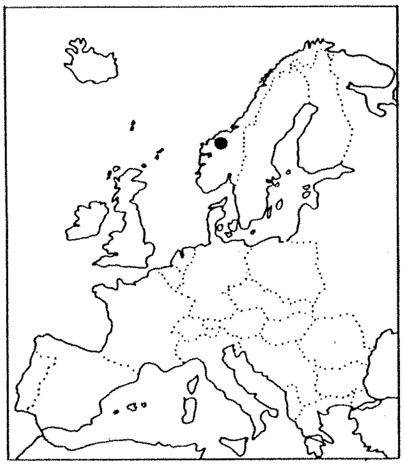
Norwegian Institute for Water Research, Norway

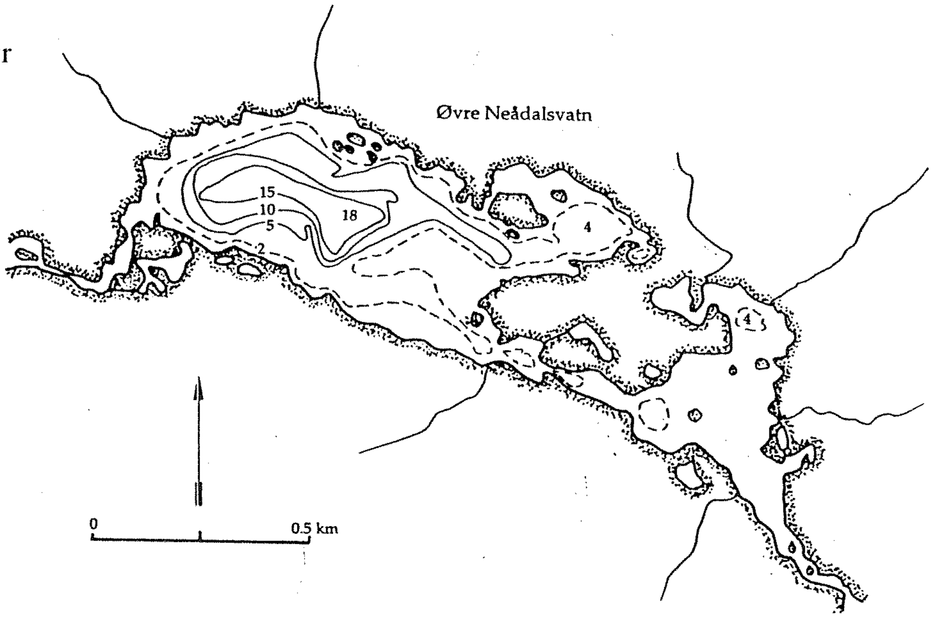
LOCATION OF AL:PE 2 SITES:

1. ØVRE NEÅDALSVATN
2. STAVSVATN
3. LILLE HOVVATN
4.1 LOCHNAGAR
4.2 SANDY LOCH
4.3 LOCH NAN EUN
5.1 LAGO PAIONE SUPERIORE
5.2 LAGO PAIONE INFERIORE
6.1 LAGO LUNGO
6.2 LAGO DI LATTE
7.3 LAC BLANC
7.4 LAC NOIR
8 ÉTANG d'AUBÉ
9 ARRESJØEN
10 LOUGH MAAM
11 SCHWARZSEE OB SÖLDEN
12.1 ESTANY AGUILÓ
12.2 ESTANY REDO
13 LA CALDERA
14 LAGOA ESCURA
15.1 STAROLESNIANSKE PLESO
15.2 NIZNE TERIANSKE PLESO
15.3 DLUGI STAW
15.4 ZIELONI STAW
16 LAGUNA CIMERA
17 CHUNA
18 CHIBINI
19 ZGORNJE KRISKO JEZERO

1. ØVRE NEÅDALSVATN

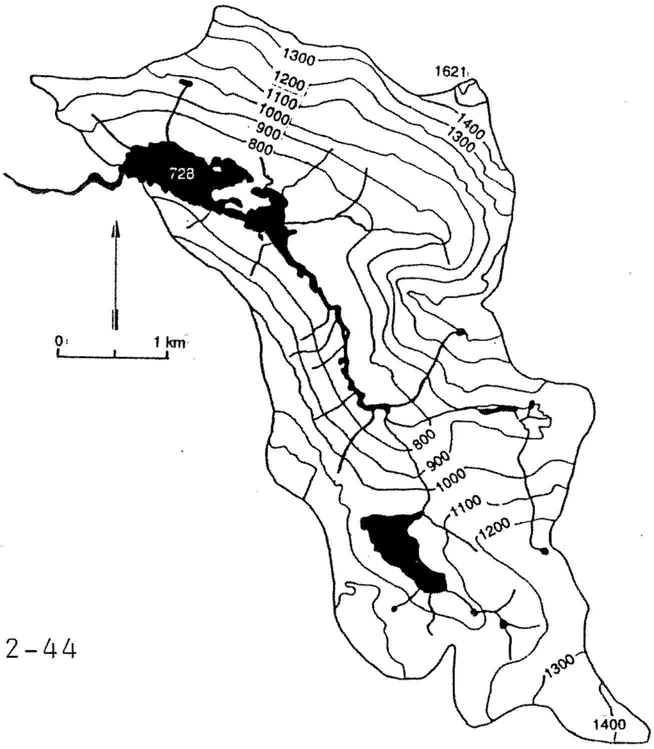
Country:	Norway
Latitude:	62°46'30" N
Longitude:	9°00' E
Lake altitude:	728 m
Lake area:	50 ha
Max. depth:	18 m
Mean depth:	3.9 m
Volume:	1.95 x 10^6 m^3
Retention time:	23.5 days
Ice free period:	June - October
Catchment area:	16 km^2
Catchment geology:	Gneiss
Catchment soils:	Alpine soils
Catchment vegetation:	Alpine heath, pasture, bare rock.
Annual precipitation:	1500 mm
Annual run off:	60 l/sec/km2
Annual deposition (S):	0.24 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout, reproduction





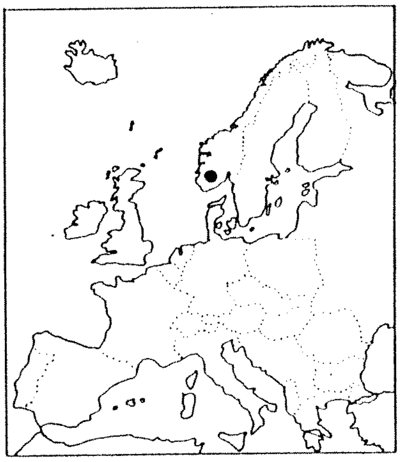
Water chemistry (1993):

pH	6.16
Alk µeq/l	26
Cond. mS/m	0.87
Ca mg/l	0.38
Mg "	0.09
Na "	0.76
K "	0.12
SO_4 "	0.65
Cl "	1.04
NO_3N µg/l	10
NH_4N µg/l	<5
Tot-N µg/l	57
RAl "	<10
ILAl "	<10
TOC mg/l	0.73
F µg/l	< 0.1
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	<2

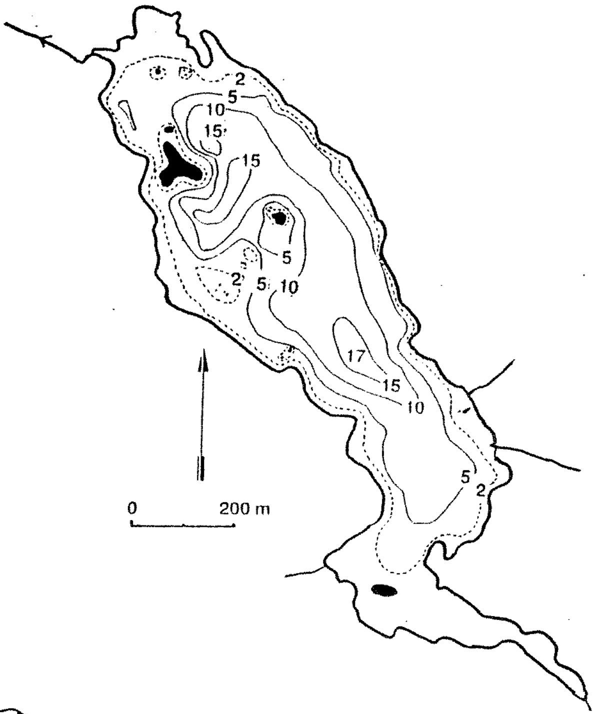


2. STAVSVATN

Country:	Norway
Latitude:	59°38' N
Longitude:	8°07' E
Lake altitude:	1053 m
Lake area:	40 ha
Max. depth:	17 m
Mean depth:	6.2 m
Volume:	2.5 x 10^6 m^3
Retention time:	380 days
Ice free period:	June - Sept./Oct.
Catchment area:	2.43 km^2
Catchment geology:	Granite
Catchment soils:	Alpine soils and peat.
Catchment vegetation:	Pasture, alpine heath, some birch trees, bare rock.
Annual precipitation:	c. 1000 mm
Annual run off:	31 l/sec/km^2
Annual deposition (S):	0.55 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout, no reproduction

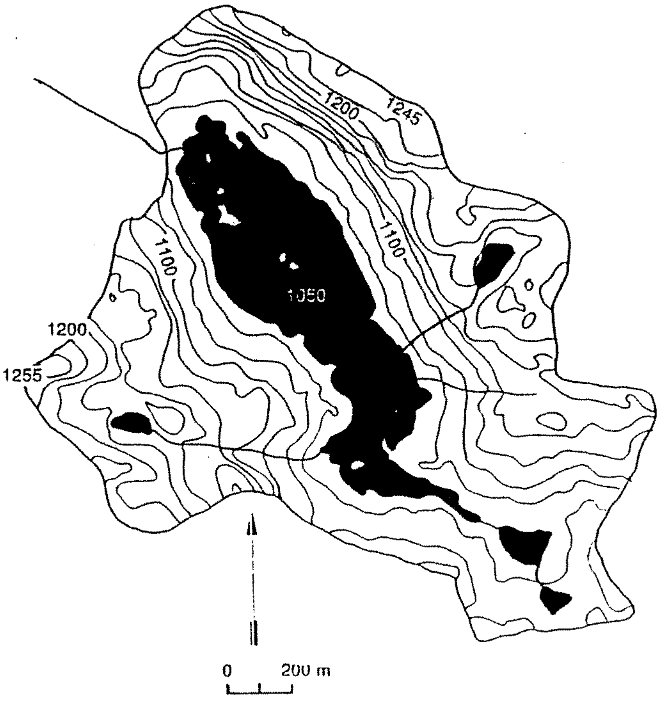


Stavsvatn



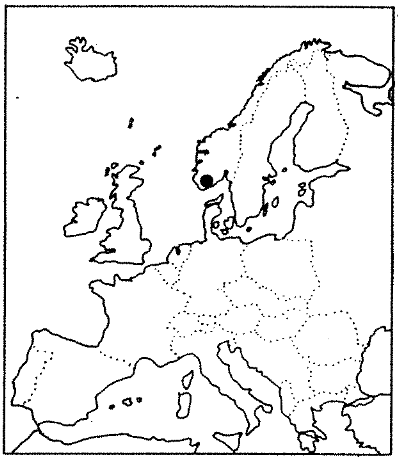
Water chemistry (1993):

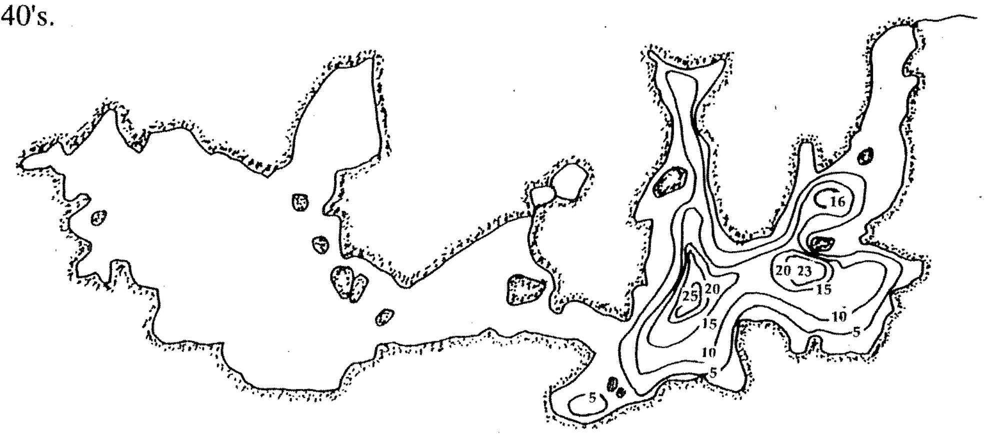
pH	5.94
Alk µeq/l	6
Cond. mS/m	1.15
Ca mg/l	0.92
Mg "	0.13
Na "	0.60
K "	0.10
SO_4 "	1.8
Cl "	0.8
NO_3N µg/l	43
NH_4N µg/l	17
Tot-N µg/l	155
Tot-P	2
RAl "	75
ILAl "	19
TOC mg/l	0.73
F µg/l	1.33
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	<2



3. LILLE HOVVATN

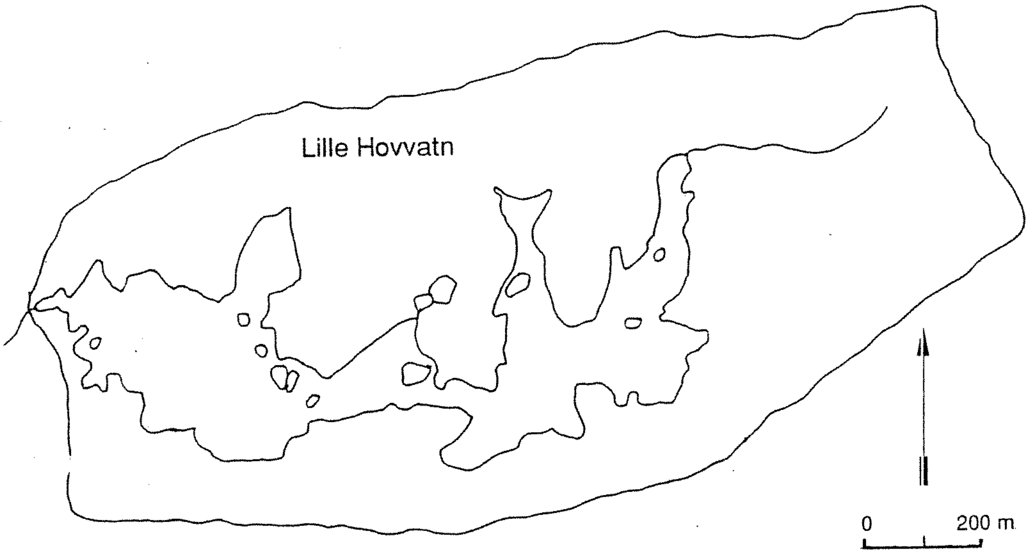
Country:	Norway
Latitude:	58°36'30" N
Longitude:	8°02' E
Lake altitude:	503 m
Lake area:	21 ha
Max. depth:	25 m
Mean depth:	5 m
Volume:	1.05 x 10^6 m^3
Retention time:	1 year
Ice free period	May - November
Catchment area:	0.95 km^2
Catchment geology:	Granite
Catchment soils:	Podzolic and mor soils
Catchment vegetation:	Bare rock, peat,some birch, pine and spurce.
Annual precipitation:	c. 1300 mm
Annual run off:	35 l/sec/km^2
Annual deposition (S):	1.1 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout, extinct 1940's.





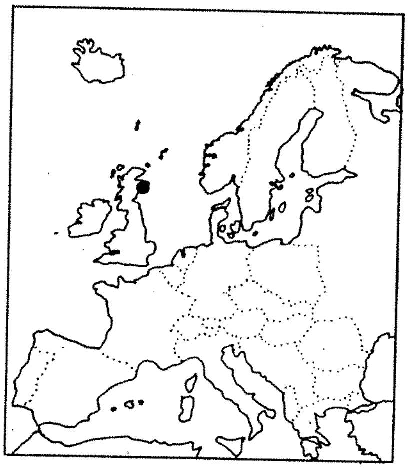
Water chemistry (1993):

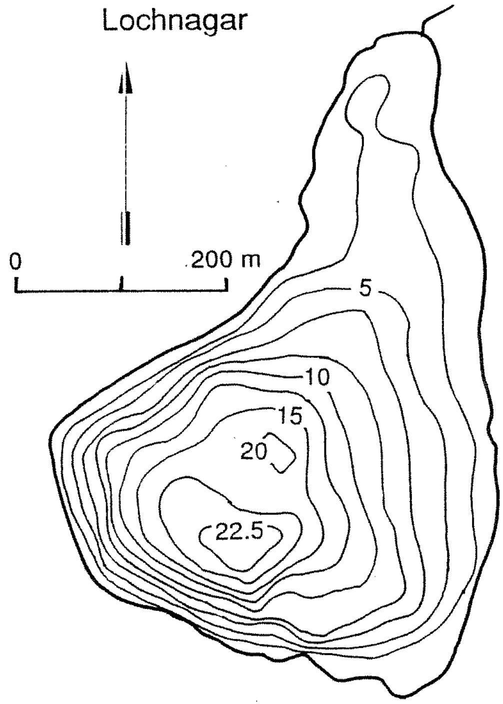
pH	4.65
Alk µeq/l	0
Cond. mS/m	3.07
Ca mg/l	0.46
Mg "	0.24
Na "	2.19
K "	0.12
SO_4 "	2.8
Cl "	4.15
NO_3N µg/l	153
NH_4Nµg/l	91
Tot-N µg/l	260
RAl "	217
ILAl "	29
TOC mg/l	1.81
F µg/l	< 0.1
Cd µg/l	< 0.1
Pb µg/l	1.9
Hg ng/l	< 2.0



4.1. LOCHNAGAR

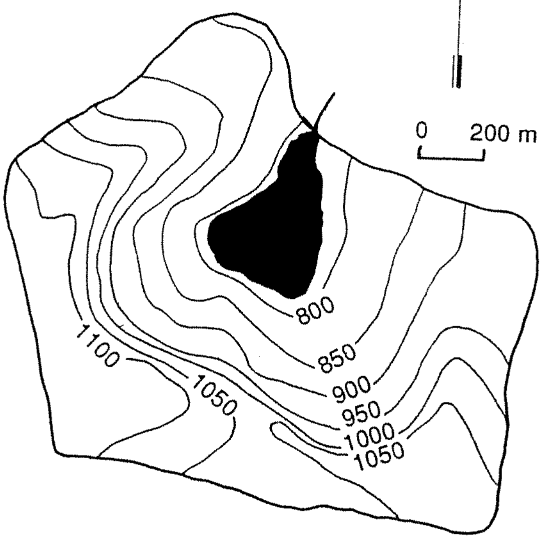
Country:	United Kingdom
Latitude:	56° 57' 29" N
Longitude:	3° 13' 5" W
Lake altitude:	785 m
Lake area:	9.8 ha
Max. depth:	24 m
Mean depth:	8.4 m
Volume:	0.82 x 10^6 m^3
Retention time:	315 days
Ice free period:	c. 8 months
Catchment area:	1.02 km^2
Catchment geology:	Granite
Catchment soils:	Peat and alpine soils
Catchment vegetation:	Dwarf shrub (alpine) heath, bare rock.
Annual precipitation:	1034 mm (1990)
Annual run off:	90 % of rainfall ≈ 29.5 l/sec/km^2
Annual deposition (S):	≈ 0.47 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout, reproduction in outflow.



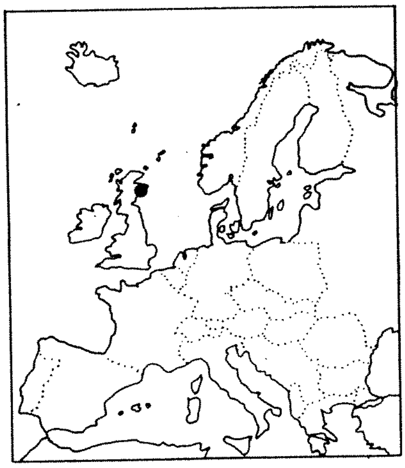


Water chemistry (1993):

pH	5.32
Alk µeq/l	11
Cond. mS/m	2.4
Ca mg/l	0.62
Mg "	0.34
Na "	2.14
K "	0.25
SO_4 "	2.79
Cl "	3.24
NO_3N µg/l	252
NH_4N µg/l	
Tot-N µg/l	
RAl "	53
ILAl "	12
DOC mg/l	0.8
F µg/l	0.2
Cd µg/l	0.99
Pb µg/l	17.6
Hg ng/l	<2



4.2. SANDY LOCH

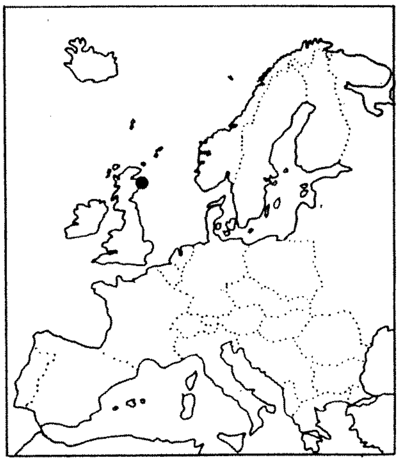


Country:	United Kingdom
Latitude:	56° 57' 45" N
Longitude:	3° 16' 15" W
Lake altitude:	790 m
Lake area:	4.4 ha
Max. depth:	2 m
Mean depth:	
Volume:	
Retention time:	
Ice free period:	c. 8 months
Catchment area:	2.02 km^2
Catchment geology:	Granite
Catchment soils:	Alpine soils and peat
Catchment vegetation:	Dwarf shrub (alpine) heath, bare rock.
Annual precipitation:	1034 mm (1990)
Annual run off:	90 % of rainfall ≈ 29.5 l/sec/km^2
Annual deposition (S):	≈ 0.47 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout.

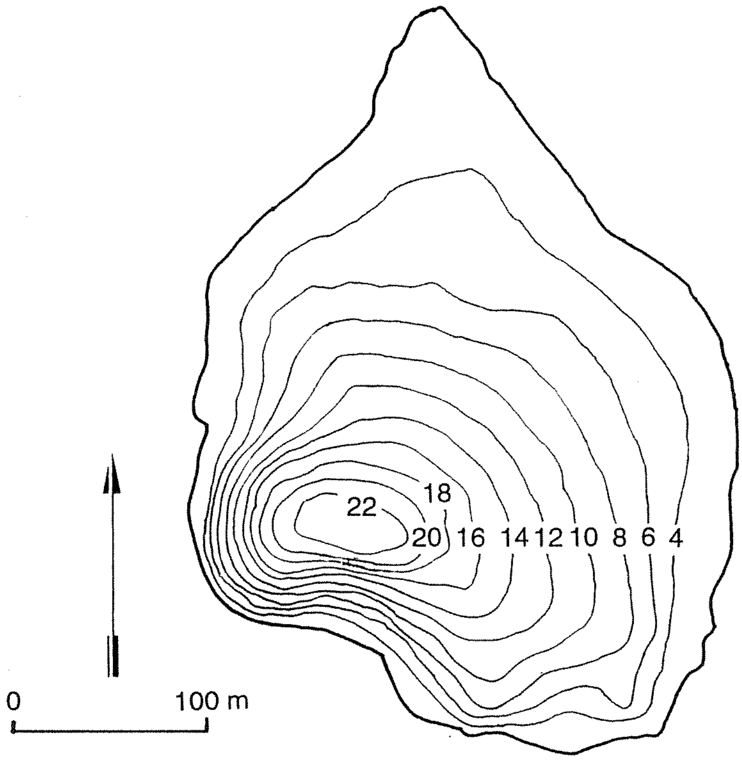
Water chemistry (1993):

pH	6.09
Alk µeq/l	27
Cond. mS/m	1.9
Ca mg/l	0.83
Mg "	0.23
Na "	1.89
K "	0.15
SO_4 "	2.56
Cl "	2.35
NO_3N µg/l	98
NH_4N µg/l	
Tot-N µg/l	
RAl "	10
ILAl "	9
TOC mg/l	1.1
F µg/l	
Cd µg/l	<0.05
Pb µg/l	<0.5
Hg ng/l	3

4.3. LOCH NAN EUN



Country:	United Kingdom
Latitude:	56° 57' 10" N
Longitude:	3° 16' 3" W
Lake altitude:	890 m
Lake area:	8.1 ha
Max. depth:	23 m
Mean depth:	7.7 m
Volume:	0.62 x 10^6 m^3
Retention time:	265 days
Ice free period:	c. 8 months
Catchment area:	0.92 km^2
Catchment geology:	Granite
Catchment soils:	Alpine soils and peat
Catchment vegetation:	Dwarf shrub (alpine) heath, bare rock
Annual precipitation:	1034 mm (1990)
Annual run off:	90 % of rainfall ≈ 29.5 l/sec/km^2
Annual deposition (S):	≈ 0.47 g S/m^2/yr
Remarks: (e.g. fish):	



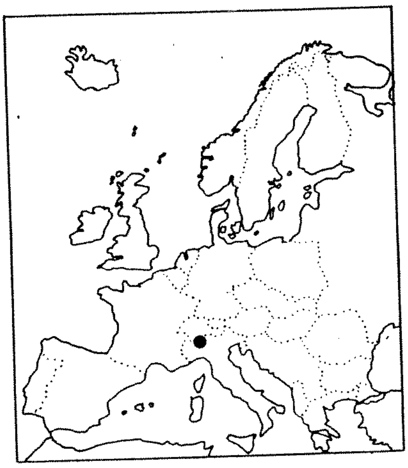
Loch Nan Eun Bathymetry

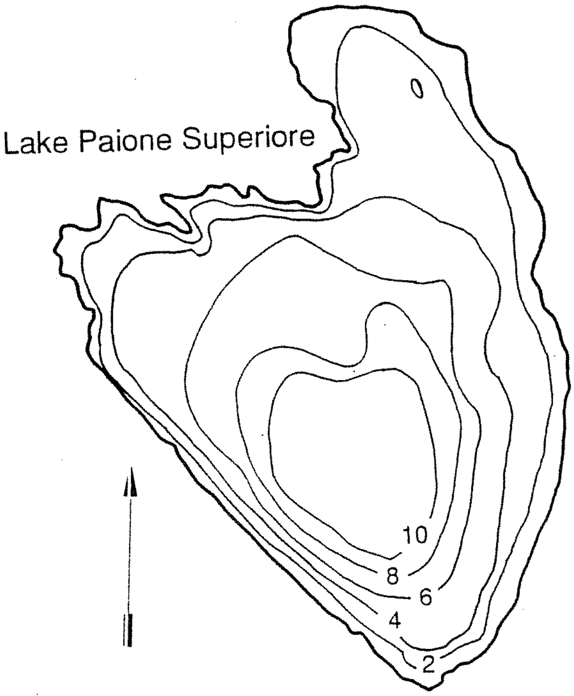
Water chemistry (1993):

pH	5.4
Alk µeq/l	11
Cond. mS/m	3.9
Ca mg/l	0.63
Mg "	0.53
Na "	4.85
K "	0.23
SO_4 "	2.3
Cl "	8.49
NO_3N µg/l	131
NH_4N µg/l	
Tot-N µg/l	
RAl "	32
ILAl "	6
TOC mg/l	2
F µg/l	
Cd µg/l	0.05
Pb µg/l	0.7
Hg ng/l	<2

5.1. LAGO PAIONE SUPERIORE

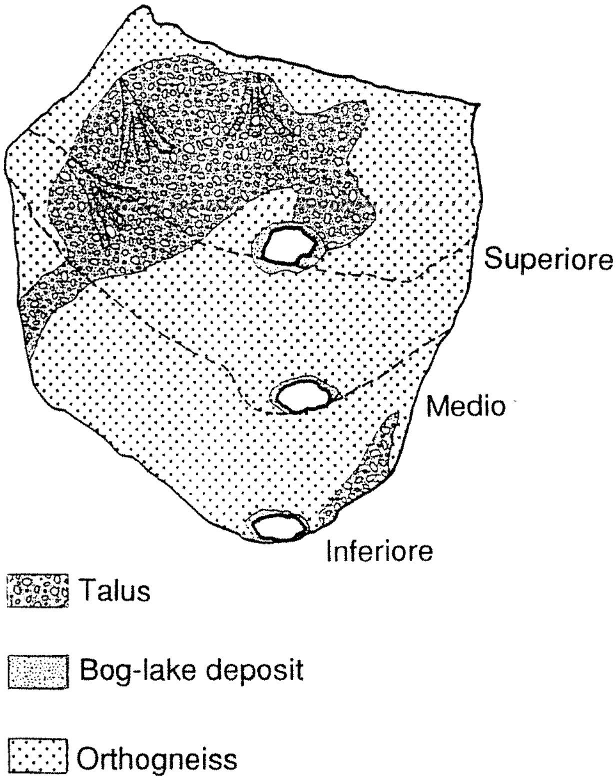
Country:	Italy
Latitude:	46°10'26" N
Longitude:	8°11'27" E
Lake altitude:	2269 m
Lake area:	1.36 ha
Max. depth:	11.5 m
Mean depth:	5.12 m
Volume:	0.069 x 10^6 m^3
Retention time:	33 days
Ice free period:	August - October
Catchment area:	0.55 km^2
Catchment geology:	Gneiss
Catchment soils:	
Catchment vegetation:	Alpine pasture bare rock
Annual precipitation:	1400 mm
Annual run off:	44 l/sec/km^2
Annual deposition (S):	0.4-0.6 g S/m^2/yr
Remarks: (e.g. fish):	No fish





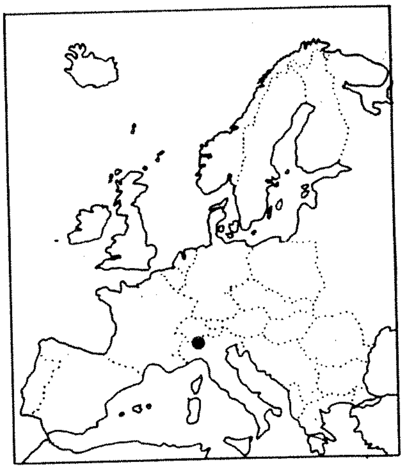
Water chemistry (1993):

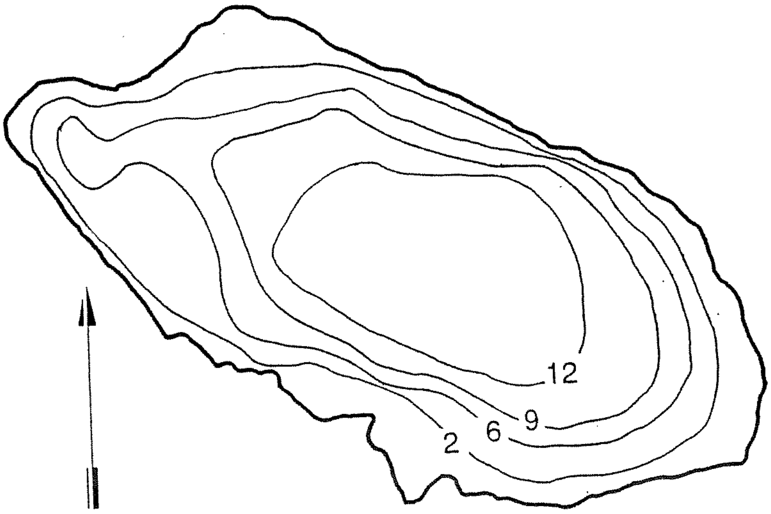
pH	5.64
Alk µeq/l	1
Cond. mS/m	1.0
Ca mg/l	1.03
Mg "	0.11
Na "	0.24
K "	0.26
SO_4 "	2.28
Cl "	0.13
NO_3N µg/l	358
NH_4N µg/l	226
Tot-N µg/l	
Tot-P "	3
RAl "	25
ILAl "	< 10
TOC mg/l	0.33
F µg/l	8
Cd µg/l	0.09
Pb µg/l	1.35
Hg ng/l	11



5.2. LAGO PAIONE INFERIORE

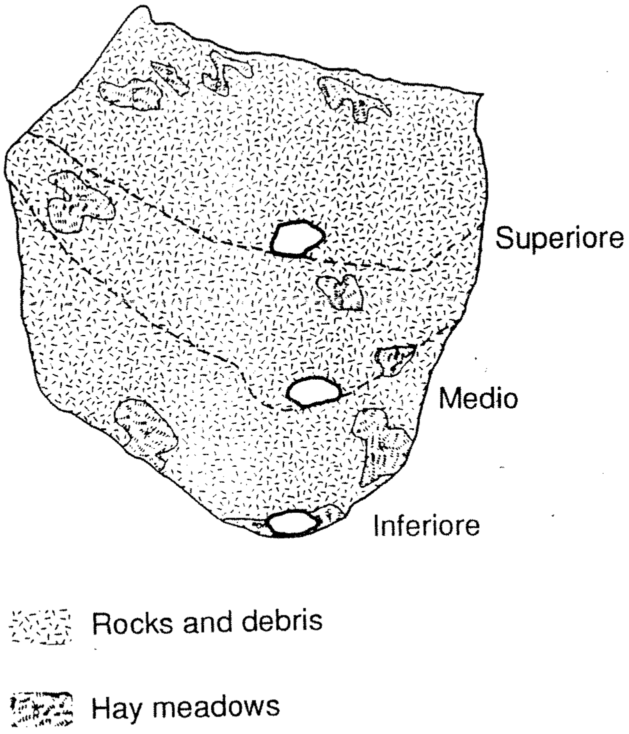
Country:	Italy
Latitude:	46°10'1" N
Longitude:	8°11'23" E
Lake altitude:	2002 m
Lake area:	1.4 ha
Max. depth:	13.5 m
Mean depth:	7.35 m
Volume:	0.103×10^6 m^3
Retention time:	23 days
Ice free period:	July - October
Catchment area:	1.14 km^2
Catchment geology:	Gneiss
Catchment soils:	
Catchment vegetation:	Alpine pasture bare rock
Annual precipitation:	1450 mm
Annual run off:	46 l/sec/km^2
Annual deposition (S):	0.4-0.6 g S/m^2/yr
Remarks: (e.g. fish):	Rainbow trout



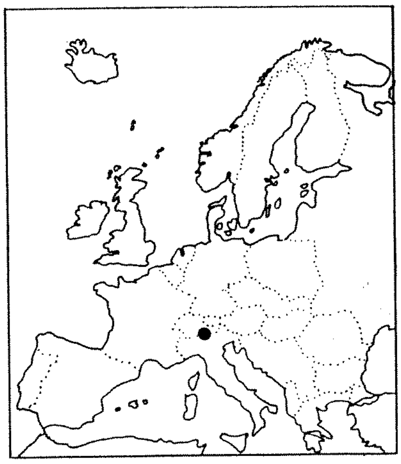


Water chemistry (1993):

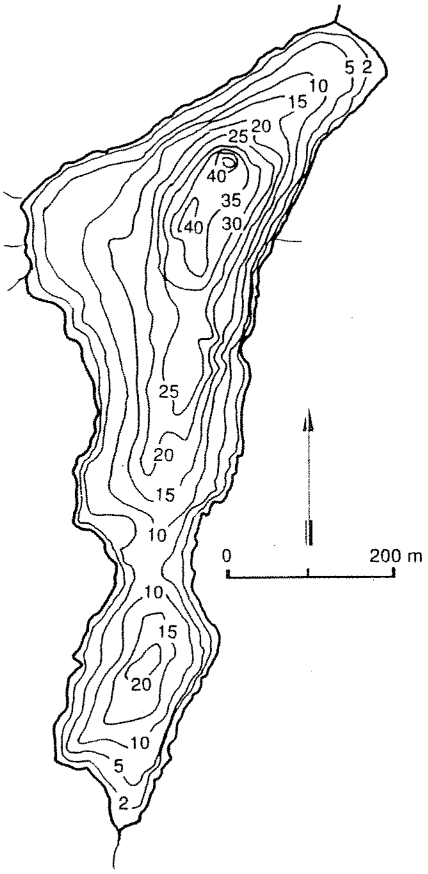
pH	6.43
Alk µeq/l	27
Cond. mS/m	1.23
Ca mg/l	1.63
Mg "	0.15
Na "	0.32
K "	0.33
SO_4 "	2.57
Cl "	0.13
NO_3N µg/l	370
NH_4N µg/l	2
Tot-N µg/l	390
Tot-P "	2
RAl "	<10
ILAl "	< 10
DOC mg/l	0.59
F µg/l	14
Cd µg/l	0.07
Pb µg/l	<0.5
Hg ng/l	4



6.1. LAGO LUNGO (LANGSEE)

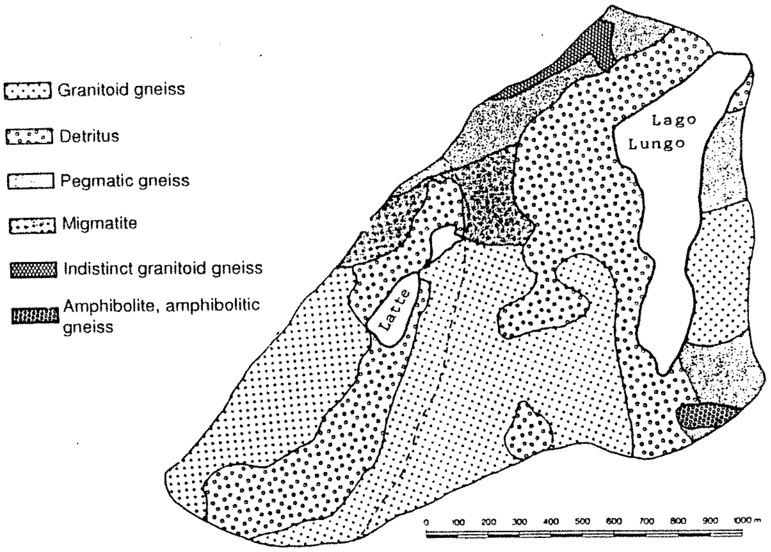


Country:	Italy .
Latitude:	46°43'36" N
Longitude:	11°05' E
Lake altitude:	2384 m
Lake area:	20.05 ha
Max. depth:	45 m
Mean depth:	12.9 m
Volume:	2.583 x 10^6 m^3
Retention time:	c. 500 days
Ice free period:	July - October
Catchment area:	2.07 km^2
Catchment geology:	Gneiss
Catchment soils:	
Catchment vegetation:	Glaciers, rocks and debris, some pasture
Annual precipitation:	c. 1000 mm
Annual run off:	29 l/sec/km^2
Annual deposition (S):	0.53 g S/m^2/yr
Remarks: (e.g. fish):	Arctic char (reproduction) Brown trout, Grayling.



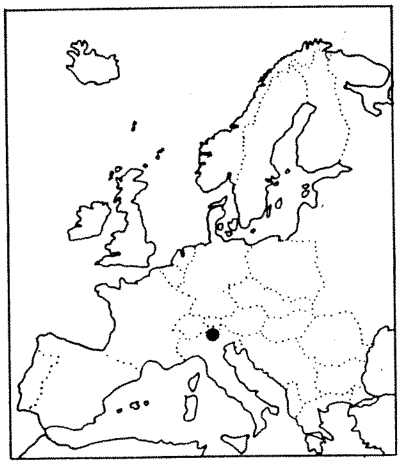
Water chemistry (1993):

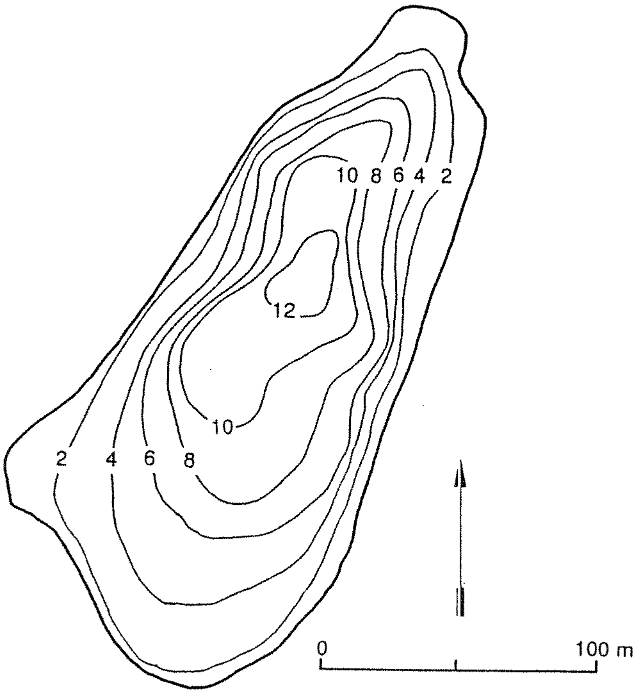
pH	6.43
Alk µeq/l	21
Cond. mS/m	1.35
Ca mg/l	1.63
Mg "	0.19
Na "	0.4
K "	0.29
SO_4 "	3.37
Cl "	0.15
NO_3N µg/l	195
NH_4N µg/l	10
Tot-N µg/l	244
Tot-P "	4
RAl "	< 10
ILAl "	< 10
TOC mg/l	0.9
F µg/l µg/l	<0.1
Cd µg/l	0.06
Pb µg/l	<0.5
Hg ng/l	<2



6.2. LAGO DI LATTE (MILCHSEE)

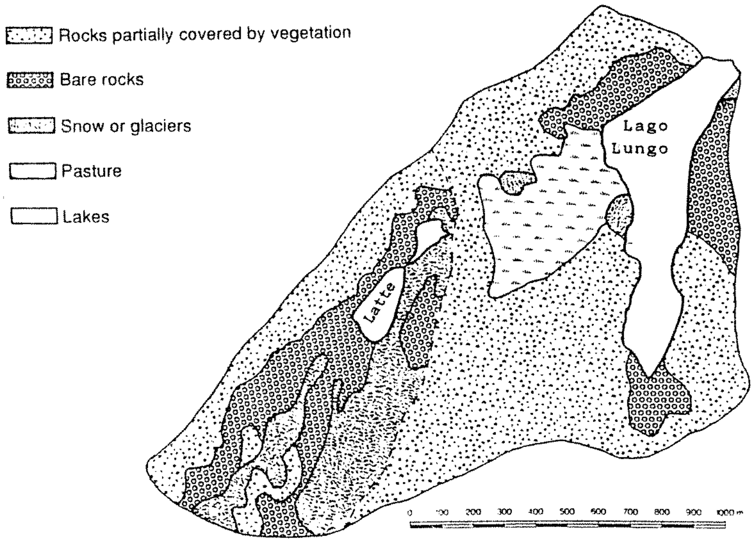
Country:	Italy
Latitude:	46°43'32" N
Longitude:	11°04'21" E
Lake altitude:	2540 m
Lake area:	2.34 ha
Max. depth:	12.3 m
Mean depth:	5.34 m
Volume:	0.125 x 10^6 m^3
Retention time:	71 days
Ice free period	July - October
Catchment area:	0.654 km^2
Catchment geology:	Gneiss
Catchment soils:	
Catchment vegetation:	Bare rocks, alpine pasture, permanent ice
Annual precipitation:	c. 1000 mm
Annual run off:	31 l/sec/km2
Annual deposition (S):	0.53 g S/m^2/yr
Remarks: (e.g. fish):	Arctic char (reproduction)



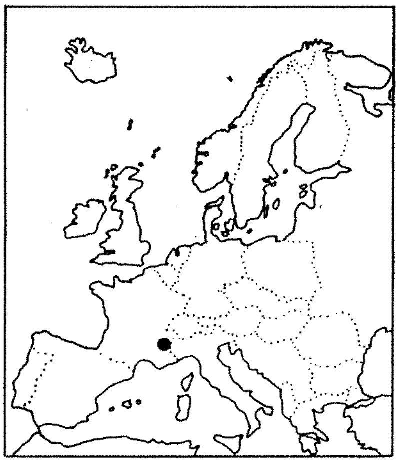


Water chemistry (1993):

pH	6.6
Alk µeq/l	46
Cond. mS/m	1.53
Ca mg/l	1.95
Mg "	0.16
Na "	0.42
K "	0.39
SO_4 "	2.85
Cl "	0.15
NO_3N µg/l	321
NH_4N µg/l	9
Tot-N µg/l	357
Tot-P µg/l	2
ILAl "	< 10
TOC mg/l	0.9
F µg/l	<0.1
Cd µg/l	0.05
Pb µg/l	<0.5
Hg ng/l	<2



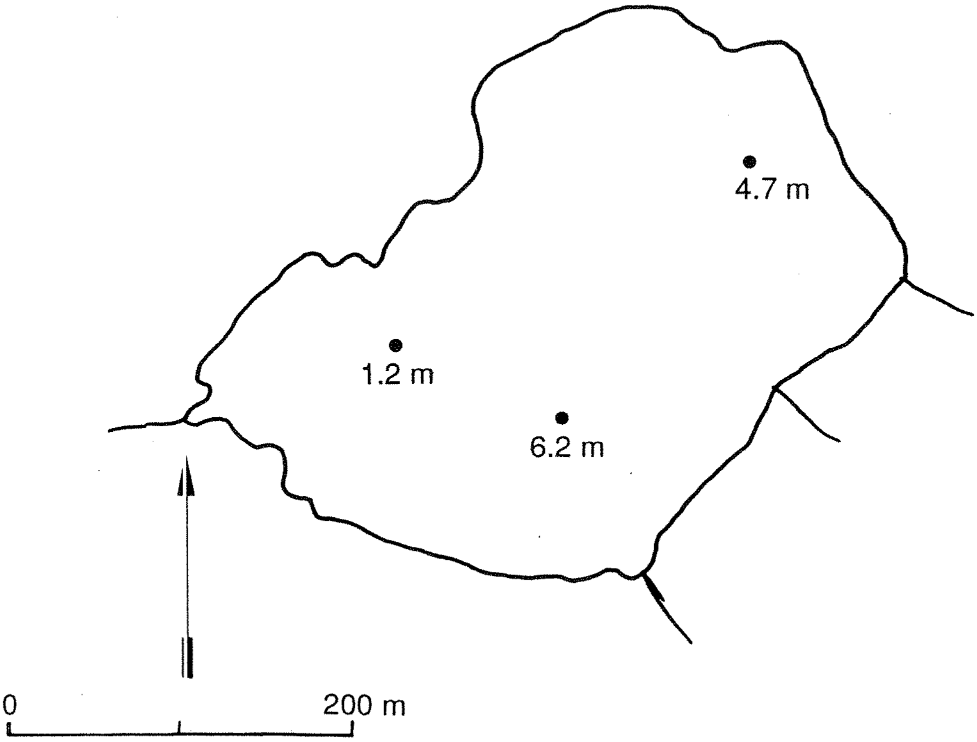
7.3. LAC BLANC



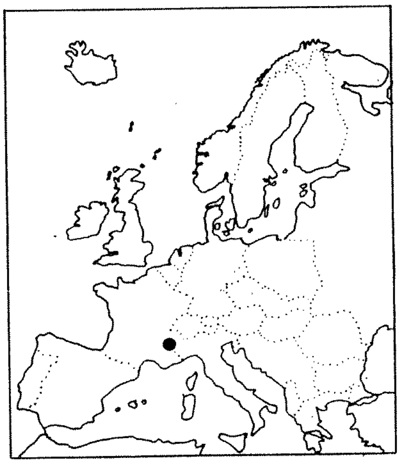
Country:	France
Latitude:	
Longitude:	
Lake altitude:	2753 m
Lake area:	4.17 ha
Max. depth:	6 m
Mean depth:	
Volume:	
Retention time:	
Ice free period:	
Catchment area:	2.66 km^2
Catchment geology:	Orthogneiss
Catchment soils:	
Catchment vegetation:	
Annual precipitation:	
Annual run off:	
Annual deposition (S):	
Remarks: (e.g. fish):	No fish

Water chemistry (1993):

pH	7.1
Alk µeq/l	
Cond. mS/m	2.05
Ca mg/l	2.45
Mg "	0.4
Na "	0.8
K "	0.48
SO_4 "	1.8
Cl "	0.2
NO_3N µg/l	265
NH_4N µg/l	12
Tot-N µg/l	345
RAl "	<10
ILAl "	<10
TOC mg/l	1.11
F µg/l	0.15
Cd µg/l	<0.1
Pb µg/l	1.2



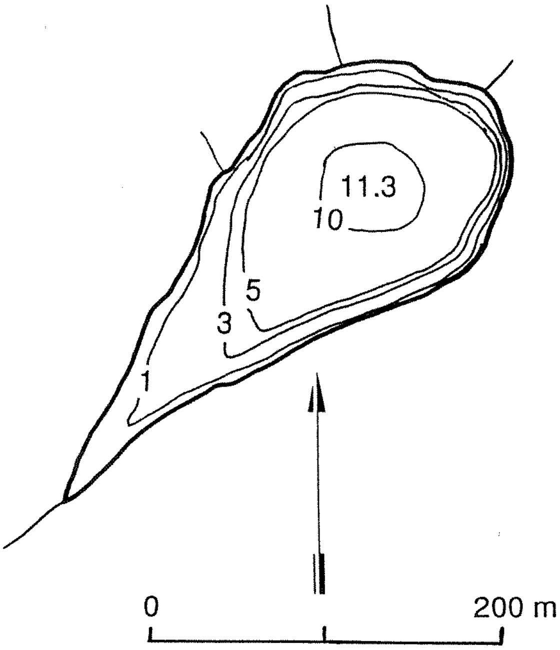
7.4. LAC NOIR



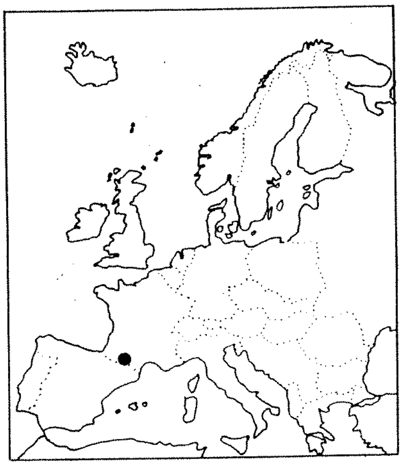
Country:	France
Latitude:	
Longitude:	
Lake altitude:	2750 m
Lake area:	1.2 ha
Max. depth:	11 m
Mean depth:	5.2 m
Volume:	0.063×10^6 m^3
Retention time:	
Ice free period:	
Catchment area:	0.59 km^2
Catchment geology:	Orthogneiss
Catchment soils:	
Catchment vegetation:	
Annual precipitation:	
Annual run off:	
Annual deposition (S):	
Remarks: (e.g. fish):	No fish

Water chemistry (1992):

pH	7.3
Alk µeq/l	130
Cond. mS/m	2.6
Ca mg/l	3.4
Mg "	0.5
Na "	0.3
K "	0.2
SO_4 "	4.5
Cl "	0.1
NO_3N µg/l	130
NH_4N µg/l	0
Tot-N µg/l	140
Tot-P "	
RAl "	
ILAl "	
TOC mg/l	
F µg/l	
Cd µg/l	
Pb µg/l	
Hg ng/l	



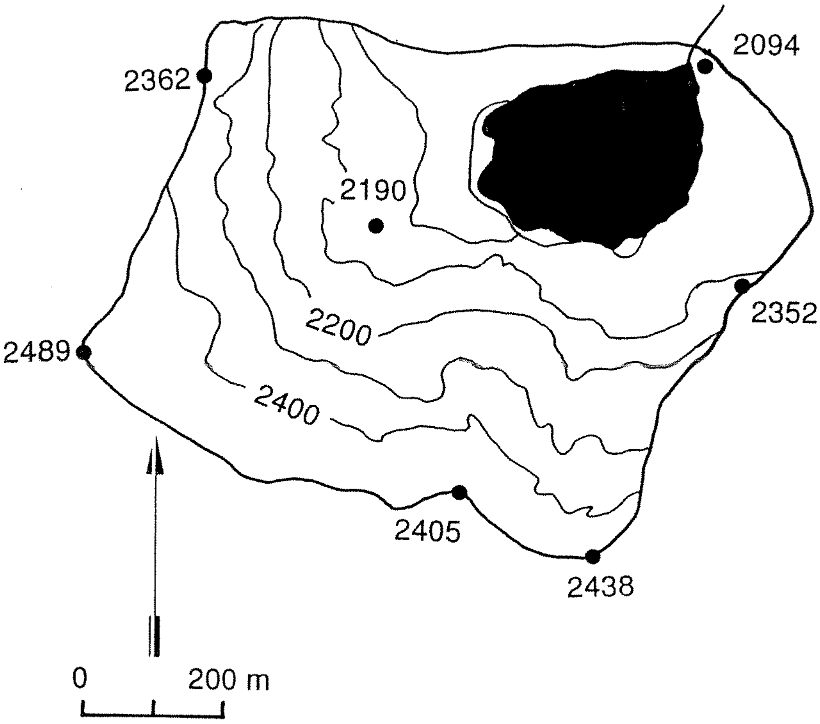
8. ÉTANG D'AUBÉ



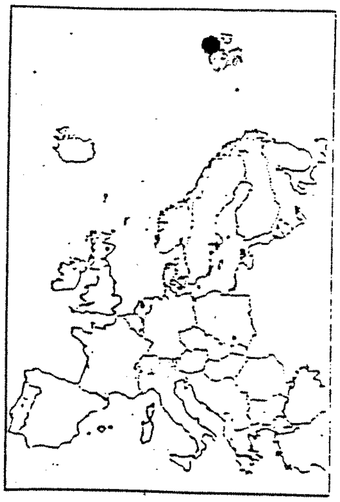
Country:	France
Latitude:	42° 44' 44" N
Longitude:	1° 20' E
Lake altitude:	2091 m
Lake area:	8.6 ha
Max. depth:	45 m
Mean depth:	
Volume:	
Retention time:	
Ice free period:	June - October
Catchment area:	0.77 km^2
Catchment geology:	Granit
Catchment soils:	
Catchment vegetation:	Rocks, debris, some pasture.
Annual precipitation:	2500 - 3000 mm (1992)
Annual run off:	>1000 mm
Annual deposition (S):	
Remarks: (e.g. fish):	Brown trout and dace - no reproduction. Lake char - reproduction is likely Arctic char

Water chemistry (1993):

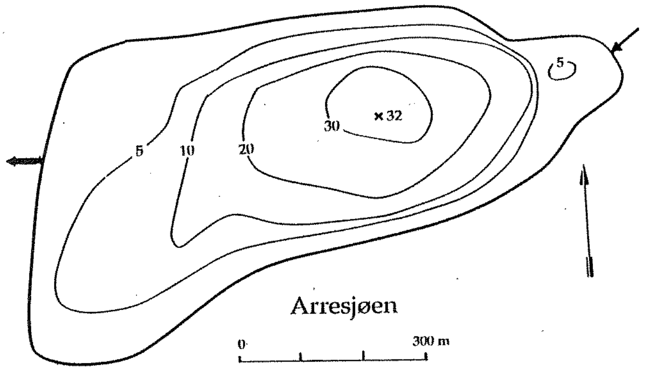
pH	6.32
Alk µeq/l	13
Cond. mS/m	0.8
Ca mg/l	.64
Mg "	0.1
Na "	0.35
K "	0.12
SO_4 "	1.25
Cl "	0.25
NO_3N µg/l	140
NH_4N µg/l	<10
Tot-N µg/l	690
Tot-P	5
RAl "	< 10
ILAl "	< 10
TOC mg/l	0.9
F µg/l	< 0.1
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	14



9. ARRESJØEN

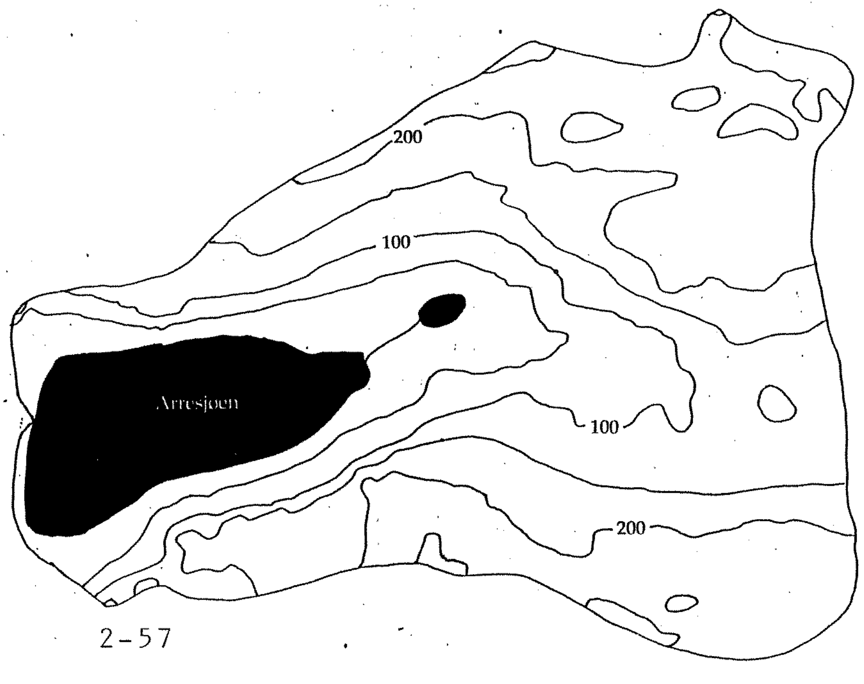


Country:	Norway
Latitude:	79° 40' N
Longitude:	10° 48' E
Lake altitude:	ca 20 m
Lake area:	35 ha
Max. depth:	32 m
Mean depth:	10.9 m
Volume:	3.8×10^6 m^3
Retention time:	3 years
Ice free period:	July - September (2 months)
Catchment area:	3 km^2
Catchment geology:	Migmatite
Catchment soils:	Permanent frozen except for the few upper dm in July/September.
Catchment vegetation:	Rocks, debris.
Annual precipitation:	ca 500 mm
Annual run off:	13 l/sec/km^2
Annual deposition (S):	0.17 g S/m^2/yr
Remarks: (e.g. fish):	Arctic char (Landlocked with reproduction)



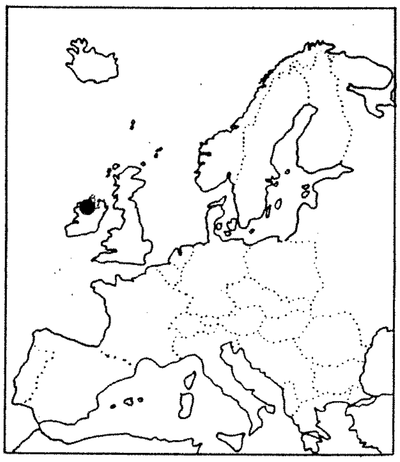
Water chemistry (1993):

pH	5.81
Alk µeq/l	24
Cond. mS/m	3.76
Ca mg/l	0.71
Mg "	0.59
Na "	4.76
K "	0.24
SO_4 "	1.55
Cl "	8.25
NO_3N µg/l	<1
NH_4N µg/l	5
Tot-N µg/l	94
Tot-P µg/l	4
RAl "	<10
ILAl "	<10
TOC mg/l	0.43
F µg/l	<0.1
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	17



10 LOUGH MAAM

Country: Ireland
Latitude: 54° 59' 19" N
Longitude: 8° 7' 0" W
Lake altitude: 436 m
Lake area: ca 5 ha
Max. depth: 8.5 m
Mean depth:
Volume:
Retention time:
Ice free period:
Catchment area:
Catchment geology: Granite
Catchment soils: Peat and morain
Catchment vegetation: Heather
Annual precipitation:
Annual run off:
Annual deposition (S): <0.4 - 0.5 g S/m^2/yr
Remarks: (e.g. fish): Brown trout.
(declining population)

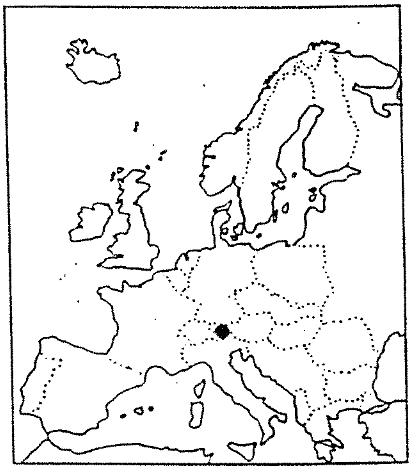


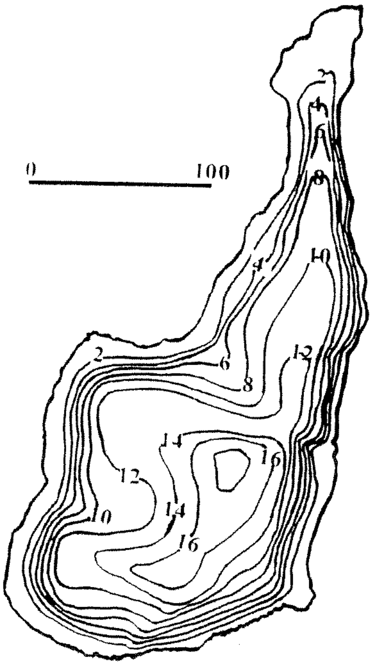
Water chemistry (1993):

pH	4.96
Alk µeq/l	7
Cond. mS/m	5.95
Ca mg/l	0.81
Mg "	0.76
Na "	7.84
K "	0.37
SO$_4$ "	2.93
Cl "	13.9
NO$_3$N µg/l	46
NH$_4$N µg/l	18
Tot-N µg/l	285
RAl "	54
ILAl "	40
TOC mg/l	3.23
F µg/l	<0.1
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	3

11. SCHWARZSEE OB SÖLDEN

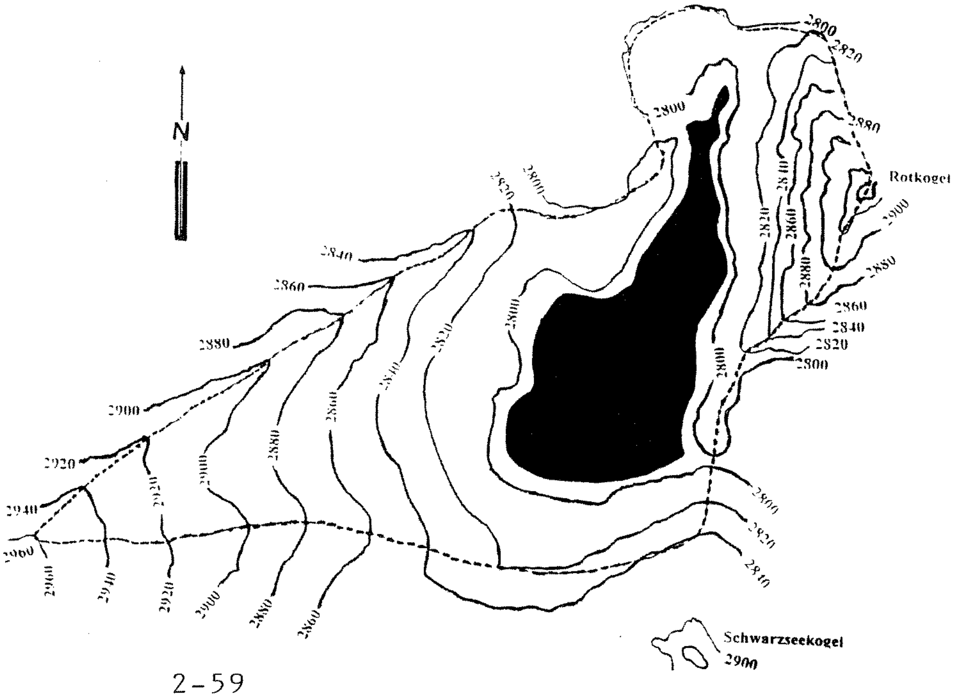
Country:	Austria
Latitude:	46° 57' 57"N
Longitude:	10° 56' 46"E
Lake altitude:	2796 m
Lake area:	3.05 ha
Max. depth:	17 m
Mean depth:	10 m
Volume:	343 060 m^3
Retention time:	2 years
Ice free period:	3 months
Catchment area:	0.14 km^2
Catchment geology:	Gneiss, granite diorite
Catchment soils:	Raw soils
Catchment vegetation:	Scarce, lichenes
Annual precipitation:	≈ 1500 mm
Annual run off:	No outflow (38 l/sec/km^2 20 % evaporation)
Annual deposition (S):	0.64 g S/m^2/yr
Remarks: (e.g. fish):	Arctic char (reduced reproduction)





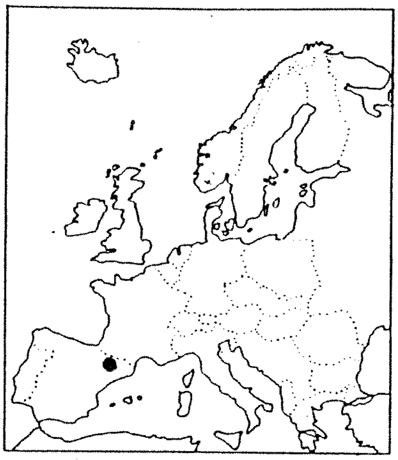
Water chemistry (1993):

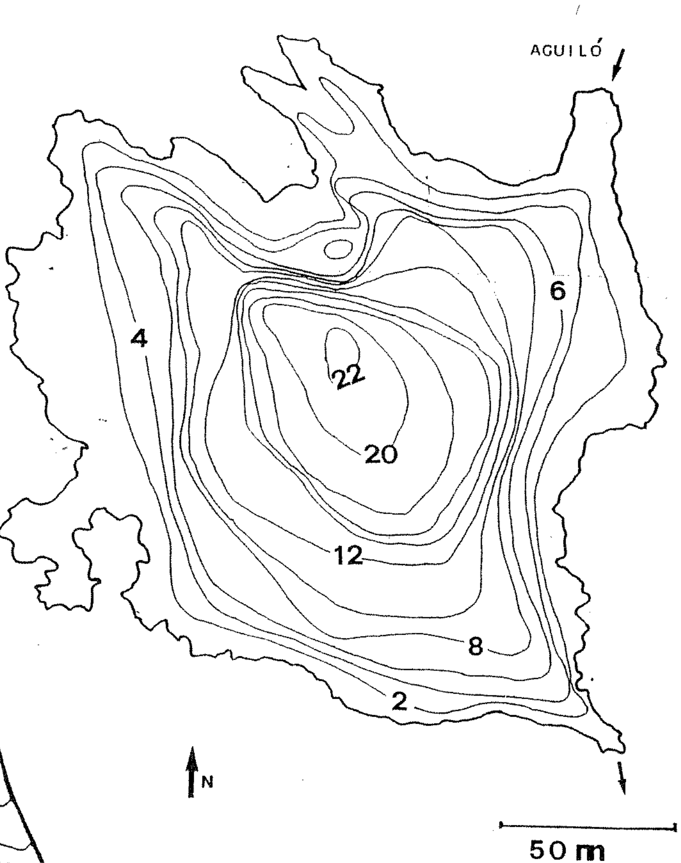
pH	5.56
Alk µeq/l	0
Cond. mS/m	1.3
Ca mg/l	1.02
Mg "	0.22
Na "	0.28
K "	0.11
SO_4 "	3.34
Cl "	0.08
NO_3N µg/l	177
NH_4N µg/l	8.7
Tot-N µg/l	290
Tot-P µg/l	2.6
RAl "	28
ILAl "	<10
TOC mg/l	0.4
F µg/l	4.3
Cd µg/l	<0.1
Pb µg/l	<0.5
Hg ng/l	7760 ??



12.1 ESTANY AGUILÓ

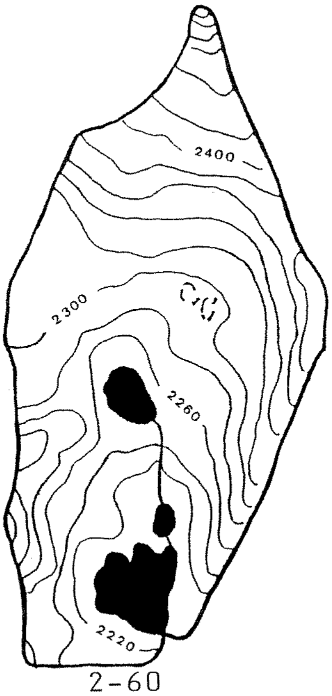
Country: Spain
Latitude: 42° 42' 46" N
Longitude: 1° 20' 0" E
Lake altitude: 2210 m
Lake area: 3.5 ha
Max. depth: 24 m
Mean depth: 7.42 m
Volume: 0.259 x 10^6 m^3
Retention time: 0.2 years
Ice free period: June- December
Catchment area: 0.88 km^2
Catchment geology: Granodiorite
Catchment soils: Ranker soil
Catchment vegetation: *Festuca eskia* (fields), *Sparganium augustifolium, Isoëtes lacustris, Sphagnum denticulatum,* other mosses (in lake)
Annual precipitation: 1300 mm
Annual run off: 33 l/sec/km^2 (20% evapoation)
Annual deposition (S): 0.8819 g S/m^2/yr
Remarks: (e.g. fish): No fish observed





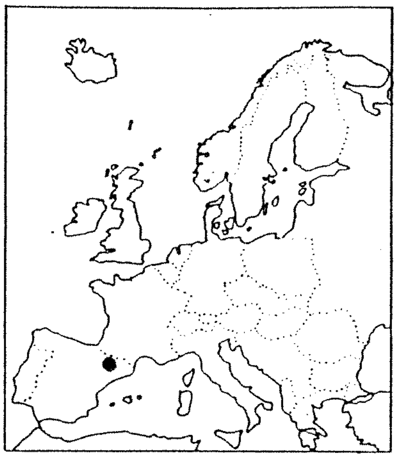
Water chemistry (1993):

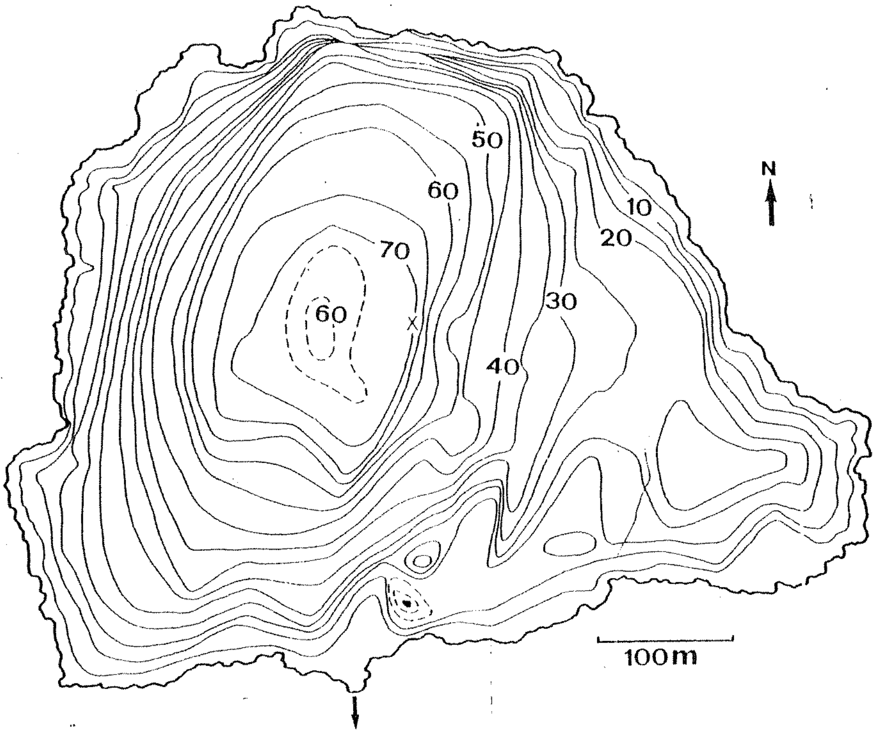
pH	5.61
Alk µeq/l	18
Cond. mS/m	0.61
Ca mg/l	0.49
Mg "	0.08
Na "	0.19
K "	0.06
SO_4 "	0.9
Cl "	0.3
NO_3N µg/l	42
NH_4N µg/l	7.1
Tot-N µg/l	147
Tot-P µg/l	4 - 7
RAl "	<10
ILAl "	12
TOC mg/l	0.73
F µg/l	<0.1
Cd µg/l	<0.5
Pb µg/l	<0.5
Hg ng/l	9



12.2 ESTANY REDO

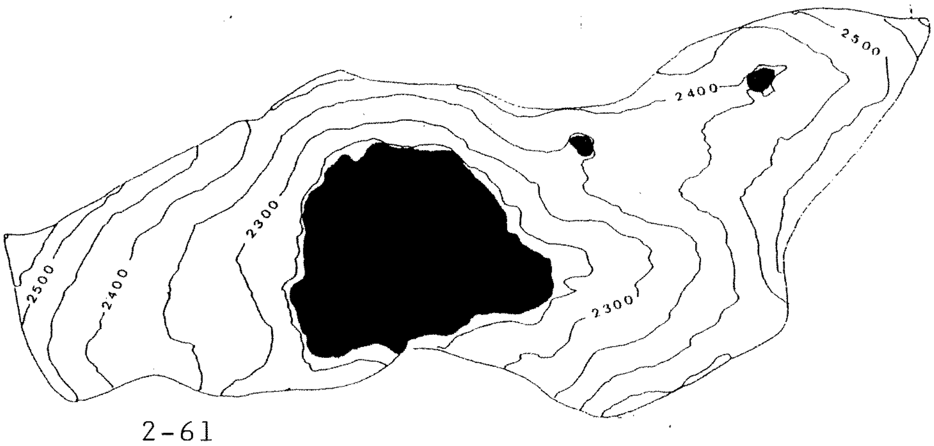
Country:	Spain
Latitude:	42° 38' 34" N
Longitude:	0° 46' 13" E
Lake altitude:	2240 m
Lake area:	24 ha
Max. depth:	73 m
Mean depth:	32 m
Volume:	7.75×10^6 m^3
Retention time:	3 years
Ice free period:	June-December (6 months)
Catchment area:	1.55 km^2
Catchment geology:	Granodiorite, few rocks bearing calcite
Catchment soils:	> 50% bare rock, ranker soil <10 cm deep
Catchment vegetation:	*Festuca eskia* fields, few mosses
Annual precipitation:	1300 - 1500 mm
Annual run off:	35 l/sec/km^2 (20% evapoation)
Annual deposition (S):	1.1232 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout





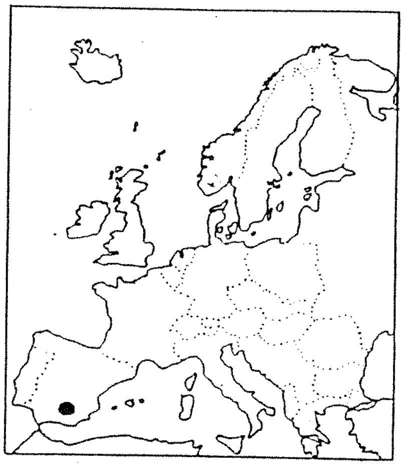
Water chemistry (1993):

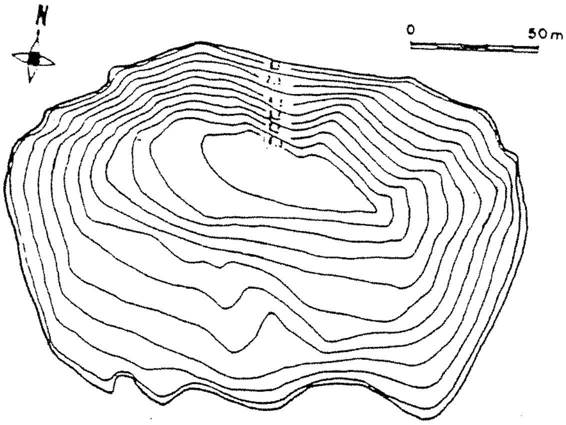
pH	6.32
Alk µeq/l	41
Cond. mS/m	1.2
Ca mg/l	1.5
Mg "	0.17
Na "	0.2
K "	0.06
SO_4 "	1.48
Cl "	0.18
NO_3N µg/l	192
NH_4N µg/l	14.7
Tot-N µg/l	
Tot-P µg/l	3.8
RAl "	11
ILAl "	<10
TOC mg/l	0.76
F µg/l	<0.1
Cd µg/l	<0.5
Pb µg/l	<0.5
Hg ng/l	<2



13 LA CALDERA

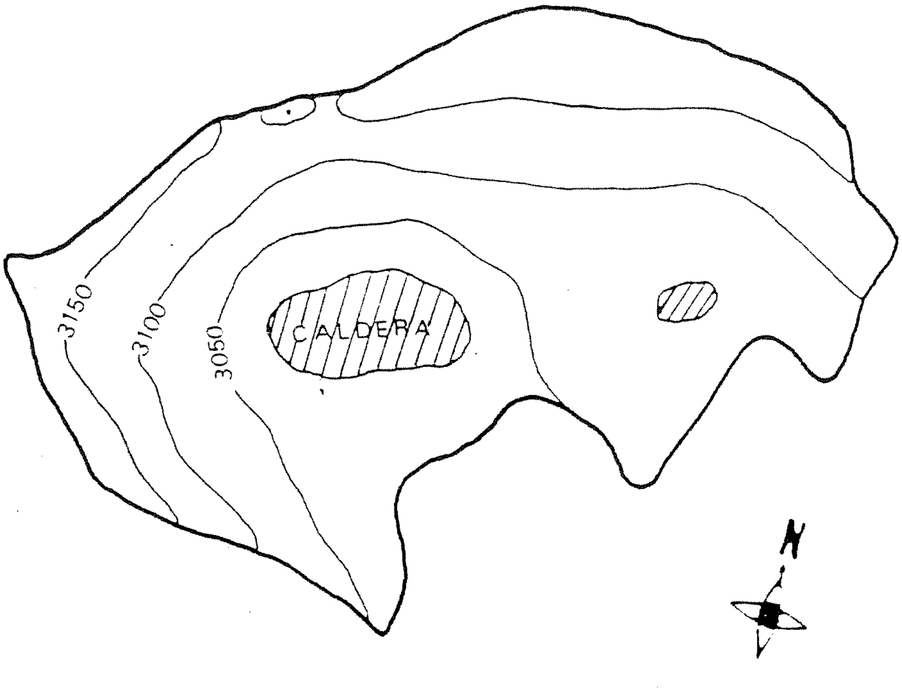
Country:	Spain
Latitude:	37° 03' N
Longitude:	3° 20' W
Lake altitude:	3050 m
Lake area:	2.3 ha
Max. depth:	11.3 m
Mean depth:	4.6 m
Volume:	$0.1076 \times 10^6\ m^3$
Retention time:	13 months
Ice free period:	June-October (4-5 months)
Catchment area:	0.18 km^2
Catchment geology:	Micaschists, brechoid marbels amphibolites
Catchment soils:	Dystric cambisols, dystric regosols
Catchment vegetation:	Debris, rocks.
Annual precipitation:	c 710 mm 471 - 1734 (1970 - 1983)
Annual run off:	18 l/sec/km^2 (20% evaporation)
Annual deposition (S):	g S/m^2/yr
Remarks: (e.g. fish):	No fish. In 1993-94 Max.depth was 7 m, mean depth 3.3 m, lake area 1.12 ha and volume $0.0337 \times 10^6\ m^3$ due to low precipitation





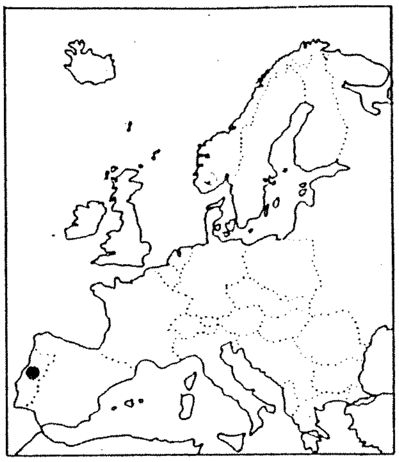
Water chemistry (1993):

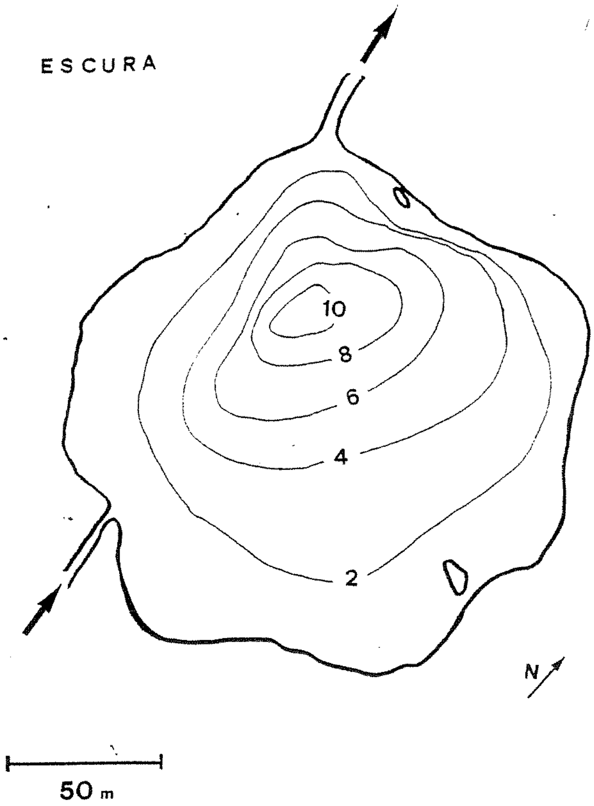
pH	8.05
Alk µeq/l	195
Cond. mS/m	2.6
Ca mg/l	3.95
Mg "	0.38
Na "	0.40
K "	0.12
SO_4 "	0.89
Cl "	0.54
NO_3N µg/l	75
NH_4N µg/l	30
Tot-N µg/l	244
Tot-P µg/l	10
RAl "	
ILAl "	
TOC mg/l	3.08
F µg/l	<0.1
Cd µg/l	0.85
Pb µg/l	1.05
Hg ng/l	0.88



14. LAGOA ESCURA

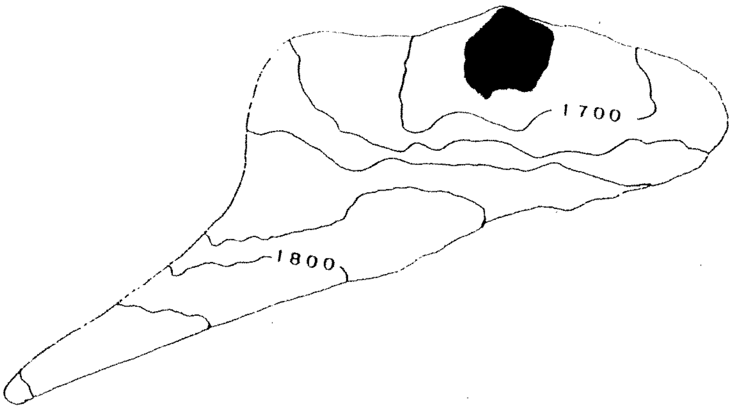
Country:	Portugal
Latitude:	40° 21' 17" N
Longitude:	7° 38' 6" W
Lake altitude:	1680 m
Lake area:	0.216 ha
Max. depth:	12.5 m
Mean depth:	3.2 m
Volume:	6925 m^3
Retention time:	
Ice free period:	
Catchment area:	0.051 km^2
Catchment geology:	
Catchment soils:	
Catchment vegetation:	Bare rock, debris, bushes and meadows
Annual precipitation:	
Annual run off:	
Annual deposition (S):	
Remarks: (e.g. fish):	Rainbow trout



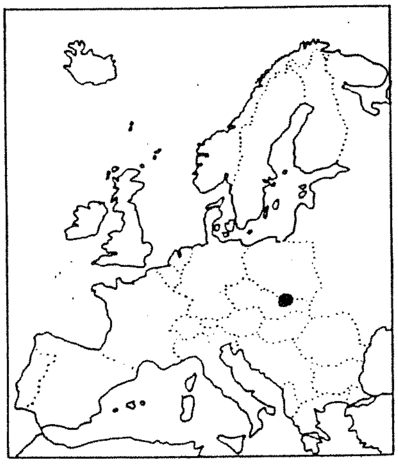


Water chemistry (1993):

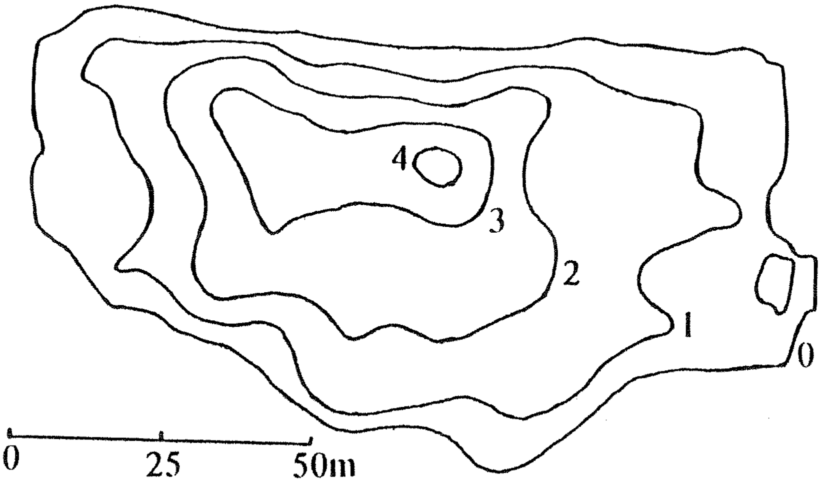
pH	5.34
Alk µeq/l	0
Cond. mS/m	1.21
Ca mg/l	0.36
Mg "	0.16
Na "	0.98
K "	0.11
SO_4 "	1.1
Cl "	1.7
NO_3N µg/l	5
NH_4N µg/l	8
Tot-N µg/l	123
Tot-P µg/l	6.9
RAl "	32
ILAl "	20
TOC mg/l	1.2
F µg/l	<0.1
Cd µg/l	<0.5
Pb µg/l	<0.5
Hg ng/l	716



15.1 STAROLESNIANSKE PLESO

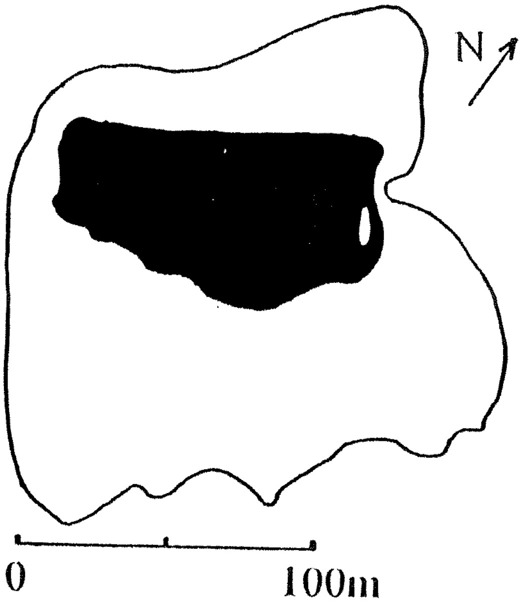


Country:	Slovakia
Latitude:	49° 10' N
Longitude:	20° 10' E
Lake altitude:	2000 m
Lake area:	0.7472 ha
Max. depth:	4.1 m
Mean depth:	1.57 m
Volume:	11 750 m^3
Retention time:	75 days
Ice free period:	June - October (5 months)
Catchment area:	0.027 km^2
Catchment geology:	Granite
Catchment soils:	
Catchment vegetation:	Alpine meadows : bare rock (3:1)
Annual precipitation:	2496 mm
Annual run off:	67 l/sec/km^2 (15% evaporation)
Annual deposition (S):	3.69 g S/m^2/yr
Remarks: (e.g. fish):	No fish

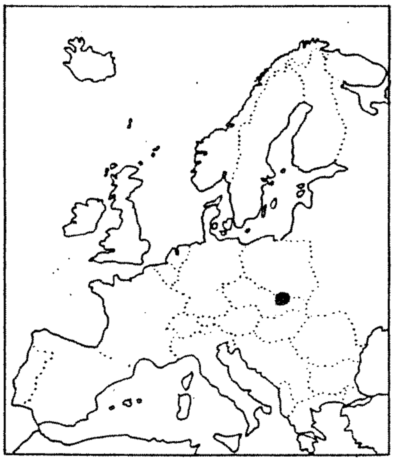


Water chemistry (1993):

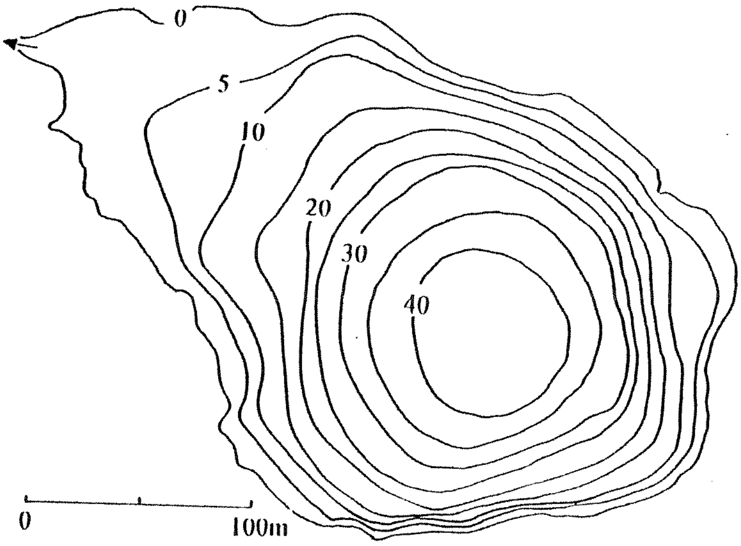
pH	4.89
Alk µeq/l	- 13 (Gran titr.)
Cond. mS/m	1.53
Ca mg/l	0.82
Mg "	0.08
Na "	0.02
K "	0.07
SO_4 "	3.1
Cl "	0.2
NO_3N µg/l	175
NH_4N µg/l	11
Tot-N µg/l	476
Tot-P µg/l	8
RAl "	179
ILAl "	11
TOC mg/l	4.18
DOC mg/l	2.75
F µg/l	<0.1
Cd µg/l	0.24
Pb µg/l	2.6
Hg ng/l	61



15.2 NIZNE TERIANSKE PLESO

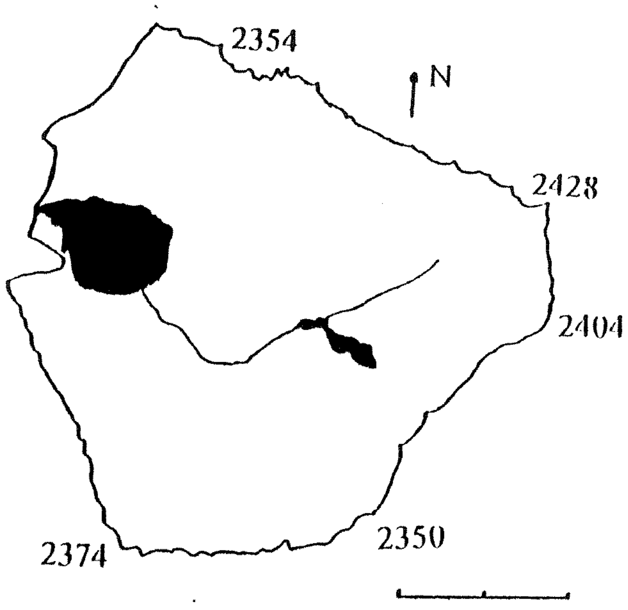


Country: Slovakia
Latitude: 49° 10' N
Longitude: 20° 00' E
Lake altitude: 1941 m
Lake area: 4.832 ha
Max. depth: 44.4 m
Mean depth: 18.4 m
Volume: 0.8912 x 10^6 m^3
Retention time: 0.57 yr (estimate)
Ice free period: July - October (4 months)
Catchment area: 1.1 km^2
Catchment geology: Granite
Catchment soils:
Catchment vegetation: Alpine meadows : bare rock (1:1)
Annual precipitation: 1400 - 2150 mm (estmated range)
Annual run off: 45.1 l/sec/km^2 (estmated)
Annual deposition (S): 2.1 - 3.2g S/m^2/yr (estmated range)
Remarks: (e.g. fish): No fish



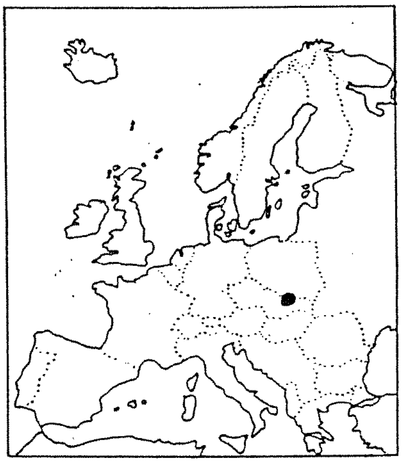
Water chemistry (1993):

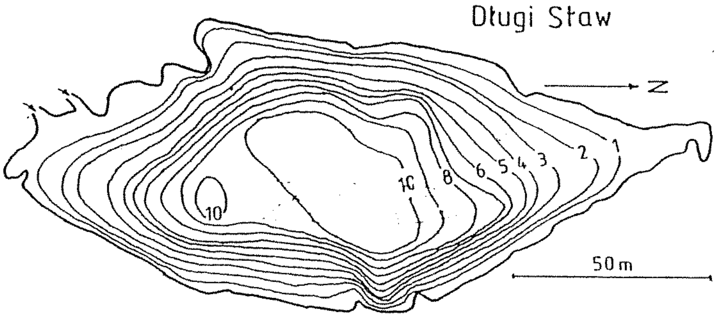
pH	6.92
Alk µeq/l	70 (Gran titr.)
Cond. mS/m	2.21
Ca mg/l	3.2
Mg "	0.08
Na "	0.13
K "	0.11
SO_4 "	3.1
Cl "	0.2
NO_3N µg/l	585
NH_4N µg/l	<5
Tot-N µg/l	599
Tot-P µg/l	1
RAl "	13
ILAl "	<10
TOC mg/l	0.92
DOC mg/l	0.75
F µg/l	<0.1
Cd µg/l	0.06
Pb µg/l	<0.5
Hg ng/l	<2



15.3 DLUGI STAW

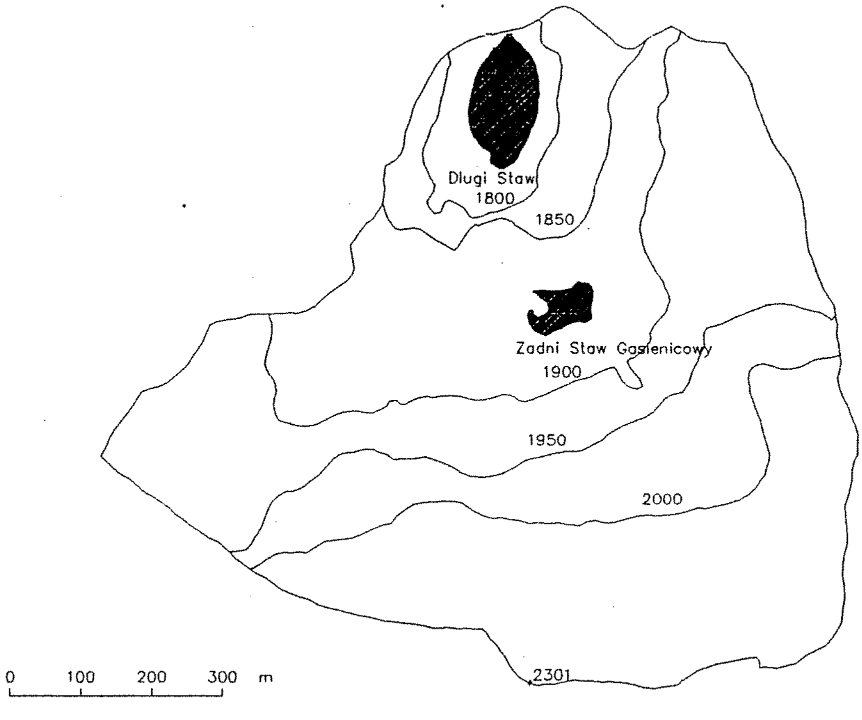
Country:	Poland
Latitude:	49° 13'.36" N
Longitude:	20° 00' 39" E
Lake altitude:	1783 m
Lake area:	1.58ha
Max. depth:	10.6 m
Mean depth:	5.06 m
Volume:	0.081 x 10^6 m^3
Retention time:	34 days
Ice free period:	May/July - Sept./Nov.
Catchment area:	0.66 km^2
Catchment geology:	Granitoids covered by moraine
Catchment soils:	Primitive soil / podsolic soil
Catchment vegetation:	Dwarf pine,alpine meadows, rocks
Annual precipitation:	ca 1800 mm
Annual run off:	42 l/sec/km^2
Annual deposition (S):	2.6 g S/m^2/yr
Remarks: (e.g. fish):	No fish (Brook trout stocked in 1960)



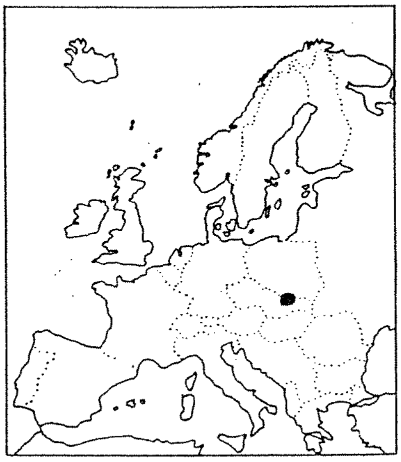


Water chemistry (1993):

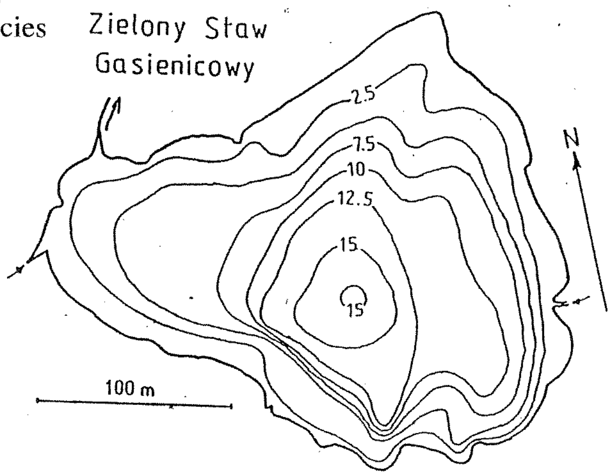
pH	5.97
Alk µeq/l	
Cond. mS/m	1.94
Ca mg/l	2.2
Mg "	0.1
Na "	0.15
K "	0.13
SO_4 "	3.6
Cl "	0.2
NO_3N µg/l	755
NH_4N µg/l	6
Tot-N µg/l	770
Tot-P µg/l	<1
RAl "	33
ILAl "	<10
TOC mg/l	0.23
F µg/l	<0.1
Cd µg/l	0.05
Pb µg/l	<0.5
Hg ng/l	650



15.4 ZIELONY STAW

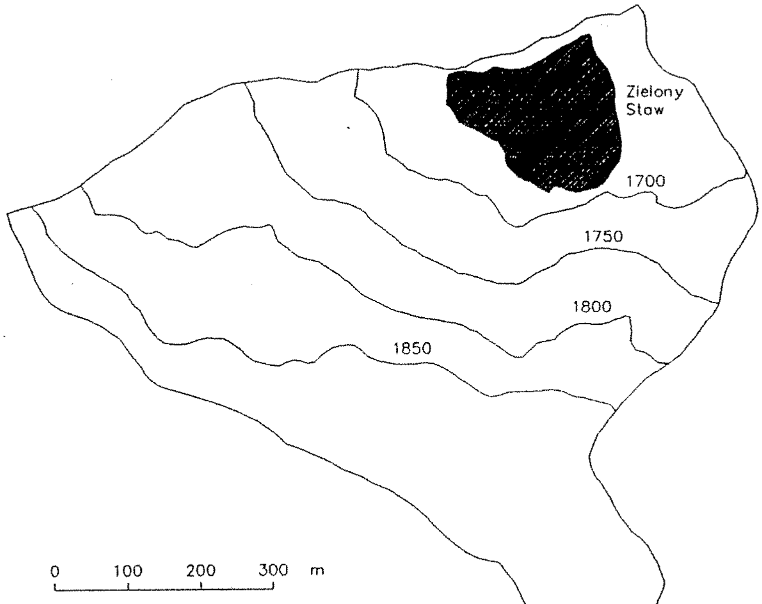


Country:	Poland
Latitude:	49° 13' 44" N
Longitude:	20° 00' 05" E
Lake altitude:	1671 m
Lake area:	3.84 ha
Max. depth:	15.1 m
Mean depth:	6.8 m
Volume:	0.2605×10^6 m^3
Retention time:	4.8 months
Ice free period:	May/June - Oct./Nov.
Catchment area:	0.5 km^2
Catchment geology:	Granitoids partly limestone, covered by moreine
Catchment soils:	Primitive soil / podsolic soil
Catchment vegetation:	Dwarf pine,alpine meadows, rocks
Annual precipitation:	ca 1600 mm
Annual run off:	42 l/sec/km^2
Annual deposition (S):	2.6 g S/m^2/yr
Remarks: (e.g. fish):	Brook trout, Brown trout, and hybrid of the two species



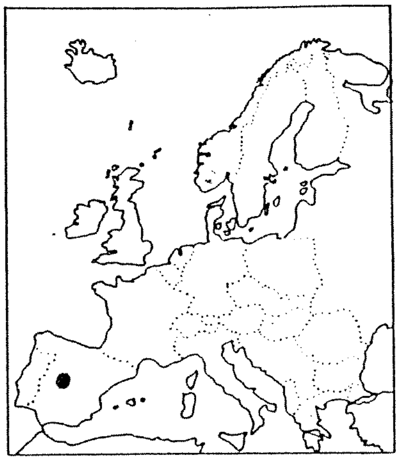
Water chemistry (1993):

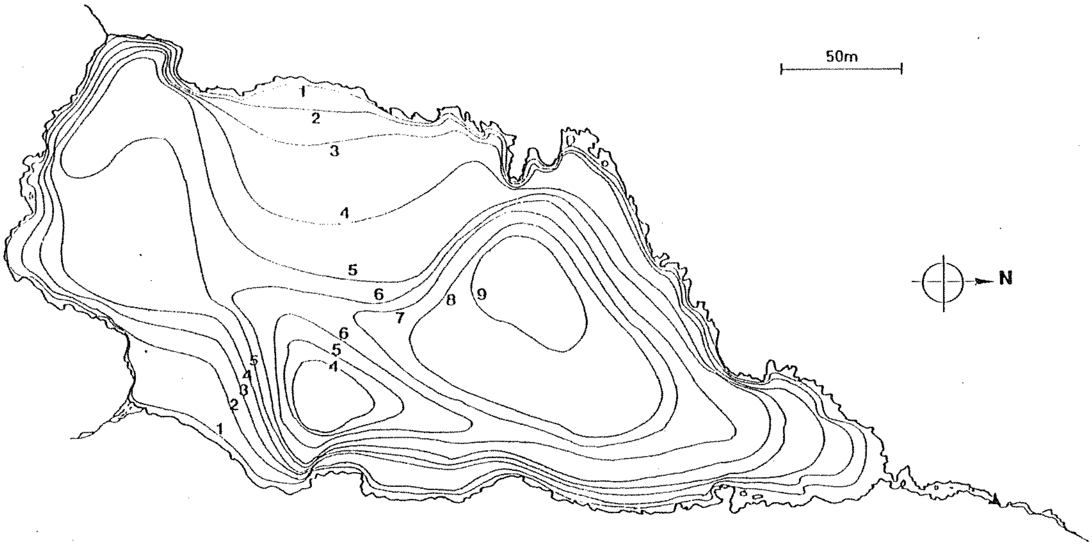
pH	7.07
Alk µeq/l	83
Cond. mS/m	2.32
Ca mg/l	3.11
Mg "	0.19
Na "	0.27
K "	0.19
SO_4 "	3.5
Cl "	0.3
NO_3N µg/l	390
NH_4N µg/l	<5
Tot-N µg/l	470
Tot-P µg/l	3
RAl "	13
ILAl "	<10
TOC mg/l	1.59
F µg/l	<0.1
Cd µg/l	0.15
Pb µg/l	<0.5
Hg ng/l	54.5



16. LAGUNA CIMERA

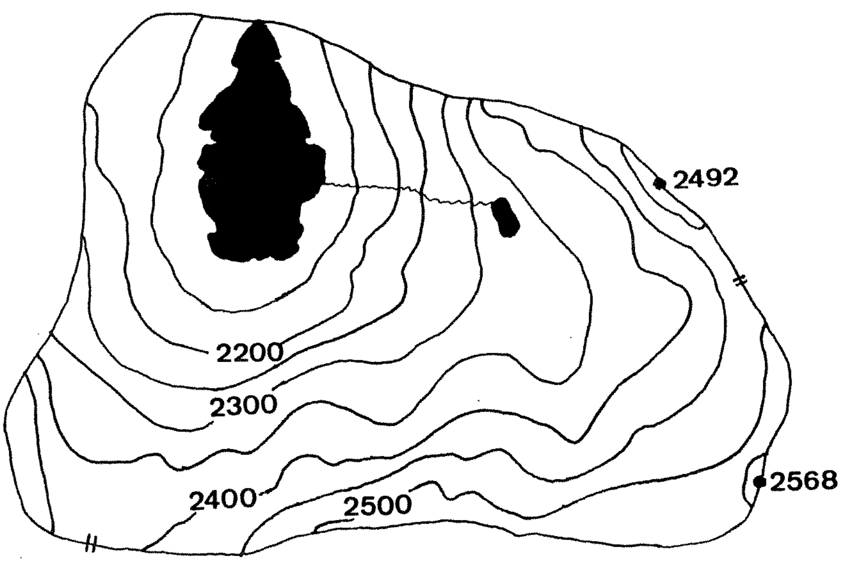
Country:	Spain
Latitude:	40° 16'.N
Longitude:	**4° 36' 50" W ???**
Lake altitude:	2140 m
Lake area:	4.49 ha
Max. depth:	9.35 m
Mean depth:	4.83 m
Volume:	0.217 x 10^6 m^3
Retention time:	90 days
Ice free period:	June-October (5 months)
Catchment area:	0.85 km^2
Catchment geology:	Granite
Catchment soils:	Stony, hydromorphic and psychroxerophilous soils
Catchment vegetation:	Rocks and debris with small alpine meadows.
Annual precipitation:	1300 mm
Annual run off:	33 l/sec/km^2 (20% evaportin)
Annual deposition (S):	g S/m^2/yr
Remarks: (e.g. fish):	Brook trout





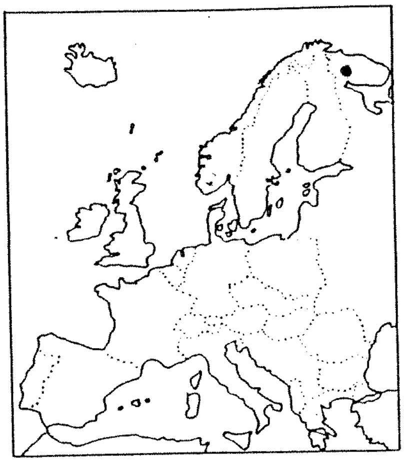
Water chemistry (1993):

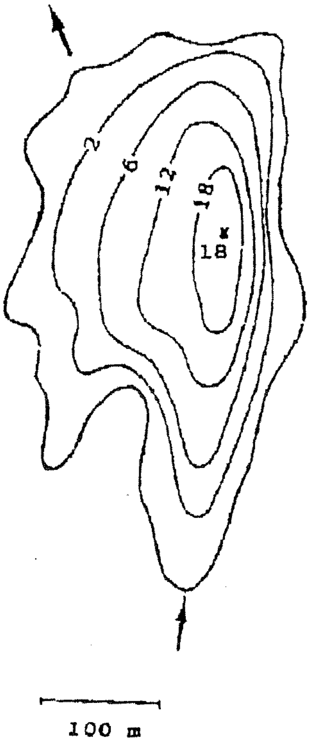
pH	6.3
Alk µeq/l	37
Cond. mS/m	0.73
Ca mg/l	0.6
Mg "	0.17
Na "	0.27
K "	0.07
SO_4 "	0.9
Cl "	0.3
NO_3N µg/l	1
NH_4N µg/l	<5
Tot-N µg/l	116
Tot-P µg/l	7
RAl "	<10
ILAl "	<10
TOC mg/l	1.59
F µg/l	<0.1
Cd µg/l	<0.05
Pb µg/l	<0.5
Hg ng/l	<2



17. LAKE CHUNA

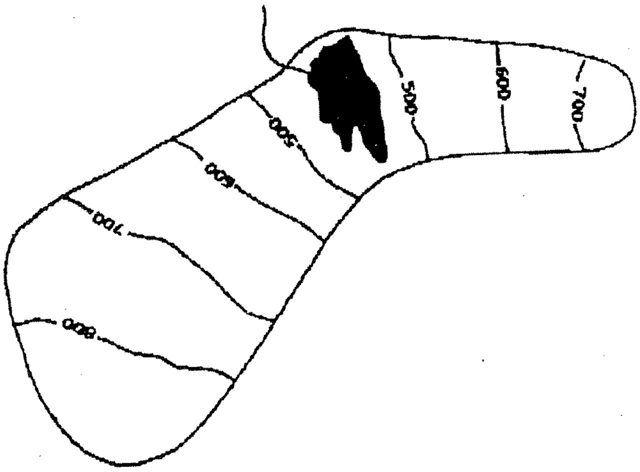
Country:	Russia
Latitude:	67° 57' N
Longitude:	32° 29' E
Lake altitude:	475 m
Lake area:	12.5 ha
Max. depth:	18 m
Mean depth:	10 m
Volume:	1.25 x 10^6 m^3
Retention time:	1 year
Ice free period:	6 months
Catchment area:	2.05 km^2
Catchment geology:	Gabbro
Catchment soils:	Tundra soils, bare rock
Catchment vegetation:	Tundra vegetation
Annual precipitation:	900 mm
Annual run off:	18 l/sec/km^2
Annual deposition (S):	0.4 g S/m^2/yr
Remarks: (e.g. fish):	Brown trout





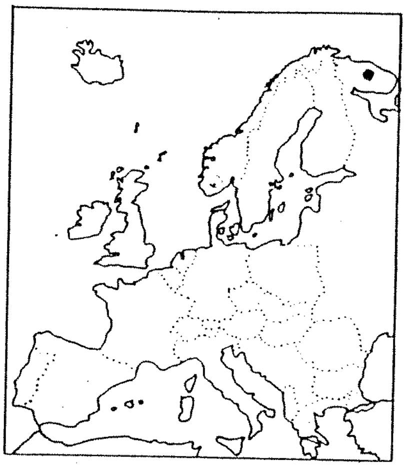
Water chemistry (1993):

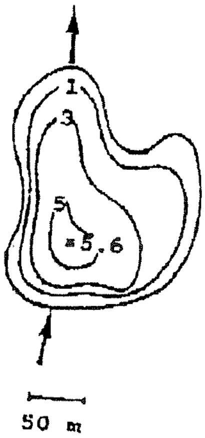
pH	6.56
Alk µeq/l	62
Cond. mS/m	1.72
Ca mg/l	1.61
Mg "	0.26
Na "	1.06
K "	0.09
SO_4 "	2.0
Cl "	1.1
NO_3N µg/l	165
NH_4N µg/l	17
Tot-N µg/l	245
Tot-P µg/l	3.0
RAl "	<10
ILAl "	<10
TOC mg/l	1.59
F µg/l	<0.1
Cd µg/l	0.13
Pb µg/l	0.5
Hg ng/l	4.5



18. LAKE CHIBINI

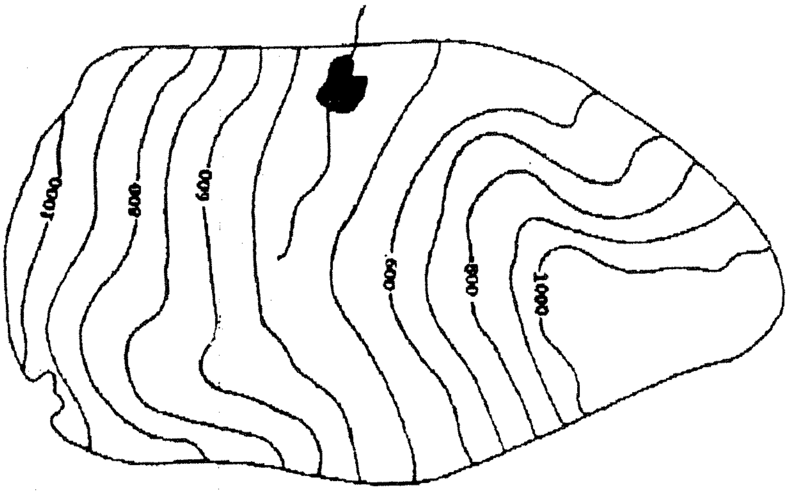
Country:	Russia
Latitude:	67° 41'N
Longitude:	33°37' E
Lake altitude:	434 m
Lake area:	3.5 ha
Max. depth:	5.6 m
Mean depth:	3.2 m
Volume:	0.11×10^6 m^3
Retention time:	11 days
Ice free period:	6 months
Catchment area:	5.25 km^2
Catchment geology:	Nepheline syenite
Catchment soils:	Tundra soils, bare rock
Catchment vegetation:	Tundra vegetation, *Betula nana*
Annual precipitation:	850 mm
Annual run off:	18 l/sec/km^2
Annual deposition (S):	0.6 g S/m^2/yr
Remarks: (e.g. fish):	Arctic char (reproduction)





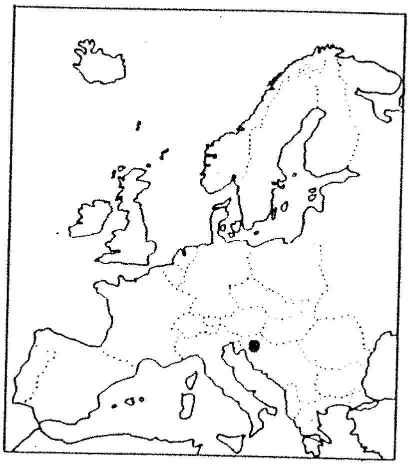
Water chemistry (1993):

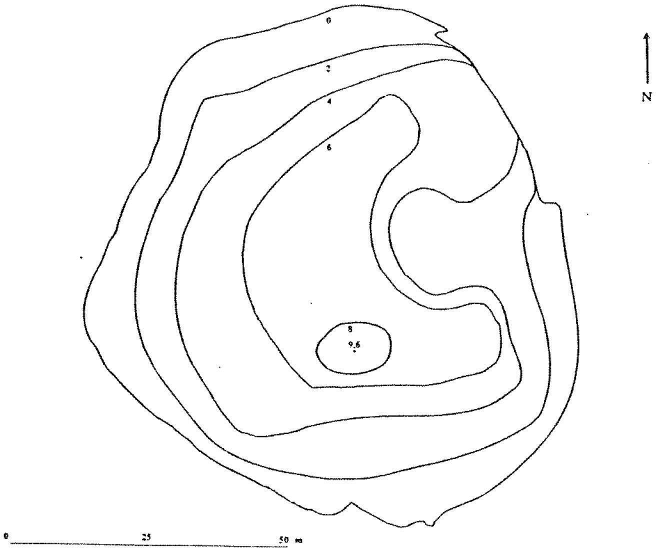
pH	7.15
Alk μeq/l	56
Cond. mS/m	1.54
Ca mg/l	1.78
Mg "	0.21
Na "	0.64
K "	0.06
SO_4 "	2.4
Cl "	0.5
NO_3N μg/l	165
NH_4N μg/l	<5
Tot-N μg/l	190
Tot-P μg/l	<1
RAl "	<10
ILAl "	<10
TOC mg/l	0.3
F μg/l	<0.1
Cd μg/l	<0.1
Pb μg/l	<0.5
Hg ng/l	<2



19. ZGORNJE KRISKO JEZERO

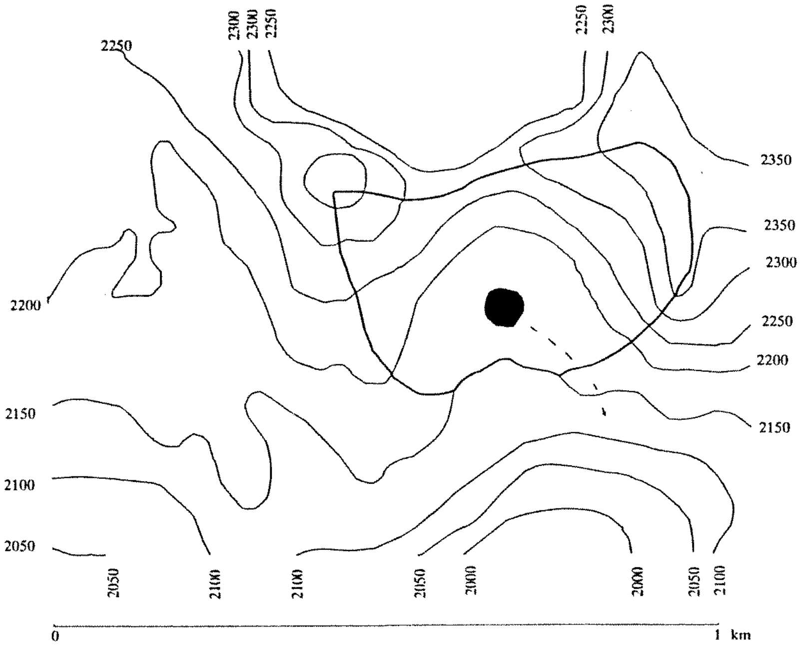
Country:	Slovenia
Latitude:	46° 25' 08" N
Longitude:	13° 48' 34" E
Lake altitude:	2150 m
Lake area:	0.64 ha
Max. depth:	9.6 m
Mean depth:	3.9 m
Volume:	0.026×10^6 m^3
Retention time:	1.5 - 2 years
Ice free period:	June - October (4 - 5 months)
Catchment area:	<1 km^2 (not defined due to Karstic geology)
Catchment geology:	Jurassic limestone with Karst formation
Catchment soils:	No soil (bare rock)
Catchment vegetation:	No vegetation except chasmophyta in rock fissures
Annual precipitation:	2500 - 3000 mm
Annual run off: (35% evapor.)	50 - 60 l/sec/km^2
Annual deposition (S):	0.04g S/m^2/yr
Remarks: (e.g. fish):	No fish





Water chemistry (1994):

pH	7.86
Alk µeq/l	467
Cond. mS/m	8.6
Ca mg/l	10.5
Mg "	0.8
Na "	0.9
K "	0.04
SO_4 "	10
Cl "	0.2
NO_3N µg/l	190
NH_4N µg/l	28
Tot-N µg/l	275
Tot-P µg/l	6
RAl "	
ILAl "	
TOC mg/l	0.41
F µg/l	< 0.1
Cd µg/l	< 0.1
Pb µg/l	< 0.5
Hg ng/l	5.5



AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Appendix 2

Water chemistry data

Part A.

Analytical results for each water sample taken in 1993 and 1994 within the AL:PE programme. Only values for surface water to 0,5 m are given. Results marked with an (N) mean that the analysis is performed at NIVA.

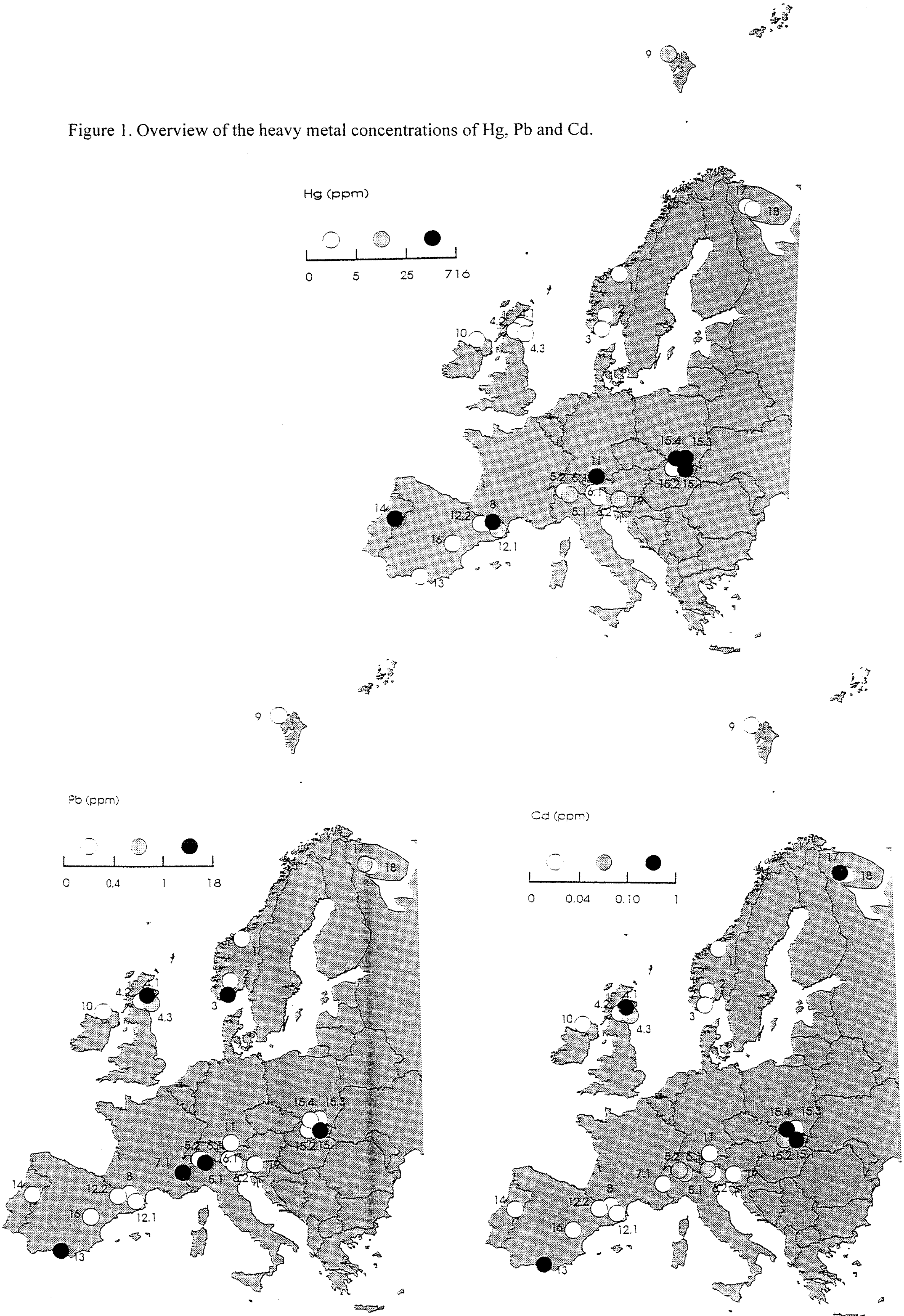
Part B.

Overview of the heavy metal concentrations of Pb, Cd and Hg in the AL:PE lakes.

Part C.

Principal component analysis diagrams of the mean values from each of the AL:PE 1 and AL:PE 2 lakes

Figure 1. Overview of the heavy metal concentrations of Hg, Pb and Cd.



AL:PE 2 Water chemistry for 1993-1994

Lake n°		Date	pH	Cond. µS/cm 25°C	Cond. mS/m 25°C	NH4 µgN/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Alk µeq /l	SO4 mg/l	SO4* mg/l	NO3 µgN/l	Cl mg/l	F µg/l	TN µgN/l	TP µg/l	TOC mg C/l	TAL µg/l	RAL µg/l	ILAL µg/l	LAL µg/l	Cd µg/l	Pb µg/l	Hg ng/l
1	Ø. Neådalsvatn	06/06/93	5,96	13,20	1,32		0,47	0,17	1,16	0,14	8	0,80	0,48	28	2,30		57		0,50		10	<10	0			
1	Ø. Neådalsvatn	24/06/93	6,07	10,00	1,00		0,41	0,12	0,96	0,13	21	0,60	0,39	22	1,50		51		0,83		10	<10	0			
1	Ø. Neådalsvatn	08/07/93	6,29	8,20	0,82		0,30	0,10	0,87	0,10	15	0,70	0,55	17	1,10		56		0,62		<10	<10	0			
1	Ø. Neådalsvatn	21/07/93	6,12	10,60	1,06		0,30	0,07	0,68	0,10	15	0,60	0,47	11	0,90		55		0,49		<10	<10	0			
1	Ø. Neådalsvatn	05/08/93	6,00	7,40	0,74		0,34	0,07	0,65	0,10	12	0,60	0,47	4	0,90		36		0,62		<10	<10	0			
1	Ø. Neådalsvatn	27/08/93	6,16	7,10	0,71		0,34	0,07	0,60	0,11	15	0,60	0,52	<1	0,60		75		0,81		10	10	0			
1	Ø. Neådalsvatn	07/09/93	6,28	7,10	0,71		0,35	0,07	0,62	0,10	25	0,60	0,52	<1	0,60		51		0,90		<10	<10				
1	Ø. Neådalsvatn	21/09/93	6,41	7,10	0,71		0,41	0,09	0,60	0,11	25	0,60	0,52	2	0,60		57		0,77		<10	<10				
1	Ø. Neådalsvatn	30/09/93	6,40	7,70	0,77		0,44	0,08	0,73	0,15	28	0,70	0,60	2	0,70		77		0,91		<10	<10	0			
1	Ø. Neådalsvatn	29/10/93	5,94	8,40	0,84	<5	0,39	0,09	0,75	0,15	13	0,70	0,53	15	1,20	<0.1	53	2	0,89		15	11		<0.10	<0.5	<2.0
1	Ø. Neådalsvatn	13/11/93	6,28	1,03	0,10		0,62	0,16	0,97	0,20		0,80	0,62	18	1,30		170		1,10		17	13	4			
1	Ø. Neådalsvatn	24/11/93	6,23	1,21	0,12		0,66	0,17	1,02	0,19		0,90	0,70	17	1,40		78		0,86		15	11	4			
Mean 93	**Ø. Neådalsvatn**	**M 93**	**6,18**	**7,42**	**0,74**		**0,42**	**0,11**	**0,80**	**0,13**	**18**	**0,68**	**0,53**	**14**	**1,09**		**68**	**2**	**0,78**		**13**	**11**	**1**			
1	Øvre Neådalsvatn	06/01/94	6,11	10,00	1,00		0,80	0,15	0,96	0,20	41	1,10	0,95	14	1,10		50		0,60	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	29/01/94	6,31	10,10	1,01		0,92	0,20	0,99	0,21	49	1,30	1,15	15	1,10		57		0,49							
1	Øvre Neådalsvatn	12/02/94	6,09	12,30	1,23		0,85	0,19	0,94	0,20	48	1,20	1,05	16	1,10		40		0,59	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	28/02/94	6,17	32,00	3,20		0,97	0,19	1,00	0,73	54	1,90	1,75	19	1,10		74		0,54	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	12/03/94	5,95	11,60	1,16		0,84	0,18	0,98	0,20	47	1,10	0,96	17	1,00		53		0,56	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	15/04/94	6,16	13,60	1,36		0,90	0,19	0,92	0,20	50	1,10	0,95	19	1,10		60		0,53	19	M 10.00	9				
1	Øvre Neådalsvatn	24/04/94	5,99	14,00	1,40		1,01	0,19	0,97	0,22	50	1,20	1,03	17	1,20		92		0,59	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	01/05/94	5,90	22,60	2,26		1,15	0,34	1,98	0,43	31	1,40	0,94	68	3,30		135		1,40	12	9	3				
1	Øvre Neådalsvatn	07/05/94	5,77	21,10	2,11		0,85	0,32	1,85	0,37	21	1,20	0,74	44	3,30		113		1,50	19	M 10.00	9				
1	Øvre Neådalsvatn	17/05/94	6,00	14,20	1,42		0,61	0,22	1,33	0,23	18	0,60	0,25	42	2,50		75		0,69	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	22/05/94	5,80	14,80	1,48		0,60	0,21	1,35	0,25	19	0,80	0,45	38	2,50		93		0,88	M 10.00	M 10.00	0				
1	Øvre Neådalsvatn	01/06/94	5,90	13,90	1,39		0,65	0,19	1,23	0,23	21	0,90	0,61	36	2,10		89		0,92	12	<10.00	2				
1	Øvre Neådalsvatn	11/06/94	6,15	9,70	0,97		0,42	0,13	0,90	0,18	22	0,70	0,52	31	1,30		71		0,95	<10.00	<10.00	0				
1	Øvre Neådalsvatn	19/06/94	5,90	9,10	0,91		0,36	0,12	0,79	0,17	31	0,60	0,45	23	1,10		72		0,96	18	20	-2				
1	Øvre Neådalsvatn	25/06/94	6,25	7,30	0,73		0,29	0,10	0,64	0,12	15	0,50	0,36	18	1,00		53		0,89	<10.00	<10.00	0				
1	Øvre Neådalsvatn	30/06/94	6,12	8,90	0,89		0,43	0,12	0,81	0,15	21	0,60	0,45	18	1,10		87		0,73	12	11	1				
1	Øvre Neådalsvatn	09/07/94	6,75	7,90	0,79		0,32	0,08	0,62	0,11	20	0,50	0,37	10	0,90		50		0,39	<10.00	<10.00	0				
1	Øvre Neådalsvatn	17/07/94	6,24	6,60	0,66		0,25	0,02	0,63	0,10	21	0,50	0,40	10	0,70		47		0,52	<10.00	<10.00	0				
1	Øvre Neådalsvatn	24/07/94	6,35	7,10	0,71		0,16	0,04	0,66	0,10	24	0,50	0,42	<1.00	0,60		44		0,71	<10.00	<10.00	0				
1	Øvre Neådalsvatn	01/08/94	6,35	7,50	0,75		0,20	0,05	0,68	0,11	21	0,50	0,42	3	0,60		38		0,49	<10.00	<10.00	0				
1	Øvre Neådalsvatn	21/08/94	6,37	7,40	0,74		0,21	0,09	0,70	0,10	42	0,60	0,53	<1.00	0,50		60		0,85	<10.00	11	-1				
1	Øvre Neådalsvatn	28/08/94	6,32	8,30	0,83		0,45	0,10	0,74	0,12	29	0,50	0,43	<1.00	0,50		71		0,78	<10.00	<10.00	0				
1	Øvre Neådalsvatn	05/09/94	6,45	8,10	0,81		0,43	0,10	0,74	0,11	31	0,80	0,70	2	0,70		60		1,01	<10.00	<10.00	0				
1	Øvre Neådalsvatn	12/09/94	6,15	7,60	0,76		0,41	0,08	0,70	0,13	35	0,80	0,69	<1.00	0,80		54		1,02	10	<10.00	0				
1	Øvre Neådalsvatn	18/09/94	6,37	7,60	0,76		0,45	0,06	0,69	0,15	32	0,80	0,70	2	0,70		54		0,94	<10.00	<10.00	0				
1	Øvre Neådalsvatn	26/09/94	6,39	7,80	0,78		0,44	0,08	0,67	0,14	35	0,80	0,69	<1.00	0,80		68		0,86	12	<10.00	2				
1	Øvre Neådalsvatn	02/10/94	6,35	8,00	0,80		0,41	0,08	0,70	0,15	31	0,80	0,69	<1.00	0,80		63		0,93	10	<10.00	0				
1	Øvre Neådalsvatn	08/10/94	6,21	8,50	0,85	<5	0,32	0,05	0,68	0,10		0,70	0,60	4	0,70	<0.1	60	1	0,64	10				<0.10	<0.5	<2.0
1	Øvre Neådalsvatn	13/10/94	6,42	8,90	0,89		0,53	0,13	0,87	0,15		0,70	0,52	5	1,30		65		0,80		10	<10.00	0			
1	Øvre Neådalsvatn	31/10/94	6,30	10,10	1,01		0,54	0,14	1,00	0,21		0,80	0,59	11	1,50		123		0,88		13	<10.00	3			
1	Øvre Neådalsvatn	13/11/94	6,31	9,70	0,97		0,61	0,14	0,93	0,14		0,80	0,63	23	1,20		65		0,95		22	18	4			
1	Øvre Neådalsvatn	04/12/94	6,18	14,90	1,49		0,82	0,21	1,38	0,18		1,10	0,79	28	2,20		50		0,68		16	11	5			
1	Øvre Neådalsvatn	21/12/94	6,14	13,70	1,37		0,88	0,21	1,24	0,18		1,00	0,69	18	2,20		56		0,72		20	14	6			
Mean94	**Øvre Neådalsvatn**	**M94**	**6,19**	**11,36**	**1,14**		**0,58**	**0,14**	**0,95**	**0,19**	**31,81**	**0,86**	**0,68**	**20**	**1,29**		**68**	**1**	**0,79**	**13**	**15**	**2**	**4**			

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
2	Stavsvatn	29/03/93	5,76	12,10	1,21	25	1,02	0,14	0,63	0,11	13	2,00	1,89	64	0,80	0		2	1,00		74	15				
2	Stavsvatn	23/09/93	6,12	10,90	1,09	9	0,82	0,12	0,57	0,08	0	1,60	1,49	22	0,80	2	155	2	1,01		76	22		<0.5	<0.5	<2
Mean 93	**Stavsvatn**	**M 93**	**5,94**	**11,50**	**1,15**	**17**	**0,92**	**0,13**	**0,60**	**0,10**	**7**	**1,80**	**1,69**	**43**	**0,80**	**1**	**155**	**2**	**1,01**		**75**	**19**		**<0.5**	**<0.5**	**<2**
2	Stavsvatn	28/09/94	6,00	7,33		14	0,80	0,11	0,49	0,08	46	1,60	1,52	46	0,60	0,15	135	2	1,30		76	23		<0.10	<5	<2
Mean 94	**Stavsvatn**	**M 94**	**6,00**	**7,33**		**14**	**0,80**	**0,11**	**0,49**	**0,08**	**46**	**1,60**	**1,52**	**46**	**0,60**	**0,15**	**135**	**2**	**1,30**		**76**	**23**		**<0.11**	**<5**	**<2**
3	L. Hovvatn	23/02/93	4,34	47,90	4,79		0,44	0,31	3,10	0,11		2,80	1,92	170	6,30				2,90		245	75				
3	L. Hovvatn	11/05/93	4,58	24,40	2,44		0,42												2,60		228	43				
3	L. Hovvatn	30/06/93	4,63	28,70	2,87		0,40	0,21	1,99	0,12		2,80	2,30	160	3,60				1,30		218	<10				
3	L. Hovvatn	27/07/93	4,86	25,40	2,54		0,53	0,22	1,88	0,11		2,70	2,24	140	3,30				0,86		197	<10				
3	L. Hovvatn	21/09/93	4,85	27,20	2,72		0,53	0,22	1,80	0,12		2,90	2,42	142	3,40				1,40		195	28				
Mean 93	**L. Hovvatn**	**M 93**	**4,65**	**30,72**	**3,07**		**0,46**	**0,24**	**2,19**	**0,12**		**2,80**	**2,22**	**153**	**4,15**				**1,81**		**217**	**49**				
3	Lille Hovvatn	06/01/94	4,54	28,30	2,83		0,49	0,20	1,62	0,09	<4,50	3,40	3,08	215	2,30				3,70		225	109	116			
3	Lille Hovvatn	16/03/94	4,50	33,00	3,30		0,46	0,22	1,78	0,09		3,40	3,04	260	2,60		510		3,40		243	68	175			
3	Lille Hovvatn	31/05/94	4,90	22,60	2,26		0,37	0,16	1,46	0,09	8	3,00	2,68	155	2,30		350		2,40		185	42	143			
3	Lille Hovvatn	03/08/94	4,79	22,40	2,24		0,34				11								1,70		132	20	112			
3	Lille Hovvatn	07/09/94	4,80	20,40	2,04		0,47	0,17	1,12	0,15	<5	2,60	2,35	127	1,80		475		3,60		152	61	91			
3	Lille Hovvatn	07/09/94	4,57	21,40	2,14	19	0,35	0,15	1,22	0,10		3,00	2,73	126	1,90	<0,1	335	6	2,50		134	48	86	<0,10	1,9	<2,0
3	Lille Hovvatn	02/11/94	4,60	20,70	2,07		0,39	0,17	1,29	0,14	7	3,10	2,79	149	2,20		425		3,90		185	67	118			
Mean 94	**Lille Hovvatn**	**M 94**	**4,67**	**24,11**	**2,41**	**19,00**	**0,41**	**0,18**	**1,42**	**0,11**	**8,67**	**3,08**	**2,78**	**172**	**2,18**		**419**	**6**	**3,03**		**179**	**59**	**120**		**1,90**	
9	Arresjøen	13/08/93	5,59	37,60	3,76	5	0,71	0,59	4,77	0,24	20	1,60	0,45	<1	8,20	<0.1	116	4	0,47		<10	<10	0	<0.1	<0.5	23,5
9	Arresjøen	17/08/93	6,03	37,50	3,75	<5	0,70	0,59	4,74	0,24	27	1,50	0,34	<1	8,30	<0.1	71	4	0,39		<10	<10	0	<0.1	<0.5	10,5
Mean 93	**Arresjøen**	**M 93**	**5,81**	**37,55**	**3,76**	**5**	**0,71**	**0,59**	**4,76**	**0,24**	**24**	**1,55**	**0,40**	**<1**	**8,25**	**<0.1**	**94**	**4**	**0,43**		**<10**	**<10**	**0**	**<0.1**	**<0.5**	**17,0**
4.1 (N)	Lochnagar	R 15.10.93	5,53	22,30	2,23	74	0,52	0,36	2,10	0,43	14	2,90	2,48	235	3,00	<0.1	510	3	0,69		55	51		0,99	17,6	
4.1 (N)	Lochnagar	R 22.11.93																								<2.0
4,1	Lochnagar	09/03/93	5,01	28,00	2,80		0,62	0,31	2,65	0,27		2,74	2,15	294	4,20				1,00		147	10	137			
4,1	Lochnagar	05/06/93	5,61	23,00	2,30		0,66	0,36	2,09	0,20	15	2,74	2,32	252	2,98				0,30		9	5	4			
4,1	Lochnagar	07/07/93	5,26	22,00	2,20		0,56	0,30	1,96	0,16	9	2,54	2,15	238	2,84				0,50		28	10	18			
4,1	Lochnagar	30/08/93	5,38	21,00	2,10		0,56	0,32	2,00	0,20	12	2,83	2,41	238	3,05				0,70		23	10	13			
4,1	Lochnagar	01/09/93	5,70	22,00	2,20		0,80	0,29	2,05	0,39	17	2,69	2,27	224	3,01				0,60		6	4	2			
4,1	Lochnagar	04/12/93	4,95	27,00	2,70		0,50	0,46	2,12	0,31	0	3,22	2,74	266	3,40				1,60		105	34	71			
Mean 93	**Lochnagar**	**M 93**	**5,35**	**23,61**	**2,36**	**74,00**	**0,60**	**0,34**	**2,14**	**0,28**	**11,17**	**2,81**	**2,36**	**250**	**3,21**		**510**	**3**	**0,77**		**53**	**18**	**41**	**0,99**	**####**	
4,1	Lochnagar	28/03/94	5,05	29,00	2,90	84	0,74	0,57	2,92	0,31	-5	2,93	2,27	392	4,68			18	0,70	125		16	109			
4,1	Lochnagar	01/07/94	5,26	22,00	2,20	0	0,66	0,47	2,23	0,23	-3	2,59	2,15	280	3,19				0,90	40		17	23			
4,1	Lochnagar	24/08/94	5,30	20,00	2,00	0	0,78	0,46	2,07	0,39	-3	2,59	2,18	266	2,94				0,60	19		12	7			
4,1	Lochnagar	04/09/94	5,40	20,00	2,00	70	0,96	0,57	2,07	0,27	-3	2,79	2,39	266	2,84				0,50	25		10	15			
Mean 94	**Lochnagar**	**M 94**	**5,25**	**22,75**	**2,28**	**39**	**0,79**	**0,52**	**2,32**	**0,30**	**-4**	**2,73**	**2,25**	**301**	**3,41**			**18**	**0,68**	**52**		**14**	**39**			
4.2 (N)	Sandy Loch	R 15.10.93	5,70	19,70	1,97	60	0,68	0,36	1,94	0,22	24	2,80	2,44	143	2,60	<0.1	390	3	1,80		60	68		<0.05	<0.5	
4.2 (N)	Sandy Loch	R 22.11.93		0,00																						3,0
4,2	Sandy Loch	06/06/93	5,86	19,00	1,90		0,88	0,24	1,79	0,20	15	2,50	2,18	126	2,24				0,70		12	10	2			
4,2	Sandy Loch	11/06/93	5,89	18,00	1,80		0,60	0,20	1,70	0,16	19	2,54	2,23	126	2,28				1,10		15	12	3			
4,2	Sandy Loch	30/08/93	6,39	19,00	1,90		0,78	0,24	2,02	0,12	37	2,59	2,25	70	2,45				1,50		7	7	0			
4,2	Sandy Loch	05/09/93	6,23	20,00	2,00		1,04	0,24	2,02	0,12	37	2,59	2,25	70	2,45				1,00		7	6	1			
Mean 93	**Sandy Loch**	**M 93**	**6,01**	**15,95**	**1,91**	**60,00**	**0,80**	**0,26**	**1,90**	**0,16**	**26,40**	**2,60**	**2,27**	**107**	**2,40**		**390**	**3**	**1,22**		**20**	**21**	**2**			**3,00**
4,2	Sandy Loch	24/08/94	5,05	18,00	1,80	0	1,04	0,41	2,02	0,20	9	2,55	2,22	112	2,30				2,70	59		54	5			
Mean 94	**Sandy Loch**	**M 94**	**5,05**	**18,00**	**1,80**	**0**	**1,04**	**0,41**	**2,02**	**0,20**	**9**	**2,55**	**2,22**	**112**	**2,30**				**2,70**	**59**		**54**	**5**			
4.3 (N)	L.Nan Eun	R 14.10.93																						0,05	0,7	
4.3 (N)	L.Nan Eun	R 22.11.93																								<2.0
4,3	L.Nan Eun	19/02/93	5,35	81,00	8,10		0,84	1,14	10,65	0,47	11	3,07	0,19	0	20,62				1,90		5	5	0			

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
4,3	L.Nan Eun	26/05/93	6,10	64,00	6,40		0,84	0,97	8,99	0,43	27	2,40	0,20	0	15,72				3,80		4	4	0			
4,3	L.Nan Eun	11/06/93	5,04	21,00	2,10		0,52	0,23	1,73	0,16	2	2,54	2,17	280	2,66				1,00		73	4	69			
4,3	L.Nan Eun	11/07/93	5,62	29,00	2,90		0,42	0,41	4,39	0,12	18	0,96	0,00	0	6,83				4,30		12	9	3			
4,3	L.Nan Eun	13/07/93	5,11	20,00	2,00		0,58	0,23	1,66	0,12	4	2,40	2,04	266	2,59				0,50		44	7	37			
4,3	L.Nan Eun	30/08/93	5,15	20,00	2,00		0,56	0,23	1,70	0,12	6	2,45	2,10	238	2,52				0,50		53	8	45			
Mean 93	**L.Nan Eun**	**M 93**	**5,40**	**39,17**	**3,92**		**0,63**	**0,53**	**4,85**	**0,23**	**11**	**2,30**	**1,12**	**131**	**8,49**				**2,00**		**32**	**6**	**26**			
4,3	Loch Nan Eun	24/08/94	5,06	19,00	1,90	0	0,68	0,30	1,75	0,16	-7	2,35	1,99	266	2,59				0,60	55		7	48			
Mean 94	**L.Nan Eun**	**M 94**	**5,06**	**19,00**	**1,90**	**0**	**0,68**	**0,30**	**1,75**	**0,16**	**-7**	**2,35**	**1,99**	**266**	**2,59**				**0,60**	**55**		**7**	**48**			
10 (N)	L. Maam	10/09/93	5,45	27,80	2,78	18	0,45	0,40	4,13	0,16		1,80	0,89	55	6,50	<0.1	285	4			79	70		<0.1	<0.5	3,0
10	L. Maam	23/03/93	4,97	100,00	10,00		1,20	1,42	12,97	0,51	0	4,66	1,38	56	23,42				2,70		60	35	25			
10	L. Maam	26/04/93	4,24	54,00	5,40		0,86	0,65	6,90	0,35	9	2,45	0,69	28	12,53				3,00		38	28	10			
10	L. Maam	23/05/93	5,26	54,00	5,40		0,72	0,68	7,41	0,47	9	2,88	1,01	42	13,34				2,60		48	38	10			
10	L. Maam	10/09/93	5,36	30,00	3,00		0,46	0,30	4,07	0,16	10	1,73	0,85	56	6,27				4,60		68	58	10			
Mean 93	**L. Maam**	**M 93**	**4,96**	**59,50**	**5,95**		**0,81**	**0,76**	**7,84**	**0,37**	**7**	**2,93**	**0,98**	**46**	**13,89**			**4**	**3,23**		**54**	**40**	**14**			
5.1 (N)	L.Paione Sup.	21/09/93	5,53	11,00	1,10	34	0,91	0,07	0,13	0,26	31	2,20	2,17	340	0,20	<<0.1	415	3	0,33		25	<10	<0.1	0,09	1,4	11,0
5,1	L.Paione S.	12/01/93	5,78	11,11	1,11	10	1,02	0,10	0,24	0,27	1	2,31	2,29	288	0,11		298	2		34						
5,1	L.Paione S.	09/03/93	5,81	11,29	1,13	6	1,10	0,12	0,25	0,26	1	2,29	2,27	275	0,13		281	3		28						
5,1	L.Paione S.	25/05/93	5,36	17,29	1,73	152	1,34	0,14	0,28	0,41	-2	3,00	2,98	604	0,15		756	3		135						
5,1	L.Paione S.	29/06/93	5,55	10,52	1,05	79	0,98	0,11	0,26	0,26	-3	1,83	1,81	351	0,16		430	1		90						
5,1	L.Paione S.	07/07/93	5,52	10,07	1,01	66	0,89	0,09	0,20	0,23	1	1,88	1,86	348	0,14		414	2		68						
5,1	L.Paione S.	27/07/93	5,66	10,60	1,06	42	0,95	0,10	0,20	0,23	-6	1,96	1,95	366	0,09		408	5		43						
5,1	L.Paione S.	21/09/93	5,58	11,32	1,13	30	0,98	0,11	0,22	0,26	-2	2,27	2,25	339	0,11		369	1		48						
5,1	L.Paione S.	09/11/93	5,66	10,72	1,07	25	0,87	0,10	0,22	0,25	0	2,15	2,13	285	0,13		310	2		45						
Mean 93	**L.Paione S.**	**M 93**	**5,61**	**11,55**	**1,15**	**49,33**	**1,00**	**0,10**	**0,22**	**0,27**	**2,33**	**2,21**	**2,19**	**355**	**0,14**		**409**	**2**	**0,33**	**61**	**25**			**0,09**	**1,35**	**11,00**
5,1	L.Paione S.	05/07/94	5,70	9,20	0,92	42	0,77	0,08	0,19	0,16	2	1,50	1,48	293	0,12		335	5								
5,1	L.Paione S.	26/07/94	5,84	8,09	0,81	38	0,73	0,07	0,15	0,18	0	1,48	1,47	242	0,10		280	4								
5,1	L.Paione S.	13/09/94	5,76	10,30	1,03	41	0,90	0,10	0,19	0,27	0	1,92	1,90	329	0,14		370	6								
5,1	L.Paione S.	27/10/94	6,05	10,59	1,06	14	1,05	0,11	0,23	0,31	3	1,98	1,96	331	0,17		345	3								
Mean 94	**L.Paione S.**	**M 94**	**5,84**	**9,54**	**0,95**	**34**	**0,86**	**0,09**	**0,19**	**0,23**	**1**	**1,72**	**1,70**	**299**	**0,13**		**333**	**5**								
5.2 (N)	L.Paione Inf.	21/09/93	6,39	13,30	1,33	14	1,50	0,11	0,25	0,33	8	2,70	2,67	365	0,20	<0.1	415	3	0,66		<10	<10	<0.1	0,07	<0.5	4,0
5,2	L.Paione Inf.	12/01/93	6,56	14,96	1,50	3	1,66	0,15	0,35	0,38	34	2,74	2,72	326	0,12		329	1		10						
5,2	L.Paione Inf.	09/03/93	6,49	15,78	1,58	4	1,92	0,17	0,35	0,36	40	2,75	2,73	326	0,13		330	1		10						
5,2	L.Paione Inf.	25/05/93	6,21	14,96	1,50	14	1,67	0,15	0,32	0,30	26	2,40	2,38	442	0,15		456	3								
5,2	L.Paione Inf.	29/06/93	6,38	12,86	1,29	11	1,52	0,15	0,29	0,31	15	2,33	2,31	439	0,13		450	1								
5,2	L.Paione Inf.	07/07/93	6,42	13,44	1,34	7	1,60	0,16	0,31	0,33	20	2,40	2,38	455	0,12		462	1								
5,2	L.Paione Inf.	27/07/93	6,61	14,38	1,44	3	1,68	0,16	0,33	0,37	22	2,62	2,60	414	0,12		417	5								
5,2	L.Paione Inf.	21/09/93	6,39	14,03	1,40	3	1,50	0,14	0,31	0,31	22	2,66	2,64	346	0,13		349	1								
5,2	L.Paione Inf.	09/11/93	6,37	13,21	1,32	5	1,41	0,14	0,26	0,29	24	2,48	2,46	297	0,14		302	1								
Mean 93	**L.Paione Inf.**	**M 93**	**6,43**	**14,20**	**1,42**	**6**	**1,62**	**0,15**	**0,31**	**0,33**	**25**	**2,55**	**2,53**	**381**	**0,13**		**387**	**2**		**10**						
5,2	L.Paione Inf.	25/01/94	6,49	15,55	1,55	4	1,76	0,16	0,35	0,30	41	2,73	2,71	332	0,15		336	1								
5,2	L.Paione Inf.	31/05/94	6,39	13,68	1,37	11	1,45	0,15	0,37	0,29	17	2,28	2,25	454	0,18		465	1								
5,2	L.Paione Inf.	23/06/94	6,48	12,16	1,22	3	1,32	0,13	0,26	0,22	17	2,10	2,09	364	0,10		367	1								
5,2	L.Paione Inf.	05/07/94	6,50	12,63	1,26	6	1,34	0,13	0,30	0,17	19	2,18	2,16	374	0,16		380	2								
5,2	L.Paione Inf.	26/07/94	6,60	12,86	1,29	14	1,43	0,13	0,29	0,34	23	2,30	2,28	334	0,12		348	3								
5,2	L.Paione Inf.	13/09/94	6,58	13,79	1,38	8	1,58	0,14	0,30	0,35	28	2,47	2,45	327	0,12		335	3								
5,2	L.Paione Inf.	27/10/94	6,70	14,14	1,41	2	1,66	0,15	0,33	0,39	34	2,48	2,46	320	0,16		322	1								
Mean 94	**L.Paione Inf.**	**M 94**	**6,53**	**13,54**	**1,35**	**7**	**1,51**	**0,14**	**0,31**	**0,29**	**26**	**2,36**	**2,34**	**358**	**0,14**		**365**	**2**								

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
6.1 (N)	Lago Lungo	20/09/93	6,53	13,40	1,34	9	1,56	0,15	0,27	0,22	60	2,60	2,60	150	<0.2	<0.1	360	7	0,90		<10	<10	0	0,06	<0.5	<2
6,1	Lago Lungo	01/02/93	6,34	14,10	1,41	15	1,71	0,19	0,42	0,33	31	3,60	3,58	184	0,15		241	3								
6,1	Lago Lungo	31/03/93	6,01	17,70	1,77	29	2,22	0,25	0,50	0,38	33	4,60	4,57	258	0,18		319	6								
6,1	Lago Lungo	12/07/93	6,51	11,50	1,15	6	1,43	0,16	0,33	0,24	30	2,70	2,68	196	0,11			4								
6,1	Lago Lungo	02/08/93	6,47	11,70	1,17	3	1,42	0,15	0,31	0,22	28	2,90	2,88	176	0,11		239	4								
6,1	Lago Lungo	20/09/93	6,83	12,10	1,21	5	1,43	0,16	0,35	0,24	27	3,00	2,98	146	0,14		211	6								
6,1	Lago Lungo	06/12/93	6,43	13,70	1,37	4	1,57	0,25	0,46	0,33	30	3,40	3,37	209	0,19		210	4								
Mean 93	**Lago Lungo**	**M 93**	**6,43**	**13,47**	**1,35**	**10**	**1,63**	**0,19**	**0,40**	**0,29**	**30**	**3,37**	**3,35**	**195**	**0,15**		**244**	**4**								
6,1	Lago Lungo	05/09/94	6,76	11,82	1,30	1	1,31	0,15	0,27	0,18	28	2,81	2,80	137	0,07			6								
6,1	Lago Lungo	18/07/94	6,20	10,89	1,20	10	1,31	0,13	0,23	0,17	24	2,54	2,52	220	0,13			4								
6,1	Lago Lungo	10/05/94	5,58	15,13	1,66	101	1,46	0,17	0,32	0,19	16	3,30	3,28	409	0,16		654									
6,1	Lago Lungo	24/01/94	6,14	13,10	1,44	13	1,49	0,16	0,31	0,18	40	2,84	2,82	142	0,12		240	4								
Mean94	**Lago Lungo**	**M94**	**6,17**	**12,74**	**1,40**	**31**	**1,39**	**0,15**	**0,28**	**0,18**	**27**	**2,87**	**2,86**	**227**	**0,12**		**447**	**5**								
6.2 (N)	Lago di Latte	21/09/93	6,71	17,00	1,70	9	2,16	0,15	0,34	0,33	86	2,70	2,70	320	<0.2	<0.1	440	2	0,90		<10	<10		0,05	<0.5	<2
6,2	Lago di Latte	20/01/93	6,44	15,30	1,53	11	1,98	0,15	0,41	0,42	43	2,80	2,79	324	0,10			2								
6,2	Lago di Latte	05/05/93	6,37	16,10	1,61	22	2,11	0,17	0,44	0,41	45	3,10	3,07	369	0,18		411	3								
6,2	Lago di Latte	13/07/93	6,64	14,70	1,47	4	1,91	0,15	0,41	0,37	64	2,70	2,68	303	0,11		268	3								
6,2	Lago di Latte	03/08/93	6,81	14,40	1,44	4	1,83	0,15	0,36	0,33	53	2,70	2,69	301	0,10		340	2								
6,2	Lago di Latte	21/09/93	6,67	15,80	1,58	9	2,03	0,15	0,41	0,40	61	2,90	2,88	306	0,13		382	5								
6,2	Lago di Latte	13/12/93	6,67	15,40	1,54	5	1,84	0,21	0,50	0,39	54	2,90	2,86	324	0,27		386	4								
Mean 93	**Lago di Latte**	**M 93**	**6,60**	**15,28**	**1,53**	**9**	**1,95**	**0,16**	**0,42**	**0,39**	**53**	**2,85**	**2,83**	**321**	**0,15**		**357**	**3**								
6,2	Lago di Latte	06/09/94	6,79	15,99	1,76	0	1,92	0,15	0,35	0,30	58	3,00	3,00	244	0,03		390	5								
6,2	Lago di Latte	21/07/94	6,27	11,86	1,30	19	1,53	0,10	0,25	0,28	38	2,26	2,24	292	0,14		460									
6,2	Lago di Latte	09/05/94	6,08	15,60	1,72	97	1,84	0,13	0,29	0,28	41	2,95	2,93	388	0,17		575									
6,2	Lago di Latte	24/01/94	6,26	15,60	1,72	15	2,05	0,14	0,33	0,28	66	2,63	2,61	288	0,12		468	2								
Mean94	**Lago di Latte**	**M94**	**6,35**	**14,76**	**1,62**	**33**	**1,84**	**0,13**	**0,31**	**0,29**	**51**	**2,71**	**2,69**	**303**	**0,12**		**473**	**4**								
7.3 (N)	Blanc	06/11/93	7,10	20,50	2,05	12	2,45	0,40	0,80	0,48		1,80	1,77	265	0,20	0	345	5	1,11		<10	<10		<0.1	1,2	
7,3	Blanc	24/07/93	6,70	9,00	0,90		1,10	0,16	0,10			0,40	0,40	136		140		6		51						
7,3	Blanc	24/07/93	6,76	11,00	1,10		1,40	0,18	0,20			0,50	0,50	113		130		6		42						
7,3	Blanc	24/07/93	6,76	10,00	1,00		1,10	0,17	0,10			0,50	0,50	113		130				55						
7,3	Blanc	24/07/93	6,80	10,00	1,00		1,30	0,17	0,10			0,40	0,40	113		140				43						
7,3	Blanc	04/11/93	7,04	20,00	2,00		3,00	0,04	0,80			1,90	1,90	249												
Mean 93	**Blanc**	**M 93**	**6,81**	**12,00**	**1,20**		**1,58**	**0,14**	**0,26**			**0,74**	**0,74**	**145**		**135**		**6**		**48**						
7,3	Blanc	12/10/94	7,02	14,03	1,40	27	1,50	0,23	0,30	0,40	72	1,30	1,29	200	0,10		227	3								
Mean 94	**Blanc**	**M 94**	**7,02**	**14,03**	**1,40**	**27**	**1,50**	**0,23**	**0,30**	**0,40**	**72**	**1,30**	**1,29**	**200**	**0,10**		**227**	**3**								
7,4	Noir	24/07/93	7,30	24,00	2,40	0	3,50	0,33	0,20			0,90	0,90	113		50		33		6						
7,4	Noir	24/07/93	6,80	16,00	1,60	0	1,90	0,32	0,20			0,90	0,90	113		60		29		9						
7,4	Noir	24/07/93	7,01	17,00	1,70	0	2,00	0,33	0,20			0,80	0,80	113		60		33		9						
7,4	Noir	24/07/93	7,00	17,00	1,70	0	2,10	0,33	0,20			1,00	1,00	113		6				7						
7,4	Noir	04/11/93	7,23	25,00	2,50	0	3,50	0,45	0,80	0,30		2,10	2,10	203				29								
Mean 93	**Noir**	**M 93**	**7,07**	**19,80**	**1,98**	**0**	**2,60**	**0,35**	**0,32**			**1,14**	**1,14**	**131**		**44**		**31**		**8**						
7,4	Noir	12/10/94	7,09	19,87	1,99	7	2,50	0,40	0,30	0,18	92	3,20	3,17	155	0,20		162	31								
Mean 94	**Noir**	**M 94**	**7,09**	**19,87**	**1,99**	**7**	**2,50**	**0,40**	**0,30**	**0,18**	**92**	**3,20**	**3,17**	**155**	**0,20**		**162**	**31**								
8	Etang d'Aube	15/07/93	6,00	8,00	0,80	<14	0,64	0,10	0,35	0,12	12	1,25	1,22	140	0,25											
8(N)	Etang d'Aube		6,32	13,60	1,36	139	0,71	0,07	0,85	0,82	37	1,20	1,03	136	1,20	<0.1	690	5	0,90		<10	<10		<0.1	<0.5	14,0
8	Etang d'Aube	13/10/93	6,12	7,91	0,79	126	0,64	0,07	0,41	0,20	20	1,25	1,20	126	0,35											
Mean 93	**Etang d'Aube**	**M 93**	**6,22**	**10,76**	**1,08**	**133**	**0,68**	**0,07**	**0,54**	**0,51**	**29**	**1,23**	**1,12**	**131**	**0,60**		**690**	**5**	**0,90**							**14,0**
8	Etang d'Aube	31/08/94	6,17	7,00	0,70	46	0,55	0,07	0,42	0,11	48	1,10	1,06	127	0,30			1								35,0

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
8	Etang d'Aube	09/09/94	6,05	6,71	0,67	14	0,56	0,07	0,32	0,08	12	0,58	0,53	308	0,32					13						
Mean94	**Etang d'Aube**	**M94**	**6,11**	**6,86**	**0,69**	**30**	**0,56**	**0,07**	**0,37**	**0,09**	**30**	**0,84**	**0,79**	**218**	**0,31**			**1**		**13**						**35,0**
11 (N)	Schwarzsee ob Sõlden	18/08/93	5,16	15,60	1,56	8	1,14	0,21	0,22	0,10		3,70	3,66	200	0,30	<0.1	290	2	0,41		43	<10		<0.1	<0.5	
11	Schwarzsee ob Sõlden	02/07/93	5,49	9,40	0,94	14	0,84	0,16	0,23	0,08	0	2,43	2,42	115	0,06	4		3			38					
11	Schwarzsee ob Sõlden	18/08/93	5,85	12,80	1,28	3	1,07	0,24	0,29	0,11	0	3,90	3,89	97	0,07	4		2			18					
11	Schwarzsee ob Sõlden	20/09/93	5,33	16,80	1,68	9	1,14	0,25	0,32	0,13	0	3,70	3,69	320	0,10	5		2			28					
Mean 93	**Schwarzsee ob Sõlden**	**M 93**	**5,56**	**13,00**	**1,30**	**9**	**1,02**	**0,22**	**0,28**	**0,11**	**0**	**3,34**	**3,33**	**177**	**0,08**	**4**		**3**			**28**					
11	Schwarzsee ob Sólden	14/01/94	5,80	16,85	1,69	22	1,51	0,31	0,43	0,17	9	4,50	4,49	170	0,11	6,00		3	0,45		1					
11	Schwarzsee ob Sólden	23/02/94	5,77	16,40	1,64	27	1,50	0,31	0,40	0,15	6	4,90	4,89	145	0,11	5,00		5	0,40		1					
11	Schwarzsee ob Sólden	28/03/94	5,68	16,20	1,62	30	1,47	0,30	0,40	0,17	6	4,00	3,98	140	0,14	6,00		5	0,30		1					
11	Schwarzsee ob Sólden	20/04/94	5,54	16,72	1,67	26	1,43	0,30	0,39	0,16	17	5,00	4,99	140	0,12	7,00		5	0,25		1					
11	Schwarzsee ob Sólden	11/05/94	5,66	18,08	1,81	32	1,45	0,31	0,37	0,16	3	4,40	4,39	180	0,10	5,00		4	0,35		1					
11	Schwarzsee ob Sólden	31/05/94	5,35	15,77	1,58	47	1,38	0,26	0,32	0,15	8	3,70	3,68	210	0,16	4,00		3	0,45		1					
11	Schwarzsee ob Sólden	12/07/94	5,38	11,20	1,12	16	0,95	0,20	0,35	0,11	2	2,80	2,79	140	0,10	4,00		2	0,25		1					
11	Schwarzsee ob Sólden	01/09/94	5,65	16,22	1,62	3	1,20	0,30	0,36	0,14	7	3,90	3,89	105	0,09	5,00		9			1					
11	Schwarzsee ob Sólden	09/09/94																								68,0
Mean94	**Schwarzsee ob Sólden**	**M94**	**5,60**	**15,93**	**1,59**	**25**	**1,36**	**0,29**	**0,38**	**0,15**	**7**	**4,15**	**4,14**	**154**	**0,12**	**5,25**		**4**	**0,35**		**1**					
12.1 (N)	Aguilo	19/10/93	5,61	6,10	0,61	15	0,49	0,08	0,19	0,06	-7	0,90	0,86	48	0,30	<0.1	147	2	0,73		<10	12		<0.5	<0.5	9,0
12,1	L. Aguilo	19/10/93	5,79	6,40	0,64	7	0,44	0,16	0,21	0,08	18	0,72	0,70	42	0,18			5	1,28							
Mean 93	**L. Aguilo**	**M 93**	**5,79**	**6,40**	**0,64**	**7**	**0,44**	**0,16**	**0,21**	**0,08**	**18**	**0,72**	**0,70**	**42**	**0,18**			**5**	**1,28**							
12,1	Lago Aguilo	10/10/94	6,10	5,40	0,54	7	0,37	0,12	0,20	0,07	11	0,64	0,61	30	0,25			5	0,59							
Mean 94	**L. Aguilo**	**M 94**	**6,10**	**5,40**	**0,54**	**7**	**0,37**	**0,12**	**0,20**	**0,07**	**11**	**0,64**	**0,61**	**30**	**0,25**			**5**	**0,59**							
12,2	L. Redo	16/10/93	6,32	12,30	1,23	15	1,50	0,17	0,21	0,08	42	1,49	1,46	196	0,18			4	0,95							
Mean 93	**L. Redo**	**M 93**	**6,32**	**12,30**	**1,23**	**15**	**1,50**	**0,17**	**0,21**	**0,08**	**42**	**1,49**	**1,46**	**196**	**0,18**			**4**	**0,95**							
12,2	Lago Redo	11/10/94	6,69	11,80	1,18	8	1,41	0,15	0,23	0,08	44	1,12	1,08	155	0,28			7	0,63							
Mean 94	**L. Redo**	**M 94**	**6,69**	**11,80**	**1,18**	**8**	**1,41**	**0,15**	**0,23**	**0,08**	**44**	**1,12**	**1,08**	**155**	**0,28**			**7**	**0,63**							
13	La Caldera	14/07/93	8,46	22,00	2,20	9	3,58	0,33	0,31	0,12	180	0,80	0,75	124	0,37		266	12	3,22	29				1,30	0,6	0,8
13	La Caldera	07/09/93	7,64	30,00	3,00	51	4,31	0,43	0,49	0,11	209	0,98	0,88	25	0,72		223	8	2,94	35				0,40	1,5	1,0
Mean 93	**La Caldera**	**M 93**	**8,05**	**26,00**	**2,60**	**30**	**3,95**	**0,38**	**0,40**	**0,12**	**195**	**0,89**	**0,82**	**75**	**0,54**		**244**	**10**	**3,08**	**32**				**0,85**	**1,1**	**0,9**
13	La Caldera	20/07/94	8,40	22,00	2,20	1	4,56	0,46	0,93	0,22	270	0,85		72	0,49		84	9	1,39					0,20	1,6	<1
13	La Caldera	02/08/94	8,10	30,00	3,00	28	4,37	0,56	2,85	0,83	268	1,14		103	1,26		528	12	4,48					0,30	10,0	<1
13	La Caldera	01/09/94	7,85	36,00	3,60	67	6,44	0,58	1,14	0,25	284	1,45		25	0,81		107	12	1,88					0,10	5,0	<1
13	La Caldera	13/09/94	7,31	32,00	3,20	87	5,61	0,57	0,30	0,17	330	1,20	1,13	13	0,50	<0.5	285	6	0,99		19	<10		<0.10	0,7	10,5
13	La Caldera	13/09/94	7,34	32,70	3,27	103	5,57	0,54	0,28	0,16	346	1,80	1,49	16	2,20	<0.1	280	5	0,78		17	<10		<0.10	1,9	13,0
Mean94	**La Caldera**	**M94**	**7,80**	**30,54**	**3,05**	**57**	**5,31**	**0,54**	**1,10**	**0,33**	**300**	**1,29**	**1,31**	**46**	**1,05**		**257**	**9**	**1,90**		**18**			**0,20**	**3,84**	**11,75**
14 (N)	Escura	06/10/93	5,34	12,10	1,21	15	0,36	0,16	0,98	0,11	-10	1,10	0,86	5	1,70	<0.1	123	6	1,20		32	20		<0.5	<0.5	716,0
14	L. Escura	06/10/93	5,31	13,30	1,33	7	0,24	0,28	0,64	0,08	6	1,06	0,90	0	1,09			7	1,81							
Mean 93	**L. Escura**	**M 93**	**5,31**	**13,30**	**1,33**	**7**	**0,24**	**0,28**	**0,64**	**0,08**	**6**	**1,06**	**0,90**	**0**	**1,09**			**7**	**1,81**							
14	Lago Escura	17/09/94	5,41	11,00	1,10	7	0,25	0,22	0,73	0,21	-5	0,66	0,48	0	1,31			10	2,15							
Mean 94	**L. Escura**	**M 94**	**5,41**	**11,00**	**1,10**	**7**	**0,25**	**0,22**	**0,73**	**0,21**	**-5**	**0,66**	**0,48**	**0**	**1,31**			**10**	**2,15**							
15.1 (N)	Starolesnianske pleso	28/09/93	4,89	15,30	1,53	11	0,82	0,08	0,02	0,07		3,10	3,07	175	0,20	<0.1	405	8	1,80		179	11		0,24	2,6	61,0
15,1	Starolesnianske pleso	VS-15	4,70	15,10	1,51	17	0,73	0,10	0,19	0,08		4,04	4,02	169	0,17			9	2,75		193	17	176			
Mean 93	**Starolesnianske pleso**	**M 93**	**4,80**	**15,20**	**1,52**	**14,00**	**0,78**	**0,09**	**0,11**	**0,08**		**3,57**	**3,54**	**172**	**0,19**		**405**	**9**	**2,28**		**186**	**14**	**176**	**0,24**	**2,60**	**61,00**
15,1	Starolesnianske Pleso	27/10/94	4,69	14,30		39	0,59	0,07	0,08	0,11	-18	2,50	2,49	147	0,10	0,01	339	8	1,55							
Mean 94	**Starolesnianske pleso**	**M 94**	**4,69**	**14,30**		**39**	**0,59**	**0,07**	**0,08**	**0,11**	**-18**	**2,50**	**2,49**	**147**	**0,10**	**0,01**	**339**	**8**	**1,55**							
15.2 (N)	Terianske pleso	29/09/93	6,92	22,10	2,21	<5	3,20	0,08	0,13	0,11	61	3,10	3,07	585	0,20	<0.1	630	1	0,27		13	<10		0,06	<0.5	<2
15,2	Terianske pleso	NE-3	6,80	20,40	2,04	9	3,18	0,14	0,45	0,13		3,42	3,39	510	0,18			2	0,75		9					
Mean 93	**Terianske pleso**	**M 93**	**6,86**	**21,25**	**2,13**	**9,00**	**3,19**	**0,11**	**0,29**	**0,12**	**61,00**	**3,26**	**3,23**	**548**	**0,19**		**630**	**2**	**0,51**		**11**			**0,06**		

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
15,2	Terianske Pleso	27/10/94	6,40	18,70		4	2,87	0,08	0,36	0,16	68	2,65	2,63	428	0,16	0,03	481	3	0,41							
Mean 94	**Terianske pleso**	**M 94**	**6,40**	**18,70**		**4**	**2,87**	**0,08**	**0,36**	**0,16**	**68**	**2,65**	**2,63**	**428**	**0,16**	**0,03**	**481**	**3**	**0,41**							
15.3 (N)	Dlugi Staw	23/09/93	5,97	19,40	1,94	6	2,20	0,10	0,15	0,13	-2	3,60	3,57	755	0,20	<0.1	770	<1	0,23		33	<10		0,05	<0.5	650,0
15,3	Dlugi Staw	GA-4		18,00	1,80	12	2,15	0,13	0,39	0,18		3,94	3,91		0,18			2			48					
15,3	Dlugi Staw	03/01/93	6,26	22,60	2,26		2,89	0,15	0,44	0,11	21	4,20		885	0,40		910		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	19/01/93	6,38	21,70	2,17	1	2,95	0,20	0,46	0,18	61	3,90		580	0,30		640		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	31/01/93	6,41	22,40	2,24	<5	2,57	0,16	0,47	0,14	22	3,80	3,76	885	0,30		900		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	01/03/93	6,47	23,40	2,34	3	2,75	0,14	0,46	0,17	27	4,10	4,04	885	0,40		925		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	06/04/93	6,21	23,10	2,31		2,91	0,16	0,46	0,13	25	4,20	4,16	905	0,30		970		0,55		M 10.00	M 10.0	0			
15,3	Dlugi Staw	15/04/93	6,25	22,50	2,25	5	2,96	0,16	0,47	0,15	23	3,60	3,56	895	0,30		930		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	20/04/93	6,37	24,60	2,46	8	3,11	0,15	0,49	0,14	21	4,40	4,33	940	0,50		965		M 0.20		M 10.00	M 10.0	0			
15,3	Dlugi Staw	03/05/93	6,06	23,50	2,35	13	2,82	0,14	0,33	0,14	6	4,00	3,96	980	0,30		1020		0,14		M 10.00	M 10.0	0			
15,3	Dlugi Staw	17/05/93	5,14	21,20	2,12		1,83	0,10	0,30	0,16	0	3,30	3,24	870	0,40		980		0,33		135	M 10.0	125			
15,3	Dlugi Staw	01/06/93	5,22	16,00	1,60	29	1,52	0,08	0,17	0,12	3	2,90	2,86	675	0,30		725		M 0.20		130	M 10.0	120			
15,3	Dlugi Staw	14/06/93	5,33	15,90	1,59	11	1,56	0,08	0,24	0,13	4	3,10	3,06	615	0,30		650		0,37		68	M 10.0	58			
15,3	Dlugi Staw	01/07/93	5,43	17,40	1,74	8	1,65	0,08	0,25	0,11	0	2,90	2,86	625	0,30		660		0,25		57	M 10.0	47			
15,3	Dlugi Staw	12/07/93	5,94	18,50	1,85	<5	2,10	0,10	0,29	0,13	6	3,10	3,07	705	0,20		745		M 0.20		10	M 10.0	0			
15,3	Dlugi Staw	22/08/93	5,89	19,50	1,95	26	2,24	0,12	0,40	0,22	5	3,20	3,16	730	0,30		840		0,28		M 10.00	M 10.0	0			
15,3	Dlugi Staw	02/09/93	5,72	17,20	1,72	<5	1,97	0,12	0,31	0,14	0	3,60	3,57	625	0,20		655		M 0.20		46	M 10.0	36			
15,3	Dlugi Staw	13/09/93	5,84	18,40	1,84	11	2,09	0,10	0,33	0,15		3,50	3,47	750	0,20		800		0,85		31	M 10.0	21			
15,3	Dlugi Staw	23/09/93	5,97	19,40	1,94	6	2,20	0,10	0,15	0,13	0	3,60	3,57	755	0,20	M 0.10	770	M 1.0	0,23		33	M 10.0	23	0,05	M 0.5	650,0
15,3	Dlugi Staw	27/09/93	5,92	19,10	1,91	<5	2,25	0,11	0,37	0,15	18	3,70	3,66	755	0,30		795		0,26		22	M 10.0	12			
15,3	Dlugi Staw	01/10/93																2								
15,3	Dlugi Staw	15/11/93	6,05	21,60	2,16	<5	2,73	0,15	0,38	0,13	21	4,10	4,07	790	0,20		830		0,25		<10.00	<10.00	0			
15,3	Dlugi Staw	30/11/93	6,06	22,50	2,25	<5	2,79	0,16	0,38	0,15	24	4,20	4,14	825	0,40		915		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	14/12/93	6,41	23,20	2,32	<5	3,00	0,15	0,46	0,14	20	4,20	4,16	865	0,30		965		<0.20		<10.00	<10.00	0			
Mean 93	**Dlugi Staw**	**M 93**	**5,97**	**20,48**	**2,05**	**10,72**	**2,40**	**0,13**	**0,35**	**0,14**	**14**	**3,70**	**3,63**	**786**	**0,29**		**835**	**2**	**0,34**		**56**		**21**	**0,05**		
15,3	Dlugi Staw	01/01/94	6,26	23,10	2,31	<5	2,92	0,15	0,48	0,13	20	4,20	4,17	850	0,20		880		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	17/01/94	6,65	24,90	2,49	11	3,45	0,24	0,48	0,18	91	3,80	3,77	500	0,20		570		0,41		<10.00	<10.00	0			
15,3	Dlugi Staw	04/02/94	6,63	23,20	2,32	<5	2,87	0,16	0,50	0,14	24	4,10	4,07	855	0,20		850		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	15/02/94	6,40	22,70	2,27	<5	2,92	0,16	0,45	0,14	25	4,20	4,17	860	0,20		875		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	28/02/94	6,17	22,30	2,23	<5	2,88	0,15	0,44	0,12	26	4,60	4,56	845	0,30		880		0,20		<10.00	<10.00	0			
15,3	Dlugi Staw	14/03/94	6,16	22,70	2,27	<5	2,84	0,14	0,47	0,14	23	4,10	4,07	865	0,20		885		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	29/03/94	6,17	23,10	2,31	<5	2,87	0,16	0,49	0,13	24	4,10	4,07	925	0,20		895		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	19/04/94	6,18	24,90	2,49	6	3,17	0,17	0,49	0,14	31	4,00	3,96	910	0,30		1040		0,42		<10.00	<10.00	0			
15,3	Dlugi Staw	04/05/94	5,96	23,40	2,34	<5	2,93	0,16	0,42	0,13	15	3,80	3,76	960	0,30		995		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	17/05/94	5,67	18,40	1,84	36	2,04	0,12	0,34	0,12	4	3,00	2,96	670	0,30		730		0,44		16	<10.00	6			
15,3	Dlugi Staw	22/05/94	5,36	16,10	1,61	45	1,47	0,10	0,26	0,14	0	2,90	2,86	625	0,30		695		0,35		87	<10.00	77			
15,3	Dlugi Staw	31/05/94	5,32	15,60	1,56	21	1,46	0,10	0,26	0,13	2	2,90	2,87	590	0,20		650		0,20		92	<10.00	82			
15,3	Dlugi Staw	20/06/94	5,27	16,30	1,63	15	1,54	0,06	0,26	0,11	2	2,90	2,87	545	<0.20		600		0,20		74	<10.00	64			
15,3	Dlugi Staw	04/07/94	5,63	15,10	1,51	9	1,50	0,05	0,30	0,12	6	2,80	2,77	490	<0.20		555		<0.20		41	<10.00	31			
15,3	Dlugi Staw	18/07/94	5,54	14,10	1,41	10	1,42	0,04	0,25	0,10	3	2,70	2,67	470	<0.20		510		<0.20		25	<10.00	15			
15,3	Dlugi Staw	25/07/94	5,91	17,00	1,70	<5	1,97	0,11	0,35	0,12	11	3,90	3,87	535	<0.20		595		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	16/08/94	5,95	17,70	1,77	15	1,93	0,11	0,41	0,23	12	3,30	3,26	560	0,30		655		<0.20		<10.00	<10.00	0			
15,3	Dlugi Staw	29/08/94	5,86	15,90	1,59	16	1,83	0,09	0,26	0,16	12	3,20	3,17	595	0,20		655		<0.20		23	<10.00	13			
15,3	Dlugi Staw	19/09/94	5,91	16,20	1,62	22	1,92	0,11	0,40	0,15	10	3,20	3,16	715	0,30		725		<0,2		20	<10.00	10			
15,3	Dlugi Staw	02/10/94	5,99	17,80	1,78	21	2,08	0,12	0,47	0,22	12	3,40	3,37	705	0,20		830		0,26		19	<10.00	9			
15,3	Dlugi Staw	18/10/94	5,94	17,80	1,78	14	2,16	0,12	0,33	0,13	11	3,40	3,39	715	0,10		735		0,29		13	<10.00	3			

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
15,3	Dlugi Staw	01/11/94	5,73	17,90	1,79	8	2,25	0,13	0,39	0,16	13	3,50	3,47	725	0,20		745		0,25		13	<10.00	3			
15,3	Dlugi Staw	15/11/94	6,05	18,20	1,82	<5	2,31	0,13	0,32	0,13	15	3,50	3,47	780	0,20		770		0,20		<10	<10.00	0			
15,3	Dlugi Staw	30/11/94	6,09	18,40	1,84	<5	2,44	0,14	0,36	0,12	18	3,60	3,56	775	0,30		755		0,26		<10	<10.00	0			
15,3	Dlugi Staw	23/12/94	6,25	19,50	1,95	<5	2,52	0,13	0,45	0,11		3,90	3,86	775	0,30		775		<0.20		<10.00	<10.00	0			
Mean94	**Dlugi Staw**	**M94**	**5,96**	**19,29**	**1,93**	**17,79**	**2,31**	**0,13**	**0,39**	**0,14**	**17,07**	**3,56**	**3,53**	**714**	**0,24**		**754**		**0,29**		**38**		**13**			
15.4 (N)	Zieloni Staw	23/09/93	7,07	23,20	2,32	<5	3,11	0,19	0,27	0,19	79	3,50	3,46	390	0,30	<0.1	470	3	0,52		13	<10		0,15	<0.5	54,5
15,4	Zieloni Staw	GA-7	6,70	22,20	2,22	13	3,08	0,24	0,63	0,25		3,75	3,72	350	0,25			5								
15,4	Zieloni Staw	03/01/93	6,45	23,00	2,30		3,04	0,21	0,47	0,16	64	3,70	3,66	525	0,30		595		0,25		M 10.00	M 10.0	0			
15,4	Zieloni Staw	19/01/93	6,32	21,30	2,13	3	2,85	0,15	0,45	0,14	16	3,90	3,86	905	0,30		905		M 0.20		M 10.00	M 10.0	0			
15,4	Zieloni Staw	31/01/93	6,53	22,70	2,27	13	2,65	0,20	0,47	0,19	59	3,60	3,56	590	0,30		650		0,26		M 10.00	M 10.0	0			
15,4	Zieloni Staw	16/02/93	6,51	21,40	2,14	36	2,98	0,21	0,44	0,20	65	3,50	3,46	560	0,30		635		0,30		M 10.00	M 10.0	0			
15,4	Zieloni Staw	01/03/93	6,66	24,00	2,40	16	3,03	0,21	0,47	0,21	84	3,80	3,76	510	0,30		590		0,28		M 10.00	M 10.0	0			
15,4	Zieloni Staw	06/04/93	6,57	25,00	2,50		3,23	0,22	0,50	0,24	86	3,80	3,76	575	0,30		780		0,40		M 10.00	M 10.0	0			
15,4	Zieloni Staw	15/04/93	6,52	23,80	2,38	13	3,26	0,22	0,47	0,19	79	3,30	3,26	545	0,30		610		M 0.20		M 10.00	M 10.0	0			
15,4	Zieloni Staw	20/04/93	6,45	26,60	2,66	142	3,31	0,22	0,55	0,21	74	3,90	3,84	630	0,40		855		0,37		M 10.00	M 10.0	0			
15,4	Zieloni Staw	03/05/93	5,98	24,90	2,49	137	2,85	0,19	0,40	0,18	23	4,40	4,34	770	0,40		950		0,68		10	M 10.0	0			
15,4	Zieloni Staw	17/03/93	6,24	19,70	1,97		2,53	0,16	0,34	0,15	51	3,00	2,96	480	0,30		570		0,43		M 10.00	M 10.0	0			
15,4	Zieloni Staw	01/06/93	6,65	22,60	2,26	5	3,24	0,21	0,37	0,17	89	3,50	3,46	485	0,30		535		0,36		M 10.00	M 10.0	0			
15,4	Zieloni Staw	14/06/93	6,81	22,20	2,22	8	2,91	0,19	0,43	0,17	82	3,50	3,46	460	0,30		515		0,38		10	M 10.0	0			
15,4	Zieloni Staw	01/07/93	6,82	22,20	2,22	10	2,94	0,19	0,41	0,16	84	3,40	3,36	420	0,30		500		0,25		10	M 10.0	0			
15,4	Zieloni Staw	12/07/93	6,72	22,70	2,27	23	3,00	0,20	0,38	0,16	84	3,20	3,16	415	0,30		495		0,30		M 10.00	M 10.0	0			
15,4	Zieloni Staw	22/08/93	6,63	21,80	2,18	21	2,96	0,19	0,43	0,18	71	3,30	3,27	410	0,20		480		0,51		M 10.00	M 10.0	0			
15,4	Zieloni Staw	02/09/93	6,71	21,80	2,18	26	3,01	0,21	0,39	0,18	79	3,50	3,47	395	0,20		470		0,59		M 10.00	M 10.0	0			
15,4	Zieloni Staw	13/09/93	6,70	22,10	2,21	17	2,96	0,19	0,43	0,19	79	3,40	3,36	410	0,30		500		0,71		M 10.00	M 10.0	0			
15,4	Zieloni Staw	23/09/93	7,07	23,20	2,32	<5	3,11	0,19	0,27	0,19	83	3,50	3,46	390	0,30	M 0.10	470	3	0,52		13	M 10.0	3	0,15	M 0.5	54,5
15,4	Zieloni Staw	27/09/93	6,78	22,20	2,22	23	3,09	0,20	0,46	0,18	73	3,60	3,56	400	0,30		490		0,50		M 10.00	M 10.0	0			
15,4	Zieloni Staw	10/01/93	6,70	22,20	2,22	13	3,08	0,24	0,63	0,25		3,75	3,72	350	0,25		130	5								
15,4	Zieloni Staw	15/11/93	6,66	23,30	2,33		3,31	0,23	0,43	0,17	94	3,70	3,67	405	0,20		540		0,59		314	M 10.0	304			
15,4	Zieloni Staw	30/11/93	6,74	27,40	2,74	6	3,71	0,26	0,47	0,20	105	4,60	4,54	460	0,40		550		0,42		<10.00	<10.00	0			
15,4	Zieloni Staw	14/12/93	6,83	26,20	2,62	14	3,93	0,27	0,56	0,21	109	4,30	4,26	495	0,30		590		0,47		<10.00	<10.00	0			
Mean 93	**Zieloni Staw**	**M 93**	**6,63**	**23,11**	**2,31**	**28,37**	**3,09**	**0,21**	**0,44**	**0,19**	**74,31**	**3,66**	**3,61**	**493**	**0,30**		**578**	**4**	**0,43**		**62**		**14**	**0,15**		**54,50**
15,4	Zieloni Staw	01/01/94	6,73	25,20	2,52	20	3,54	0,24	0,51	0,18	96	3,80	3,77	465	0,20		560		0,42		<10.00	<10.00	0			
15,4	Zieloni Staw	17/01/94	6,39	23,50	2,35	<5	2,91	0,16	0,45	0,13	21	4,10	4,07	835	0,20		865		<0.10		<10.00	<10.00	0			
15,4	Zieloni Staw	01/02/94	6,65	26,30	2,63	57	3,39	0,24	0,60	0,23	94	3,60	3,56	515	0,30		745		0,37		<10.00	<10.00	0			
15,4	Zieloni Staw	15/02/94	6,69	25,30	2,53	27	3,31	0,23	0,51	0,25	93	3,60	3,56	485	0,30		600		0,23		<10.00	<10.00	0			
15,4	Zieloni Staw	28/02/94	6,56	24,50	2,45	52	3,27	0,21	0,44	0,19	94	3,60	3,56	485	0,30		655		0,34		<10.00	<10.00	0			
15,4	Zieloni Staw	14/03/94	6,61	24,20	2,42	9	3,29	0,22	0,47	0,17	92	3,50	3,46	490	0,30		560		0,39		<10.00	<10.00	0			
15,4	Zieloni Staw	29/03/94	6,45	24,50	2,45	13	3,27	0,23	0,50	0,16	87	3,50	3,46	550	0,30		610		0,51		<10.00	<10.00	0			
15,4	Zieloni Staw	19/04/94	6,41	25,40	2,54	42	3,32	0,23	0,47	0,18	80	3,50	3,46	570	0,30		715		0,30		<10.00	<10.00	0			
15,4	Zieloni Staw	04/05/94	6,17	22,60	2,26	100	2,75	0,18	0,39	0,14	55	3,50	3,46	570	0,30		720		0,44		12	<10.00	2			
15,4	Zieloni Staw	17/05/94	6,15	21,70	2,17	57	2,66	0,18	0,40	0,15	46	3,10	3,06	555	0,30		645		0,55		<10.00	<10.00	0			
15,4	Zieloni Staw	22/05/94	6,41	19,80	1,98	14	2,57	0,17	0,40	0,16	66	3,10	3,07	460	0,20		515		0,27		12	<10.00	2			
15,4	Zieloni Staw	31/05/94	6,47	19,70	1,97	6	2,60	0,17	0,39	0,15	73	3,00	2,97	430	0,20		460		0,23		<10.00	<10.00	0			
15,4	Zieloni Staw	20/06/94	6,87	21,60	2,16	6	3,04	0,15	0,40	0,15	88	3,20	3,17	380	<0.20		420		0,25		<10.00	<10.00	0			
15,4	Zieloni Staw	04/07/94	6,83	20,50	2,05	14	2,58	0,11	0,39	0,15	72	3,40	3,37	355	<0.20		405		0,33		<10.00	<10.00	0			
15,4	Zieloni Staw	18/07/94	6,71	19,70	1,97	16	2,51	0,14	0,40	0,14	67	3,30	3,27	340	<0.20		405		0,39		<10.00	<10.00	0			
15,4	Zieloni Staw	25/07/94	6,50	19,60	1,96	21	2,55	0,17	0,44	0,16	65	3,70	3,66	330	0,30		435		0,52		<10.00	<10.00	0			
15,4	Zieloni Staw	16/08/94	6,79	20,30	2,03	34	2,65	0,18	0,42	0,16	73	3,80	3,77	335	0,20		450		0,47		<10.00	<10.00	0			

Lake n°		Date	pH	Cond.	Cond.	NH4	Ca	Mg	Na	K	Alk	SO4	SO4*	NO3	Cl	F	TN	TP	TOC	TAL	RAL	ILAL	LAL	Cd	Pb	Hg
				µS/cm 25°C	mS/m 25°C	µgN/l	mg/l	mg/l	mg/l	mg/l	µeq /l	mg/l	mg/l	µgN/l	mg/l	µg/l	µgN/l	µg/l	mg C/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	ng/l
15,4	Zieloni Staw	29/08/94	6,78	18,70	1,87	39	2,61	0,17	0,32	0,18	80	3,30	3,27	315	0,20		415		0,47		10	<10.00	0			
15,4	Zieloni Staw	19/09/94	6,74	20,20	2,02	37	2,87	0,20	0,54	0,22	95	3,30	3,27	300	0,20		440		0,66		<10.00	<10.00	0			
15,4	Zieloni Staw	02/10/94	6,84	20,30	2,03	42	2,88	0,20	0,43	0,17	94	3,80	3,77	295	<0,2		435		0,49		<10.00	<10.00	0			
15,4	Zieloni Staw	18/10/94	6,76	20,90	2,09	30	3,01	0,22	0,44	0,18	95	3,40	3,37	325	<0,2		410		0,48		<10.00	<10.00	0			
15,4	Zieloni Staw	01/11/94	6,57	20,10	2,01	19	2,94	0,19	0,44	0,16	90	3,30	3,27	325	0,20		395		0,56		<10.00	<10.00	0			
15,4	Zieloni Staw	15/11/94	6,59	20,70	2,07	<5	2,88	0,21	0,39	0,18	90	3,40	3,37	340	0,20		400		0,49		<10.00	<10.00	0			
Mean94	**Zieloni Staw**	**M94**	**6,59**	**21,97**	**2,20**	**31**	**2,93**	**0,19**	**0,44**	**0,17**	**78,51**	**3,47**	**3,44**	**437**	**0,25**		**533**		**0,42**		**11**		**0**			
16 (N)	Laguna Cimera	mar-93		9,30	0,93																					
16	Laguna Cimera	jun-93	5,83	7,10	0,71						25															
16	Laguna Cimera	jul-93	6,15	7,60	0,76						25															
16	Laguna Cimera	aug-93	5,95	6,30	0,63						26															
16	Laguna Cimera	sep-93	6,06	7,20	0,72						29															
16	Laguna Cimera	nov-93	5,44	8,40	0,84						13															
16	Laguna Cimera	18/09/93	6,30	7,30	0,73	<5	0,60	0,17	0,27	0,07	37	0,90	0,86	1	0,30	<0.1	116	7	0,80		<10	<10		<0.05	<0.5	<2
16	Laguna Cimera	18/09/93	6,06	7,20	0,72	<100	0,62	<0.01	0,70	<0.2		0,75	0,70		0,36			<100								
Mean 93	**Laguna Cimera**	**M 93**	**5,97**	**7,55**	**0,76**		**0,61**	**0,17**	**0,49**	**0,07**	**26**	**0,83**	**0,78**	**1**	**0,33**		**116**	**7**	**0,80**							
16	Laguna Cimera	22/01/94	5,78	2,60	0,26		0,15	0,14	<0.15	<0.2	9	0,40		320	<0.10			<10								
16	Laguna Cimera	16/10/94	5,59	5,70	0,57		0,40	0,07	0,70	<0.2	25	0,65		240	0,33			<10								
Mean 94	**Laguna Cimera**	**M 94**	**5,69**	**4,15**	**0,42**		**0,28**	**0,11**	**0,70**		**17,15**	**0,53**		**280**	**0,33**			**<10**								
17	Chuna	R25.10.93	6,57	17,00	1,70		1,21	0,25	0,53	0,14	62	2,00	1,83	162	1,21			0		5						
17 (N)	Chuna		6,56	17,20	1,72	17	1,61	0,26	1,06	0,09	60	2,00	1,85	165	1,10	<0.1	245	1	0,28		<10	<10		0,13	0,5	4,5
Mean 93	**Chuna**	**M 93**	**6,57**	**17,10**	**1,71**	**17**	**1,41**	**0,26**	**0,80**	**0,12**	**61,00**	**2,00**	**1,84**	**164**	**1,16**		**245**	**1**	**0,28**	**5**				**0,13**	**0,5**	**4,5**
17	Chuna	27/03/94	6,72	25,00	2,50	40	2,00	0,34	1,10	0,27	80	3,20	3,03	156	1,20					8						
17	Chuna	21/04/94	6,24	20,00	2,00	45	1,40	0,22	1,20	0,30	33	2,70	2,49	48	1,50					10						
17	Chuna	17/08/94	6,40	10,00	1,00	6	0,90	0,13	0,50	0,05	23	1,80	1,71	26	0,62					36						
17	Chuna	17/08/94	6,37	10,00	1,00	13	0,95	0,16	0,48	0,03	24	1,70	1,61	36	0,62					47						
17	Chuna	07/09/94	6,43	10,00	1,00	2	0,85	0,14	0,56	0,05	26	1,90	1,82	17	0,60					11						
Mean94	**Chuna**	**M94**	**6,43**	**15,00**	**1,50**	**21**	**1,22**	**0,20**	**0,77**	**0,14**	**37**	**2,26**	**2,13**	**57**	**0,91**					**22**						
18	Chibini	R25.10.93	7,15	35,00	3,50		0,39	0,06	6,00	1,47	251	3,18	3,05	79	0,91			0		77						
18 (N)	Chibini		6,64	15,40	1,54	<5	1,78	0,21	0,64	0,06	56	2,40	2,33	165	0,50	<0.1	190	<1	0,30		<10	<10		<0.1	<0.5	<2
Mean 93	**Chibini**	**M 93**	**6,90**	**25,20**	**2,52**		**1,09**	**0,14**	**3,32**	**0,77**	**154**	**2,79**	**2,69**	**122**	**0,71**		**190**	**0**	**0,30**	**77**						
18	Chibini	10/07/94	7,39	36,00	3,60	7	0,70	0,07	5,80	1,55	234	2,80	2,68	273	0,83					60						
18	Chibini	10/07/94	7,54	32,00	3,20	6	0,65	0,07	5,63	1,50	190	2,50	2,39	190	0,81					54						
Mean94	**Chibini**	**M94**	**7,47**	**34,00**	**3,40**	**7**	**0,68**	**0,07**	**5,72**	**1,53**	**212**	**2,65**	**2,54**	**232**	**0,82**					**57**						
19	Krisko jezero	31/08/93	7,70	104,60	10,46	19	15,70		1,00	0,48	737	7,01	7,01	110			528	5								
Mean 93	**Krisko jezero**	**M 93**	**7,70**	**104,60**	**10,46**	**19**	**15,70**		**1,00**	**0,48**	**737**	**7,01**	**7,01**	**110**			**528**	**5**								
19	Zgornje krisko jezero	27/07/94	7,86	75,60	7,56	28	14,90	0,80	0,11	0,04	467			190	0,20	0,10	275	3	0,41					<0.10	<0.5	5,5
19	Zgornje krisko jezero	31/08/94	7,66	87,30	8,73	0	13,50		1,20	0,17	647	4,80	4,77	92			600	2								
Mean94	**Zgornje krisko jezero**	**M94**	**7,76**	**81,45**	**8,15**	**14**	**14,20**	**0,80**	**0,66**	**0,11**	**557**	**4,80**	**4,77**	**141**	**0,20**	**0,10**	**438**	**3**	**0,41**							**5,5**

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Ø. Neådalsvatn	06/06/93	1,1		23	14	50	4	8	17	2	65		93	92	0,56	184	13	13	12
Ø. Neådalsvatn	24/06/93	0,9		20	10	42	3	21	12	2	42		76	77	-0,73	154	10	10	10
Ø. Neådalsvatn	08/07/93	0,5		15	8	38	3	15	15	1	31		64	62	1,81	126	8	8	8
Ø. Neådalsvatn	21/07/93	0,8		15	6	30	3	15	12	1	25		54	54	-0,04	107	11	11	7
Ø. Neådalsvatn	05/08/93	1,0		17	6	28	3	12	12	0	25		55	50	4,19	105	7	7	7
Ø. Neådalsvatn	27/08/93	0,7		17	6	26	3	15	12		17		52	44			7	7	
Ø. Neådalsvatn	07/09/93	0,5		17	6	27	3	25	12		17		53	54			7	7	
Ø. Neådalsvatn	21/09/93	0,4		20	7	26	3	25	12	0	17		57	55	2,32	112	7	7	7
Ø. Neådalsvatn	30/09/93	0,4		22	7	32	4	28	15	0	20		65	62	1,62	127	8	8	8
Ø. Neådalsvatn	29/10/93	1,1		19	7	33	4	13	15	1	34			62			8	8	
Ø. Neådalsvatn	13/11/93	0,5		31	13	42	5	26	17	1	37				11,22				
Ø. Neådalsvatn	24/11/93	0,6		33	14	44	5	35	19	1	39				2,69				
Ø. Neådalsvatn	**M 93**	**0,71**		**21**	**9**	**35**	**3**	**20**	**14**	**1**	**31**		**63**	**61**	**2,63**	**131**	**9**	**9**	**8**
Øvre Neådalsvatn	06/01/94	0,8		40	12	42	5	41	23	1	31		100	96	2,07	196	10	11	
Øvre Neådalsvatn	29/01/94	0,5		46	16	43	5	49	27	1	31		111	109	1,26	220	10	12	
Øvre Neådalsvatn	12/02/94	0,8		42	16	41	5	48	25	1	31		105	105	-0,28	210	12	11	
Øvre Neådalsvatn	28/02/94	0,7		48	16	44	19	54	40	1	31		127	125	0,56	252	32	14	
Øvre Neådalsvatn	12/03/94	1,1		42	15	43	5	47	23	1	28		106	100	2,94	205	12	11	
Øvre Neådalsvatn	15/04/94	0,7		45	16	40	5	50	23	1	31		106	106	0,33	212	14	11	
Øvre Neådalsvatn	24/04/94	1,0		50	16	42	6	50	25	1	34		115	110	1,98	225	14	12	
Øvre Neådalsvatn	01/05/94	1,3		57	28	86	11	31	29	5	93		184	159	7,37	342	23	20	
Øvre Neådalsvatn	07/05/94	1,7		42	26	80	9	21	25	3	93		160	142	6,09	302	21	18	
Øvre Neådalsvatn	17/05/94	1,0		30	18	58	6	18	12	3	71		113	104	4,51	217	14	12	
Øvre Neådalsvatn	22/05/94	1,6		30	17	59	6	19	17	3	71		114	108	2,45	222	15	13	
Øvre Neådalsvatn	01/06/94	1,3		32	16	54	6	21	19	3	59		109	101	3,54	210	14	12	
Øvre Neådalsvatn	11/06/94	0,7		21	11	39	5	22	15	2	37		76	75	0,55	151	10	9	
Øvre Neådalsvatn	19/06/94	1,3		18	10	34	4	31	12	2	31		68	76	-5,80	144	9	8	
Øvre Neådalsvatn	25/06/94	0,6		14	8	28	3	15	10	1	28		54	55	-0,98	109	7	6	
Øvre Neådalsvatn	30/06/94	0,8		21	10	35	4	21	12	1	31		71	66	4,11	137	9	8	
Øvre Neådalsvatn	09/07/94	0,2		16	7	27	3	20	10	1	25		53	56	-3,37	109	8	6	
Øvre Neådalsvatn	17/07/94	0,6		12	2	27	3	21	10	1	20		45	52	-7,20	96	7	5	
Øvre Neådalsvatn	24/07/94	0,5		8	3	29	3	24	10	0	17		43	51	-8,88	94	7	5	
Øvre Neådalsvatn	01/08/94	0,5		10	4	30	3	21	10	0	17		47	48	-1,43	95	8	5	
Øvre Neådalsvatn	21/08/94	0,4		10	7	30	3	42	12	0	14		51	69	-14,44	120	7	6	
Øvre Neådalsvatn	28/08/94	0,5		22	8	32	3	29	10	0	14		66	54	10,43	120	8	6	
Øvre Neådalsvatn	05/09/94	0,4		21	8	32	3	31	17	0	20		65	68	-2,20	133	8	7	
Øvre Neådalsvatn	12/09/94	0,7		20	7	30	3	35	17	0	23		62	74	-9,14	135	8	7	
Øvre Neådalsvatn	18/09/94	0,4		22	5	30	4	32	17	0	20		62	69	-5,63	131	8	7	
Øvre Neådalsvatn	26/09/94	0,4		22	7	29	4	35	17	0	23		62	74	-9,01	136	8	7	
Øvre Neådalsvatn	02/10/94	0,5		20	7	30	4	31	17	0	23		62	71	-6,75	133	8	7	
Øvre Neådalsvatn	08/10/94	0,6																	
Øvre Neådalsvatn	13/10/94	0,4		26	11	38	4	35	15	0	37				-7,00		9	9	
Øvre Neådalsvatn	31/10/94	0,5		27	12	44	5	32	17	1	42				-4,40		10	10	
Øvre Neådalsvatn	13/11/94	0,5		30	12	40	4	30	17	2	34				3,97		10	9	
Øvre Neådalsvatn	04/12/94	0,7		41	17	60	5	32	23	2	62				4,04		15	14	
Øvre Neådalsvatn	21/12/94	0,7		44	17	54	5	32	21	1	62				3,81		14	13	
Øvre Neådalsvatn	**M94**	**0,73**		**29**	**12**	**42**	**5**	**32**	**18**	**1**	**37**		**87**	**86**	**-0,83**	**173**	**11**	**10**	

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Stavsvatn	29/03/93	1,7	2	51	12	27	3	13	42	5	23	0	96	82	8,08	178	12	12	
Stavsvatn	23/09/93	0,8	1	41	10	25	2	0	33	2	23	0	79	57	15,81	136	11	9	
Stavsvatn	**M 93**	**1,2**	**1**	**46**	**11**	**26**	**2**	**7**	**37**	**3**	**23**	**0**	**88**	**70**	**11,94**	**157**	**12**	**11**	
Stavsvatn	28/09/94	1,0	1	40	9	21	2	16	33	3	17		74	70	3,05	144	0	8	
Stavsvatn	**M 94**	**1,0**	**1**	**40**	**9**	**21**	**2**	**16**	**33**	**3**	**17**		**74**	**70**	**3,05**	**144**	**0**	**8**	
L. Hovvatn	23/02/93	45,7		22	25	135	3		58	12	178		231	248	-3,62	479	48	45	
L. Hovvatn	11/05/93	26,3		21													24	10	
L. Hovvatn	30/06/93	23,4		20	17	87	3		58	11	102		150	171	-6,52	322	29	28	
L. Hovvatn	27/07/93	13,8		26	18	82	3		56	10	93		143	159	-5,42	302	25	24	
L. Hovvatn	21/09/93	14,1		26	18	78	3		60	10	96		140	166	-8,62	306	27	25	
L. Hovvatn	**M 93**	**24,7**		**23**	**20**	**95**	**3**		**58**	**11**	**117**		**166**	**186**	**-6,04**	**352**	**31**	**26**	
Lille Hovvatn	06/01/94	28,8		25	17	70	2	0	71	15	66		143	152	-3,13	295	28	25	2,79
Lille Hovvatn	16/03/94	31,6		23	18	77	2	0	71	19	74		153	164	-3,51	316	33	27	3,01
Lille Hovvatn	31/05/94	12,6		19	13	63	2	0	63	11	66		110	139	-11,67	250	23	18	2,04
Lille Hovvatn	03/08/94	16,2		17	0	0	0	0							99,65	33	22	6	0,67
Lille Hovvatn	07/09/94	15,8		24	14	49	4	0	54	9	51		106	115	-3,93	221	20	17	1,93
Lille Hovvatn	07/09/94	26,9	1	18	13	53	3		63	9	54		114	126	-4,97	240	21	21	2,39
Lille Hovvatn	02/11/94	25,1		20	14	56	4	0	65	11	63		118	138	-7,67	257	21	22	2,45
Lille Hovvatn	**M 94**	**22,45**	**1**	**21**	**13**	**53**	**2**	**0**	**64**	**12**	**62**		**124**	**139**	**9,25**	**230**	**24**	**20**	**2,18**
Arresjøen	13/08/93	2,6	0	35	49	207	6	20	33		231		300	285			38	34	
Arresjøen	17/08/93	0,9		35	49	206	6	27	31		234		297	292	0,74	589	38	34	
Arresjøen	**M 93**	**1,8**	**0**	**35**	**49**	**207**	**6**	**24**	**32**		**233**		**300**	**288**			**38**		
Lochnagar	R 15.10.93	3,0	5	26	30	91	11	14	60	17	85		166	176	-2,83	342	22	23	
Lochnagar	R 22.11.93																0	0	
Lochnagar	09/03/93	9,8		31	26	115	7		57	21	118		188	196	-2,09	385	28	28	
Lochnagar	05/06/93	2,5		33	30	91	5	15	57	18	84		161	174	-3,84	335	23	22	
Lochnagar	07/07/93	5,5		28	25	85	4	9	53	17	80		147	159	-3,86	306	22	21	
Lochnagar	30/08/93	4,2		28	27	87	5	12	59	17	86		151	174	-7,11	325	21	22	
Lochnagar	01/09/93	2,0		40	24	89	10	17	56	16	85		165	174	-2,74	338	22	22	
Lochnagar	04/12/93	11,2		25	38	92	8	0	67	19	96		174	182	-2,26	355	27	27	
Lochnagar	**M 93**	**5,44**	**5**	**30**	**28**	**93**	**7**	**11**	**58**	**18**	**90**		**165**	**176**	**-3,53**	**341**	**21**	**21**	
Lochnagar	28/03/94	8,9	6	37	47	127	8	0	61	28	132		234	221	2,84	455	29	29	3,22
Lochnagar	01/07/94	5,5	0	33	39	97	6	7	54	20	90		180	171	2,70	351	22	22	2,42
Lochnagar	24/08/94	5,0	0	39	38	90	10	8	54	19	83		182	164	5,21	346	20	21	2,37
Lochnagar	04/09/94	4,0	5	48	47	90	7	11	58	19	80		201	168	8,94	369	20	22	2,47
Lochnagar	**M 94**	**5,9**	**3**	**39**	**43**	**101**	**8**	**7**	**57**	**22**	**96**		**199**	**181**	**4,92**	**380**	**23**	**24**	**2,32**
Sandy Loch	R 15.10.93	2,0	4	34	30	84	6	24	58	10	73		160	166	-1,85	326	20	21	
Sandy Loch	R 22.11.93																		
Sandy Loch	06/06/93	1,4		44	20	78	5	15	52	9	63		148	139	3,10	287	19	19	
Sandy Loch	11/06/93	1,3		30	17	74	4	19	53	9	64		126	145	-7,05	271	18	18	
Sandy Loch	30/08/93	0,4		39	20	88	3	37	54	5	69		150	165	-4,76	315	19	20	
Sandy Loch	05/09/93	0,6		52	20	88	3	37	54	5	69		163	165	-0,56	328	20	21	
Sandy Loch	**M 93**	**1,13**	**4**	**40**	**21**	**82**	**4**	**26**	**54**	**8**	**68**		**149**	**156**	**-2,22**	**305**	**19**	**20**	
Sandy Loch	24/08/94	8,9	0	52	34	88	5	9	53	8	65		188	135	16,39	323	18	21	2,30
Sandy Loch	**M 94**	**8,9**	**0**	**52**	**34**	**88**	**5**	**9**	**53**	**8**	**65**		**188**	**135**	**16,39**	**323**	**18**	**21**	**2,30**
L.Nan Eun	R 14.10.93																		
L.Nan Eun	R 22.11.93																		
L.Nan Eun	19/02/93	4,5		42	94	463	12	11	64	0	581		615	656	-3,24	1271	81	83	

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
L.Nan Eun	26/05/93	0,8		42	80	391	11	27	50	0	443		525	520	0,43	1045	64	66	
L.Nan Eun	11/06/93	9,1		26	19	75	4	2	53	20	75		133	150	-6,07	283	21	21	
L.Nan Eun	11/07/93	2,4		21	34	191	3	18	20	0	192		251	230	4,25	481	29	31	
L.Nan Eun	13/07/93	7,8		29	19	72	3	4	50	19	73		130	146	-5,62	276	20	20	
L.Nan Eun	30/08/93	7,1		28	19	74	3	6	51	17	71		131	145	-5,17	276	20	20	
L.Nan Eun	**M 93**	**5,3**		**31**	**44**	**211**	**6**	**11**	**48**	**9**	**239**		**297**	**308**	**-2,57**	**605**	**39**	**40**	
Loch Nan Eun	24/08/94	8,7	0	34	25	76	4	-7	49	19	73		148	134	4,87	282	19	19	2,10
L.Nan Eun	**M 94**	**8,7**	**0**	**34**	**25**	**76**	**4**	**-7**	**49**	**19**	**73**		**148**	**134**	**4,87**	**282**	**19**	**19**	**2,10**
L. Maam	10/09/93	3,5	1	22	33	180	4		37	4	183		244	225	4,09	469	28	31	
L. Maam	23/03/93	10,7		60	116	564	13	0	97	4	660		764	761	0,18	1525	100	101	
L. Maam	26/04/93	57,5		43	53	300	9	9	51	2	353		463	415	5,40	878	54	73	
L. Maam	23/05/93	5,5		36	56	322	12	9	60	3	376		432	448	-1,86	880	54	58	
L. Maam	10/09/93	4,4		23	25	177	4	10	36	4	177		233	227	1,38	460	30	30	
L. Maam	**M 93**	**19,5**		**40**	**63**	**341**	**9**	**7**	**61**	**3**	**392**		**473**	**463**	**1,28**	**936**	**60**	**66**	
L.Paione Sup.	21/09/93	3,0	2	45	6	6	7	31	46	24	6		69	107			11	12	
L.Paione S.	12/01/93	1,7	1	51	8	10	7	1	48	21	3		79	73	3,85	151	11	11	
L.Paione S.	09/03/93	1,5	0	55	10	11	7	1	48	20	4		84	72	7,94	156	11	11	
L.Paione S.	25/05/93	4,4	11	67	12	12	10	-2	62	43	4		117	108	3,91	224	17	17	
L.Paione S.	29/06/93	2,8	6	49	9	11	7	-3	38	25	5		84	65	13,21	149	11	11	
L.Paione S.	07/07/93	3,0	5	44	7	9	6	1	39	25	4		74	69	3,70	143	10	11	
L.Paione S.	27/07/93	2,2	3	47	8	9	6	-6	41	26	3		75	63	8,43	139	11	10	
L.Paione S.	21/09/93	2,6	2	49	9	10	7	-2	47	24	3		79	73	4,10	151	11	11	
L.Paione S.	09/11/93	2,2	2	43	8	10	6	0	45	20	4		71	69	1,76	140	11	10	
L.Paione S.	**M 93**	**2,60**	**4**	**50**	**8**	**10**	**7**	**2**	**46**	**25**	**4**		**81**	**78**	**6**	**157**	**12**	**11**	
L.Paione S.	05/07/94	2,0	3	38	7	8	4	2	31	21	3		62	58	4,02	120	9	9	
L.Paione S.	26/07/94	1,4	3	36	6	7	5	0	31	17	3		57	51	6,05	108	8	8	
L.Paione S.	13/09/94	1,7	3	45	8	8	7	0	40	23	4		73	67	3,96	140	10	10	
L.Paione S.	27/10/94	0,9	1	52	9	10	8	3	41	24	5		81	73	5,60	154	11	11	
L.Paione S.	**M 94**	**1,5**	**2**	**43**	**7**	**8**	**6**	**1**	**36**	**21**	**4**		**69**	**62**	**4,91**	**131**	**10**	**9**	
L.Paione Inf.	21/09/93	0,4	1	75	9	11	8	8	56	26	6		105	96	4,34	201	13	13	
L.Paione Inf.	12/01/93	0,3	0	83	12	15	10	34	57	23	3		120	118	1,16	238	15	15	
L.Paione Inf.	09/03/93	0,3	0	96	14	15	9	40	57	23	4		134	124	3,96	259	16	16	
L.Paione Inf.	25/05/93	0,6	1	83	12	14	8	26	50	32	4		119	112	3,12	231	15	15	
L.Paione Inf.	29/06/93	0,4	1	76	12	13	8	15	49	31	4		110	99	5,47	208	13	14	
L.Paione Inf.	07/07/93	0,4	0	80	13	13	8	20	50	32	3		115	106	4,35	221	13	14	
L.Paione Inf.	27/07/93	0,2	0	84	13	14	9	22	55	30	3		121	109	4,97	230	14	15	
L.Paione Inf.	21/09/93	0,4	0	75	12	13	8	22	55	25	4		109	106	1,39	214	14	14	
L.Paione Inf.	09/11/93	0,4	0	70	12	11	7	24	52	21	4		102	101	0,46	202	13	13	
L.Paione Inf.	**M 93**	**0,4**	**0**	**81**	**13**	**14**	**8**	**25**	**53**	**27**	**4**		**116**	**109**	**3,11**	**226**	**14**	**15**	
L.Paione Inf.	25/01/94	0,3	0	88	13	15	8	41	57	24	4		124	126	-0,51	250	16	16	
L.Paione Inf.	31/05/94	0,4	1	72	12	16	7	17	47	32	5		109	102	3,52	211	14	14	
L.Paione Inf.	23/06/94	0,3	0	66	11	11	6	17	44	26	3		94	90	2,46	184	12	12	
L.Paione Inf.	05/07/94	0,3	0	67	11	13	4	19	45	27	5		96	96	0,05	191	13	12	
L.Paione Inf.	26/07/94	0,3	1	71	11	13	9	23	48	24	3		105	98	3,20	203	13	13	
L.Paione Inf.	13/09/94	0,3	1	79	12	13	9	28	51	23	3		113	106	3,21	219	14	14	
L.Paione Inf.	27/10/94	0,2	0	83	12	14	10	34	52	23	5		120	113	2,94	233	14	15	
L.Paione Inf.	**M 94**	**0,3**	**0**	**75**	**12**	**14**	**8**	**26**	**49**	**26**	**4**		**109**	**104**	**2,12**	**213**	**14**	**14**	

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Lago Lungo	20/09/93	0,3	1	78	12	12	6	60	54	11			108	125			13	13	
Lago Lungo	01/02/93	0,5	1	85	16	18	8	31	75	13	4		129	123	2,32	253	14	16	
Lago Lungo	31/03/93	1,0	2	111	21	22	10	33	96	18	5		166	152	4,27	318	18	21	
Lago Lungo	12/07/93	0,3	0	71	13	14	6	30	56	14	3		106	103	1,16	209	12	13	
Lago Lungo	02/08/93	0,3	0	71	12	13	6	28	60	13	3		103	104	-0,58	207	12	13	
Lago Lungo	20/09/93	0,1	0	71	13	15	6	27	62	10	4		106	104	1,21	210	12	13	
Lago Lungo	06/12/93	0,4	0	78	21	20	8	30	71	15	5		128	121	2,77	249	14	16	
Lago Lungo	**M 93**	**0,4**	**1**	**81**	**16**	**17**	**7**	**30**	**70**	**14**	**4**		**123**	**118**	**1,86**	**241**	**13**	**16**	
Lago Lungo	05/09/94	0,2	0	65	12	12	5	28	59	10	2	0	94	98	-2,06	193	12	11	1,23
Lago Lungo	18/07/94	0,6	1	65	11	10	4	24	53	16	4	0	92	96	-2,39	188	11	11	1,23
Lago Lungo	10/05/94	2,6	7	73	14	14	5	16	69	29	5	0	115	118	-1,27	234	15	15	1,62
Lago Lungo	24/01/94	0,7	1	74	13	13	5	40	59	10	3	0	107	113	-2,46	220	13	13	1,40
Lago Lungo	**M94**	**1,0**	**2**	**69**	**13**	**12**	**5**	**27**	**60**	**16**	**3**	**0**	**102**	**106**	**-2,04**	**209**	**13**	**12**	**1,37**
Lago di Latte	21/09/93	0,2	1	108	12	15	8	86	56	23			144	165			17	17	
Lago di Latte	20/01/93	0,4	1	99	12	18	11	43	58	23	3		141	127	5,08	268	15	17	
Lago di Latte	05/05/93	0,4	2	105	14	19	10	45	65	26	5		151	141	3,40	292	16	18	
Lago di Latte	13/07/93	0,2	0	95	12	18	9	64	56	22	3		135	145	-3,39	280	15	17	
Lago di Latte	03/08/93	0,2	0	91	12	16	8	53	56	21	3		128	134	-2,04	262	14	16	
Lago di Latte	21/09/93	0,2	1	101	12	18	10	61	60	22	4		143	147	-1,50	289	16	18	
Lago di Latte	13/12/93	0,2	0	92	17	22	10	54	60	23	8		141	145	-1,31	286	15	18	
Lago di Latte	**M 93**	**0,3**	**1**	**97**	**13**	**18**	**10**	**53**	**59**	**23**	**4**		**140**	**140**	**0,04**	**280**	**15**	**17**	
Lago di Latte	06/09/94	0,2	0	96	12	15	8	58	62	17	1		131	139	-2,79	270	16	15	1,66
Lago di Latte	21/07/94	0,5	1	76	8	11	7	38	47	21	4		105	110	-2,43	214	12	12	1,36
Lago di Latte	09/05/94	0,8	7	92	11	13	7	41	61	28	5		130	135	-1,84	265	16	15	1,71
Lago di Latte	24/01/94	0,5	1	102	12	14	7	66	55	21	3		137	145	-2,76	282	16	16	1,73
Lago di Latte	**M94**	**0,5**	**2**	**92**	**11**	**13**	**7**	**51**	**56**	**22**	**3**		**126**	**132**	**-2,45**	**258**	**15**	**15**	**1,61**
Blanc	06/11/93	0,1	1	122	33	35	12		37	19	6	0	203	62	53,21	265	21	15	
Blanc	24/07/93	0,2		55	13	4			8	10		7	73	18	60,20	91	9	5	
Blanc	24/07/93	0,2		70	15	9			10	8		7	94	18	67,01	112	11	6	
Blanc	24/07/93	0,2		55	14	4			10	8		7	73	18	59,78	92	10	5	
Blanc	24/07/93	0,2		65	14	4			8	8		7	83	16	67,13	100	10	6	
Blanc	04/11/93	0,1		150	3	35			40	18			188	57	53,23	245	20	14	
Blanc	**M 93**	**0,2**		**79**	**12**	**11**			**15**	**10**		**7**	**102**	**26**			**12**		
Blanc	12/10/94	0,1	2	75	19	13	10	72	27	14	3		119	116	1,23	235	14	14	
Blanc	**M 94**	**0,1**	**2**	**75**	**19**	**13**	**10**	**72**	**27**	**14**	**3**		**119**	**116**	**1,23**	**235**	**14**	**14**	
Noir	24/07/93	0,1	0	175	27	9			19	8		3	211	27	77,41	237	24	13	
Noir	24/07/93	0,2	0	95	26	9			19	8		3	130	27	65,81	157	16	9	
Noir	24/07/93	0,1	0	100	27	9			17	8		3	136	25	69,18	160	17	9	
Noir	24/07/93	0,1	0	105	27	9			21	8			141	29	65,94	170	17	9	
Noir	04/11/93	0,1	0	175	37	35	8		44	14			254	58	62,73	312	25	17	
Noir	**M 93**	**0,1**	**0**	**130**	**29**	**14**	**8**		**24**	**9**		**3**	**174**	**33**			**20**		
Noir	12/10/94	0,1	0	125	33	13	5	92	67	11	6		176	175	0,16	351	20	21	
Noir	**M 94**	**0,1**	**0**	**125**	**33**	**13**	**5**	**92**	**67**	**11**	**6**		**176**	**175**	**0,16**	**351**	**20**	**21**	
Etang d'Aube	15/07/93	1,0		32	8	15	3	12	26	10	7		59	55	3,82	115	8	7	
Etang d'Aube		0,5	10	35	6	37	21	37	25	10	34		110	106	1,85	215	14	14	
Etang d'Aube	13/10/93	0,8	9	32	6	18	5	20	26	9	10		70	65	4,07	135	8	9	
Etang d'Aube	**M 93**	**0,6**	**9**	**34**	**6**	**23**	**13**	**29**	**26**	**9**	**17**		**90**	**85**	**2,96**	**175**	**11**	**11**	
Etang d'Aube	31/08/94	0,7	3	27	6	18	3	48	23	9	8		58	88	-20,59	147	7	8	0,88

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Etang d'Aube	09/09/94	1,0	1	28	6	14	2		12	22	9	7		52	51,00	1	7	6	0,65
Etang d'Aube	**M94**	**0,8**	**2**	**28**	**6**	**16**	**2**	**48**	**17**	**16**	**9**	**7**	**58**	**70**	**15,21**	**74**	**7**	**7**	**0,76**
Schwarzsee ob Sölden	18/08/93	6,9	1	57	17	10	3		77	14	8		94	100	-3,10	194	16	15	
Schwarzsee ob Sölden	02/07/93	3,2	1	42	13	10	2	0	51	8	2		71	60	8,24	132	9	10	
Schwarzsee ob Sölden	18/08/93	1,4	0	53	20	13	3	0	81	7	2		90	90	0,05	180	13	13	
Schwarzsee ob Sölden	20/09/93	4,7	1	57	21	14	3	0	77	23	3		100	103	-1,33	203	17	15	
Schwarzsee ob Sölden	**M 93**	**3,1**	**1**	**51**	**18**	**12**	**3**	**0**	**70**	**13**	**2**		**87**	**84**	**2,32**	**172**	**13**	**13**	
Schwarzsee ob Sölden	14/01/94	1,6	2	75	26	19	4	9	94	12	3		127	118	3,7	248	17	15	1,62
Schwarzsee ob Sölden	23/02/94	1,7	2	75	26	17	4	6	102	10	3		125	122	1,5	250	16	15	1,65
Schwarzsee ob Sölden	28/03/94	2,1	2	73	25	17	4	6	83	10	4		124	103	9,1	231	16	13	1,50
Schwarzsee ob Sölden	20/04/94	2,9	2	71	25	17	4	17	104	10	3		122	135	-5,0	260	17	15	1,69
Schwarzsee ob Sölden	11/05/94	2,2	2	72	26	16	4	3	92	13	3		123	110	5,2	236	18	14	1,55
Schwarzsee ob Sölden	31/05/94	4,5	3	69	21	14	4	8	77	15	5		116	105	5,1	226	16	13	1,44
Schwarzsee ob Sölden	12/07/94	4,2	1	47	16	15	3	2	58	10	3		87	73	8,8	165	11	9	1,04
Schwarzsee ob Sölden	01/09/94	2,2	0	60	25	16	4	7	81	8	3		106	98	3,9	208	16	12	1,35
Schwarzsee ob Sölden	09/09/94																		
Schwarzsee ob Sölden	**M94**	**2,5**	**2**	**68**	**24**	**16**	**4**	**7**	**86**	**11**	**3**		**52**	**108**	**4,04**	**228**	**16**	**13**	**1,48**
Aguilo	19/10/93	2,5	1	24	7	8	2	7	19	3	8		44	38	8,21	82	6	5	
L. Aguilo	19/10/93	1,6	0	22	13	9	2	18	15	3	5		48	41	7,86	89	6	6	
L. Aguilo	**M 93**	**1,6**	**0**	**22**	**13**	**9**	**2**	**18**	**15**	**3**	**5**		**48**	**41**	**7,86**	**89**	**6**	**6**	
Lago Aguilo	10/10/94	0,8	0	18	10	9	2	11	13	2	7		40	33	9,11	73	5	4	0,47
L. Aguilo	**M 94**	**0,8**	**0**	**18**	**10**	**9**	**2**	**11**	**13**	**2**	**7**		**40**	**33**	**9,11**	**73**	**5**	**4**	**0,47**
L. Redo	16/10/93	0,5	1	75	14	9	2	42	31	14	5		101	92	4,82	193	12	12	
L. Redo	**M 93**	**0,5**	**1**	**75**	**14**	**9**	**2**	**42**	**31**	**14**	**5**		**101**	**92**	**4,82**	**193**	**12**	**12**	
Lago Redo	11/10/94	0,2	1	71	13	10	2	44	23	11	8		96	86	5,15	182	12	10	1,09
L. Redo	**M 94**	**0,2**	**1**	**71**	**13**	**10**	**2**	**44**	**23**	**11**	**8**		**96**	**86**	**5,15**	**182**	**12**	**10**	**1,09**
La Caldera	14/07/93	0,0	1	179	27	13	3	180	17	9	10		223	216	1,61	439	22	24	
La Caldera	07/09/93	0,0	4	215	35	21	3	209	20	2	20		278	251	5,06	530	30	29	
La Caldera	**M 93**	**0,0**	**2**	**197**	**31**	**17**	**3**	**195**	**19**	**5**	**15**		**251**	**234**	**3,33**	**484**	**26**	**26**	
La Caldera	20/07/94	0,0	0	228	38	40	6	270	18	0	2030		311	2318	-76,31	2630	22	166	
La Caldera	02/08/94	0,01	2	218	46	124	21	268	24	0	0		411	292	17,00	703	30	34	
La Caldera	01/09/94	0,01	5	321	48	50	6	284	30	0	0		430	314	15,52	744	36	36	
La Caldera	13/09/94	0,0	6	280	47	13	4	330	25	1	14		350	370	-2,71	720	32	23	2,52
La Caldera	13/09/94	0,0	7	278	44	12	4	346	37	1	62		346	446	-12,62	792	33	27	2,97
La Caldera	**M94**	**0,02**	**4**	**265**	**45**	**48**	**8**	**300**	**27**	**0**	**421**		**370**	**748**	**-12**	**1118**	**31**	**57**	**2,74**
Escura	06/10/93	4,6	1	18	13	43	3	-10	23	0	48		82	61	14,6		12	11	
L. Escura	06/10/93	4,9	0	12	23	28	2	6	22	0	31		70	59	8,93	129	13	10	
L. Escura	**M 93**	**4,9**	**0**	**12**	**23**	**28**	**2**	**6**	**22**	**0**	**31**		**70**	**59**	**8,93**	**129**	**13**	**10**	
Lago Escura	17/09/94	3,9	1	12	18	32	5	0	14	0	37		72	51	17,57	123	11	8125	0,90
L. Escura	**M 94**	**3,9**	**1**	**12**	**18**	**32**	**5**	**0**	**14**	**0**	**37**		**72**	**51**	**17,57**	**123**	**11**	**8125**	**0,90**
Starolesnianske pleso	28/09/93	12,9	1	41	7	1	2		65	12	6		64	83	-12,87	147	15	14	
Starolesnianske pleso	VS-15	20,0	1	36	8	8	2		84	12	5		76	101	-14,03	177	15	18	
Starolesnianske pleso	**M 93**	**16,42**	**1**	**39**	**7**	**5**	**2**		**74**	**12**	**5**		**70**	**92**	**-13,45**	**161,80**	**15,20**	**16,10**	
Starolesnianske Pleso	27/10/94	20,4	3	29	6	3	3	0	52	11	3		64	55	8,17	130	14	13	
Starolesnianske pleso	**M 94**	**20,4**	**3**	**29**	**6**	**3**	**3**	**0**	**52**	**11**	**3**		**64**	**55**	**8,17**	**130**	**14**	**13**	
Terianske pleso	29/09/93	0,1		160	7	6	3	61	65	42	6		175	173	0,55	348	22	20	
Terianske pleso	NE-3	0,2	1	159	12	20	3		71	36	5		194	113	26,49	307	20	18	
Terianske pleso	**M 93**	**0,14**	**1**	**159**	**9**	**13**	**3**	**61**	**68**	**39**	**5**		**184**	**143**	**13,52**	**327,18**	**21,25**	**18,82**	

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Dlugi Staw	01/11/94	1,9	1	112	11	17	4	13	73	52	6		146	143	1,04		18	18	
Dlugi Staw	15/11/94	0,9	0	115	11	14	3	15	73	56	6		144	150	-2,04		18	18	
Dlugi Staw	30/11/94	0,8	0	122	12	16	3	18	75	55	7		152	156	-1,30		18	18	
Dlugi Staw	23/12/94	0,6	0	126	11	20	3	18	81	55	8				-3,11		20	19	
Dlugi Staw	**M94**	**1,53**	**1**	**115**	**10**	**17**	**4**	**17**	**74**	**51**	**7**		**148**	**148**	**-0,67**	**299**	**6**	**18**	**2,01**
Zieloni Staw	23/09/93	0,1		155	16	12	5	79	73	28	8		187	188	-0,18	376	23	21	
Zieloni Staw	GA-7	0,2	1	154	20	27	6		78	25	7		208	110	30,85	318	22	19	
Zieloni Staw	03/01/93	0,4		152	17	20	4	64	77	37	8		194	187	1,81	381	23	21	
Zieloni Staw	19/01/93	0,5	0	142	12	20	4	19	81	65	8		178	173	1,57	351	21	21	
Zieloni Staw	31/01/93	0,3	1	132	16	20	5	59	75	42	8		175	184	-2,52	360	23	20	
Zieloni Staw	16/02/93	0,3	3	149	17	19	5	65	73	40	8		193	186	1,79	379	21	21	
Zieloni Staw	01/03/93	0,2	1	151	17	20	5	84	79	36	8		196	208	-2,99	403	24	22	
Zieloni Staw	06/04/93	0,3		161	18	22	6	86	79	41	8		207	214	-1,65	422	25	23	
Zieloni Staw	15/04/93	0,3	1	163	18	20	5	79	69	39	8		207	195	3,16	402	24	22	
Zieloni Staw	20/04/93	0,4	10	165	18	24	5	74	81	45	11		223	212	2,58	435	27	24	
Zieloni Staw	03/05/93	1,1	10	142	16	17	5	23	92	55	11		191	181	2,67	371	25	22	
Zieloni Staw	17/03/93	0,6		126	13	15	4	51	62	34	8		159	157	0,63	315	20	18	
Zieloni Staw	01/06/93	0,2	0	162	17	16	4	89	73	35	8		200	205	-1,21	405	23	22	
Zieloni Staw	14/06/93	0,2	1	145	16	19	4	82	73	33	8		185	196	-2,94	380	22	21	
Zieloni Staw	01/07/93	0,2	1	147	16	18	4	84	71	30	8		185	193	-2,07	378	22	21	
Zieloni Staw	12/07/93	0,2	2	150	16	17	4	84	67	30	8		189	188	0,05	377	23	21	
Zieloni Staw	22/08/93	0,2	2	148	16	19	5	71	69	29	6		188	175	3,71	363	22	20	
Zieloni Staw	02/09/93	0,2	2	150	17	17	5	79	73	28	6		191	185	1,56	376	22	21	
Zieloni Staw	13/09/93	0,2	1	148	16	19	5	79	71	29	8		188	187	0,34	375	22	21	
Zieloni Staw	23/09/93	0,1	0	155	16	12	5	83	73	28	8		188	192	-1,05	380	23	21	
Zieloni Staw	27/09/93	0,2	2	154	16	20	5	73	75	29	8		197	185	3,08	382	22	21	
Zieloni Staw	10/01/93	0,2	1	154	20	27	6		78	25	7		208	110	30,85	318	22	19	
Zieloni Staw	15/11/93	0,2		165	19	19	4	94	77	29	6		207	206	0,41	413	23	23	
Zieloni Staw	30/11/93	0,2	0	185	21	20	5	105	96	33	11		233	245	-2,64	478	27	26	
Zieloni Staw	14/12/93	0,2	1	196	22	24	5	109	90	35	8		249	242	1,50	491	26	27	
Zieloni Staw	**M 93**	**0,27**	**2**	**154**	**17**	**19**	**5**	**74**	**76**	**35**	**8**		**197**	**188**	**2,77**	**385**	**23**	**22**	
Zieloni Staw	01/01/94	0,2	1	177	20	22	5	96	79	61	6		225	214	2,44	439	3	24	2,66
Zieloni Staw	17/01/94	0,4	0	145	13	20	3	21	85	36	6		182	171	3,02	353	2	21	2,32
Zieloni Staw	01/02/94	0,2	4	169	20	26	6	94	75	61	8		225	214	2,49	439	3	24	2,67
Zieloni Staw	15/02/94	0,2	2	165	19	22	6	93	75	61	8		215	211	0,87	426	3	23	2,59
Zieloni Staw	28/02/94	0,3	4	163	17	19	5	94	75	60	8		208	212	-0,87	421	2	23	2,56
Zieloni Staw	14/03/94	0,3	1	164	18	20	4	92	73	62	8		208	208	-0,09	416	2	23	2,53
Zieloni Staw	29/03/94	0,4	1	163	19	22	4	87	73	66	8		209	207	0,43	417	2	23	2,54
Zieloni Staw	19/04/94	0,4	3	166	19	20	5	80	73	65	8		213	202	2,76	415	3	23	2,55
Zieloni Staw	04/05/94	0,7	7	137	15	17	4	55	73	69	8		180	177	1,07	357	2	20	2,26
Zieloni Staw	17/05/94	0,7	4	133	15	17	4	46	65	48	8		174	159	4,43	332	2	19	2,11
Zieloni Staw	22/05/94	0,4	1	128	14	17	4	66	65	44	6		165	169	-1,19	334	2	19	2,06
Zieloni Staw	31/05/94	0,3	0	130	14	17	4	73	62	42	6		165	183	-5,20		2	19	2,06
Zieloni Staw	20/06/94	0,1	0	152	12	17	4	88	67	39	6		186	199	-3,45		2	20	2,25
Zieloni Staw	04/07/94	0,2	1	129	9	17	4	72	71	35	6		160	184	-6,98		2	18	2,05
Zieloni Staw	18/07/94	0,2	1	125	12	17	4	67	69	34	6		159	175	-4,89		2	18	2,00
Zieloni Staw	25/07/94	0,3	2	127	14	19	4	65	77	38	8		166	188	-6,26		2	19	2,12
Zieloni Staw	16/08/94	0,2	2	132	15	18	4	73	79	40	6		172	198	-7,05		2	20	2,18

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Terianske Pleso	27/10/94	0,4	0	143	7	16	4	68	55	31	5		170	159	-6,79	329	19	18	
Terianske pleso	**M 94**	**0,4**	**0**	**143**	**7**	**16**	**4**	**68**	**55**	**31**	**5**		**170**	**159**	**-6,79**	**329**	**19**	**18**	
Dlugi Staw	23/09/93	1,1	0	110	8	7	3	-2	75	54	6		129	132	-1,20	262	19	18	
Dlugi Staw	GA-4		1	107	11	17	5		82		5		140	87	23,42	228	18	14	
Dlugi Staw	03/01/93	0,6		144	12	19	3	21	87	63	11		179	183	-1,00	362	23	21	
Dlugi Staw	19/01/93	0,4	0	147	16	20	5	61	81	41	8		189	192	-0,82	381	22	22	
Dlugi Staw	31/01/93	0,4	0	128	13	20	4	22	79	63	8		166	173	-1,90	339	22	20	
Dlugi Staw	01/03/93	0,3	0	137	12	20	4	27	85	63	11		174	187	-3,70	361	23	21	
Dlugi Staw	06/04/93	0,6		145	13	20	3	25	87	65	8		182	186	-0,88	368	23	22	
Dlugi Staw	15/04/93	0,6	0	148	13	20	4	23	75	64	8		186	170	4,45	356	23	21	
Dlugi Staw	20/04/93	0,4	1	155	12	21	4	21	92	67	14		193	194	-0,04	387	25	23	
Dlugi Staw	03/05/93	0,9	1	141	12	14	4	6	83	70	8		172	168	1,13	340	24	21	
Dlugi Staw	17/05/93	7,2		91	8	13	4	0	69	62	11		124	142	-6,84	266	21	18	
Dlugi Staw	01/06/93	6,0	2	76	7	7	3	3	60	48	8		101	120	-8,58	221	16	15	
Dlugi Staw	14/06/93	4,7	1	78	7	10	3	4	65	44	8		104	121	-7,74	225	16	15	
Dlugi Staw	01/07/93	3,7	1	82	7	11	3	0	60	45	8		107	113	-2,99	220	17	14	
Dlugi Staw	12/07/93	1,2	0	105	8	13	3	6	65	50	6		130	127	1,36	257	19	16	
Dlugi Staw	22/08/93	1,3	2	112	10	17	6	5	67	52	8		148	132	5,47	280	20	17	
Dlugi Staw	02/09/93	1,9	0	98	10	13	4	0	75	45	6		128	125	0,90	253	17	16	
Dlugi Staw	13/09/93	1,5	1	104	8	14	4		73	54	6		133	132	0,34	265	18	16	
Dlugi Staw	23/09/93	1,1	0	110	8	7	3	0	75	54	6		129	135	-1,95	264	19	16	
Dlugi Staw	27/09/93	1,2	0	112	9	16	4	18	77	54	8		143	157	-4,70	300	19	18	
Dlugi Staw	01/10/93												0	0		0	0	0	
Dlugi Staw	15/11/93	0,9	0	136	12	17	3	21	85	56	6		170	168	0,45	338	22	20	
Dlugi Staw	30/11/93	0,9	0	139	13	17	4	24	87	59	11		174	182	-2,14	356	23	21	
Dlugi Staw	14/12/93	0,4	0	150	12	20	4	20	87	62	8		186	177	2,49	364	23	22	
Dlugi Staw	**M 93**	**1,69**	**1**	**120**	**11**	**15**	**4**	**14**	**77**	**56**	**8**		**145**	**146**		**291**	**20**	**18**	
Dlugi Staw	01/01/94	0,6	0	146	12	21	3	20	87	61	6		183	173	2,73	357	2	21	2,35
Dlugi Staw	17/01/94	0,2	1	172	20	21	5	91	79	36	6		218	211	1,62	430	2	24	2,62
Dlugi Staw	04/02/94	0,2	0	143	13	22	4	24	85	61	6		182	176	1,75	358	2	21	2,34
Dlugi Staw	15/02/94	0,4	0	146	13	20	4	25	87	61	6		183	180	0,90	362	2	21	2,37
Dlugi Staw	28/02/94	0,7	0	144	12	19	3	26	96	60	8		179	191	-3,07	370	2	22	2,44
Dlugi Staw	14/03/94	0,7	0	142	12	20	4	23	85	62	6		178	176	0,75	354	2	21	2,33
Dlugi Staw	29/03/94	0,7	0	143	13	21	3	24	85	66	6		182	181	0,29	363	2	21	2,38
Dlugi Staw	19/04/94	0,7	0	158	14	21	4	31	83	65	8		198	188	2,59	386	2	23	2,51
Dlugi Staw	04/05/94	1,1	0	146	13	18	3	15	79	69	8		182	171	3,10	354	2	21	2,35
Dlugi Staw	17/05/94	2,1	3	102	10	15	3	4	62	48	8		134	123	4,42	257	2	16	1,77
Dlugi Staw	22/05/94	4,4	3	73	8	11	4	0	60	45	8		104	113	-4,34	218	2	14	1,61
Dlugi Staw	31/05/94	4,8	2	73	8	11	3	2	60	42	6		102	110	-3,68	212	2	14	1,57
Dlugi Staw	20/06/94	5,4	1	77	5	11	3	2	60	39	6		102	107	-2,02	209	2	14	1,57
Dlugi Staw	04/07/94	2,3	1	75	4	13	3	6	58	35	6		98	105	-3,59	203	2	13	1,43
Dlugi Staw	18/07/94	2,9	1	71	3	11	3	3	56	34	6		91	98	-3,77	190	1	12	1,36
Dlugi Staw	25/07/94	1,2	0	98	9	15	3	11	81	38	6		127	136	-3,32	263	2	16	1,79
Dlugi Staw	16/08/94	1,1	1	96	9	18	6	12	69	40	8		131	129	0,79	260	2	16	1,75
Dlugi Staw	29/08/94	1,4	1	91	7	11	4	12	67	42	6		117	127	-4,17	243	2	15	1,66
Dlugi Staw	19/09/94	1,2	2	96	9	17	4	10	67	51	9		127	136	-3,42		16	16	
Dlugi Staw	02/10/94	1,0	2	104	10	20	6	12	71	50	6		141	139	0,71		18	17	
Dlugi Staw	18/10/94	1,1	1	108	10	14	3	11	71	51	3		137	136	0,37		18	17	

	Date	H+	NH4	Ca	Mg	Na	K	Alk	SO4	NO3	Cl	F	S Cat.	S An.	% Diff.	S Ions	Measured	Measured	Calculated
		µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l	µeq/l		µeq/l		µS/cm 25°C	25°C
Zieloni Staw	29/08/94	0,2	3	130	14	14	5	80	69	43	6		166	197	-8,61		2	19	2,09
Zieloni Staw	19/09/94	0,2	3	143	9	17	4		67	51	9		176	127	16,23		20	18	
Zieloni Staw	02/10/94	0,1	3	144	10	20	6		71	50	6		183	127	18,09		20	19	
Zieloni Staw	18/10/94	0,2	2	150	10	14	3		71	51	3		179	125	17,82		21	18	
Zieloni Staw	01/11/94	0,3	1	147	11	17	4		73	52	6		180	131	15,84		20	19	
Zieloni Staw	15/11/94	0,3	1	144	11	14	3		73	56	6		173	135	12,42		21	19	
Zieloni Staw	**M94**	**0,29**	**2**	**146**	**14**	**19**	**4**	**75**	**72**	**51**	**7**		**186**	**179**	**2**	**395**	**6**	**20**	**2,31**
Laguna Cimera	mar-93												0	0		0	9	0	
Laguna Cimera	jun-93	1,5						25					1	25	-88,61	26	7	1	
Laguna Cimera	jul-93	0,7						25					1	25	-94,56	26	8	1	
Laguna Cimera	aug-93	1,1						26					1	26	-91,63	27	6	1	
Laguna Cimera	sep-93	0,9						29					1	29	-94,07	29	7	1	
Laguna Cimera	nov-93	3,6						13					4	13	-56,34	17	8	2	
Laguna Cimera	18/09/93	0,5		30	14	12	2	37	19	0	8		58	64	-5,17	122	7	6	
Laguna Cimera	18/09/93	0,9		31		30			16		10		62	26	41,45	88	7	5	
Laguna Cimera	**M 93**	**1,3**		**30**	**14**	**21**	**2**	**26**	**17**	**0**	**9**		**16**	**26**			**8**	**2**	
Laguna Cimera	22/01/94	1,7	0	7	12			9	8	23							3		
Laguna Cimera	16/10/94	2,6	0	20	6	30		25	14	17	9			65			6		
Laguna Cimera	**M 94**	**2,11**	**0**	**14**	**9**	**30**		**17**	**11**	**20**	**9**			**65**			**4**		
Chuna	R25.10.93	0,3	0	60	21	23	4	62	42	12	34		108	149	-16	257	17	16	
Chuna		0,3	1	80	21	46	2	60	42	12	31		152	144	2,42	296	17	18	
Chuna	**M 93**	**0,3**	**1**	**70**	**21**	**35**	**3**	**61**	**42**	**12**	**33**		**130**	**147**	**-7**	**277**	**17**	**17**	
Chuna	27/03/94	0,2	3	100	28	48	7	80	67	11	34		186	192	-1,61	377	25	21	2,29
Chuna	21/04/94	0,6	3	70	18	52	8	33	56	3	42		152	135	5,81	287	20	16	1,82
Chuna	17/08/94	0,4	0	45	11	22	1	23	37	2	17		79	80	-0,23	159	10	9	1,01
Chuna	17/08/94	0,4	1	47	13	21	1	24	35	3	17		84	79	2,52	163	10	9	1,03
Chuna	07/09/94	0,4	0	42	12	24	1	26	40	1	17		80	84	-2,21	164	10	9	1,03
Chuna	**M94**	**0,4**	**2**	**61**	**16**	**33**	**4**	**37**	**47**	**4**	**26**		**116**	**114**	**0,86**	**230**	**15**	**13**	**1,43**
Chibini	R25.10.93	0,1	0	19	5	261	38	251	66	6	26		323	349	-3,81	671	35	36	
Chibini		0,2		89	17	28	2	56	50	12	14		136	132	1,43	268	15		
Chibini	**M 93**	**0,1**	**0**	**54**	**11**	**144**	**20**	**154**	**58**	**9**	**20**		**229**	**240**	**-1,19**	**469**	**25**	**36**	
Chibini	10/07/94	0,0	0	35	6	252	40	234	58	19	23		333	335	-0,32	668	36	33	3,62
Chibini	10/07/94	0,0	0	32	6	245	38	190	52	14	23		322	278	7,22	600	32	29	3,27
Chibini	**M94**	**0,0**	**0**	**34**	**6**	**248**	**39**	**212**	**55**	**17**	**23**		**327**	**307**	**3,45**	**634**	**34**	**31**	**3,45**
Krisko jezero	31/08/93	0,0	1	783	0	43	12	737	146	8	0		841	891	-2,71	1732	105	95	
Krisko jezero	**M 93**	**0,0**	**1**	**783**	**0**	**43**	**12**	**737**	**146**	**8**	**0**		**841**	**891**	**-2,71**	**1732**	**105**	**95**	
Zgornje krisko jezero	27/07/94	0,0	2	744	66	5	1	467		14	6		817	694	8,12	1512	76	78	8,70
Zgornje krisko jezero	31/08/94	0,0	0	674	0	52	4	647	100	7	0	0	730	754	-1,58	1484	87	72	8,03
Zgornje krisko jezero	**M94**	**0,0**	**1**	**709**	**33**	**28**	**3**	**557**	**100**	**10**	**3**	**0**	**774**	**724**	**3,27**	**1498**	**81**	**75**	**8,37**

Figure 2. Position of the annual mean (1991-1994) for Lille Hovvatn, Norway on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

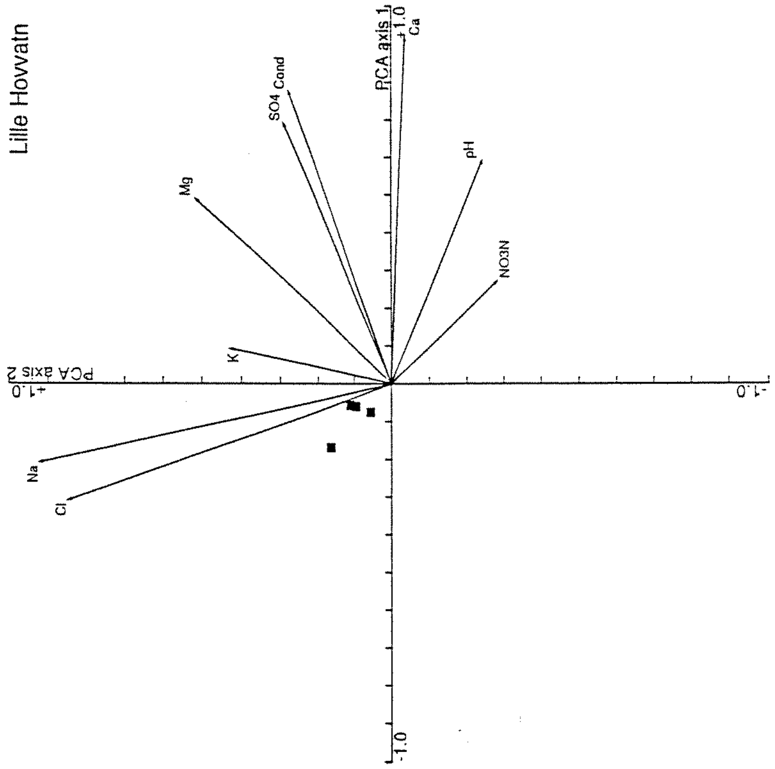


Figure 3. Position of the annual mean (1993) for Lough Maam, Ireland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

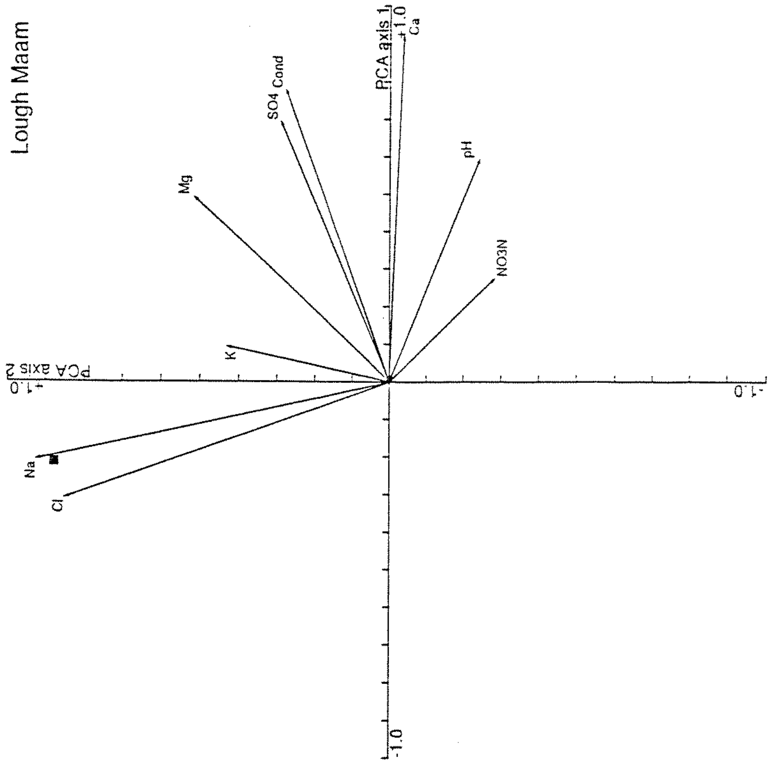


Figure 4. Position of the annual mean (1993) for Arresjøen, Spitsbergen, Norway on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

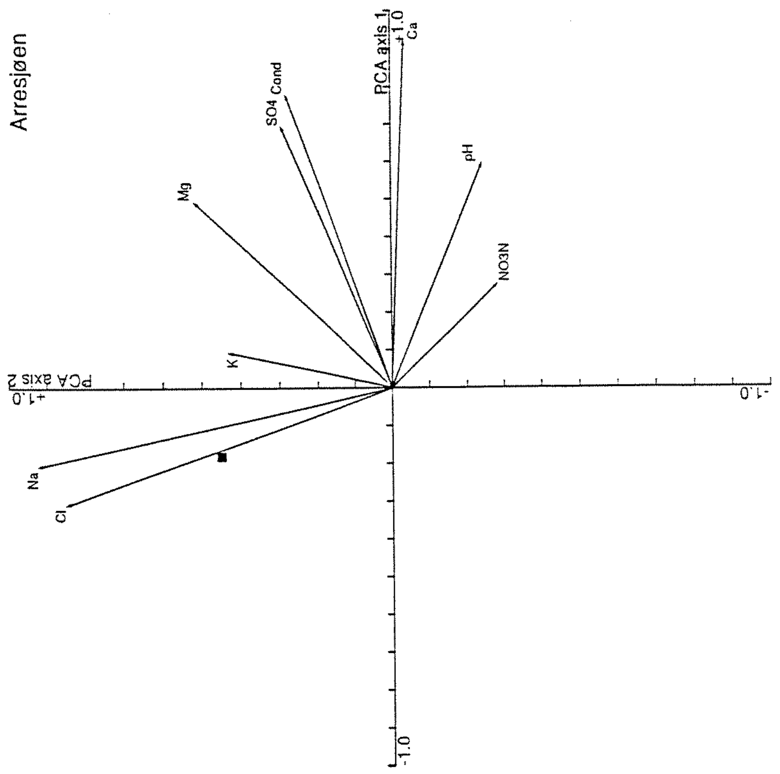


Figure 5. Position of the annual means (1991-1994) for Lochnagar, Scotland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

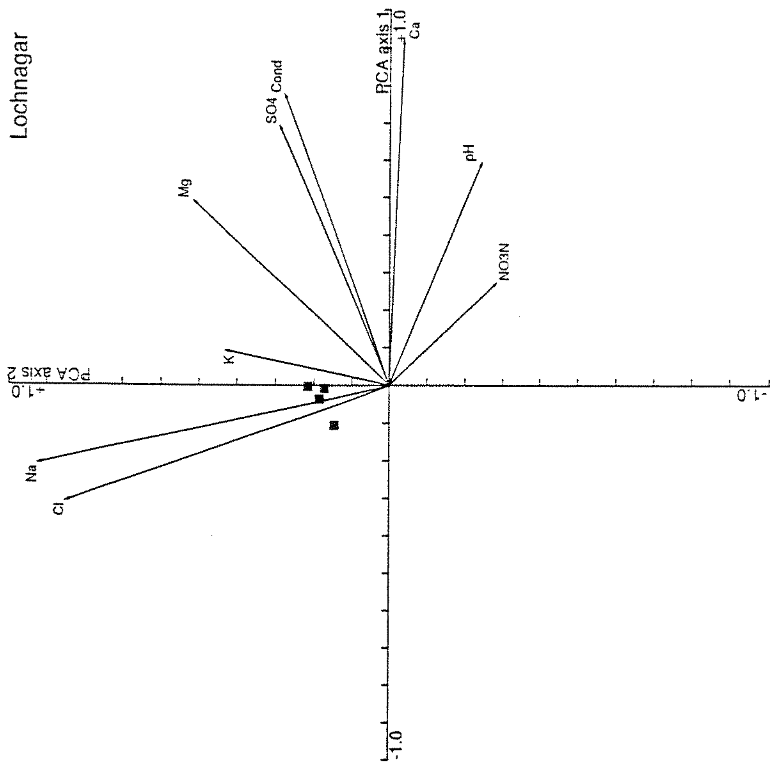


Figure 6. Position of the annual means (1991-1994) for Sandy Loch, Scotland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

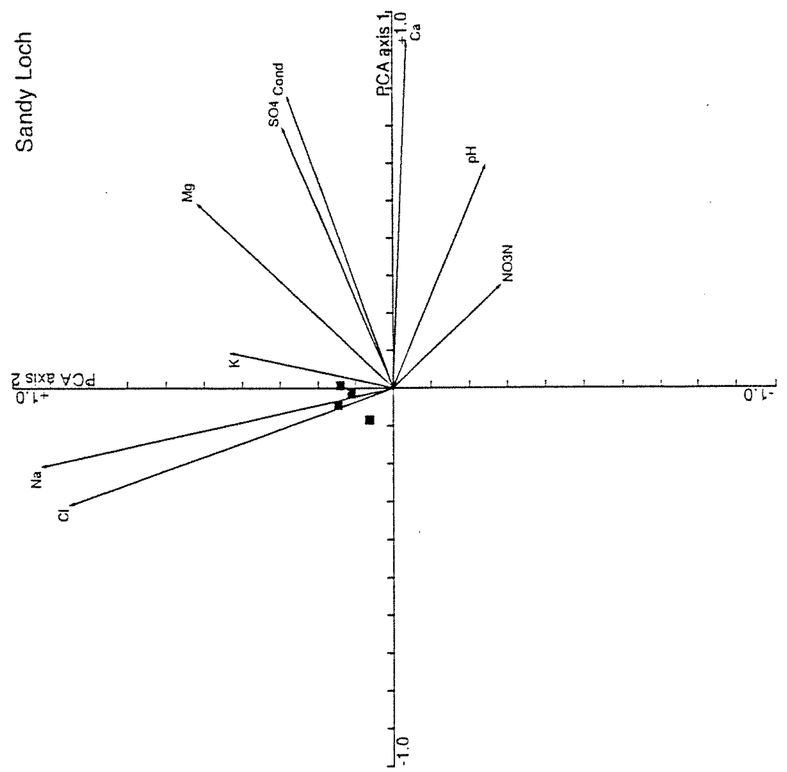


Figure 7. Position of the annual means (1991-1994) for Loch Nan Eun, Scotland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

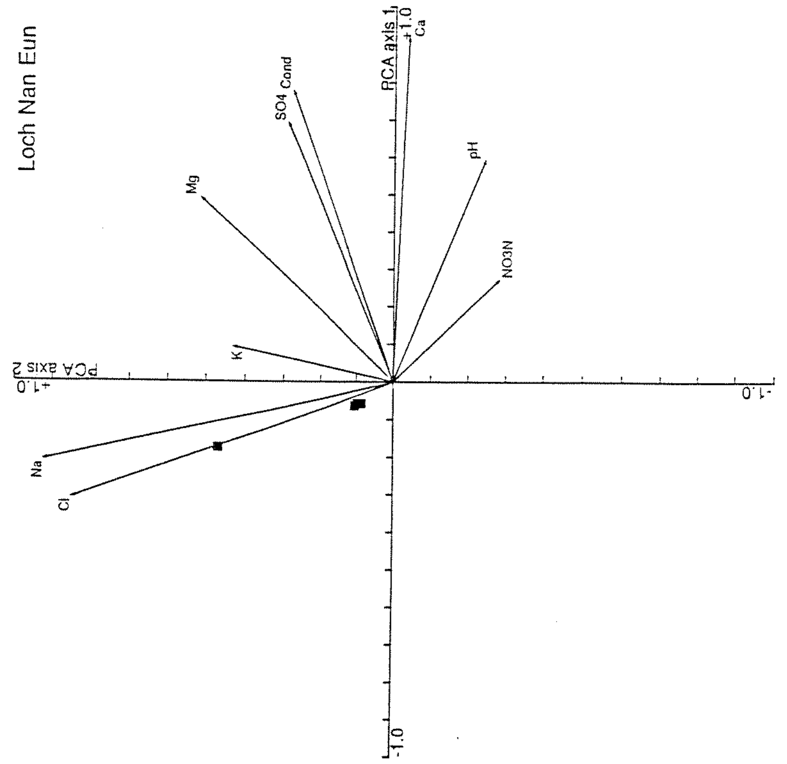


Figure 8. Position of the annual mean (1993-1994) for Chibini, Kola, Russia on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

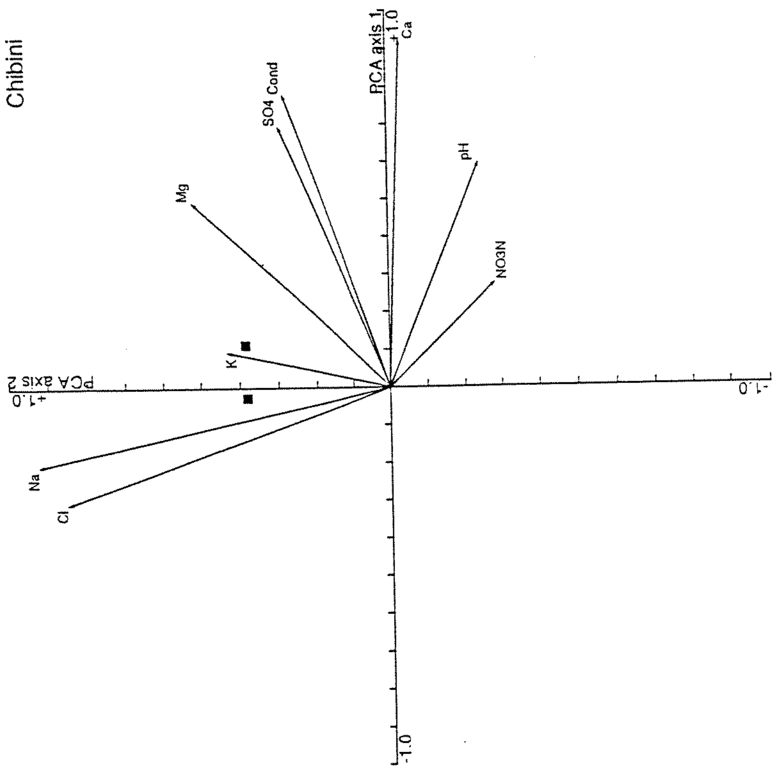


Figure 9. Position of the annual means (1993-1994) for Lago Escura, Portugal on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

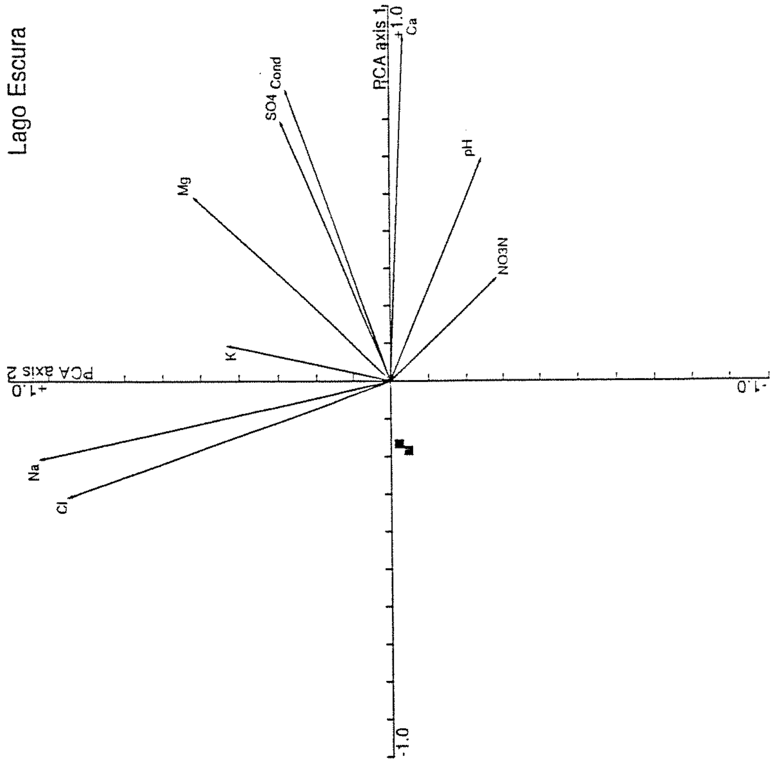


Figure 10. Position of the annual means (1993) for Laguna Cimera, Spain on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

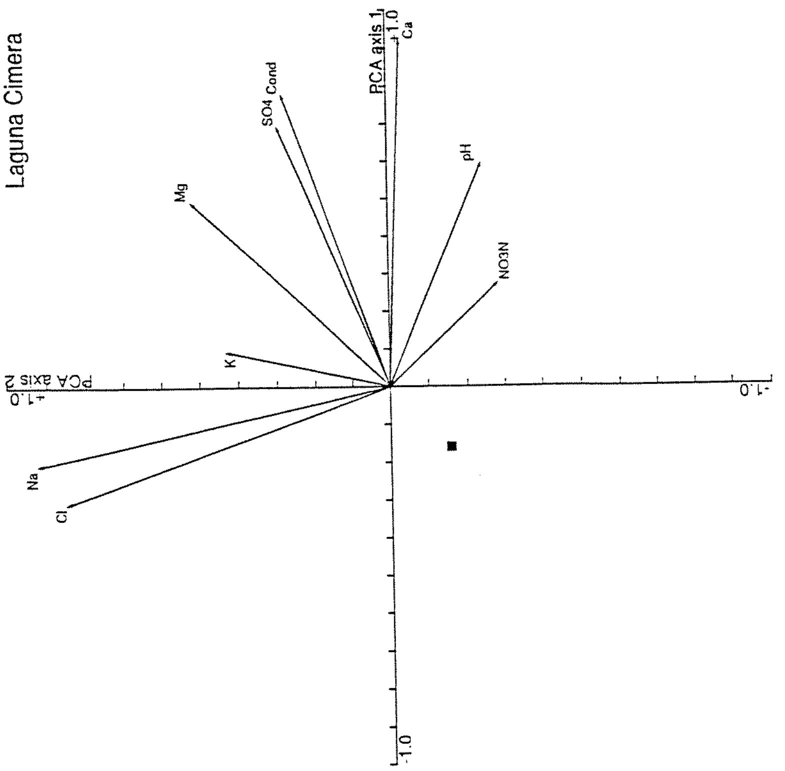


Figure 11. Position of the annual means (1993-1994) for Estany Redo, Spain on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

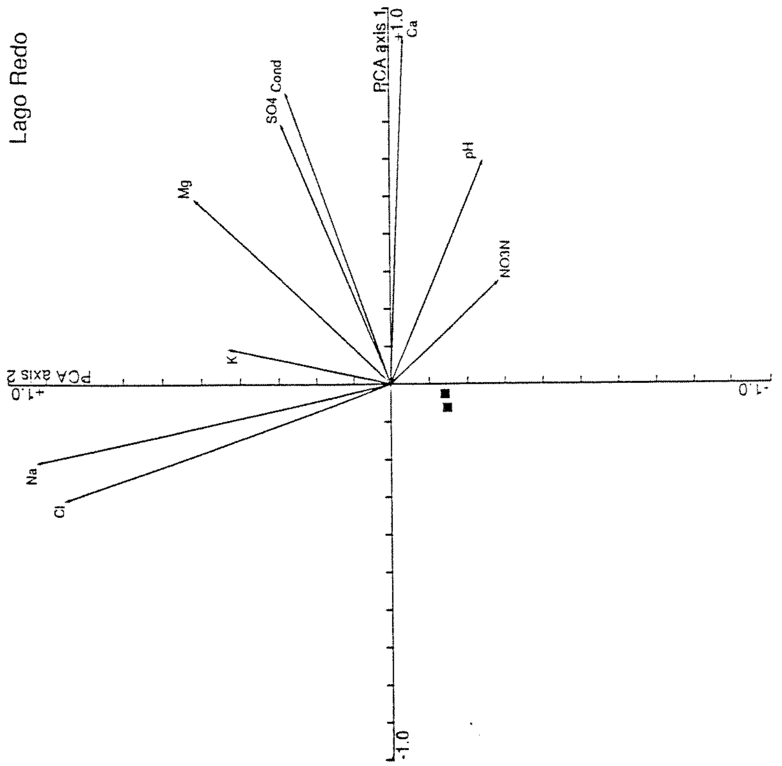


Figure 12. Position of the annual means (1993-1994) for Estany Aguiló, Spain on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

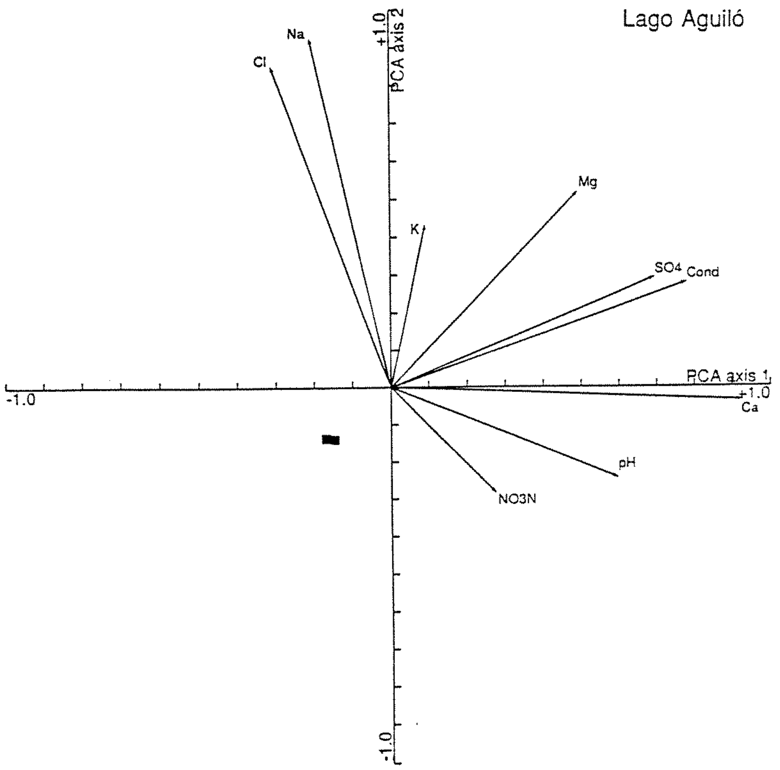


Figure 13. Position of the annual means (1991-1994) for Étang d'Aubé, France on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

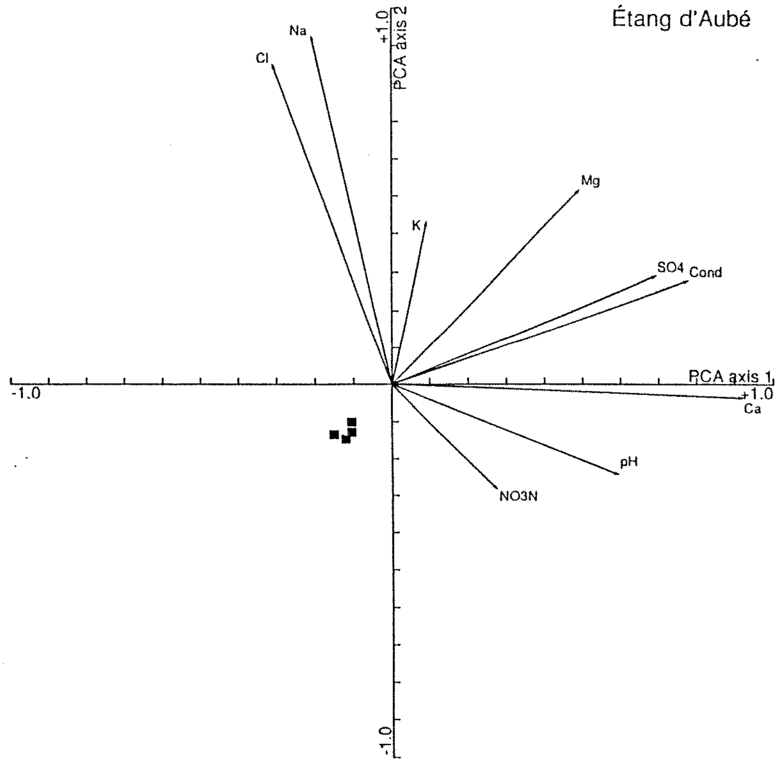


Figure 14. Position of the annual means (1991-1994) for Øvre Neådalsvatn, Norway on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

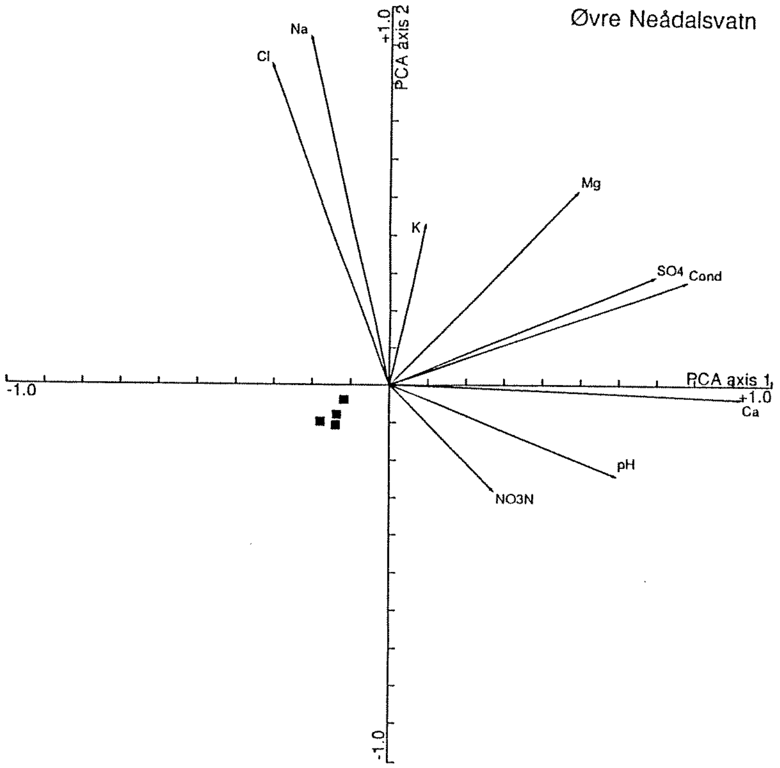


Figure 15. Position of the annual means (1991-1994) for Stavsvatn, Norway on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

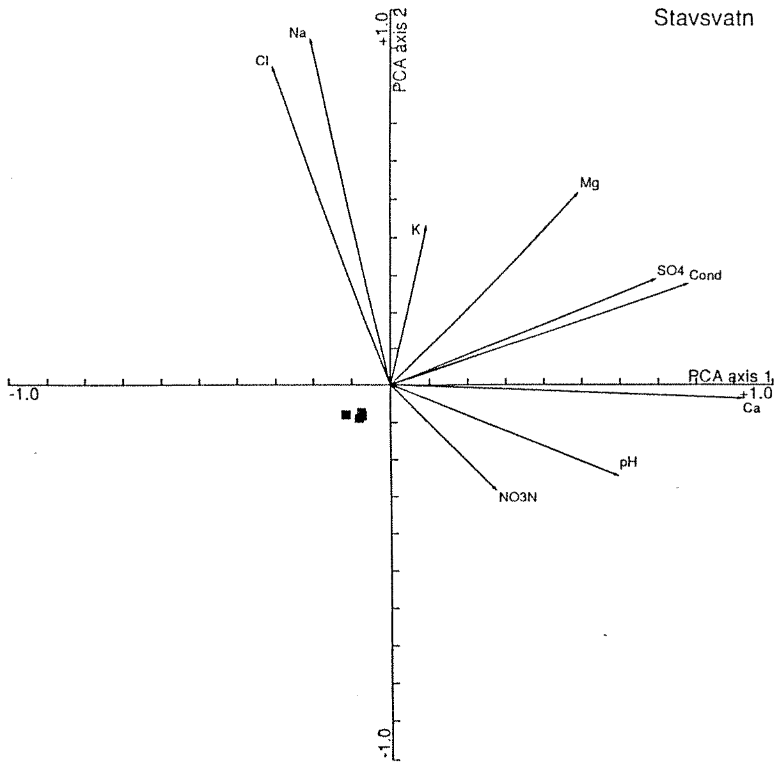


Figure 16. Position of the annual means (1991-1994) for Labo Paione Superiore, Itay on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

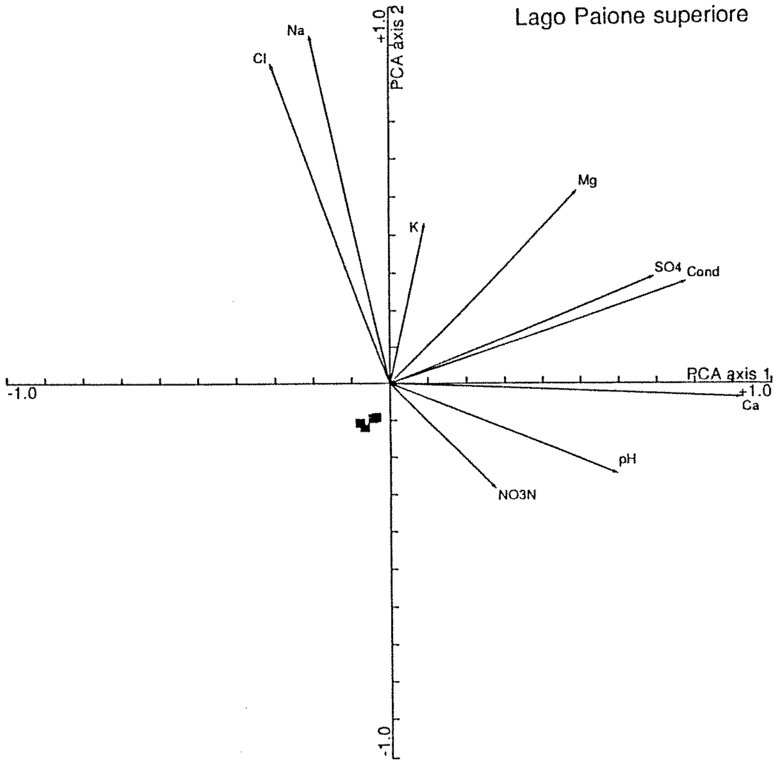


Figure 17. Position of the annual means (1993-1994) for Chuna, Kola, Russa on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

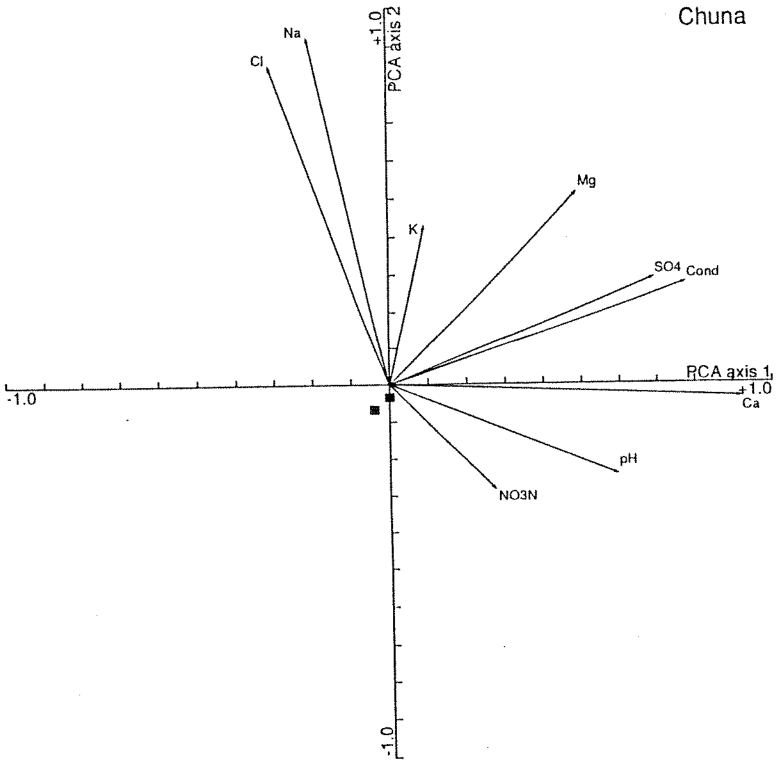


Figure 18. Position of the annual means (1993-1994) for Starolesnianske Pleso, Slovakia on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

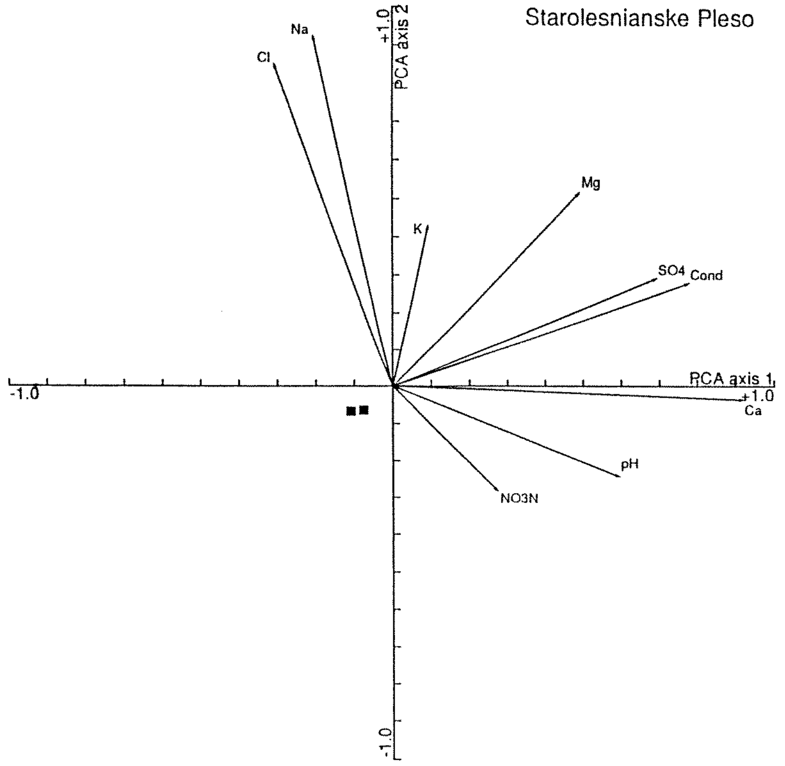


Figure 19. Position of the annual means (1993-1994) for Terianske Pleso, Slovakia on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

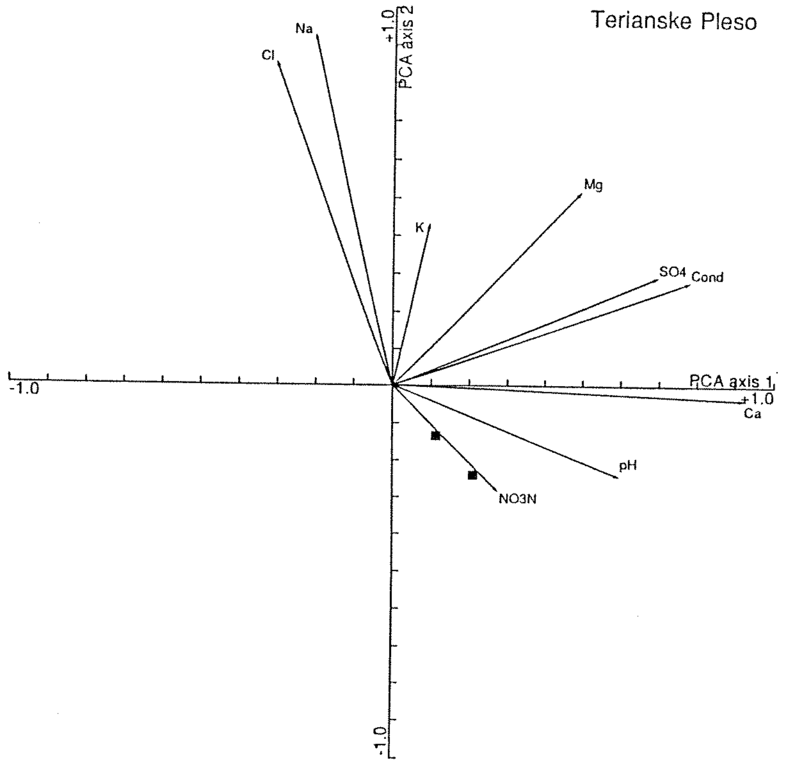


Figure 20. Position of the annual means (1993-1994) for Zieloni Staw, Poland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

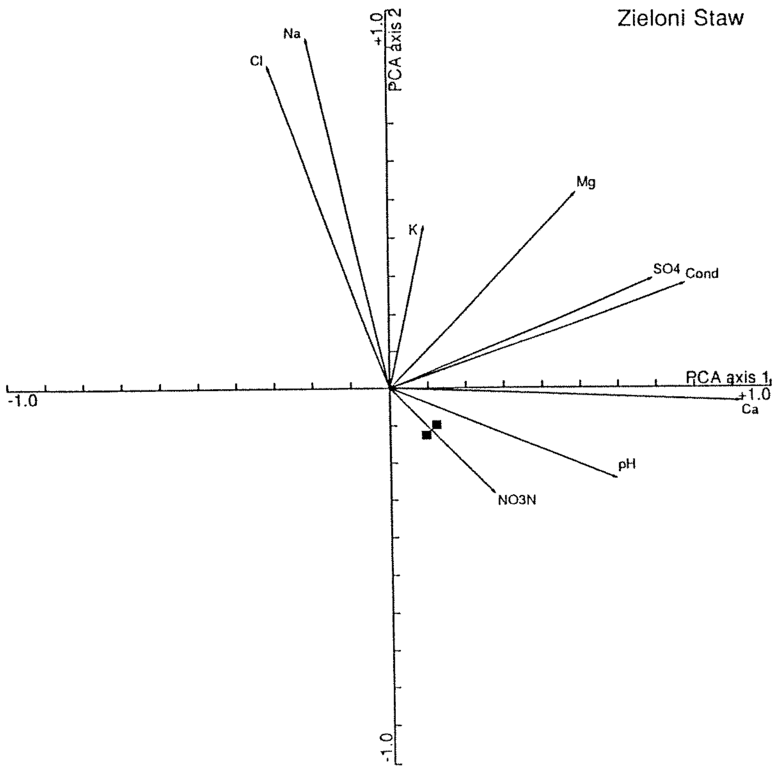


Figure 21. Position of the annual means (1993-1994) for Dlugi Staw, Poland on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

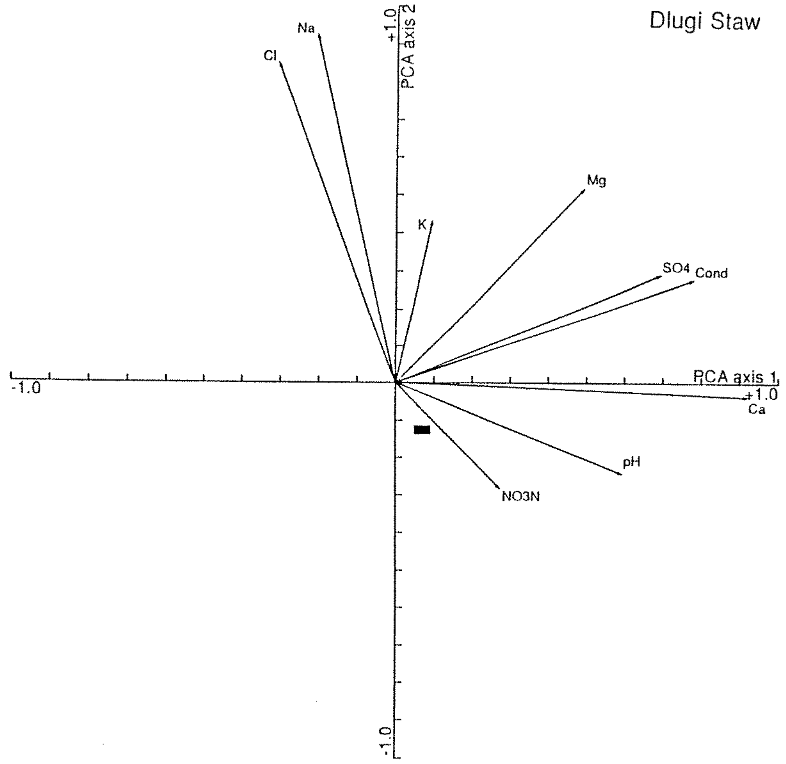


Figure 22. Position of the annual means (1993-1994) for La Caldera, Spain on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

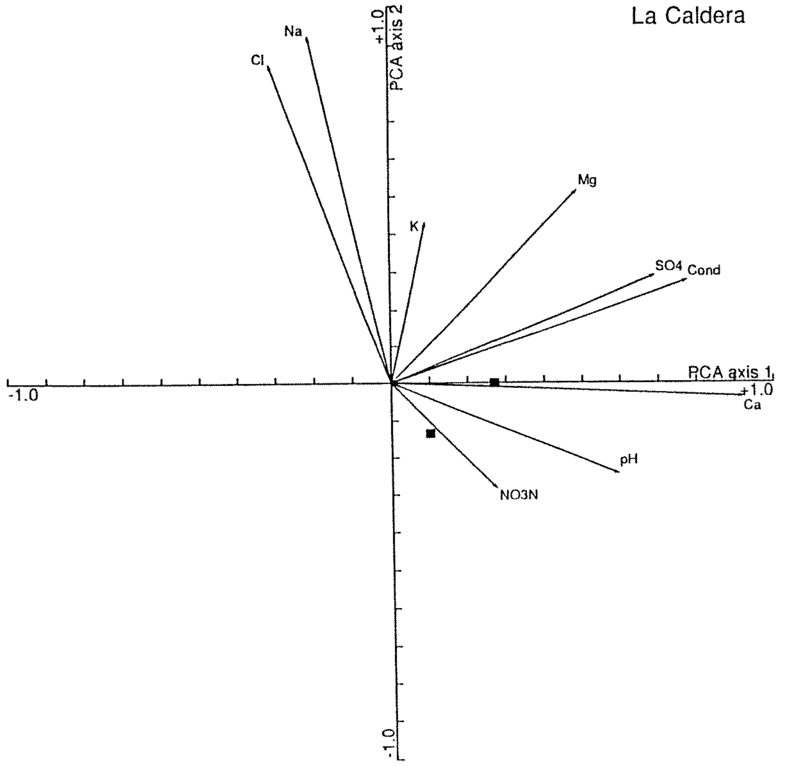


Figure 23. Position of the annual means (1991) for Combeynod, France on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

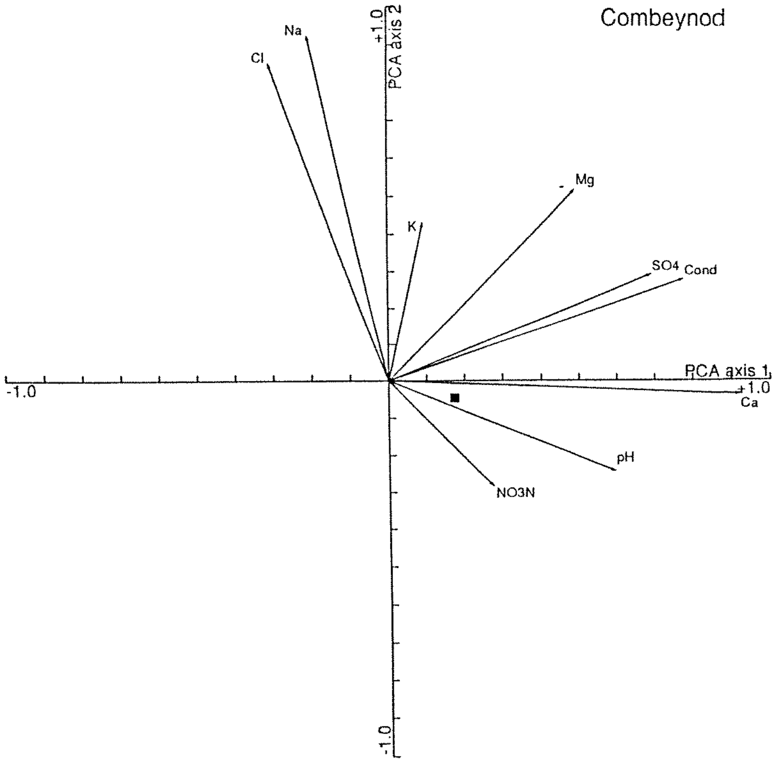


Figure 24. Position of the annual means (1992-1994) for Lac Noir, France on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

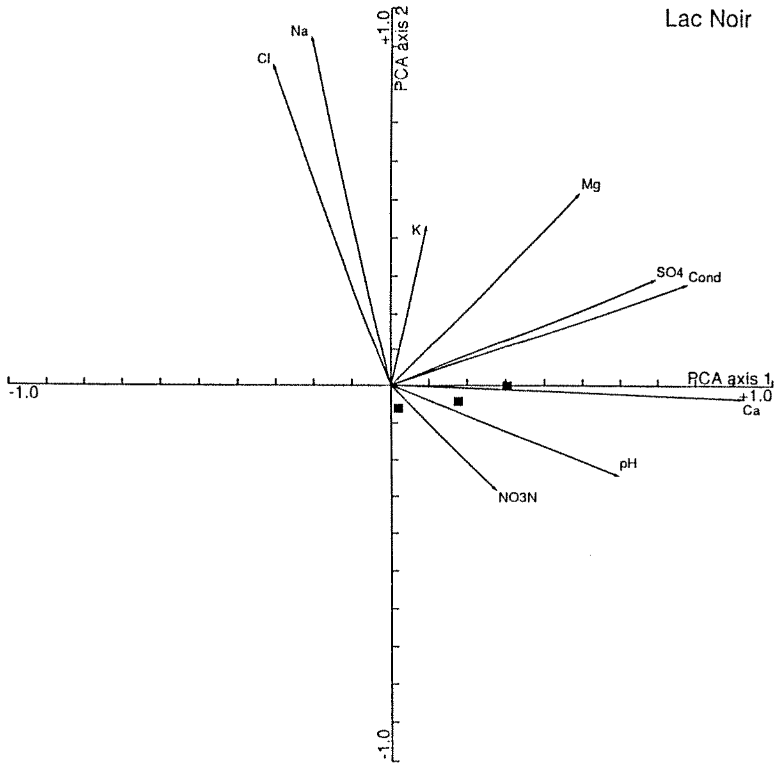


Figure 25. Position of the annual means (1992-1994) for Lago di Latte, Italy on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

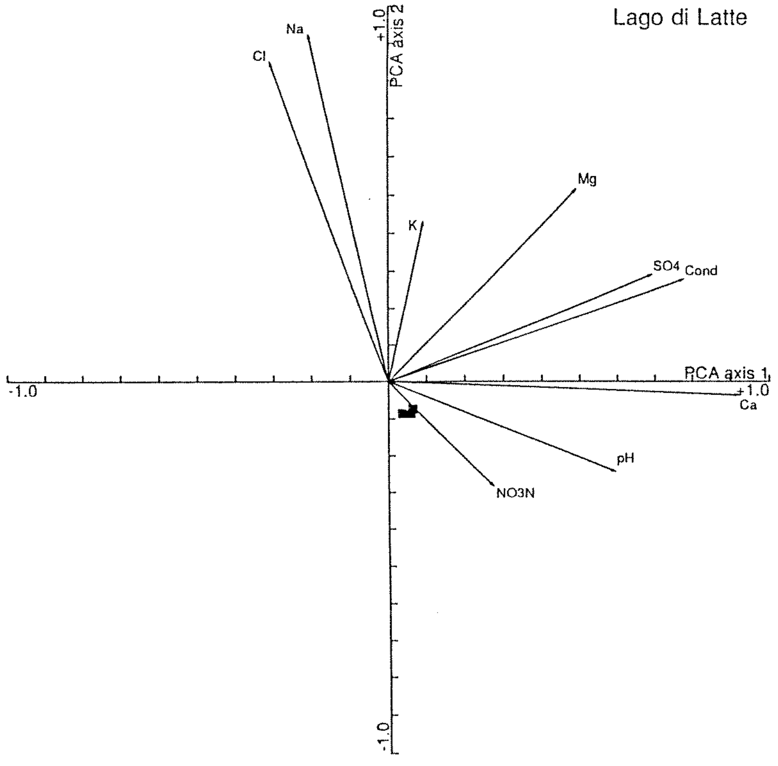


Figure 26. Position of the annual means (1991-1994) for Lago Paione Inferiore, Italy on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

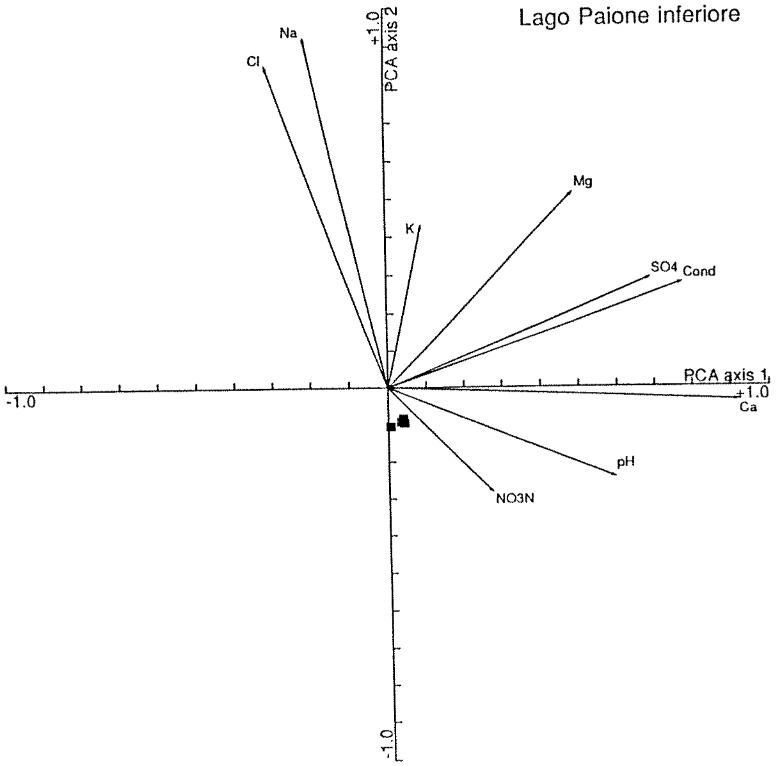


Figure 27. Position of the annual means (1991-1994) for Lago Lungo, Italy on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

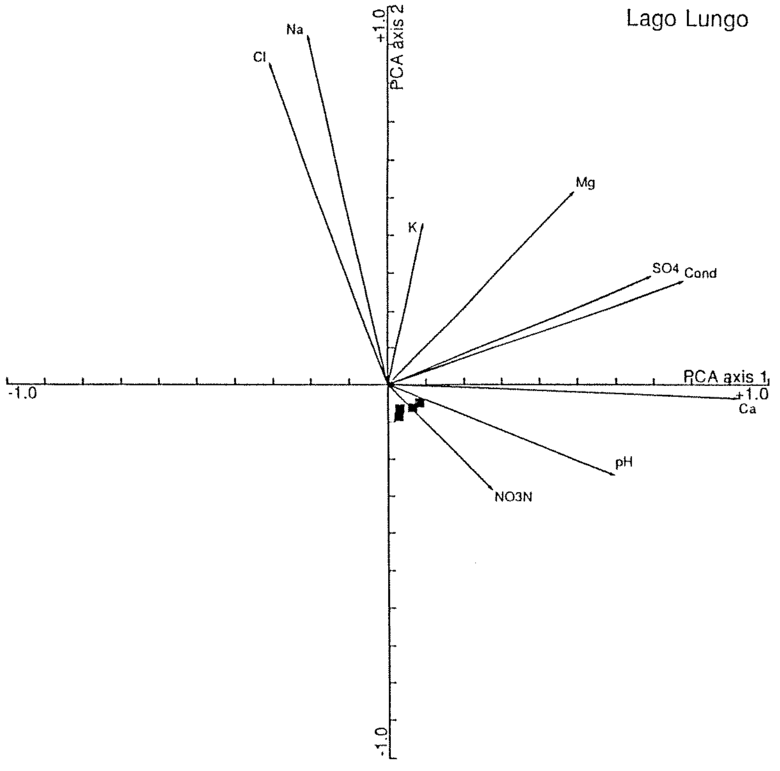


Figure 28. Position of the annual means (1991) for Lac Rond, France on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

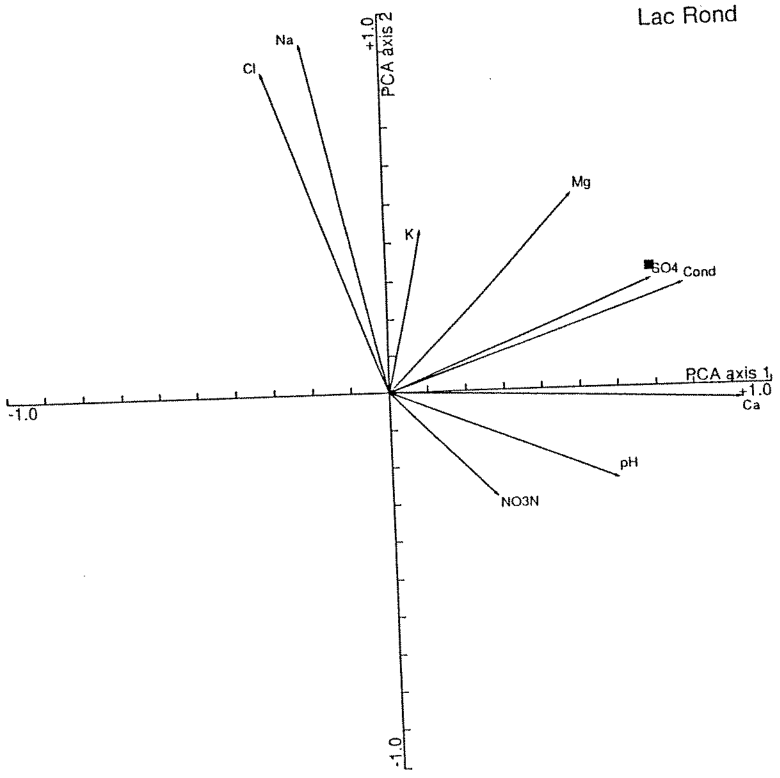


Figure 29. Position of the annual mean (1994) for Zgornje krisko jezero, Slovenia on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

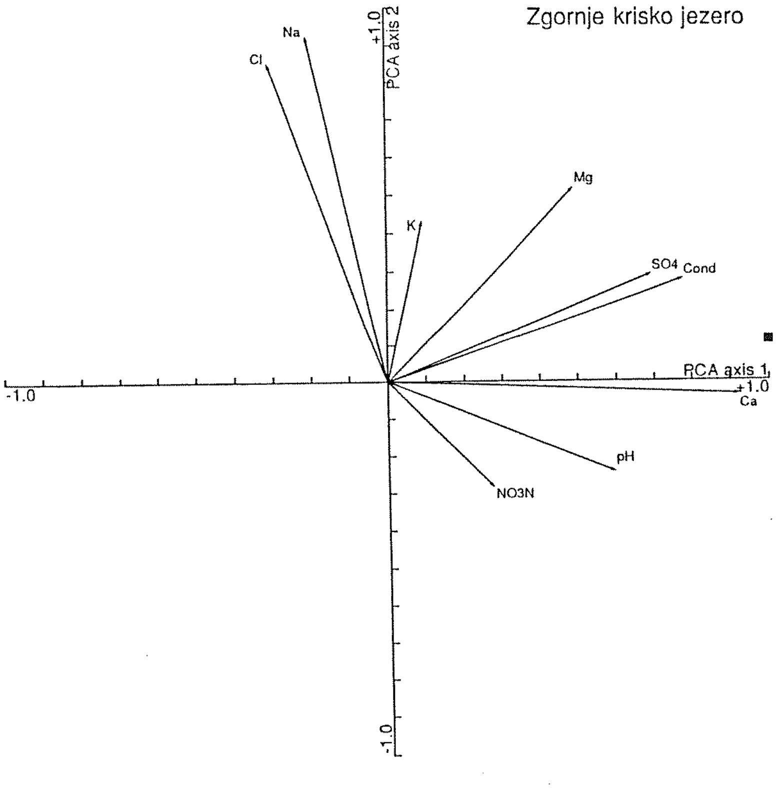


Figure 30. Position of the annual means (1992-1994) for Lac Blanc, France on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).

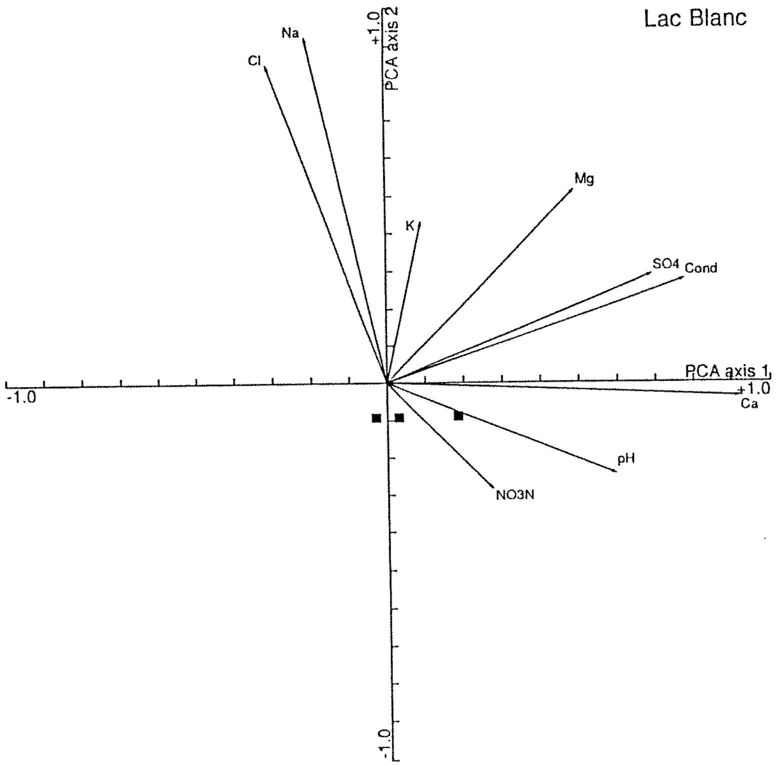
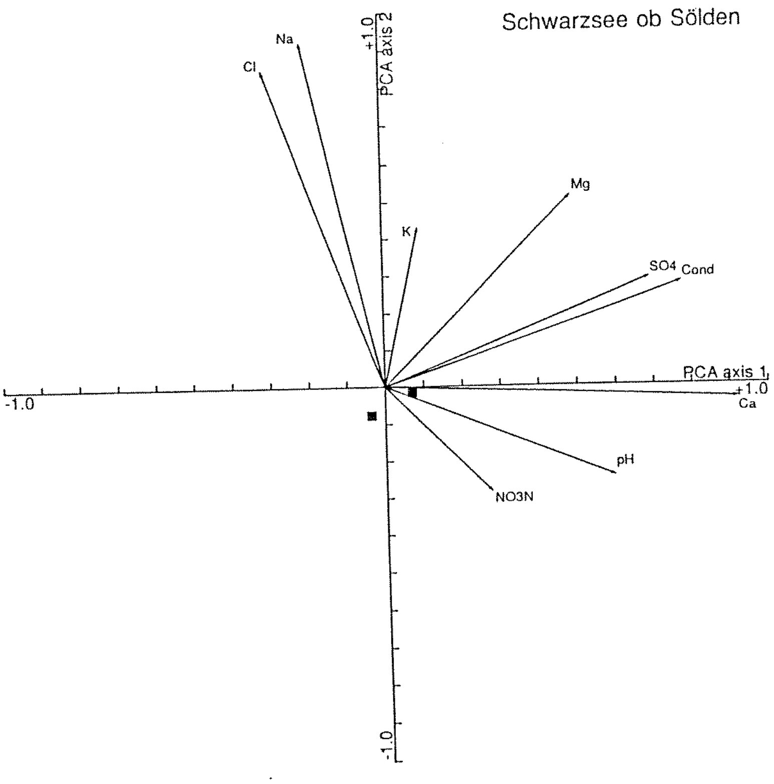


Figure 31. Position of the annual means (1993-1994) for Schwarzsee ob Sölden, Austria on PCA axes 1 and 2 in relation to the biplot arrows for the nine determinands (Figure 2.19).



APPENDIX 2

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Appendix 3.

Water chemistry - Intercalibration exercises

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Water Chemistry - Intercalibration exercises

INTERCOMPARISON EXERCISES PERFORMED IN THE FRAMEWORK OF THE AL:PE 2 RESEARCH.

1. INTRODUCTION

Intercomparison exercises are an essential tool in ensuring data quality and comparability in research projects involving many laboratories. The activity already started with the AL:PE 1 project continued in 1993 and 1994 with two sets of intercomparisons. One was organized by the Norwegian Institute for Water Research, in the framework of the International Co-operative Programme on Assessment and Monitoring of Acidification in Rivers and Lakes. The second was organized by the C.N.R. Istituto Italiano Idrobiologia, in collaboration with the Environment Institute of the European Joint Research Centre, Ispra.

The variables examined were pH, conductivity and major cations and anions, alkalinity included. The fact that the two institutes are involved in other international scientific programs prompted the suggestion to enlarge the intercomparison exercise to other laboratories, in the context of three investigations:

a) the AL:PE 2 project

b) Environmental studies in the Mediterranean basin;

c) the International Commission for the Protection of Lake Leman.

This paper deals with the results obtained by the AL:PE laboratories in this second set of intercomparison exercises, run in 1993 and 1994. A complete presentation of the results obtained from all the laboratories (99 and 120 in 1993 and 1994, respectively) is given elsewhere (Mosello *et al.* 1994, in press). Methods used in sample preparation, data elaboration and the results concerning the laboratories involved in the AL:PE project will be presented and discussed. Special attention will be devoted to alkalinity, which is such an important variable in acidification studies.

2. SAMPLE PREPARATION

Two types of samples were prepared for the exercise: artificial rain-water and sodium bicarbonate solutions, stabilized with chloroform, for the measurement of alkalinity. Simulated rainwater (samples A, B) was prepared at the JRC-EI on the basis of the techniques already experimented for the yearly intercomparisons performed since 1989, which were adequate for the purpose (Mosello *et al.* 1990). Starting material is water of the highest quality (nanopure U.W.S. Barnstead) and the purest chemicals available. The carefully weighed chemicals were dissolved and water added to make up the master solution (1 l), which was then checked analytically for correctness of the envisaged analyte concentrations. The master solution was added to approximately 20 l of nanopure water in a 50 l polyethylene container, previously conditioned with the same quality of water for two weeks. The calculated quantity of Suprapure HCl required to reach the previously fixed pH value of the final solution was added and the solution made up to a total of 50 l. The solution was mixed by rolling the container.

Samples C and D, prepared specifically for alkalinity measurements, were dilute solutions of sodium bicarbonate, stabilized with chloroform.

Bottling was performed by hand, rinsing the previously conditioned 1 l polypropylene bottles (two weeks with nanopure water) with the samples and then filling them up to the top.

The concentrations of samples A and B were chosen in the upper and lower ranges of the concentration values most often measured in atmospheric deposition in northern Italy (Mosello *et al.* 1992). Alkalinity values were chosen in the range of those present in some episodes of atmospheric deposition; however, these values are in the same range as those measured in many high altitude lakes in the Alps, and areas characterized by poorly buffered water.

3. SAMPLE HOMOGENEITY AND STABILITY

The total variance measured on a number of samples representative of the whole population is the sum of the variances resulting from the analytical method used, the non-homogeneity of the samples and other random errors:

$$S^2_{tot} = S^2_{method} + S^2_{heterog.} + S^2_{random}$$

The estimation of S_{tot} was obtained by measuring the concentrations of ten randomly selected bottles for each of the four solutions. All the measurements were performed in one laboratory by the same analyst using the same analytical method. The variance due to the analytical method was estimated by repeating the measurement ten times on the same bottle. Results were expressed as relative standard deviation, i.e., ratio between standard deviation and mean value.

Heterogeneity was estimated as the square root of the difference of the squares of the standard deviations of samples and methods; it resulted below 1% for most of the variables of the four samples, with the few exceptions, giving results in any case lower than 2%.

To check the stability of the samples, analyses were performed by the two organizing laboratories over the period allowed for the exercise. During this time the samples were kept at room temperature, but shielded from light, and analysed approximately every four week. The results (Tab. 1) demonstrate the stability of the four solutions, and refer to the duration of the exercises only.

4. RESULTS

The concentrations of solutions were measured by the laboratories of the JRC-EI and CNR-III. Methods used are:

pH: potentiometry;
Ca, Mg: ion chromatography, atomic absorption spectrophotometry;
Na, K: ion chromatography, atomic absorption and atomic emission spectrophotometry;
sulphate, nitrate and chloride: ion chromatography; alkalinity: Gran's titration (Gran 1950); two end-points and single end-point titration (Rodier 1984).

Expected results are shown in table 2 and 3 for the two intercomparison exercises, together with the results obtained from the laboratories.

Tab. 1 - Intercomparison exercises 1993 and 1994. Stability tests of solution A, B, C, and D. Conductivity: µS cm^{-1} at 20 °C; alkalinity: meq l^{-1}; ammonium, nitrate: mg N l^{-1}; other ions: mg l^{-1}.

Date	pH	Cond.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NH$_4^{+}$	SO$_4^{--}$	NO$_3^{-}$	Cl^{-}	Alk.
Exercise 1993: Sample A (alkalinity from sample C)											
07.12.93	4.43	23.6	0.35	0.14	0.18	0.21	0.39	3.49	0.13	0.88	0.040
10.01.94	4.44	23.7	0.36	0.15	0.18	0.21	0.38	3.50	0.13	0.88	0.040
24.02.94	4.45	23.8	0.36	0.14	0.19	0.21	0.38	3.50	0.13	0.89	0.039
02.05.94	4.46	23.7	0.35	0.13	0.17	0.20	0.39	3.50	0.13	0.87	0.040
Exercise 1993: Sample B (alkalinity from sample D)											
07.12.93	3.72	104.5	1.10	0.34	0.70	0.46	1.40	14.50	0.96	1.92	0.133
10.01.94	3.73	104.6	1.11	0.35	0.71	0.48	1.38	14.40	0.97	1.92	0.134
24.02.94	3.73	105.0	1.11	0.34	0.71	0.47	1.38	14.50	0.97	1.91	0.134
02.05.94	3.76	104.0	1.09	0.34	0.71	0.45	1.40	14.38	0.95	1.92	0.136
Exercise 1994: Sample A (alkalinity from sample C)											
10.10.94	4.41	26.2	0.29	0.09	0.20	0.26	0.43	4.32	0.15	0.35	0.040
11.11.94	4.40	26.2	0.28	0.09	0.21	0.25	0.44	4.31	0.16	0.35	0.038
07.12.94	4.42	26.0	0.29	0.09	0.20	0.25	0.43	4.31	0.15	0.34	0.040
11.01.95	4.41	26.1	0.30	0.09	0.20	0.26	0.43	4.30	0.15	0.35	0.039
Exercise 1994: Sample B (alkalinity from sample D)											
10.10.94	3.84	96.1	1.34	0.30	1.67	0.46	1.20	13.80	1.16	1.95	0.120
11.11.94	3.82	96.0	1.32	0.29	1.68	0.44	1.18	13.82	1.17	1.96	0.118
07.12.94	3.83	95.8	1.33	0.29	1.68	0.46	1.21	13.82	1.16	1.97	0.120
11.01.95	3.85	96.0	1.33	0.29	1.69	0.46	1.19	13.78	1.16	1.95	0.121

Tab. 2 - Expected (E) and measured values for the 1993 exercise. Laboratories are referred to by numbers to preserve anonymity. Conductivity: µS cm^{-1} at 20 °C; alkalinity: meq l^{-1}; ammonium, nitrate: mg N l^{-1}; other ions: mg l^{-1}.

Sample A (alkalinity from sample C)

No.	pH	Cond.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NH$_4$$^{+}$	SO$_4$$^{--}$	NO$_3$$^{-}$	Cl^{-}	Alk.
E	4.45	23.6	0.35	0.14	0.18	0.21	0.38	3.47	0.12	0.87	0.039
1	4.24	23.6	0.35	0.12	0.15	0.18	0.39	3.41	0.13	0.80	0.039
2	4.43	23.2	0.37	0.14	0.16	0.20	0.38	3.55	0.12	0.85	0.037
3	4.45	28.0	0.35	0.27	0.15	0.15	0.38	3.59	0.12	0.58	0.036
4	4.41	24.0	0.21	0.12	0.11	0.12	0.38	3.50	0.13	0.96	0.037
5	4.83	27.1	0.40	0.90	0.50	0.61	0.34	10.06	0.14	1.70	0.300
6	4.43	24.0	0.37	0.14	0.19	0.20	0.36	3.20	0.12	1.00	-
7	4.46	25.0	0.39	0.14	0.21	0.18	0.43	3.53	0.13	0.89	0.040
8	4.27	26.3	0.50	0.10	0.20	0.20	0.41	3.10	0.10	1.50	0.037
9	4.07	28.1	-	-	-	-	-	-	-	-	0.034
10	4.45	24.0	0.21	0.12	0.30	0.20	0.38	3.50	0.11	0.90	0.043
11	4.44	24.2	0.40	0.13	0.17	0.18	0.36	3.20	0.12	0.90	0.069
12	4.44	26.8	0.33	0.12	0.15	0.20	0.34	3.72	0.14	1.09	0.039
13	4.68	20.2	0.35	0.13	0.18	0.23	0.28	3.34	0.16	1.01	0.120
14	-	-	0.11	0.14	0.00	0.00	-	2.62	0.16	0.69	-
15	4.47	23.7	0.37	0.14	0.19	0.22	0.38	3.45	0.13	0.88	0.036

Sample B (alkalinity from sample D)

No.	pH	Cond.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NH$_4$$^{+}$	SO$_4$$^{--}$	NO$_3$$^{-}$	Cl^{-}	Alk.
E	3.73	104.1	1.08	0.34	0.70	0.45	1.40	14.5	0.97	1.91	0.134
1	3.63	102.0	1.12	0.31	0.66	0.42	1.37	14.8	0.86	2.37	0.132
2	3.72	104.0	1.06	0.33	0.68	0.43	1.38	14.7	0.99	1.84	0.137
3	3.72	117.6	1.05	0.69	0.61	0.36	1.43	14.4	1.00	1.72	0.111
4	3.70	101.0	0.80	0.30	0.42	0.30	1.35	14.5	0.92	2.10	0.128
5	4.35	92.1	0.20	0.90	0.50	0.52	1.31	19.2	1.10	0.90	0.275
6	3.70	105.0	1.10	0.33	0.71	0.43	0.69	12.8	0.98	1.92	-
7	3.76	107.0	1.12	0.32	0.74	0.43	1.48	14.4	0.99	1.81	0.136
8	3.57	116.3	1.10	0.30	0.70	0.40	1.30	14.1	0.80	2.20	0.131
9	3.47	117.0	-	-	-	-	-	-	-	-	0.108
10	3.73	105.2	0.90	0.31	0.83	0.32	1.30	14.1	0.90	1.96	0.137
11	3.74	106.4	1.17	0.32	0.73	0.40	1.32	13.2	0.97	1.80	0.162
12	3.72	115.3	0.98	0.27	0.50	0.35	1.25	16.8	1.12	2.40	0.132
13	3.68	99.1	0.98	0.34	0.61	0.42	1.02	13.5	0.92	1.97	0.250
14	-	-	0.82	0.42	0.60	0.82	-	14.4	0.90	1.59	-
15	3.74	104.9	1.11	0.34	0.73	0.48	1.33	14.5	0.97	1.94	0.134

Tab. 3 - Expected (E) and measured values for the 1994 exercise. Laboratories are referred to by numbers to preserve anonymity. Conductivity: µS cm^{-1} at 20 °C; alkalinity: meq l^{-1}; ammonium, nitrate: mg N l^{-1}; other ions: mg l^{-1}.

No.	pH	Cond.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NH_4^{+}	SO_4^{--}	NO_3^{-}	Cl^{-}	Alk.
Sample A (alkalinity from sample C)											
E	4.42	25.9	0.29	0.09	0.20	0.25	0.42	4.32	0.15	0.35	0.039
1	4.47	25.9	0.32	0.10	0.21	0.27	0.40	4.33	0.15	0.35	0.039
2	4.37	23.5	0.30	0.09	0.06	0.30	0.46	4.60	0.13	0.30	0.042
3	4.45	21.9	0.31	0.09	0.19	0.23	0.42	4.10	0.18	0.20	0.075
4	4.35	25.0	0.29	0.09	0.20	0.23	0.41	4.15	0.15	0.36	0.040
5	4.38	29.0	0.42	0.11	0.22	0.27	0.34	4.37	0.15	0.30	0.044
6	4.33	28.0	0.18	0.08	0.09	0.21	0.49	4.32	0.16	0.18	0.036
7	4.43	26.0	0.26	0.17	0.18	0.22	0.48	3.93	0.16	0.14	0.046
8	4.35	26.3	0.28	0.09	0.20	0.26	0.40	5.10	0.18	0.34	0.040
9	3.22	23.0	0.30	0.10	0.20	0.30	0.20	4.32	0.18	0.36	0.044
10	4.08	29.9	-	-	-	-	-	-	-	-	0.047
11	4.56	21.3	0.20	0.08	0.16	0.22	0.33	4.13	0.15	0.30	0.088
12	4.34	25.1	0.22	0.09	0.19	0.23	0.43	4.20	0.15	0.35	0.041
13	4.38	24.3	-	-	-	-	0.34	6.87	0.15	-	0.087
14	-	-	0.23	0.06	0.10	0.24	-	4.20	0.76	0.30	-
Sample B (alkalinity from sample D)											
E	3.85	95.5	1.33	0.29	1.67	0.45	1.15	13.8	1.16	1.95	0.121
1	3.90	95.8	1.34	0.28	1.65	0.47	1.12	13.8	1.16	1.95	0.121
2	3.80	94.7	1.28	0.29	1.70	0.44	1.28	14.1	1.10	2.00	0.123
3	3.87	81.9	1.36	0.28	1.74	0.43	1.16	13.1	1.17	1.90	0.157
4	3.78	96.0	1.28	0.28	1.65	0.43	1.14	13.3	1.15	2.10	0.116
5	3.80	107.0	1.45	0.30	1.70	0.55	1.13	13.6	1.18	1.83	0.142
6	3.76	100.0	1.20	0.28	1.91	0.40	1.30	13.3	1.09	1.71	0.116
7	3.84	104.0	1.22	0.57	1.40	0.40	1.24	12.0	1.18	2.06	0.119
8	3.78	95.5	1.29	0.28	1.68	0.48	1.13	14.4	1.15	1.70	0.116
9	2.94	93.0	1.30	0.30	1.80	0.60	0.50	14.0	1.21	1.80	0.132
10	3.63	110.0	-	-	-	-	-	-	-	-	0.116
11	3.86	82.0	1.24	0.25	1.52	0.42	0.91	14.0	1.23	2.31	0.168
12	3.78	94.0	0.13	0.28	1.61	0.42	1.13	13.4	1.22	2.00	0.120
13	3.88	96.8	-	-	-	-	1.09	21.8	1.25	-	0.170
14	-	-	1.22	0.28	1.56	0.59	-	14.4	5.42	1.90	-

Altogether 99 and 120 laboratories participated in the intercomparisons in 1993 and 1994, respectively. The AL:PE laboratories are listed below:

Norwegian Institute for Water Research, Oslo, (N)
Laboratorio Biologico Provinciale, Laives, (I)
CNR Istituto Italiano di Idrobiologia, Pallanza, (I)
Freshwater Fisheries Laboratory, Faskally, Scotland (GB)
Dept. Hydrobiology, Charles University, Praha (CS)
Czech Geological Survey, Praha (CS)
Inst. Hydrobiology, Academy Sciences, Ceské Budějovice (CS)
Inst. Zoologie, University Innsbruck (A)
Dept. Ecologia, University Barcelona (E)
Dept. Ecologia, Universidad Autonoma Madrid (E)
Inst. Agua, University Granada (E)
Inst. Biology, Dept. Freshwater Ecology, Ljubljana (SLO)
Inst. Ecology Problems, Kola Science Centre, Apatity (SU)
Inst. Ecology Industrial Areas, Katowice (PL)
Centro Ciencias Medioambientales, Madrid (E)

5. DATA ELABORATION

As a first presentation, the data for each solution and each variable are plotted in distribution graphs, in comparison with the expected values and with a range of ±20% of the expected values (±0.2 units for pH). This range has no statistical meaning nor does it represent a goal to be reached, but is only an aid to seeing the data distribution. Results are divided according to the analytical methods, if several techniques were used.

Outliers were identified by means of the method used at the Norwegian Institute for Water Research (NIVA), Oslo, for the inter-comparisons performed in the framework of the 'Convention on long-range transboundary pollution' (Hovind 1989). This technique excludes data outside the range of ±50% of the expected values, then calculates the mean and standard deviation of the remaining results, excluding values outside the range ±3 standard deviations.

A further graphical presentation of the data is given using the Youden's plot (Youden & Steiner 1975). This procedure uses the data relative to two samples, analysed with the same method, which are plotted in a scatter diagram, in comparison with the expected values or, alternatively, the median values of the results. This graphical presentation makes it possible to distinguish between the random and systematic errors affecting the results. The diagram is divided into four quadrants by the two straight lines representing the expected values for the two samples. In a hypothetical case, when the analysis is affected by random errors only, the results will be spread randomly over the four quadrants. However, the results are usually located in the lower left and the upper right quadrant, forming a characteristic elliptical pattern along the line passing through the origin and the expected value. This is due to systematic errors, which underestimate or overestimate the concentrations in both samples.

The 20% range around the expected values is represented by a circle with its centre at the expected values, i.e. at the intersection of the two straight lines in the diagram. The distance between the centre of the circle and the mark representing the laboratory is a measure of the total error of the results. The distance along the line passing through the origin and the expected values gives the magnitude of the systematic error, while the distance perpendicular to the same line indicates the magnitude of the random error. In conclusion, the location of the laboratory in the Youden's diagram gives important information about the size and type of analytical error, which assists in the identification of the causes of the error.

Examples of distribution graphs and of the Youden plot are reported for alkalinity (Fig. 1 and 2).

6. RESULTS AND DISCUSSION

Both artificial and natural stabilized samples resulted adequate for the aims of the intercomparisons, as they were chemically stable over the period of the exercise and no significant heterogeneity among bottles was detected.

The chemical results obtained by the AL:PE laboratories are reported in Tab. 2, compared with the expected values. For the whole set of results see Mosello *et al.* (1994, in press). Only a minor number of outlier data were present among the results of the AL:PE laboratories, although some results appear significantly different from the expected values. Furthermore some data were lacking, indicating that the laboratories were unable to perform all the analyses.

The main observation emerging from the elaboration of the whole set of data is the prevalence of systematic over random errors. This is well shown in Fig. 2 in the case of alkalinity, but it is true for most of the determinations, pH included. pH measurements resulted critical in the samples with low solute concentrations, which are poorly buffered.

Special attention was paid to alkalinity because of its importance in studies dealing with freshwater acidification. The results of both intercomparisons show a wide scatter of values, and a high number of different methods used. This is partially explained by the fact that not all the laboratories involved were used to analysing low alkalinity solutions. In the case of the AL:PE laboratories the results are good, even though they could be improved (Tabs 2 and 3). A substantial improvement was observed from the first intercomparisons, performed in 1991, to the 1994 exercise. The improvement in the case of alkalinity is largely explained by the fact that manual acid titration, with dye as indicator of the equivalence point, has been replaced by titration performed with an automatic burette, using the Gran titration or the two end-point titration.

Part of the dispersion of the results is explained by the fact that titrations consider different end-points; these aspects are extensively discussed in the reports of the whole set of results (Mosello *et al.*, 1994, in press).

7. CONCLUSIONS

Our results confirm the importance of intercomparison exercises in testing and improving analytical quality. The solutions used proved stable enough for the duration of the exercise, and there were no problems with results from samples sent by mail.

For all variables, the use of Youden plots clearly indicates the prevalence of systematic errors over random errors. The calibration technique and standard solutions used may be responsible for such results.

Compared with the first exercise, the second revealed an improvement in the overall performance of the laboratories; the conclusion is that regular intercomparison exercises are an important tool for assuring analytical quality and comparability of the results produced in international scientific and monitoring programmes.

8. REFERENCES

Gran, G. 1950. Determination of the equivalence point in potentiometric titration. *Acta Chem. Scan.*, 4: 559-577.

Hovind, H. 1989. *Intercalibration 8903. Dissolved organic carbon, and aluminium fractions.* NIVA Report, Oslo, 27 pp.

Mosello, R., A. Marchetto and F. Decet. 1992. Chemistry of atmospheric deposition and freshwater acidification: research in Italy. *Mem. Ist. Ital. Idrobiol.*, 50: 417-455 pp.

Mosello, R., M. Bianchi, H. Geiss, A. Marchetto, H. Muntau e G. Serrini. 1990. Intercalibrazione RIDEP 1/89. RIDEP n. 2. *Documenta Ist. Ital. Idrobiol.*, 24: 43 pp.

Mosello, R., M. Bianchi, H. Geiss, A. Marchetto, G.A. Tartari, G. Serrini, G. Serrini Lanza and H. Muntau. 1994. AQUACON-MedBas Subproject 6. Acid Rain Analysis. Intercomparison 1/93. *Documenta Ist. Ital. Idrobiol.*, 47: 36 pp.

Mosello, R., M. Bianchi, H. Geiss, A. Marchetto, G.A. Tartari, G. Serrini, G. Serrini Lanza and H. Muntau. In press. AQUACON-MedBas Subproject 6. Acid Rain Analysis. Intercomparison 1/94. *Documenta Ist. Ital. Idrobiol.*.

Rodier, J. 1984. *L'analyse de l'eau.* Dunod. Orleans: 1365 pp.

Youden, W.J. and E.H. Steiner. 1975. *Statistical manual of the Association of Official Analytical Chemists.* Statistical Techniques for Collaborative Tests. Arlington.

Fig. 1-Distribution plot of alkalinity in exercise 1994. Unit: meq l^{-1}. Lines indicate expected values ± 20%

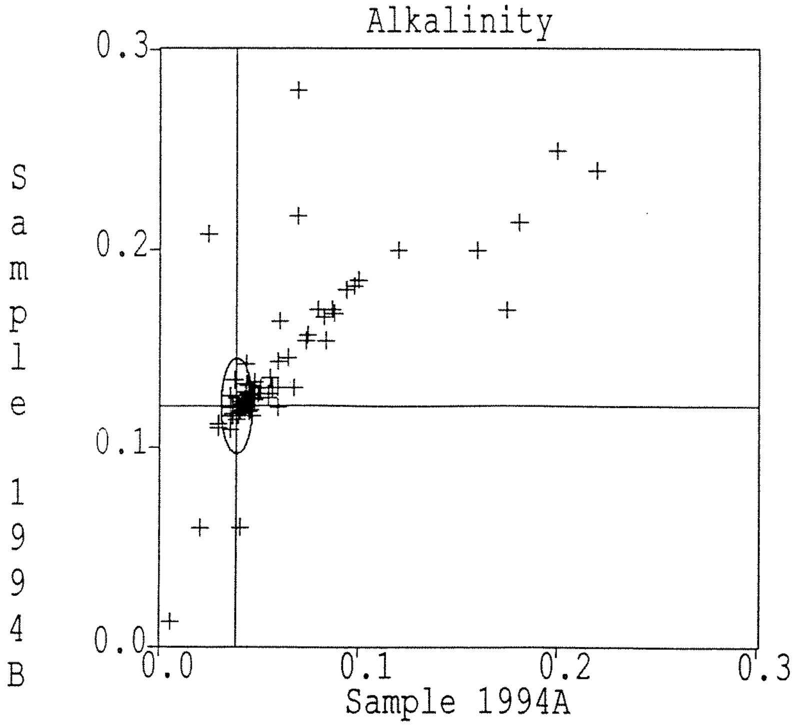
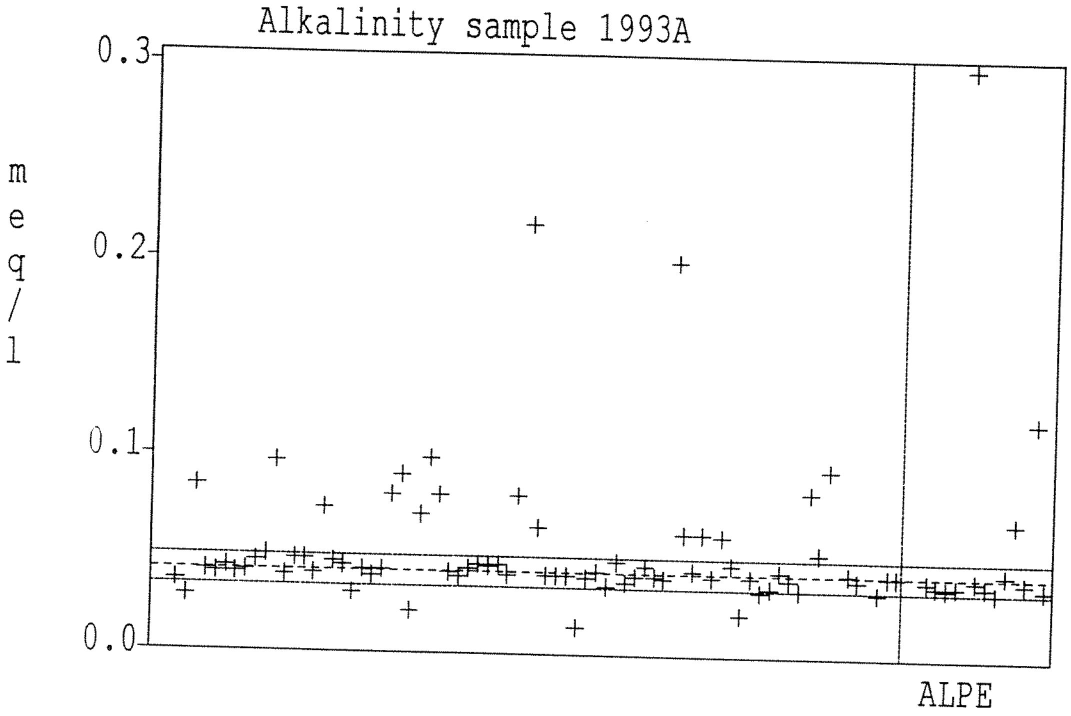
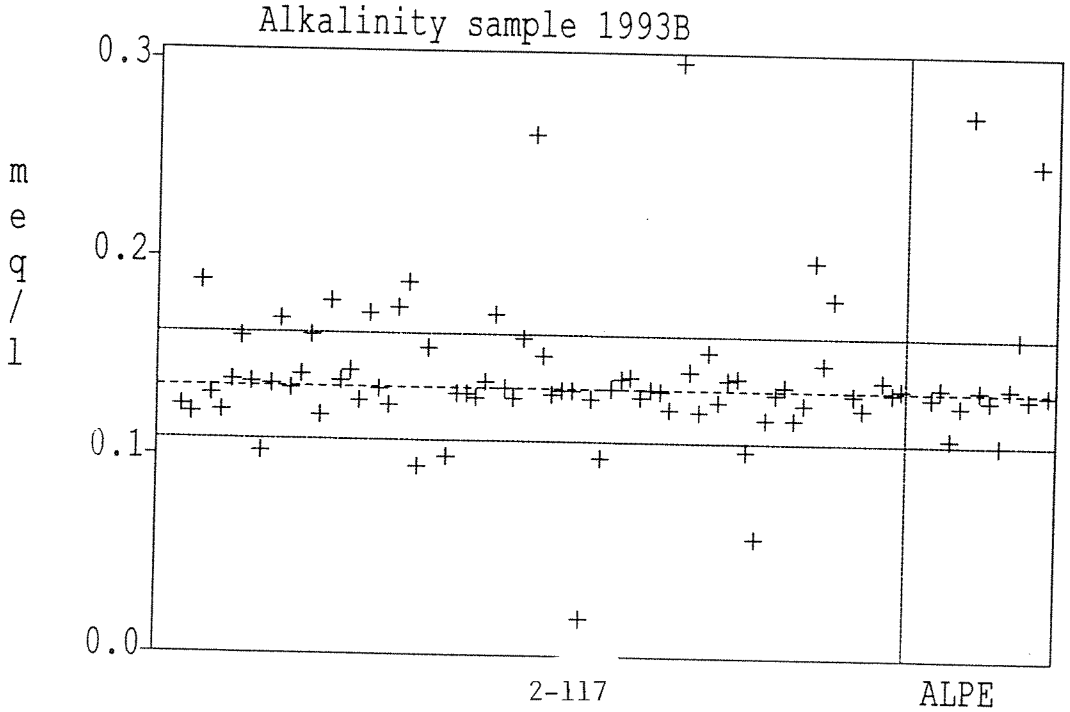


Fig. 2 - Youden's plot of alkalinity in exercise 1993 and 1994. Straight lines indicate expected values, the ellipses an interval of ± 20% of the expected values.





AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Chapter 3.

Contemporary biology

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3.1 Diatoms

3.1.1 Introduction

The rationale for the investigation, and the significance, of epilithic diatom communities in remote lakes is discussed in the AL:PE 1 report (Wathne *et.al.* 1995). Epilithic diatoms are an important (eg. in terms of biomass), perennial and sensitive component of remote lake ecosystems. Analysis of diatom epilithon composition complements the analysis of fish, invertebrate and zooplankton communities in the comparative assessment of the status of these remote lakes.

3.1.2 Methods

The methods used in the diatom investigation are published in the AL:PE 1 report (Wathne *et.al.* 1995). Sampling was carried out during the summer period of 1993 and all workers involved in the AL:PE 2 project have followed these protocols. Diatom sample and slide preparation was carried out using standard methods (Battarbee 1986). Diatom taxonomy followed the decisions of a workshop held in Mondsee during 1994 (see Appendix). DCA was carried out using the CANOCO programme (ter Braak 1987).

3.1.3 Site & Regional Summaries

A total of twenty-two lakes were investigated, including the twelve lakes of the AL:PE 1 programme. Epilithic diatom samples from Lough Maam and La Caldera were not countable because of very low diatom concentrations (probably as a result of water level change near to the time of sampling) and samples are at present unavailable from Laguna Cimera, Nizne Terianske, Zgornje Krisko Jezero and Chuna lakes. A total of 92 diatom samples were counted, with 3-6 replicate samples from each site, and 273 diatom taxa were identified in these samples.

For practical reasons it has been necessary to base characterisation of the diatom epilithon on single groups of samples collected during the summers of 1991 and 1993. Therefore, although within sampling period variability can be evaluated, there is at present no study of inter and intra-annual community variations at these remote lakes. However, there is little seasonal variation in the composition of epilithon and other diatom communities of upland acid lakes (Jones & Flower 1986).

The results from all sites are summarised in Figure 3.1 which shows the abundances across all sites of the 20 taxa which occurred at percentages of more than 20%. The composition of samples from the AL:PE 1 sites is described elsewhere (Wathne *et.al.* 1995), here the whole epilithic dataset will be considered.

Figure 3.1a. AL:PE 2. Epilithic diatoms. Summary diagram showing species occuring at abundances greater than 20%.

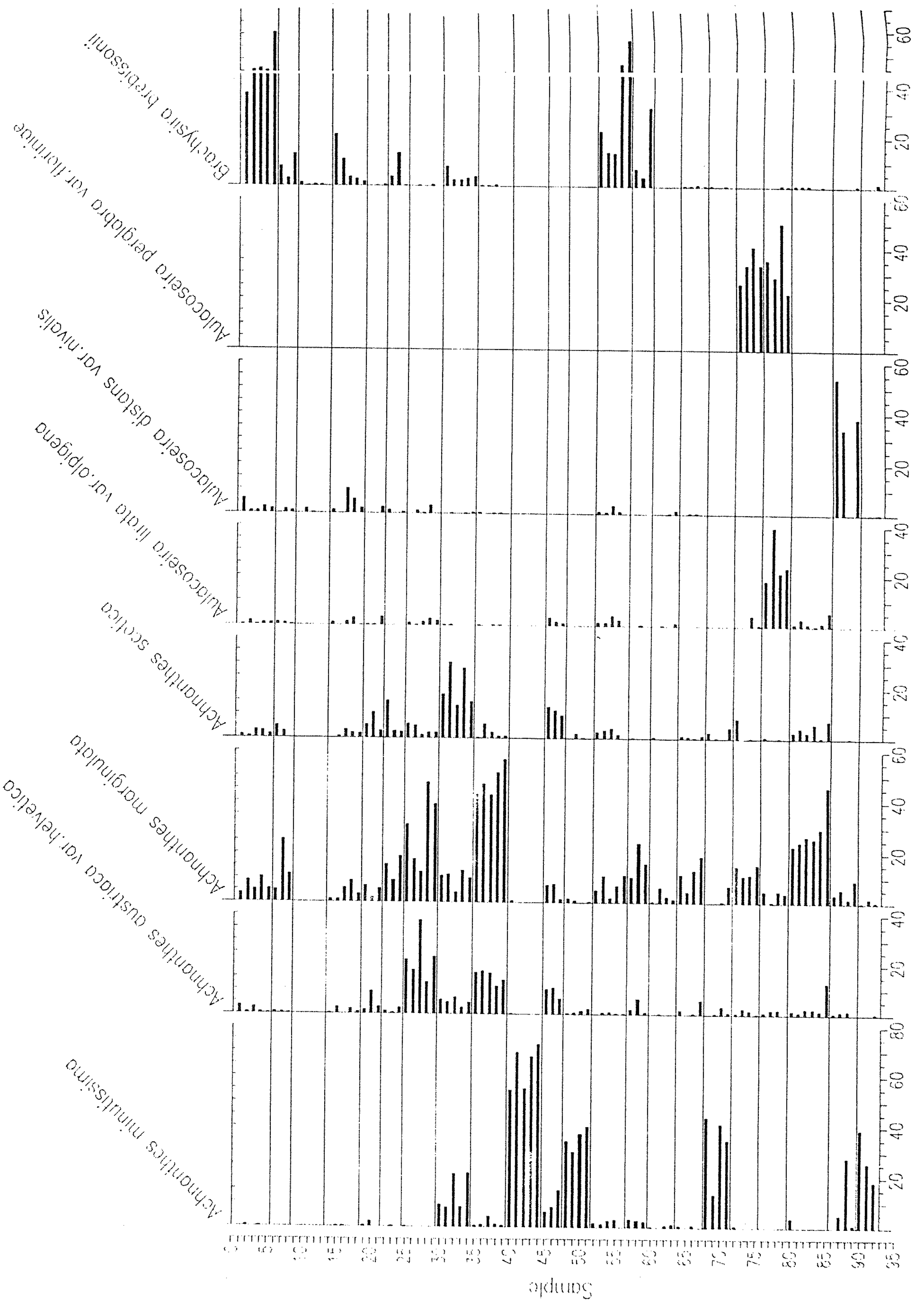
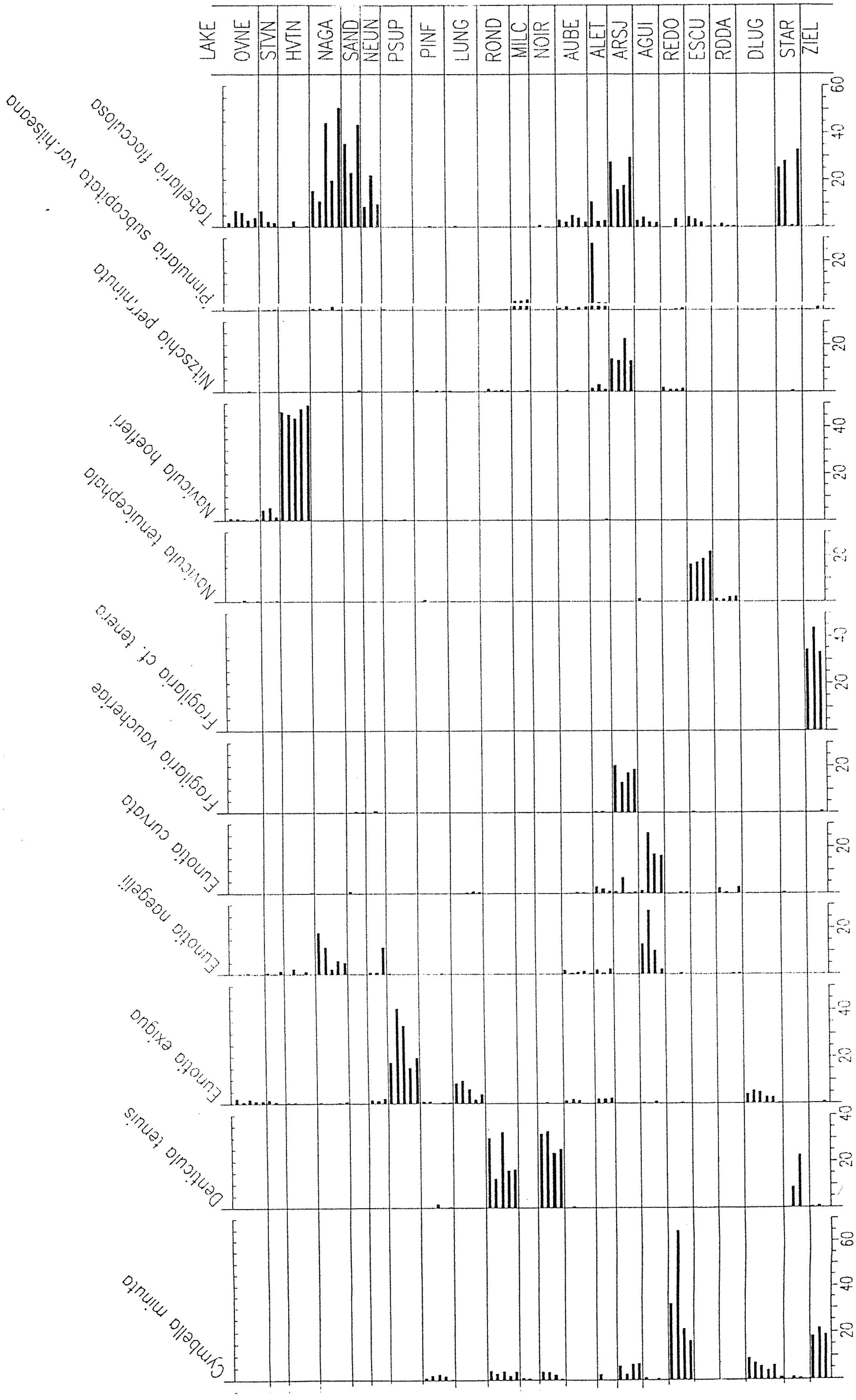


Figure 3.1b. AL:PE 2. Epilithic diatoms. Summary diagram showing species occurring at abundances greater than 20% (Continued).



a) Svalbard

The epilithic diatom community of Arresjoen (ARSJ) is relatively diverse. The most abundant diatom taxa in the lake are *Tabellaria flocculosa, Nitzchia perminuta, Fragilaria vaucheriae* and *Cymbella minuta.*

b) Kola

Analysis of the epilithic diatom community of lakes Chuna and Chibini are not available at present.

c) Norway

The epilithic diatom communities of Øvre Neådalsvatn (OVNE), Stavsvatn (STVN) and Lille Hovatn (HVTN) are described in (Wathne *et.al.* 1995).

d) British Isles

The epilithic diatom communities of Lochnagar (NAGA) Sandy Loch (SAND) and Lochan nan Eun (NEUN) are described in (Wathne *et.al.* 1995). Diatom epilithon was affected by a recent water level rise before sampling in Loch Maam.

e) Iberia

The diatom epilithon samples taken from La Caldera at the time of sediment coring had extremely low diatom concentrations and were not countable as a result. Although diatom epilithon from this site has been recorded previously (Sanchez-Castillo 1988). Diatom epilithon from Lagoa Escura is dominated by *Aulacoseira perglabra* var. *florinae, Navicula tenuicephala* and *Achnanthes marginulata.* Diatom epilithon samples were unavailable from Laguna Cimera.

f) Pyrenees

The epilithic diatom community of Étang d'Aubé is described in (Wathne *et.al.* 1995). In addition to this site epilithic diatoms were analysed from samples taken in 1993 from Étang d'Alet the French Pyrenean site close to Étang d'Aubé. This lake has a diverse diatom epilithon with *Achnanthes marginulata, Brachysira brebissonii* and *Tabellaria flocculosa* the most abundant taxa. *Pinnularia subcapitata* var. *hilseana* was dominant in a single sample.

In the Spanish Pyrenees, at sites close to the French Pyrenean lakes, diatom epilithon was analysed at two sites: Lago Aguilo and Lago Redo. The flora of Lago Aguilo is dominated by *Achnanthes marginulata, Eunotia naegelii* and *Eunotia curvata.* Diatom communities in Lago Redo are dominated by *Cymbella minuta* and *Achnanthes minutissima.*

g) Alps

The epilithic diatom community of Lac Rond (ROND) is described in (Wathne *et.al.* 1995). Lac Noir (NOIR) has a diatom community dominated by the circumneutral diatoms, *Achnanthes minutissima* and *Denticula tenuis*, very similar to that of Lac Rond. Like the diatom community of Lac Rond the species found in Lac Noir reflect a high lakewater pH resulting from the buffering effect of catchment geology on lakewater chemistry.

The epilithic diatom communities of Lago Lungo (LUNG), Lago di Latte (MILC), Lago Paione Superiore (PSUP) and Lago Paione Inferiore (PINF) are described in (Wathne *et.al.* 1995). Diatom epilithon samples are unavailable from Zgornje Krisko Jezero (ZKJZ).

h) Tatra

The diatom epilithon of Dlugi Staw (DLUG) is dominated by *Achnanthes marginulata*, with *Cymbella minuta* and *Eunotia exigua* common. *Achnanthes austriaca* var. *helvetica* is abundant (c. 15%) in a single sample. There is some variation in the diatom epilithon of Starolesnianske Pleso (STAR). In three samples *Tabellaria flocculosa* and *Aulacoseira distans* var. *nivalis* are most common, and in two samples *Denticula tenuis* and *Achnanthes minutissima* are the dominant taxa. The diatom epilithon of Zielowny Staw (ZIEL) is dominated by *Achnanthes minutissima, Cymbella minuta* and *Fragilaria* cf. *tenera*. Diatom epilithon samples are unavailable from Nizne Terianske.

As amongst the AL:PE 1 group of diatom epilithon data, clear differences in species composition between sites are apparent in the combined dataset (Figure 3.1). Given the multivariate nature of the sample/species data (Figure 1 shows only the 20 taxa occurring at abundances of more than 20%) the ability to compare samples within and between sites is limited using only histograms of the dominant species to represent the data. Therefore detrended correspondence analysis (DCA), is used to compare the floristic composition of all 92 samples. All taxa are used in the ordination, however, rare taxa are downweighted.

In Figure 2 (see Appendix for sample/site codes) the sample scores along the first two ordination axes are plotted for each sample. A second DCA plot (Figure 3.3) shows the scores of the main species on the same ordination axes. This species plot indicates the diatom taxa that are most influential in determining the position of samples (see species list in the Appendix for diatom species codes). The similarity in species composition of some samples causes them to plot close together, obscuring other points and labels. Therefore, for clarity, sample scores for the replicate samples from each site are plotted separately in the Appendix.

The consistency of diatom composition within sites is clear from the close proximity of the replicate samples from each site (Figure 3.2 & individual site plots in the Appendix). Only at Starloesnianske Pleso (086-089), as is apparent from both the histogram and DCA sample plot, is there significant within site variability in sample composition.

Sites within each region usually have similar diatom epilithon composition. This can be seen both from the histogram and from the DCA axis 1 and axis 2 scores. For example the group of samples from the 3 sites in the Cairngorm Mountains in the British Isles plot close together (019-026 & 047-049). The same is true for lakes Paione Superiore and Paione Inferiore (032-041); Lagoa Redonda and Lagoa Escura (061-064, 069-072); Lago Lungo and Lago di Latte (011-015, 016-018); and for some of the Zielowny Staw and Starolesnianske Pleso samples (090-092, 086-089), but Dlugi Staw (076-081) is separated from these Tatra sites. However, the diatom epilithon compositions of the Pyrenean sites Aube, Alet and Aguilo (Aube 001-005, Alet 073-075, Aguilo 065-068) are similar whilst that of Redo is different. This is shown most clearly by the higher axis 1 scores of Lake Redo samples(057-060) in the DCA plot.

There are also some similarities in diatom composition between regions. For example, at the extreme right of the DCA plot are the samples from Lac Rond (042-046) and Lac Noir (053-056). Closest in the plot to these French Alps lakes are samples from Zielowny Staw (090-092), a site which also has a high

Figure 3.2. DCA of samples analysed for epilithic diatoms.

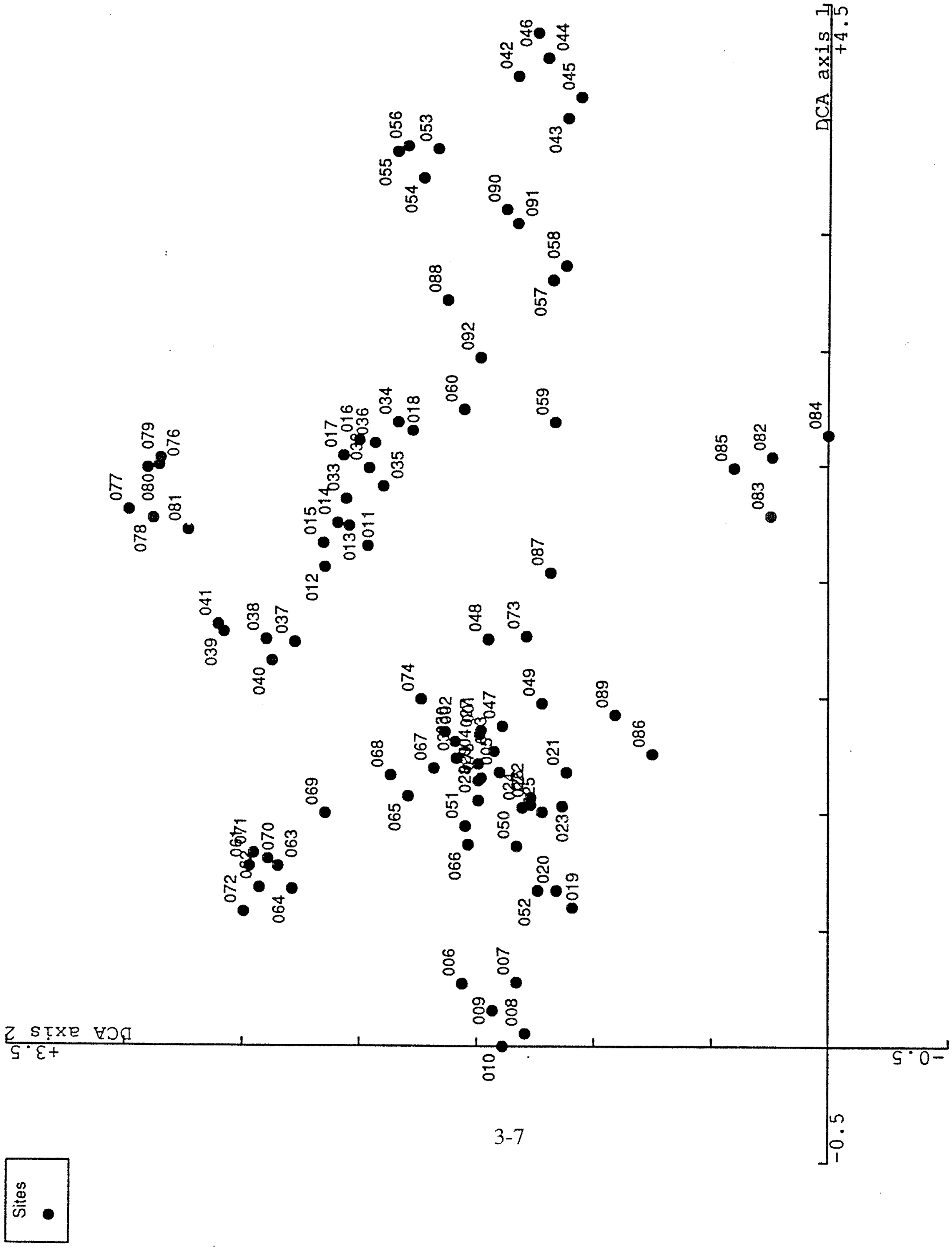
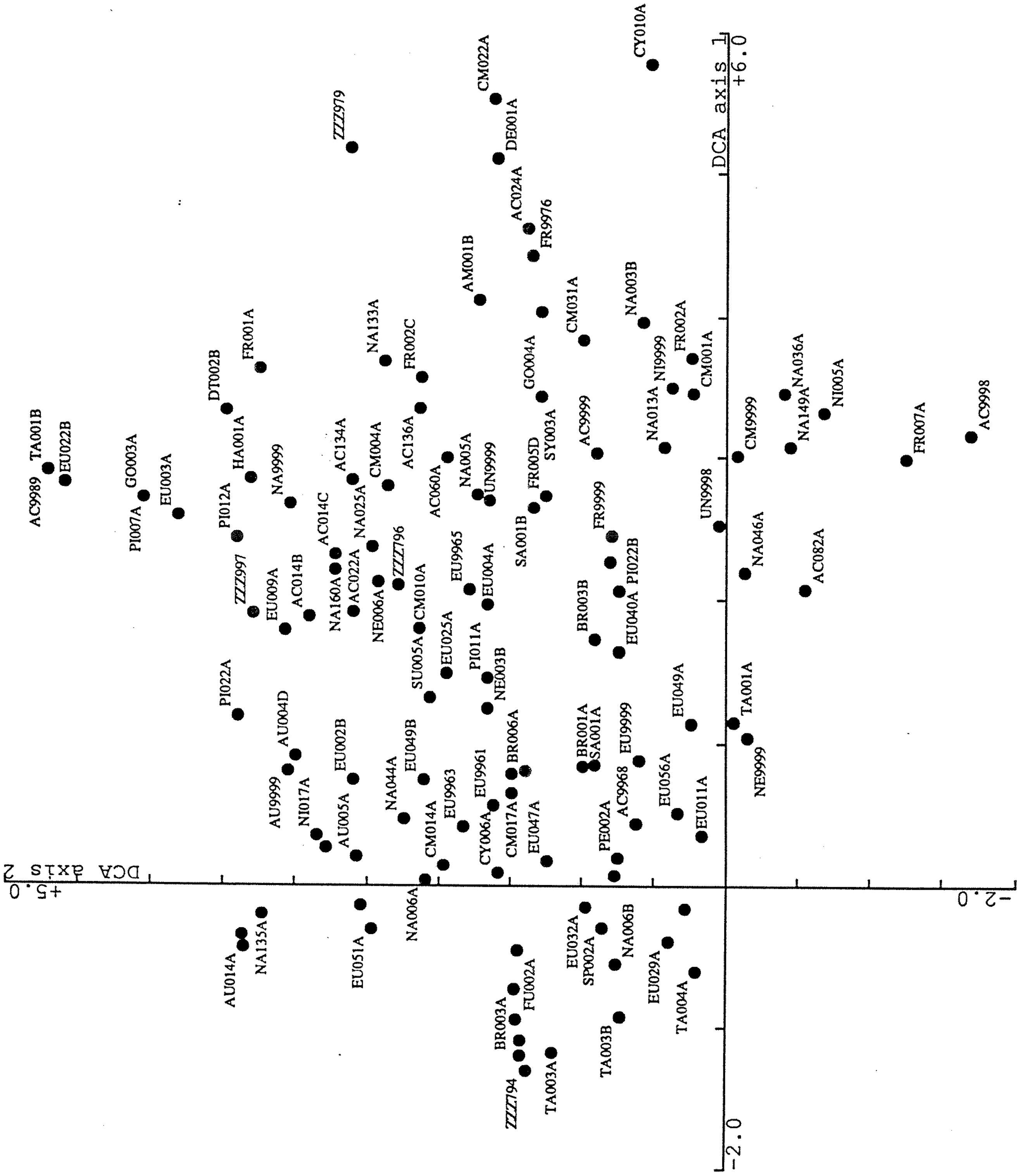


Figure 3.3. DCA of main taxa in epilithic diatom samples.



measured lakewater pH. The species influencing these sites can be seen on the species plot of the main taxa (Figure 3.3). Circumneutral and alkalophilous taxa such as *Cymbella minuta*, *Denticula tenuis*, *Cymbella affinis* and *Amphora ovalis* var. *libyca*. Similarly a group of lower pH lakes in the British Isles (Lochnagar 019-023, Sandy Loch 047-049, Loch Nan Eun 023-026), the Pyrenees (Aube 001-005, Alet 073-075, Aguilo 065-068), and the Norwegian lakes Ovre Neadalsvatn (027-031) and Stavsvatn (050-052) form a group towards the left of the plot. In this case the species influencing the sample positions appear to include various *Tabellaria* sp., *Eunotia* sp and *Brachysira* sp. At the extreme left Lake Lille Hovatn is the most acid of the AL:PE sites (1991 pH 4.67).In part, therefore, axis 1 shows a gradient of low to high pH. In contrast some samples appear to have no analogues amongst the others, for example the replicate samples from Arresjoen (082-085) plot as outliers with the lowest axis 2 scores whilst those samples from Dlugi Staw (076-081) have exceptionally high axis 2 scores. These lakes have approximately similar mean measured pH values (5.81 and 5.78 respectively), as would be expected from their similar DCA axis 1 scores, but their diatom compositions must reflect other differences in lake characteristics.

As suggested in the report on AL:PE 1 diatom epilithon it is possible to use diatom epilithon as a means of estimating mean lakewater pH. Using the new AL:PE diatom surface sediment/water chemistry calibration set the possibilities of this method have been tried (Birks pers.comm.) and show that even using the calibration set which was developed from and for diatom surface sediments, quite good pH estimates can be made from diatom epilithon. It is noted that of the 273 epilithic taxa only 232 are present in the calibration set. This suggests that further taxonomic harmonisation of the epilithic data set is required. The results of the exploratory pH reconstruction are presented in the Appendix.

3.1.4 Overall Summary and Conclusions

Several points emerge from the analysis of the diatom epilithon, extending and confirming the results of the AL:PE 1 epilithic diatom programme.

i. Each of the 22 groups of samples shows small within site variation in species composition. This is indicated by the clustering of samples from each of the lakes. Rarely is there significant dispersion of the samples when DCA axis 1 and axis 2 species scores are plotted. Within site variation is generally less than between site variation.

ii. In many cases groups of samples from the same region also cluster together. This is principally the result of similar geologies and/or the influence of similar levels of atmospheric deposition. Therefore where there are different catchment geologies within a region, as in the case of the Pyrenean and Tatra groups of lakes there is variability in the epilithic diatom communities.

iii. Axis 1 can be interpreted principally as an axis of increasing pH (or related chemical factors). Low pH sites plot to the left and high pH sites to the right. However, there are significant variations due to a combination of other lake catchment and water chemistry variables.

iv. The possibility of using epilithic diatom communities to estimate present day mean pH has been demonstrated using the new AL:PE surface sediment diatom/water chemistry calibration set applied to epilithic samples.

In the AL:PE project the analysis of epilithic diatom communities has been used to compare the floristic composition of study sites. Variation in epilithic diatom composition can be ascribed primarily to between site differences in water chemistry and catchment characteristics. The technique therefore has potential for continued use, for example in the monitoring of such sites (see for example Patrick *et.al.* in press), and as an aid to determining the sensitivity and acidification status of sites.

3.1.5 References

Battarbee, R.W. (1986). Diatom analysis. *Handbook of Holocene Palaeoecology and Palaeohydrology* (ed. B.E. Berglund), pp. 527 - 570. Wiley, Chichester.

Jones, V.J. & R.J. Flower (1986) Spatial and temporal variability in periphytic communities: palaeoecological significance in an acidified lake. In *Diatoms and lake acidity* (ed. J.P. Smol, R.W. Battarbee, R.B. Davis, & J. Meriläinen), pp 87 - 94.

Patrick, S.T., D.T. Monteith & A. Jenkins (eds.) *UK Acid Waters Monitoring Network: the first five years. Analysis and interpretation of results April 1988 to March 1993.* Ensis, London, in press.

Sanchez-Castillo, P.M. (1988) Algas de las lagunas de alta montana de Sierra Nevada (Granada, Espana) *Acta Botanica Malacitana*, 13: 21-52.

ter Braak, C.J.F. (1987) CANOCO - A FORTRAN *program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1)* TNO Institute of Applied Computer Science, Statistics Department, Wageningen, Netherlands, 95pp

Wathne, B.M., S.T. Patrick, D.T. Monteith & H. Barth (eds.) (1995) *AL:PE 1 Report for the period April 1991 - April 1993.* Report 9, Ecosystems Research Report Series, E.C., Brussels. 292 pp

3.2. Zooplankton

3.2.1 Introduction

The idea of using planktonic crustaceans to monitor environmental changes, recorded in the ecosystems of high mountain lakes, was based on the experience of Fott et al. (1994) from the High Tatra Mountains (Slovakia). They found that in alpine lakes which were acidified to pH 6.1 - 5.0, the original limnetic (open-water, planktonic) species (*Daphnia pulicaria, Arctodiaptomus alpinus, Cyclops abyssorum*) disappeared, and were not replaced by other limnetic species. Some small and shallow high mountain lakes have been acidified to the pH range 4.9 - 4.6. The original inhabitants of the open water of these lakes (*Ceriodaphnia quadrangula, Mixodiaptomus tatricus)* also disappeared. At present the only Crustacea to be found in the open water of both groups of lakes are the ubiquitous species *Chydorus sphaericus* and *Acanthocyclops vernalis.* A similar dissapearance of limnetic species was observed in the most acidified subalpine lakes in Sumava (Bohemia).

The AL:PE 2 project has provided an opportunity to compare the zooplankton fauna of remote lakes above the local tree line over a wide geographical range and to test whether a similar retreat of limnetic species can be observed within the group of AL:PE lakes.

3.2.2 Methods

The field and laboratory methods for studying zooplankton were designed with respect to the principles outlined by Tranter (1968) and Edmondson & Winberg (1971).

Field apparatus and equipment

Quantitative plankton net, Apstein type (with a mouth-reducing cone), 200 µm mesh size. The front opening 20 cm diameter, basis of the cone 36 cm diameter, height of the cone 38 cm, length of the net 62 cm, total length 100 cm. The net was designed for vertical hauls to sample quantitatively most Cladocera and Copepoda except of their early development stages (nauplii, early copepodites, neonates).

Qualitative plankton net with 40 µm mesh size was designed in the same dimensions as the previous one but without the cone, diameter of the front opening being 36 cm. A small net with 100 µm mesh size was used for taking samples from the littoral.

Inflatable boat, anchor.

Sampling procedure.

Zooplankton samples were taken at the same time as samples for chemical analyses and for benthic invertebrates.

The boat was anchored close to the maximum water depth. Vertical hauls (generally three) were taken with the quantitative net. The towing speed was about 0.3 m per second. The number of hauls and the towing length were noted.

A qualitative sample was taken from the open water using the 40µm net. This sample was taken in order to obtain rich material of zooplankton including small stages and small species for taxonomic determination.

A qualitative littoral sample was taken using the 100 µm net.

The samples were preserved with formol.

Determination

Cladocera and Copepoda were determined according to Herbst (1962), Kiefer (1978) and Amoros (1984). Inconclusive determinations were checked by Vladimir Korinek, Prague (Cladocera) and Zdenek Brandl, Ceske Budejovice (Copepoda).

Counting

Zooplankton from quantitative samples were counted in a Sedgwick-Rafter cell under an ordinary microscope. The total sample or its fraction was counted; fractionation was performed when prevailing species occurred in more than 400 individuals per sample. Species abundances were expressed as individuals per m^2.

Laboratories with running zooplankton programmes provided counting and determination of their samples themselves. The responsible persons were: Luis Cruz-Pizarro (Iberian and Pyreneean sites), Anton Brancelj (Zgornje Krisko Jezero), Marina Manca (Lago Paione Superiore and Inferiore), Bertha Taler and Danilo Tait (Lago di Latte and Lago Lungo), Peter Schaber (Schwarzsee o.S.). Catharine Duigan determined zooplankton from littoral samples of Lough Maam. The Kola samples were counted by Oksana Vandysh. All other samples were determined by Jan Fott and Miroslava Prazakova.

3.2.3 Results

The list of all Crustacea found in vertical hauls taken by the quantitative nets (#200 µm) is shown in Table 3.2.1, together with the species codes used in the tables and figures. The table of lakes, sampling dates, species and their mean abundance is included in the Table A5.1. Only one quantitative sample (from the year 1993 or 1994) is available for some lakes, for other lakes there are two samples, one from 1993 and the other from 1994. For the lakes where extensive national programmes were under way it was possible to include even more data, but for the sake of comparability, only samples from the period late summer - autumn were used. The data matrix for statistical analyses contains arithmetic means whenever more than one sample was available.

Classification of lakes (clustering) according to the zooplankton

The classification of lakes according to their zooplankton was performed using the TWINSPAN method, as described by van Tongeren (1987). The computation was performed on two data sets. Each data set appears as a two-dimensional table, with the lakes as rows and species abundance as columns. From the first data matrix all littoral and benthic species were excluded. These were defined taxonomically as all members of the cladoceran family Chydoridae (notably *Chydorus sphaericus*), and the copepod genera *Acanthocyclops, Eucyclops, Macrocyclops* and *Tropocyclops*. The second matrix contains all species found. The areal densities (abundances) were transformed to order-of-magnitude levels (0-9 as 1, 10-99 as 2, 100-999 as 3 etc.).

CLADOCERA	
Acroperus harpae	Acro harp
Alona affinis	Alon affi
Alona elegans	Alon eleg
Alona quadrangularis	Alon quad
Alonella nana	Alla nana
Alonopsis elongata	Alis elon
Bosmina longispina	Bosm lina
Bosmina sp.1	Bosm sp1
Bosmina sp.2	Bosm sp2
Bythotrephes longimanus s.lat.	Byth long
Daphnia longispina	Daph long
Daphnia pulicaria	Daph puli
Diaphanosoma brachyurum	Doma brac
Ceriodaphnia quadrangula	Ceri quad
Chydorus sphaericus s. lat.	Chyd spha
Drepanothrix dentata	Drep dent
Holopedium gibberum	Holo gibb
COPEPODA - CALANOIDA	
Arctodiaptomus alpinus	Arct alpi
Diaptomus cyaneus	Diap cyan
Eudiaptomus gracilis	Eudi grac
Eudiaptomus vulgaris	Eudi vulg
Heterocope saliens	Hete sali
Mixodiaptomus laciniatus	Mixo laci
COPEPODA - CYCLOPOIDA	
Acanthocyclops vernalis	Acan vern
Cyclops abyssorum	Cycl abys
Cyclops sp.	Cycl sp1
Cyclops cf. vicinus	Cycl vici
Cyclops scutifer	Cycl scut
Eucyclops serrulatus	Eucy serr
Macrocyclos albidus	Macr albi
Macrocyclops fuscus	Macr fusc
Mesocyclops leuckartii	Meso leuc
Tropocyclops prasinus	Tropo pras

Tab. 3.2.1: List of Crustacea from quantitative samples (vertical hauls). Limnetic (open-water. planktonic) species are underlined. Species codes as used in other Tabs. and Figs. in this chapter.

A. The classification of sites according to the limnetic zooplankton, with the family Chydoridae and littoral & benthic copepods excluded.

The printed output of the computation (Tab. A5.2) shows the sites, the list of limnetic species with their transformed abundances and the dichotomy of sites and species. The dichotomy of sites is shown more clearly in Table. 3.2.2.

The two acidified lakes from the Tatra region (labelled AT: Starolesnianske Pleso and Dlugi Staw) are removed from the TWINSPAN analysis, as their zooplankton consists entirely of excluded littoral and benthic species.

At the first level of dichotomy, two outliers (?T and ?F) among the sites become apparent. The lake Chibini is exceptional by its highest flowthrough (mean retention time 11 days) among all the AL:PE 2 lakes. The sample from lake Arresjoen contains a *Bosmina* species, the taxonomic status of which is uncertain; it is different from *Bosmina longispina* which occurs in other AL:PE lakes. For an unequivocal determination, an examination of males would be necessary (Vladimir Korinek, personal communication). The *Cyclops* species from Arresjoen, here quoted as *Cyclops* cf. *vicinus*, is present only as immature stages (copepodites). Neither *Cyclops vicinus* is present in any other AL:PE lake.

At the second level of dichotomy a group of southern, high mountain lakes (latitude < 50 N, altitude >1600 m) becomes apparent (label S). These belong to the Tatra region, the Alps, the Pyrenees and Iberia. But the southernmost and highest lake of all AL:PE sites, lake La Caldera, is unified at level 2 with the northern group of lakes (label N). The similarity of the low-latitude, high-altitude La Caldera with the high-latitude and low-altitude lake Chuna (N3) is due to the co-occurring *Mixodiaptomus laciniatus*.

The lake group labelled N (level 3) is composed of northern lakes from the Kola region, Norway and the British Isles (latitude 54 - 68 N) with *Bosmina longispina* and *Holopedium gibberum* as characteristic limnetic species. The group labelled N2 (northern maritime: Lochnagar, Lille Hovvatn, Lough Maam) have *Eudiaptomus gracilis* as the third characteristic species. The lakes in this group are high in chloride (Cl> 3 mg/l) and have the longest ice-free period (>7 months).

The two northern lakes, labelled as N1 (Ovre Neadalsvatn and Stavsvatn), are both ice-free for 5 months or less. *Bosmina* and *Holopedium* occur there, accompanied by *Cyclops*.

Among the northern lakes, Stavsvatn, Lochnagar and Lough Maam are in the pH group 5-6, Lille Hovvatn is a highly acidified lake with pH under 5, and Chuna has pH > 6.

The „southern, high mountain“ lakes (labelled S at the level 2) are subdivided into a loosely defined group S1 with *Daphnia longispina* (Lagoa Escura, Laguna Cimera, Lago Paione Superiore and Lago Aquilo), a well defined group S2 (Lago Lungo, Schwarzsee o.S., Terianske pleso, Zielony Staw, Lago di Latte) with *Cyclops abyssorum* as the only component of limnetic zooplankton, and the two lakes S3 (Lago Redo, Zgornje Krisko jezero) with *Daphnia pulicaria*. The rather poor zooplankton of Lago Paione Inferiore is difficult to classify - a possible reason of the absence of zooplankton might be the rather low retention time. Among the S1 group there are two lakes (Lagoa Escura, Lago Paione Superiore) falling into the pH limits 6 - 5, in the S2 group there is one (Schwarzsee o. S.).

B. Classification of sites according to the zooplankton, all species included.

The TWINSPAN table (Tab. A5.3) shows all species encountered in the samples from AL:PE lakes. The dichotomy of sites (Tab 3.2.3), which is influenced by the presence of non-planktonic species, is comparable with the dichotomy based on the planktonic species only (Tab. 3.2.2). Clustering of the „northern lakes“ (N1,N2,N3) is almost identical in both classifications, the S3 group (*Daphnia pulicaria* lakes) and TA group (acidified Tatra lakes with *Chydorus* and

Table 3.2.2: TWINSPAN two-way table of crustacean zooplankton species (rows) in ALPE lakes (columns). Only limnetic (open-water) species are included. Vlues are logarithmic (base 10) classes of abundance per unit area. Species codes are given in the Table 3.2.1. The bottom margin shows the classification of lakes with 6 levels of division. See the Table 3.2.3.

```
               KRMZNSLPAPCECCLLLSOAC
               reiiTcaagaisahMHatNrh
               idleehniuimcluaogaeri
               soclrwgIiSeudnavavaeb
               k.hoiasnlurreamarsdsi

               111 111111212
               183902467509138675412

18 Cycl vici   -------------------5-  11
 7 Bosm sp1    -------------------5-  11
 8 Bosm sp2    --------------------2  10
16 Cycl abys   55354552432----------  0111
13 Arct alpi   5------1-1-----------  011011
 6 Daph puli   55----------2--------  011010
10 Diap cyan   -3-------------------  01100
12 Eudi vulg   --------4------------  01011
 5 Daph long   --------5545---------  01010
 2 Doma brac   -----------4--4------  0100
14 Mixo laci   ------------55-------  0011
20 Meso leuc   -------------4-------  0010
 3 Holo gibb   --------4----445555--  000111
 9 Bosm lina   -------------554454--  000110
15 Hete sali   ---------------3-32--  000101
19 Cycl sp1    -----------------5---  000100
17 Cycl scut   ------------------5--  000100
 1 Byth long   ------------------2--  000100
11 Eudi grac   --------------555----  00001
 4 Ceri quad   --------------5------  00000

               000000000000000000011
               000000000000011111101
               0000000011110111111
               001111110111 011111
               01000001 001  00011
                 01111  01   01101
```

Table 3.2.3: TWINSPAN two-way table of crustacean zooplankton species (rows) in ALPE lakes (columns). All species (also the littoral and benthic ones) included. Values are logarithmic (base 10) classes of abundance per unit area. Species codes are given in the Table 3.2.1. The bottom margin shows the classification of lakes with 6 levels of division. See the Table 3.2.4.

```
                  CASDRKSMLNZPPAECCCLLLSO
                  artlerciaTiaagsihhMaHtN
                  lraudihlneeiiucmiuagoae
                  dergoswcgrlSIiuebnaavva
                  esoi.kahsiounlrriamrasd

                  2 11211111 11122
                  31210345609789122387654
29 Alon eleg      2----------------------   00000
 6 Daph puli      2---55-----------------   00001
 7 Bosm sp1       -5---------------------   000100
18 Cycl vici      -5---------------------   000100
20 Acan vern      --41-------------------   000101
26 Chyd spha      1453-34333-2-33323-----   00011
10 Diap cyan      ----3------------------   00100
16 Cycl abys      ----5553545324-2-------   001010
13 Arct alpi      -----5-----11----------   001011
21 Eucy serr      ---------2-----42------   001100
 8 Bosm sp2       ----------------2------   001101
31 Alla nana      ---------------3-------   001101
22 Trop pras      --------------43-------   001110
 5 Daph long      -----------5-554-------   001111
12 Eudi vulg      -------------4---------   001111
23 Macr fusc      --------------2--------   001111
27 Acro harp      ----------333-2--------   001111
30 Alon quad      -----------21----------   001111
33 Drep dent      --------------2--------   001111
28 Alon affi      ----------3---2----3---   01
 2 Doma brac      --------------4---4----   10
 4 Ceri quad      ------------------5----   110000
11 Eudi grac      ------------------555--   110001
 3 Holo gibb      -------------4---445555   110010
 9 Bosm lina      -----------------554454   110010
 1 Byth long      ----------------------2   110011
15 Hete sali      --------------------332   110011
17 Cycl scut      ----------------------5   110011
19 Cycl sp1       ---------------------5-   110011
24 Macr albi      -----------------3-----   1101
25 Meso leuc      -----------------4-----   1101
32 Alis elon      -----------------3-----   1101
14 Mixo laci      5----------------5-----   111

                  00000000000000000111111
                  01111111111111111011111
                   0001111111111111 00011
                   0110000001111111 01101
                    010011110000011  01
                      0100010000101
```

Acanthocyclops) appear in the both classifications. The difference between the S1 (*Daphnia longispina* - lakes) and S2 (*Cyclops abyssorum* only - lakes) disappeared, however, in the latter classification.

Species - environment relations

Relation of zooplankton species to environmental variables was examined using Canonical Correspondence Analysis performed with the programme CANOCO (ter Braak 1986, 1987). The lakes Lough Maam and Lagoa Escura were excluded from the analysis because of missing environmental values. Species occurring in only one lake were excluded, which also excluded all taxa from lake Arresjoen. The abundances were $\log_e$ transformed.

The environmental variables were chosen according to the expectancy of their importance and according to the availability of the parameters measured at most of the lakes. Labile aluminium, pH and alkalinity (not shown on the graph) have been chosen as the main chemical variables describing the acidification status. The physical variables are: ice-free period, altitude, mean depth and retention time. Chloride indicates the proximity of the sea with its influence on local climate. Presence or absence of fish has been chosen as the main biological variable.

As in the cluster analysis, the whole procedure was run on two data sets, firstly with planktonic species only (littoral and benthic species excluded) and secondly with all species.

A. Planktonic species only (Fig. 3.4)

A well defined group of species *Eudiaptomus gracilis, Heterocope saliens, Holopedium gibberum* and *Bosmina longispina* were associated with lower altitude but long ice-free period and elevated chloride (indicating the oceanic impact on the climate). Under such conditions these species tolerated lowered pH and elevated labile Al.

Two species - *Mixodiaptomus laciniatus* and *Daphnia pulicaria* were associated with high pH (and retention time). The former species with (relatively) elevated TOC, the latter species with high altitude.

The remaining three species (*Arctodiaptomus alpinus, Cyclops abyssorum* and *Daphnia longispina*) were associated with high altitudes but less with elevated pH. The occurrence of *Daphnia longispina* in the low range of TOC was surprising.

B. All species included (Fig. 3.5)

The position of the *Holopedium, Bosmina, Eudiaptomus* and *Heterocope* (shallow, long ice-free, low pH, elevated Al*)* did not change when the littoral and benthic species were included. In addition *Daphnia pulicaria, Arctodiaptomus alpinus, Cyclops abyssorum* and *Mixodiaptomus laciniatus* retained their position with respect to pH and altitude. The littoral and benthic species formed a group of their own.

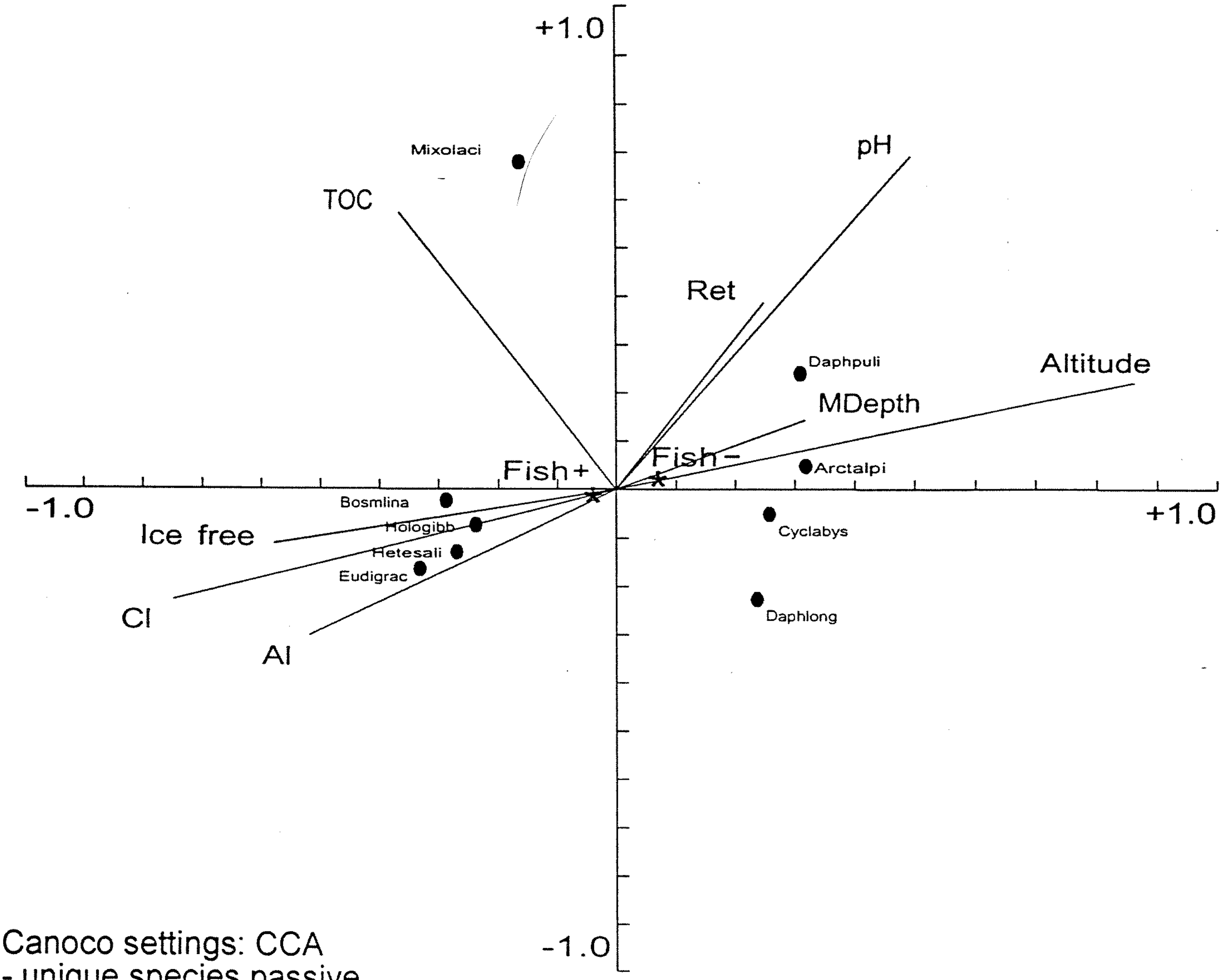
3.2.4 Discussion

Geographical limits

The AL:PE sites lie in eight of twenty zoogeographical regions in Europe, as defined by Illies (1978) in his compendium Limnofauna Europaea: 1. Iberian peninsula, 2. Pyrenees (above 1000 m line), 4. Alps, 10. Carpathians (above 500 m line), 17. Ireland, 18. British Isles, 20. Scandinavian mountains, 21. Tundra. One site (Arresjoen at Svalbard) does not fit into any of the Illies' regions.

Table 3.2.4 shows distribution of zooplankton species from AL:PE lakes in the eight regions according to Illies (1978), areas number 17+18 and 20+21 being unified. Four species from the

Fig. 3.4: Species - environment biplot based on cononical correspondense analysis of the abundances of limnetic (open-water) crustacean zooplankton, with respect to selected environmental variables. Variables: pH, labile inorganic Al, total organic carbon, mean depth, altitude, ice free period, presence or absence of fish.
Species codes are given in the Table 3.2.1.

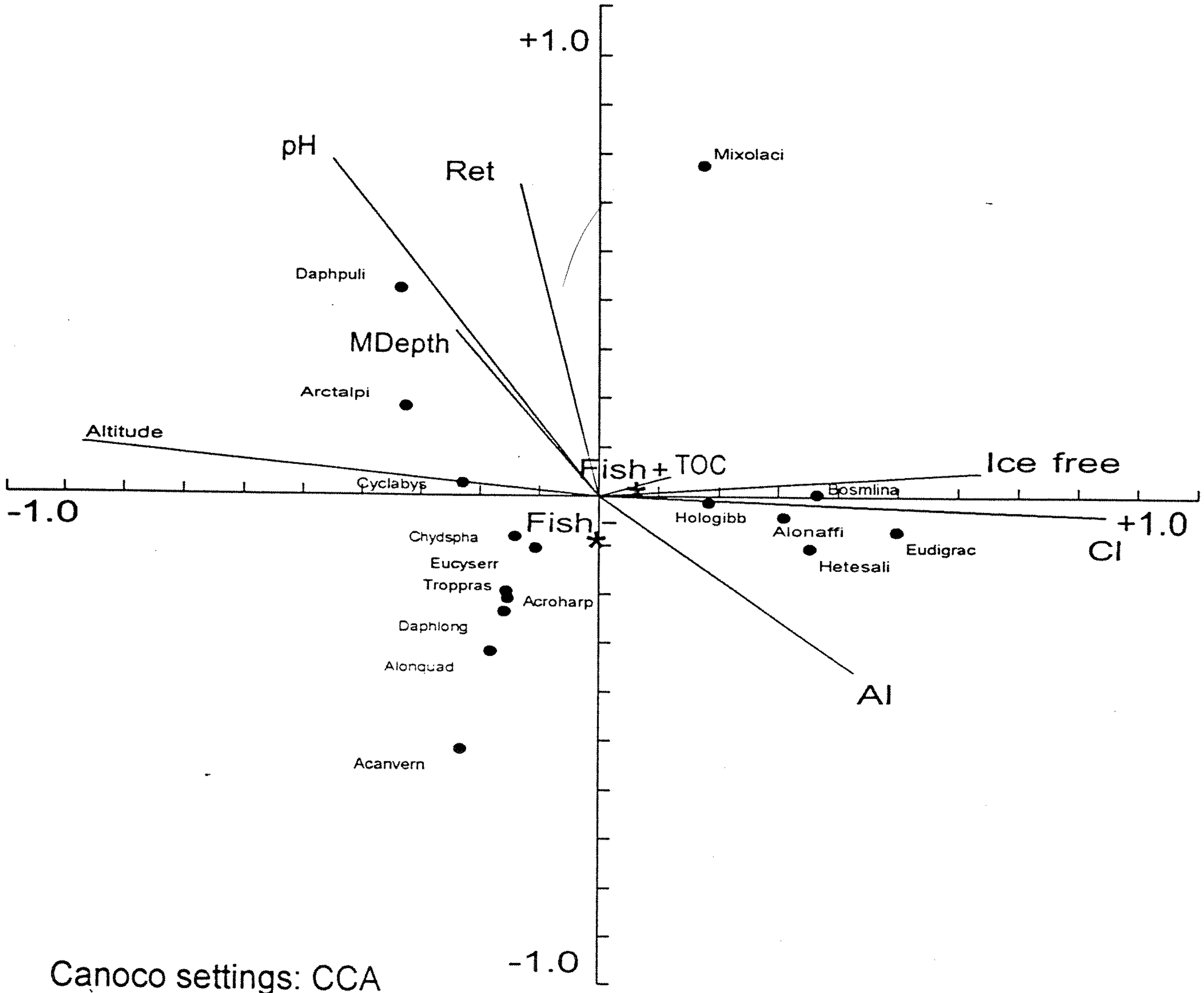


Canoco settings: CCA
- unique species passive
- Arresjoen, Escura & Lough Maam exluded
- species scores are weighted mean sample scores
- species log (ln) transfromed

Canodraw settings:
- alkalinity not shown

Source data do not include littoral & benthic species

Fig. 3.5: Species - environment biplot - as in the Figure 3.1, but with littoral and benthic species included.



Canoco settings: CCA
- unique species passive
- Arresjoen, Escura & Lough Maam exluded
- species scores are weighted mean sample scores
- species log (ln) transformed

Canodraw settings:
- alkalinity not shown

Source data include littoral & benthic species

Iberian and Pyreneean AL:PE lakes that are not mentioned by Illies (1978) from these regions (*Mixodiaptomus laciniatus, Diaptomus cyaneus, Drepanothrix dentata, Daphnia pulicaria*) were added to the fauna lists.

From the Table 3.2.4 it follows that most of the species found in the AL:PE lakes have a very broad geographical distribution. This would mean that presence or absence of a particular species in a particular lake is determined mostly by ecological factors. But the absence of some species from the British Isles or the Iberian Peninsula is almost certainly caused by geographical barriers to their dispersal. Consequently, the clustering of AL:PE lakes according to their zooplankton fauna (Tabs. 3.2.2, 3.2.3) is determined by both environmental requirements of different species and, to a lesser extent, by zoogeographical factors.

Ecological limits

Importance of environmental, rather than geographical factors follow from the fact that some species (e.g. *Ceriodaphnia quadrangula, Daphnia longispina, Diaphanosoma brachyurum, Eudiaptomus vulgaris and E. gracilis)* are more widely distributed in some regions than is reflected by their presence in AL:PE lakes. One of the factors constraining their occurrence is high altitude. For instance, *Eudiaptomus gracilis* is probably much the commonest calanoid copepod in Europe, but it avoids high mountains. In the Alps its upper limit is about 1100 m (Kiefer 1978) it has never been found in the high Tatra lakes (Minkiewicz 1917, Stuchlik & al. 1985). On the other hand, the species reaches far to the north where it inhabits lakes above the local tree line. This has also been documented by the present study. All the five AL:PE lakes in the Alps lie above 2000 m; the high altitude may itself be responsible for the simplicity of zooplankton communities of these lakes.

In his faunistic and ecological study on freshwater Crustacea of Yorkshire, Fryer (1993) published ranges of pH in which the species occur; many Yorkshire species were found in the AL:PE lakes (Tab. A5.4). The lower pH limits stated by Fryer (and by other authors - see the Tab. A5.4) are often acid. At the lowest pH limits the chance of crustaceans surviving is enhanced by the presence of dissolved humic matter that ameliorates the toxic effects of aluminium and heavy metals (Nilssen & Sandoy 1990, Sarvala & Halsinaho 1990). The high-altitude AL:PE lakes are all clearwater lakes with low concentrations of organic matter. They are all phosphorus limited oligotrophic lakes, some of them with very low phytoplankton (although not measured in the present study, except for the lakes in the Tatra and the Alps) as the food source for the zooplankton. Other constraints in high-altitude lakes are low temperature (as expressed by short ice-free period) and UV radiation. This means that zooplankton of AL:PE lakes might be more sensitive to lowered pH (and other environmental changes related to acidification) than the same species in lowland, more productive or humic lakes. A possible evidence is the recent retrieval of *Ceriodaphnia quadrangula* from the lake Starolesnianske as it is documented by comparison of the present state with earlier data in literature (Minkiewicz 1917) and by our analysis of the sediment core (Fig. A8.3.1, A8.3.2). The species has retrieved under pH and labile Al concentrations that would be tolerated in a lowland humic lake (Tab. A5.5). Other examples of very recent retrieval of *Arctodiaptomus alpinus* from acidified Tatra lakes are given by Stuchlik et al. (1985) and Fott et al. (1994).

The two species from the AL:PE survey that were not found in lowered pH are *Mixodiaptomus laciniatus* and *Daphnia pulicaria.* While nothing has been found in literature on the pH requirements of *M. laciniatus,* preferences of *D. pulicaria* can be discussed. The High Tatra populations inhabit lakes above the forest line in the pH interval 6.3 - 7.2. The species was not found in acid humic lakes below the tree line (where it is replaced by *D. longispina*), and in acidified lakes above the tree line (Hrbacek et al. 1974, Stuchlik et al. 1985).

None of the four AL:PE lakes in the High Tatra are inhabited by *Daphnia pulicaria* at present, but the species lived in three of them in the past: in Zielony Staw, Dlugi Staw and Terianske pleso (Minkiewicz 1917, *D. pulicaria* quoted by him as *D. wierzejskii*). The reasons of retrieval for disappearance from the three lakes may be different.

Table 3.2.4: Geographical distribution of zooplankton species from the ALPE lakes. Regions according to Illies: 1 - Iberian peninsula, 2 - Pyrenees. 4 - Alps, 10 - Carpathians, 17 + 18 - British Isles, 20 + 21 - Scandinavian mountains and tundra.

		GEOGRAPHICAL REGIONS					
	Species	**1**	**2**	**4**	**10**	**17+18**	**20+21**
Limnetic	Bosmina longispina			▨		▨	▨
CLADOCERA	Bythotrephes longimanus s.lat.					▨	▨
	Ceriodaphnia quadrangula	▨	▨	▨	▨	▨	▨
	Daphnia longispina	▨	▨	▨	▨	▨	▨
	Daphnia pulicaria	▨	▨	▨	▨		
	Diaphanosoma brachyurum	▨	▨	▨	▨	▨	▨
	Holopedium gibberum		▨	▨	▨	▨	▨
Limnetic	Arctodiaptomus alpinus			▨	▨		▨
COPEPODA	Diaptomus cyaneus	▨	▨	▨			
Calanoida	Eudiaptomus gracilis			▨	▨	▨	▨
	Eudiaptomus vulgaris		▨	▨	▨	▨	▨
	Heterocope saliens			▨			▨
	Mixodiaptomus laciniatus	▨	▨	▨		▨	▨
Limnetic	Cyclops abyssorum	▨	▨	▨	▨		▨
COPEPODA	Cyclops scutifer						▨
Cyclopoida	Mesocyclops leuckarti		▨	▨	▨	▨	▨
Littoral & benthic	Acroperus harpae	▨	▨	▨	▨	▨	▨
CLADOCERA	Alona affinis	▨	▨	▨	▨	▨	▨
	Alona elegans	▨	▨	▨		▨	
	Alona quadrangularis	▨	▨	▨	▨	▨	▨
	Alonell nana	▨	▨	▨	▨	▨	▨
	Alonopsis elongata			▨	▨	▨	▨
	Drepanothrix dentata	▨				▨	▨
	Chydorus sphaericus s. lat.	▨	▨	▨	▨	▨	▨
Littoral & benthic	Acanthocyclops vernalis	▨	▨	▨	▨	▨	▨
COPEPODA	Eucyclops serrulatus	▨	▨	▨	▨	▨	▨
	Macrocyclops albidus	▨	▨	▨	▨	▨	▨
	Macrocyclops fuscus	▨	▨	▨	▨	▨	▨
	Tropocyclops prasinus	▨		▨	▨	▨	

The lake Zielony Staw, which in the past was also inhabited by *Holopedium gibberum* and *Polyphemus pediculus* in the past, and was stocked by brook trout in 1948 and later on repeatedly in the 50's. The effect of fish stocking on the zooplankton of Zielony Staw and other Tatra lakes in Poland was described by Gliwicz and co-workers (the summarising paper: Gliwicz 1985). The coincidence of the time of stocking with brook trout and extinction of *Daphnia* was documented also by analysis of a sediment core (Gliwicz 1985).

Dlugi Staw was stocked with brook trout in 1960 but it is apparently fishless today. The absence of *Daphnia* might have resulted from acidification of the lake. The lake has been acidified to pH5.6, alkalinity 7 μeq/l and LAL 48 μg/l. The phytoplankton biomass is extremely low (chlorophyll *a* = 0.01 μg/l). The extremely low chlorophyll is typical for Tatra lakes in this pH group (Vyhnalek et al. 1994) and may also be regarded as a consequence of acidification.

Terianske does not show signs of acidification with an alkalinity of 70 μeq/l. However, live *Daphnia* have not been encountered there in spite of great sampling effort of E. Stuchlik, J. Fott and M. Cerny since 1978 (Stuchlik et al. 1985 and unpublished results). The assumption that fish predation was responsible was not confirmed since the test fishing carried out in 1994 gave negative results. It is unlikely that there have been extensive changes in the trophic status over the last decades because the catchment has never been extensively used for pasture. Resting eggs (ephippia) of *D. pulicaria* are present in the sediment core (Fig. A8.3.3) from Terianske, but in the upper 1 cm they are very rare; this only confirms recent disappearance of the species to the lake. A hypothesis that this loss has been brought about by a sensitive reaction to an unknown airborne pollutant is easy to formulate but difficult to test.

Although the present statistical analysis (Fig. 3.4.1, 3.5.2) did not show any large impact of fish upon zooplankton communities in alpine lakes, this impact cannot be denied. Case studies on Zielony Staw and other lakes in the Polish part of the Tatra (Gliwicz 1985) show good evidence on selective predation of brook trout on large-bodied zooplankton. However, it may be that this effect may become less distinct in very high altitudes where fish populations may live close to their ecological limits.

Dispersal, island effect

Sarvala & Halsinaho (1990) argue that as the surface area of a lake increases and the concentration of lakes in a region increases, the number of crustacean zooplankton species found will also increase. Then, in accordance with the island theory of MacArthur & Wilson (1968), the equilibrium between colonisation and extinction is shifted towards high species numbers. From this point of view some high mountain lakes behave like isolated islands. This may hold for lakes in the High Tatra. With only 785 km^2 the High Tatra can be looked at like a small island between the Alps and the central and eastern Carpathians. A short-term reaction of an isolated mountain lake to any disturbance may result in shifts to low abundance or even to the extinction of some species. An invasion of a new component, well adapted to the changed conditions, is unlikely in isolated lakes on the time scale of tens of years.

Imperfect taxonomy, genetic variation

The search for `early warning indicators' among zooplankton has shown some conflicting results. The conflicting evidence on sensitivity in European and North American species may have arisen due to the lack of distinction between two different species: *Bosmina longirostris* is regarded as acid sensitive in Europe (Nilssen & Sandoy 1990) but as acid tolerant in North America (examples in Havas 1986 and Brett 1989). We do not know any case of European *D. pulicaria* dwelling in acid conditions, which has been confirmed for the high mountain populations by the present study as well; the North-American populations are considered to be acid - tolerant (Sprules 1975, Havas 1986). The existence of closely related species pairs among European and American Cladocera was pointed out by Frey (1980).

Genetic studies of high mountain populations of *Daphnia pulicaria* in the Tatra (Cerny, unpublished) revealed that these populations are genetically different from lowland populations in Central Europe and from populations in North America. Genetic investigation of high-mountain populations from the Slovenian Alps (Zgornje Krisko jezero), Pyrenees (Lago Redo) and Sierra Nevada (La Caldera) could yield interesting results.

Chydorus sphaericus in AL:PE lakes

The cladoceran *Chydorus sphaericus* (O. F. Muller) was earlier supposed to be a single ubiquitous species of world-wide distribution, `the commonest of all Cladocera'. Since the Frey's (1980) revision it is acknowledged that the taxon *Chydorus sphaericus* s. lat. includes several distinct species and morphotypes of unknown taxonomical status (Duigan & Murray 1987, Roen 1987). It is not clear how much this division affects the supposed ubiquity of the „smaller" taxons, but recently Fryer (1993) has confirmed the extreme habitat tolerance of *Chydorus sphaericus* in Yorkshire. In the present study no attempt was made to distinguish between species or morphotypes of the *Chydorus sphaericus* complex.

Like other chydorids, *Chydorus sphaericus* inhabits the littoral zone, but in lowland lakes it becomes planktonic during periods of high productivity, using larger colonies of planktonic cyanobacteria as a substrate (Frey 1988). The population from the lake Starolesnianske seems to exhibit a similar reaction to acidification: the abundance in the open water becomes tens of individuals per litre and the meioplanktic filaments of the alga *Mougeotia* sp. may be used as a substrate.

The reaction of chydorid Cladocera to a disturbance from whatever cause often results in reduction of species diversity, with the commonest and most tolerant species becoming more dominant (Frey 1988, Whiteside & Swindoll 1988). The present state of Starolesnianske and the succession of its cladocerans seems to fit with this hypothesis. We can assume that the recent changes in zooplankton community of the last decades were brought about by atmospheric transport of pollutants, mainly acid, to the lake. It is not known, however, to what extent other pollutants have been involved.

Why the two most acidified AL:PE lakes are so different in their zooplankton

The two most acidified lakes in the AL:PE project, lakes Lille Hovvatn and Starolesnianske pleso, are almost identical with respect to pH and aluminium, the two variables that are supposed to be mostly important in their influence upon aquatic biota, namely zooplankton (Hornstrom et al., 1984). The two lakes differ totally in their zooplankton - both in the species richness and in the species encountered (Tab. 3.2.5). In the samples taken in September 1993 at Lille Hovvatn we found 3 limnetic and 6 littoral species of Crustacea. After several years of sampling at Starolesnianske pleso (Kneslova 1992 and this study) we can be sure that the lake is inhabited by only two crustacean species: *Chydorus sphaericus* and *Acanthocyclops vernalis*. From the 10 crustaceans that were identified to the species level in the two lakes, at least 8 belong to the fauna of both Scandinavian mountains and Carpathians (Illies 1978).

The main features in which the two lakes differ are: latitude, altitude, morphometry and the length of the ice free period. We can only hypothesise about main reasons that are responsible for the total dissimilarity in zooplankton of the two acidified lakes:

1. Effect of altitude, climate and depth: The high altitude, continental climate and shallow water depth of the lake Starolesnianske result in a shorter ice free period and, although not measured, higher impact of UV radiation. The *Chydorus* from Starolesnianske have black pigment, which may be understood as a protection against UV. Regardless of acidification, the zooplankton fauna of high altitude lakes is poorer than the fauna of high latitude ones.

Table 3.2.5: Lille Hovvatn and Starolesnianske Pleso - comparison of their geography, morphometry, ice free periods, hydrochemical parameters related to acidification, and their zooplankton.

	Lille Hovvatn	**Starolesnianske**	
Latitude	58 36 N	49 10 N	
Altitude	503 m	2000 m	
Area	21 ha	0.75 ha	
Mean depth	5 m	1.6 m	
Ice free period	May - November	June - October	
pH	4.6	4.7	
RAl	217 µg/l	193 µg/l	
Labile Monomeric Al	188 µg/l	176 µg/l	
TOC	1.81 mg/l	4,18 mg/l	
Zooplankton	Eudiaptomus gracilis	Chydorus sphaericus	
	Holopedium gibberum	Acanthocyclops vernalis	
	Bosmina longispina		
	Alona affinis		
Morover in the littoral:	Alonella exigua	0	
	Alonopsis elongata		
	Latona setifera		
	Sida crystallina		
	copepodites (Cyclopidae)		

Tab. 8: Lille Hovvatn and Starolesnianske Pleso - comparison of their geography, morphometry, ice free periods, hydrochemical parameters related to acidification, and their zooplankton.

2. The harsh conditions in mountain lakes may make their zooplankton more sensitive to acidification and other recent environmental changes than zooplankton in lowland lakes.

3. Geographical isolation of high mountain lakes prevents dispersal of acid tolerant species which results in further impoverishment of their zooplankton fauna after acidification.

On the other hand, we can exclude food as the factor responsible for the difference between the two lakes as neither belong to the most oligotrophic sites and their zooplankton numbers are fairly high.

3.2.5 Summary

1. When the AL:PE lakes are classified according to their zooplankton communities, the main two groups emerging from this classification can be identified as the "northern lakes" (Kola, Norway and the British Isles) and "southern lakes" (Tatra, Alps, Pyrenees and Iberia).

2. The continental, high altitude lakes (Tatra, Alps) have simple zooplankton communities which are sensitive to additional stress for example the inputs of airborne pollutants. This is most apparent in the acidified Tatra lakes. Zooplankton of northern lakes (Norway, British Isles), lying in lower altitudes under influence of maritime climate, are less sensitive to acidification.

3. The zooplankton species inhabiting the "northern" AL:PE lakes are: *Eudiaptomus gracilis, Heterocope saliens, Holopedium gibberum, Bosmina longispina.* In these lakes they tolerate lowered pH and elevated concentrations of labile aluminium.

Daphnia pulicaria is associated with high altitudes and circumneutral pH. Other species inhabiting high altitude lakes are *Arctodiaptomus alpinus, Cyclops abyssorum* and *Daphnia longispina.*

The non-pelagic, ubiquitous species *Chydorus sphaericus* and *Acanthocyclops vernalis* are the only inhabitants of the open water in the acidified Tatra lakes.

4. In order to improve the indicator value of zooplankton in AL:PE lakes, the taxonomic status of some populations should be clarified.

3.2.6 References

Amoros, C. 1984. Crustaces Cladoceres. *Bulletin mensual de la Societe Lineene de Lyon,* 53 annee, Nos. 3 et 4, 1-63.

Brett, M.T. 1989. Zooplankton communities and acidification. *Wat. Air Soil Pollut.* 44, 387-414.

Duigan, C.A. and Murray, D.A. 1987. A contribution to the taxonomy of *C. sphaericus* sens. lat. (Cladocera, Chydoridae). *Hydrobiologia* 145, 113-124.

Edmondson, W.T. and Winberg, G.G. (eds.). 1971. A manual on methods for the assessment of secondary productivity in fresh waters. IBP Handbook No 17. Blackwell Scientific Publications, Oxford and Edinburgh, 358 p.

Fott, J., Prazakova, M., Stuchlik, E., and Stuchlikova, Z. 1994. Acidification of lakes in Sumava (Bohemia) and in the High Tatra Mountains (Slovakia). *Hydrobiologia* 274, 37-47.

Frey, D.G. 1980. On the plurality of *Chydorus sphaericus* (O.F. Muller) (Cladocera, Chydoridae), and the designation of a neotype from Sjaelso, Denmark. *Hydrobiologia* 69, 83-123.

Frey, D.G. 1988. Littoral and offshore communities of diatoms, cladocerans and dipterous larvae, and their interpretation in paleolimnology. *Journ. of Paleolimnology* 1, 179-191.

Fryer, G. 1993. The freshwater Crustacea of Yorkshire. A faunistic and ecological survey. Yorkshire Natualists' Union & Leeds Philosophical and Literary Society. 312 p.

Gliwicz, Z.M. 1985. Eutrophication of Tatra lakes - fertilization or fish introduction? (in Polish, with English summary). *Wiadomosci Ekologiczne* 31, 351-390.

Havas, M. 1986. Effect of aluminum on aquatic biota. In: Havas, M. and Jaworski, J.F. (eds.), Aluminium in the Canadian Aquatic Environment, p. 79-127. National Research Council of Canada, Ottawa.

Herbst, H.V. 1962. Blatfusskrebse. Kosmos Verlag, Stuttgart.

Hornstrom, E., Eckstrom, C. and Duraini, O.,1984. Effects of pH and different levels of aluminium on lake plankton in the Swedish west coast area. Nat. Swed. Board of Fish., Inst. of Freshw. Research Drottingholm, Lund, Report No. 61, 115-127.

Hrbacek, J. , Brtek, J., Vranovsky, M. and Sterba, O., 1974. (Zooplankton and significant representatives of some groups of the Tatra lake minute water animals. In Slovak). *Treatises concerning the Tatra National Park* 16, 105-109.

Illies, J. 1978. Limnofauna Europaea. Gustav Fischer Verlag, 2nd edition, 532 p.

Kiefer, F. 1978. Freilebende Copepoda. In: *Die Binnengewasser* 26, Das Zooplankton der Binnengewasser, 2. Teil (p. 1-343). E. Schweitzerbart'sche Verlagsbuchhandlung (Nagele u. Obermiller), Stuttgart.

Kneslova, P. 1992. (Zooplankton of high mountain lakes (Tatra Mountains) at different degree of acidification. In Czech). Unpublished thesis from the Dept. of Hydrobiology, Faculty of Science, Charles University, Prague. 109 p..

MacArthur, R.H. and Wilson, E.O. 1968. The theory of island biogeography. Princeton University Press, New Jersey.

Minkiewicz, S. 1917. Die Crustaceen der Tatraseen. Eine physiographisch-faunistische skizze. *Bull. Acad. Sci. Cracov., Cl. Sci. Math. et Natur., Ser.B: Sci. Natur.* Nov.-Dec. 1916, 262-278.

Roen, U. 1987. *Chydorus arcticus* n.sp., a new cladoceran crustacean (Chydoridae: Chydorinae) from the North Atlantic Arctic and Subarctic areas. *Hydrobiologia* 145, 125-130.

Sarvala, J. and Halsinaho, S. 1990. Crustacean zooplankton of Finnish forest lakes in relation to acidity and other environmental factors. p. 1009-1027 in: Kauppi et al. (eds.), *Acidification in Finland*. Springer Verlag, Berlin.

Sprules, W.G., 1975. Midsummer crustacean zooplankton communities in acid-stressed lakes. *J. Fish. Res. Bd. Can.* 32, 389-395.

Stuchlik,E., Stuchlikova, Z., Fott, J., Ruzicka, Z. and Vrba, J. 1985. Effects of acid precipitation on waters of the TANAP territory. (In Czech, with English summary). *Treatises concerning the Tatra National Park* 26, 173-211.

Ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67, 1167-1179.

Ter Braak, C.J.F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio* 69, 69-77.

Tongeren, O.F.R. van 1987. Cluster analysis. In: Jongman, R.H.G., ter Braak, C.J.F, and van Tongeren, O.F.R., Data analysis in community and landscape ecology, p. 174-212. Wageningen.

Tranter, D.J. (ed.) 1968. Zooplankton sampling. *Monographs on Oceanographic Methodology* 2, 174 p., UNESCO.

Vyhnalek, V., Fott, J. and Kopacek, J. 1994. Chlorophyll - phosphorus relationship in acidified lakes of the High Tatra Mountains (Slovakia). *Hydrobiologia* 274, 171-177.

Whiteside, M. and Swindoll, M.R, 1988. Guidelines and limitations to cladoceran paleoecological interpretations. *Palaeography, Palaeoclimatology, Palaeoecology* 62, 405-412.

3.2.7 Extension of the AL:PE 2 programme in the High Tatra Mountains

Two new sites, lakes Terianske pleso (the name in full: Nizne Terianske pleso) and Dlugi Staw, were sampled in addition to the two already established AL:PE 2 sites, lakes Starolesnianske pleso and Zielony Staw. The work on the additional sites and reporting the results have been fully integrated into the AL:PE 2 programme (chemistry, coring, recent diatoms, benthic invertebrates, zooplankton).

Improvements in characterisation of the lakes Terianske and Starolesnianske

Nothing was known about fish in the lake Terianske. Due to obstacles at the outflow (waterfalls, underground sections) the lake could not have been invaded by fish by natural means. Introduction of fish in the past could not , however, be excluded. The idea that fish might be present in the lake was supported by the zooplankton composition (*Cyclops abyssorum, Polyarthra dolichoptera)*, which is identical to that of Zielony Staw, a lake where brook trout has been introduced (see the discussion on zooplankton in the chapter 3). Fishing at Terianske was carried out on October 4th 1994 by Jan Fott and Marek Kot. The gillnets were borrowed from NIVA. One standard gillnet, 10 mm mesh size and one combined gillnet (8 mesh sizes) were exposed for 24 hours according to the recommended AL:PE 1 procedure. Neither the gillnet fishing, nor an intense angling yielded any fish. Therefore, the lake can be considered fishless.

Although bathymetric maps for most of the Tatra lakes are available, the AL:PE lake Starolesnianske had never been surveyed. In order to obtain the necessary morphometrical parameters, a bathymetric survey was carried out by Jan Fott, Evzen Stuchlik, Petra Psenakova, Veronika Sacherova and Svetlana Varsova. The depth and shoreline measurements were based on a 10m rectangular grid. The output of the survey is a bathymetric map (see the site description), from which the following parameters have been inferred: Lake area (0.7472 ha), maximum depth (4.1 m), mean depth (1.57 m), volume 11 750 cubic meters).

Precipitation station at the lake Starolesnianske

The upper part of Velka Studena Dolina, the valley where the lake Starolesnianske (2000 m a.s.l.) is situated, is very high in precipitation; in 1993 the yearly sum was 2496 mm. In the vicinity of the lake two 'totalizers' for quantitative measurement of precipitation have been run by the Slovak Hydrometeorological Institute (Bratislava). The data (water level in the 'totalizer') have been measured quarterly. The amount of precipitation is determined by the difference between two water levels in the 'totalizer', where freezing and evaporation are prevented by presence of an anti-freeze liquid and oil surface film. One mm increase in the level inside the 'totalizer' corresponds to 8 mm of precipitation.

At the chalet Zbojnicka Chata (at a distance of several hundred meters from the lake), the amount of precipitation has been measured daily. Several basic meteorological parameters (air temperature, wind direction and velocity, height of the snowpack) have been measured daily as well. Data from all these measurements are available from the Slovak Hydrometeorological Institute.

Our new station was established in order to obtain precise data on chemistry of precipitation. The station was built close to one of the 'totalizers', at a distance of about 300 m from the lake. It is a collector consisting of a plastic bucket firmly installed in 1.5 m height. It started operation on November 18, 1994.

Samples of rain and snow are collected weekly by an employee of the Tatra National Park. At the same time he measures water level in the 'totalizer', collects a water sample from the lake, and measures air temperature, wind direction, thickness of the snowpack on the ice and that of the ice itself. Then he brings the sample from the plastic bucket to the laboratory of the National Park at Tatranska Lomnica.

After measuring the volume, the sample is then divided in two parts. One part, used for determination of ions (Ca, Mg, Na, K, NH_4, Cl, NO_3, SO_4, F), pH, Gran alkalinity and conductivity, is kept cool in a refrigerator. The second part, used for determination of total nitrogen, total phosphorus and total organic carbon, is kept deep frozen. Lakewater samples, taken in the same intervals, are treated in the same way. Samples are taken and handled with strict precautions preventing contamination. The samples are analysed bimonthly in the laboratories of the Department of Hydrobiology (Prague) and Hydrobiological Institute (Ceske Budejovice). Standard hydrochemical methods (titration, ion chromatography, spectrophotometry) are used. The both laboratories took part in regular intercalibrations organised within the ALPE project.

Weekly loads are calculated by combining concentrations from the qualitative weekly samples with the weekly amount of precipitation measured by means of the 'totalizer'. The data obtained so far are presented on the tables in the Appendix 5. The measurements will continue in order to cover at least one year.

Our data on precipitation chemistry and on the loads are the first from the altitudes around 2000 m, where most of the lakes are situated. Similar measurements have been carried out at the stations Stara Lesna and Liesek in the altitudes of 700 m. The station Chopok, which belongs to the EMEP network, lies in the 2000 m altitude, but in a distance of about 80 km southwards from our sites.

Although the establishing of the precipitation station was made possible thanks to the AL:PE 2 project, its main importance will be its continuous operation in the years to come.

Profiling in ALPE lakes

A multiprobe "Hydrolab" was purchased in August 1994 and tested during the autumn 1994 Tatra survey. The probe is capable of measuring depth, temperature, pH, redox potential, conductivity and oxygen. For methodological reasons, the first testing was performed at the lake Strbske, a subalpine lake with an anoxic hypolimnion. The measurements on the vertical were reasonably stable. Within the ALPE programme, the profiles were measured at the lakes Terianske, Zeliony Staw and Dlugi Staw. The major exploitation of the instrument, however, is expected in the studies planned for the next years. The results of the test profiling are presented in the Appendix 5.

Chlorophyll *a* concentration and chemical parameters in lakes of the whole High Tatra territory (Slovakia and Poland).

The extended AL:PE 2 programme made it possible to carry out two extensive surveys in the autumn 1993 and 1994. Lakes were sampled for major ions, aluminium, nutrients, organic carbon and chlorophyll. The objective was better understanding of variation in the main chemical parameters of lakewater in lakes over the whole Tatra territory. It would be beyond the scope of this report to discuss the results in full. The manuscript based on these data (Kopacek & al., in press) was accepted to Limnology & Oceanography. Here we are including the abstract and conclusions of the paper.

Kopacek, J., Prochazkova, L., Stuchlik, E. and Blazka, P., in press. The nitrogen : phosphorus relationship in mountain lakes: Influence of atmospheric input, watershed and pH. Manuscript accepted to *Limnology & Oceanography.*

Abstract

The effect of enhanced atmospheric deposition on acidification of fresh waters and eutrophication on marine waters is well known. The impact of high N input on trophic status of small mountain lakes was modified by the type of watershed and stage of acidification in the central European mountain ranges (the High Tatra Mts. and the Sumava Mts.). Atmospheric N deposition enhanced nitrate concentrations of lake water, but the type of watershed determined both the share of nitrate in the pool of total N and its concentrations, which increased from forest to meadow to rocky watersheds. Total N to total P (TN:TP) ratios generally reflected the highest nitrate concentrations in alpine lakes with sparse soils and vegetation in the watersheds and were lowest in forest lakes, where N retention capacities of watersheds have not yet been exceeded. Within alpine lakes, the TN:TP ratios reached a maximum level at pH values from 4.8 to 6.2, reflecting low TP concentrations in lakes at this stage of acidification. While atmospheric N deposition may contribute to acidification, it may paradoxically also contribute to oligotrophication of alpine lakes.

Another output of the whole-Tatra monitoring of lakes are graphs showing relationship of chlorophyll *a* in lakes to pH (Appendix 5). Both the 1993 and 1994 plots shows the least chlorophyll concentrations in the pH range 4.8 - 5.0, which supports our earlier hypothesis on oligotrophication of Tatra lakes at this stage of acidification.

3.3 Invertebrates

3.3.1 Introduction

The sensivity of invertebrate species to airborne pollution is frequently used as a tool in monitoring freshwater ecosystems (Raddum et al 1988, Fjellheim & Raddum 1990). In Norway, acidified freshwater ecosystems have been monitored since 1981. The same technique has been applied to limed ecosystems, which show variable degrees of recovery depending on ecological factors, such as catchment size and distance from potential colonizing populations (Fjellheim & Raddum 1995).

The distribution of invertebrates in the AL:PE 1 sites showed that the fauna mainly consisted of geographically widespread species typical of this kind of habitat (Wathne et al. 1995). The different mountain regions could thus be regarded as having similar faunas, with few exeptions. However, clear differences existed in the distribution of acid-sensitive invertebrates; the Norwegian reference site Lake Øvre Neådalsvatn having the highest number of such species.

The Chironomidae are an important group in high-altitude ecosystems partly due to their species richness and ecological diversity. However, little is done experimentally to test the sensivity of different species of chironomids towards acidity. Based on field and literature studies, Schnell & Raddum (1993) published a list of acid-sensitive and acidophilous species of chironomids. By comparing the historical development of sensitive and acidophilous species in the AL:PE 1 dataset, significant trends towards increased acidity could be detected in some of the lakes Schnell & Raddum (1993). Chironomids are also a valuable group in detecting changes in the nutrient levels of lakes. Such changes may also be connected to an early stage of acidification.

The main objective of the invertebrate studies of this report is, by enlargment of the geographical area of remote freshwater localities, to increase our understanding of high altitude freshwater ecosystems and their response to environmental changes.

3.3.2 Methods

From the initiation of the project the benthic invertebrate sampling in the AL:PE 2 programme was standardized for all participating institutions.

The sampling programme included both qualitative and quantitative data, which was preferably using samples taken at the same time as the water and fish samples. Qualitative samples were taken from the lake littoral and adjacent streams using the "kick method" (Frost et al. 1971). Primarily the outlet stream was sampled, but occasionally inlet streams were also sampled. Six parallel quantitative samples were collected from the deepest part of the lake using a Kajak sampler (Kajak 1971) or modified versions of this sampler.

The samples were sieved using a colllecting net with mesh size 250 : m and conserved in ethanol; alcohol concentration of the sample being approximately 70%.

The samples were sorted and identified at the laboratory. Most animal groups were identified to species or the nearest possible taxa. The data has been generated and processed in a database at the Institute of zoology, University of Bergen.

3.3.3 Results

Svalbard

Arresjren (9)

The total invertebrate fauna recorded in Lake Arresjren consisted of 24 taxa (Table 3.1 a and b). Chironomids were the dominant group with 17 taxa. Crustacea were the next most dominant group. The high latitude of this lake is the main reason for the poor fauna. Many insect groups, like Trichoptera, Plecoptera, Ephemeroptera and Coleoptera, which are common in more southern latitudes were absent.

Only three chironomid taxa were found in the lake profundal. Contrary to the trend in the core samples (see chapter 5.2), *Micropsectra insignilobus* was the dominant taxon and *Micropsectra radialis* was present in low concentrations. The number of chironomid larvae was remarkably similar at all depths except at 31 m, where no chironomids were found at all. The reason for this is not clear, probably there is an oxygen deficit present at this depth.

A total of five species of *Diamesa* were found in the kick samples. These are the only species of this genus that have been recorded at Svalbard. Within the genus *Trissocladius* only one species, *T. brevipalpis* have formerly been described. In both the inlet and outlet of Arresjren an undescribed species within the same genus was found. Besides *Trissocladius* n.sp., two of the recorded chironomid species, *Orthocladius trigonolabis* and *Hydrobaenus conformis* have unknown larval stages.

Three acid-sensitive species of invertebrates were found (Figure 3.3.1), the crustacean *Cyclops* sp. and the chironomids *Micopsectra insignilobus* and *M. radialis.*

Region summary - Svalbard

The insect fauna of Lake Arresjren was dominated by chironomids, which comprised a total of 15 recorded species. Three of these species were found in the profundal. The number of chironomid larvae was remarkably similar at all depths except at 31 m, where no chironomids were found at all. The high latitude of this lake is the main reason for the poor fauna. Many insect groups, like Trichoptera, Plecoptera, Ephemeroptera and Coleoptera, which are common in more southern latitudes were absent. Three invertebrate species sensitive to acidification were found.

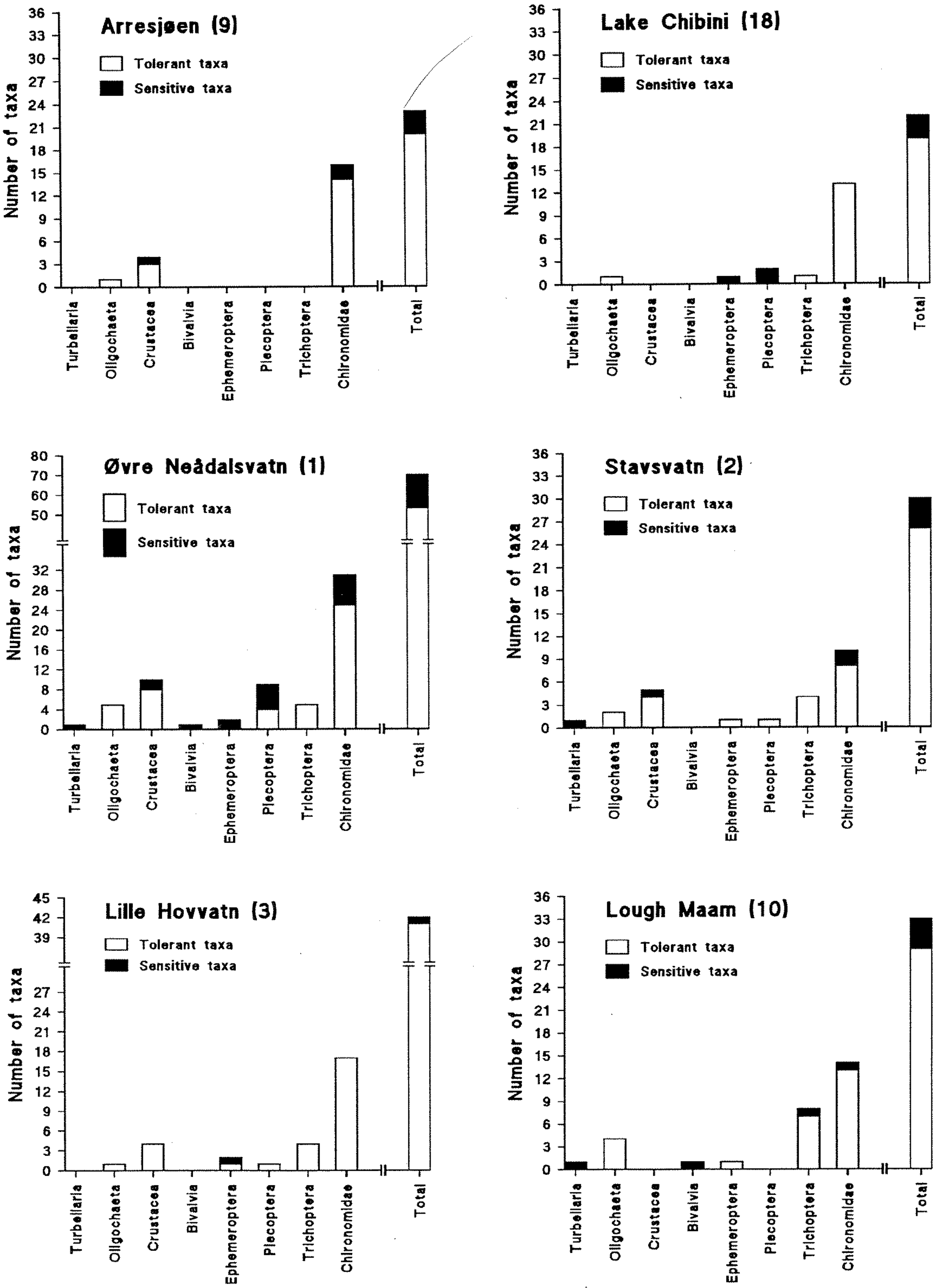
Kola

Chibini (17)

A total of 22 invertebrate taxa were recorded in Lake Chibini (Table 3.3.2). Chironomids were the dominant group with 13 species. The fauna of Ephemeroptera, Plecoptera and Trichoptera was poor, with one, two, and one taxa, respectively. The profundal samples in Lake Chibini was dominated by Chironomidae. The most common taxa were Orthocladiinae, *Diplocladius cultriger*, *Diamesa* and *Pseudodiamesa*. However, compared to other ALPE lakes, animal densities in the profundal zone were low.

Diamesa spp. dominated the inlet river fauna, while *Diplocladius cultriger* was most abundant in the littoral. The outlet area was dominated by unidentified species of Diamesini and Orthocladiinae. In the kick sample from the outlet river 4 chironomid taxa were found. *Diamesa* spp., *Cricotopus* sp., and an unidentified species of *Eukiefferiella* were most abundant.

Figure 3.3.1: Occurrence of acid sensitive and tolerant species within invertebrate groups in Arresjøen, Lake Chibini, Øvre Neådalsvatn, Stavsvatn, Lille Hovvatn and Lough Maam.



Three acid-sensitive species were recorded in Lake Chibini (Figure 3.3.1): the plecopterans *Arcynopteryx compacta* and *Isoperla obscura* and the ephemeropteran *Ameletus inopinatus*. The fauna of Lake Chibini indicated moderate acidification, with an acidification index 0.5.

Region summary - Kola

A total of 22 invertebrate taxa were recorded in Lake Chibini. Chironomids were the dominant group, while the fauna of Ephemeroptera, Plecoptera and Trichoptera was poor. Compared to other AL:PE lakes, animal densities in the profundal zone were low. Three species moderately sensitive to acidification were recorded: the stoneflies *Arcynopteryx compacta* and *Isoperla obscura* and the mayfly *Ameletus inopinatus*.

Norway

Lake Øvre Neådalsvatn (1)

The total invertebrate fauna recorded in Lake Øvre Neådalsvatn consisted of 70 taxa, of which chironomids comprised nearly half of the identified species/groups (Table 3.3.3).

In the profundal, the highest chironomid density was recorded at 17 m depth (3658 ind m^{-2}) including a total of eleven chironomid taxa. *Heterotrissocladius brundini*, *Mesocricotopus thienemanni* and *Parakiefferiella fennica* dominated. Also in 1991 samples were taken from 17 m depth in the lake. Eight taxa were found in 1991, 5 were found both years. The same three species dominated, but *Heterotrissocladius brundini* were found in much higher densities in 1991. The chironomids were also abundant in the kick samples. The inlet river contained typical rheophilic taxa like *Diamesa* spp. and *Eukiefferiella minor*. The littoral zone was dominated by *Arctopelopia* cf. *melanosoma* and *Micropsectra radialis*, while the outlet river samples were dominated by *Arctopelopia* cf. *melanosoma*, *Chaetocladius* sp., and *Thienemannimyia fusciceps*.

Ten species of Crustacea were identified. Plecoptera was the third largest group. A total of nine species were found, of which *Diura* (two species), *Isoperla* (two species) and *Capnia* sp. are considered to be acid sensitive. Two species of Ephemeroptera were recorded. The highly sensitive *Baetis rhodani* were found in both the inlet and outlet of the lake. *Siphlonurus lacustris*, which is considered to be moderate acid sensitive, was common in the littoral samples of the lake. The high abundance of *Siphlonurus* was also reflected in brown trout stomach samples from August 1991 (unpublished), where more than 90 % of the food consisted of this mayfly.

In total, 17 sensitive species of invertebrates were found in the lake (Figure 3.3.1). This is the highest number of sensitive species found in a locality in the AL:PE 2-programme. Excluding the chironomids, 11 sensitive species were found compared to 8 in 1991 (Wathne et al. 1995). The acidity index, according to Raddum et al. (1988) was 1.0 due to the presence of *B. rhodani*.

Lake Stavsvatn (2)

The total invertebrate fauna recorded in Lake Stavsvatn consisted of 31 taxa (Table 3.3.4). Chironomids were the dominant group with 10 taxa followed by Crustacea and Trichoptera.
The samples from the littoral zone and the outlet were similar, with *Arctopelopia* sp., *Psectrocladius* (*Psectrocladius*) *limbatellus*-group and *Psectrocladius* (*Psectrocladius*) cf. *sordidellus* dominating. A total of 5 and 9 taxa were found in the samples, respectively. In the sample taken downstream of the lake *Orthocladius* (*Orthocladius*) sp. dominated together with *Arctopelopia* sp.

A total of four sensitive taxa was found (Figure 3.3.1): the turbellarian *Crenobia alpina*, the crustacean *Cyclops* sp. and the chironomids *Micropsectra insignilobus* and *Zavrelimya* sp. The acidification index of the lake was 0.5, indicating moderate acidification.

Lake Lille Hovvatn (3)

The total invertebrate fauna recorded in Lake Lille Hovvatn consisted of 42 taxa (Table 3.3.5). Chironomids were the dominant group with 17 taxa followed by Crustacea and Trichoptera. The chironomid fauna was dominated by acid tolerant taxa like *Arctopelopia barbitarsis*, *Chironomus anthracinus*, *Macropelopia adaucta*, *Procladius* spp., and *Tanytarsus buchonius*. Except for one specimen of the ephemeropteran *Siphlonurus alternatus*, all benthic invertebrates in the samples belonged to the acid-tolerant group (Figure 3.3.1). During the sampling period of the ALPE 1 project the slightly acid sensitive bivalve *Pisidium* sp. was also found in the lake. This species was not recorded in the samples taken in 1993. The sporadic presence of slightly acid sensitive animals in the lake may be due to the liming of the downstream lake Store Hovvatn. *Siphlonurus alternatus* was recorded for the first time in this lake nine years after liming. The almost total absence of acid-sensitive animals in Lille Hovvatn places the lake among the most acidic in the ALPE-programme. High abundance of invertebrate predators, like species of Megaloptera, Corixidae, Odonata and Coleoptera are typical of strongly acidified lakes where fish are extinct.

Region summary - Norway

The three Norwegian lakes forms a strong gradient with respect to composition of acid-sensitive animals. Lake Øvre Neådalsvatn, which is a reference lake in the AL:PE programme, hosted a rich fauna. A total of 70 taxa were recorded, of which 17 were acid-sensitive. This is the richest number of acid-sensitive species Redo recorded in the AL:PE programme. The highly sensitive *Baetis rhodani* were found in both the inlet and outlet of the lake, indicating a community undisturbed by acidification. Lake Stavsvatn must be considered moderately acidified with respect to the fauna composition, a total of four sensitive taxa being found. The invertebrate fauna recorded in Lake Lille Hovvatn consisted of 42 taxa. The almost total absence of acid-sensitive animals in Lille Hovvatn places the lake among the most acidic in the ALPE-programme.

British isles

Lough Maam (10)

The total invertebrate fauna recorded in Lough Maam consisted of 33 taxa (Table 3.3.6). Chironomids were the dominant group with 14 taxa. Trichoptera and Oligochaeta were the next most dominant groups. The total number of taxa in the lake system is probably higher, as only littoral samples were taken. The most common chironomid species were *Arctopelopia griseipennis*, species of the genus *Psectrocladius*, *Dicrotendipes modestus* and *Heterotanytarsus apicalis*. The oligochaete fauna was dominated by naidids. Four taxa indicating moderate acidification (index 0.5) were found (Figure 3.1): Tricladidae, *Pisidium* spp., *Hydropsyche siltalai* and *Micropsectra* sp. The Chironomid fauna indicated an acid, humic lake. This was also shown by the chemical data. The TOC value was 4.7 which is the highest recorded within the ALPE-lakes. Normally the pH-tolerance of sensitive animals is higher in humic lakes compared to non-humic lakes.

Region summary - British Isles

A total of 33 invertebrate taxa were recorded in Lough Maam. The chironomids, which were the dominant group, had a species composition indicating an acid, humic lake. Normally the pH-tolerance of sensitive animals is higher in humic lakes compared to non-humic lakes. This may explain the presence of four moderately sensitive taxa.

Iberia

Caldera (13)

In contrast to the Pyreneean Lakes, La Caldera has a poor fauna. A Total of 9 taxa were recorded (Table 3.3.7). Two chironomid taxa were found in the profundal samples; *Corynoneura arctica* and *Micropsectra radialis.* These two species were also dominant in the kick and pupal exuvia samples. *Micropsectra radialis* is recognized as moderately sensitive to acidic water (Figure 3.3.2)

Escura (14)

The fauna of Lagoa Escura consisted of 26 taxa, of which chironomids comprised 12 species (Table 3.3.8). In the profundal community, three taxa of chironomids, *Procladius* (*H.*) *choreus*, *Cladopelma* sp., *Heterotrissocladius* sp., and *Pagastiella orophila* were identified.

The littoral fauna of the lake was relatively diverse, consisting of several insect groups. Eight chironomid taxa were found among the macrophytes, *Ablabesmyia longistyla*, *Psectrocladius* sp., and *Procladius choreus* dominated. In the sample taken on sand, six taxa were found. *Tanytarsus* sp. were dominant and two sensitive taxa were recorded (Figure 3.3.2).

Cimera (16)

The samples from Laguna cimera were restricted to one littoral kick sample (Table 3.3.9). A total of 25 invertebrate taxa were identified. Chironomidae were the most numerous (8 taxa), with *Heterotrissocladius marcidus* dominating the sample.

Three sensitive taxa were identified in the samples (Figure 3.3.2). The record of the freshwater snail *Ancylus fluviatilis* indicates a non-acidified locality, index 1.0.

Region summary - Iberia

The Iberian lakes had a relatively poor fauna compared to the Pyreneean lakes. The poor number of species min La Caldera can be related to a small lake area and to high fluctuations of the water level due to evaporation and periodically low precipitation. The fauna of Laguna Cimera was almost as diverse as Lago Escura, in spite that only one littoral sample was taken in Cimera. The presence of the highly acid-sensitive snail *Ancylus fluviatilis* in the latter indicates an unacidified lake, while only moderately sensitive taxa were found in the othe two Iberian lakes.

Pyrenees

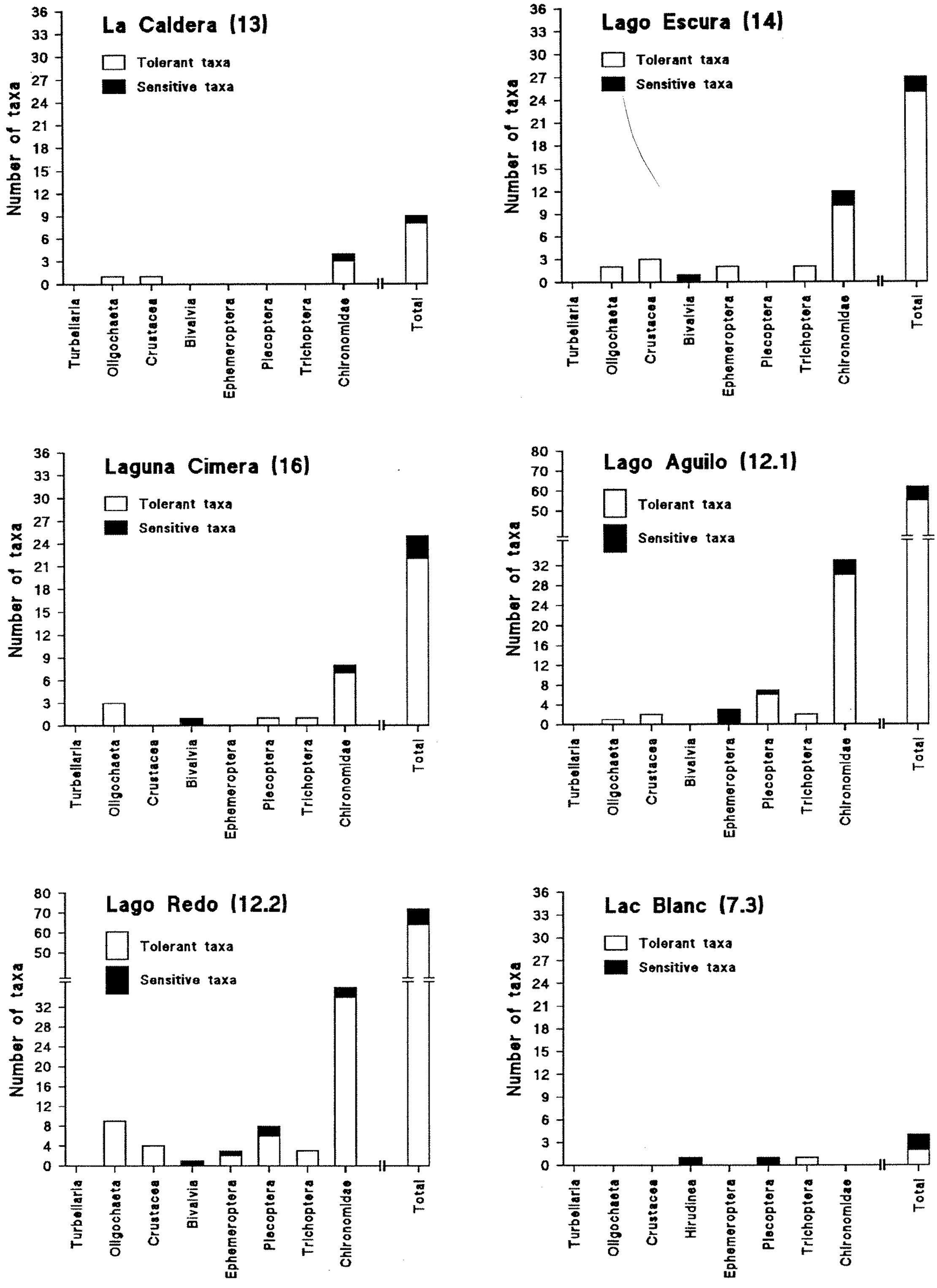
Aguilo (12.1)

The invertebrate fauna recorded in Llac Aguil\ consisted of 62 identified taxa (Table 3.3.10). Chironomids were the dominant group with more than half of the identified species. Seven species of Plecoptera and three species of Ephemeroptera were identified. The profundal fauna of the lake was poor with only one species, *Procladius sagittalis.*

The inflow stream contained 13 chironomid taxa, *Pentaneurella* sp. and *Rheocricotopus* (*R.*) *effusus* being the most frequent. *Procladius sagittalis*, *Heterotrissocladius marcidus* and *Polypedilum* sp. were most numerous in the littoral, while *Pentaneurella* sp. and *Polypedilum* sp. were the most frequent species in the outflow. Samples of pupal exuviae collected from the littoral zone gave a total of 19 species, *Procladius sagittalis*, *Psectrocladius* (*P.*) *octomaculatus*, *Pagastiella orophila*, and *Paratanytarsus laccophilus* being most numerous.

A total of seven sensitive species/groups were identified (Figure 3.3.2). Of these *Baetis* sp. is recognized as the most sensitive. *Baetis gr.vernus* occurred in high numbers in both the inlet and

Figure 3.3.2: Occurrence of acid sensitive and tolerant species within invertebrate groups in La Caldera, Lago Escura, Laguna Cimera, Lago Aguiló, Lago Redó and Lac Blanc.



outlet of the lake. In addition this *Baetis* was found in the littoral kick sample. The presence of this species shows that Llac Aguil\ is an unacidified lake, acidification index 1.0.

Redo (12.2)

Llac Redo has a rich invertebrate fauna consisting of 72 identified species (Table 3.11), of these, half belonged to the Chironomidae. Also the oligochaetes (9 species) and stoneflies (7 species) were relatively numerous compared to other AL:PE-sites. The profundal community was relatively poor, containing only two species of chironomids, *Heterotrissocladius marcidus* and *Micropsectra* sp..

The littoral fauna of the lake was rich. *Macropelopia adaucta*, *Zavrelimyia melanura*, *Psectrocladius* (*Psectrocladius*) *octomaculatus*, *Paratanytarsus austriacus*, and *Tanytarsus bathophilus* dominated in the samples. In the outlet river kick sample *Orthocladius* (*O.*) *rubicundus* and *Psectrocladius* sp. dominated. In addition drift samples were taken both in the inlet and at the outlet. Six taxa were found in the inlet drift sample, the most important was *Corynoneura* sp., while *Corynoneura lobata* and *Nanocladius parvulus* were dominant in the outlet drift.

A total of 8 species sensitive to acidification were found (Figure 3.3.2). Among these, the gastropod *Radix peregra* and the mayfly *Baetis alpinus* are considered highly sensitive to acidification, resulting in an acidification score of 1.0.

Region summary - Pyrenees

The Pyreneean lakes were characterized by a diverse fauna, a total of 62 and 72 taxa being found in Lago Aguilo and Lago Redo, respectively, of which 7 and 8 species were sensitive to acidification. In both lakes highly sensitive species were found. The results from the lake studies in Spain/Portugal indicates a diversity increase in freshwater macroinvertebrates from Iberia to the Pyrenees. This trend is perhaps more dependent upon biogeographical factors than pH.

Alps

Lac Blanc (7.3)

Data on invertebrates from this lake are poor. A total of four taxa were identified (Table 3.12). The complete absence of chironomids was the most striking feature of the samples. Presence of the moderate sensitive leech, *Glossiphonia* sp. (Figure 3.3.2) gives the lake an acidification index of 0.5.

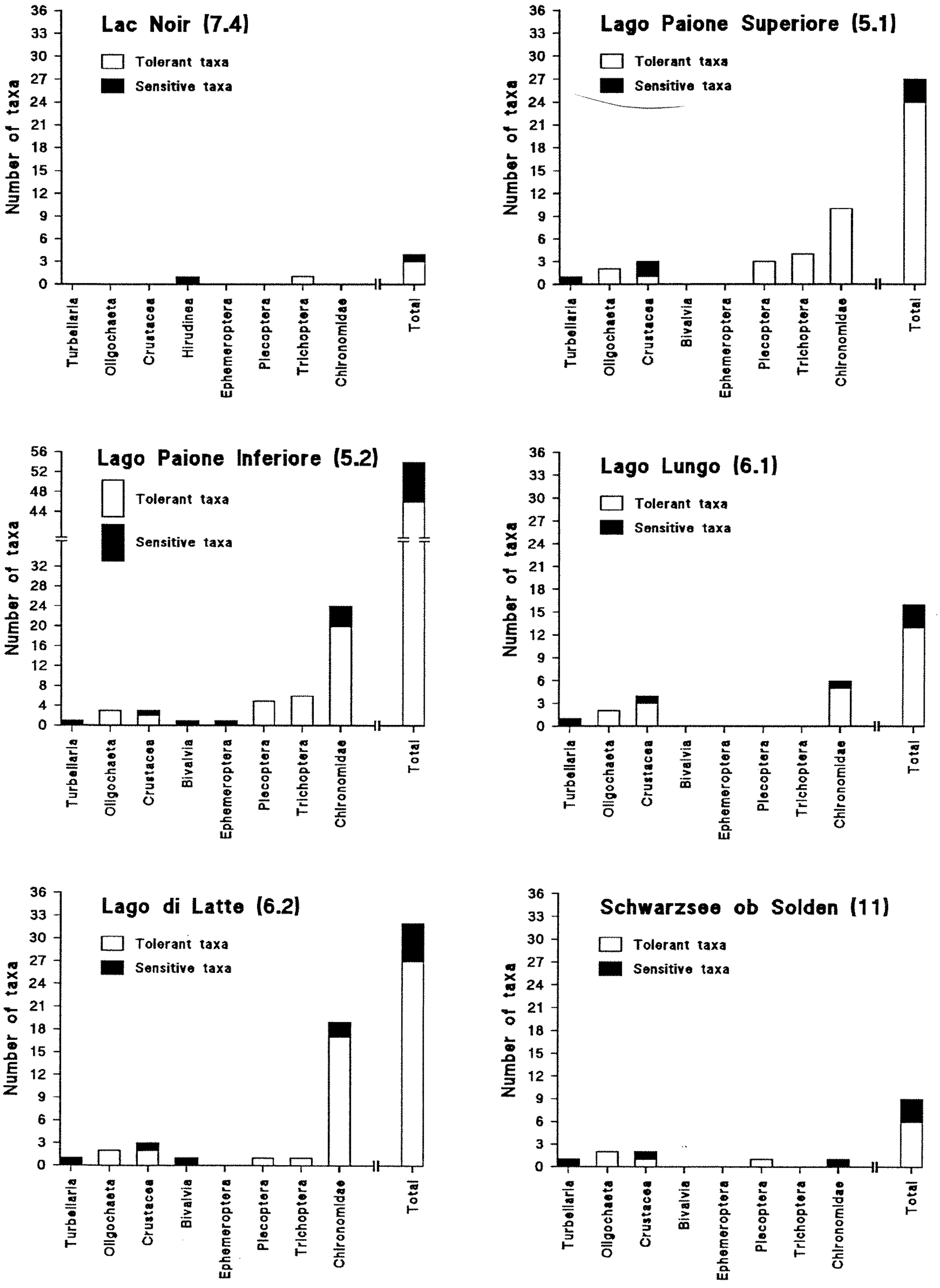
Lac Noir (7.4)

Data on invertebrates from this lake are poor. A total of four taxa were identified (Table 3.12). The complete absence of chironomids was the most striking feature of the samples. As in the case of Lac Blanc, the moderately sensitive leech, *Glossiphonia* sp., was found (Figure 3.3.3) giving the lake an acidification index of 0.5.

Lago Paione Superiore (5.1)

A total of 27 taxa were recorded in the lake, of which the chironomids were the most numerous group, both with respect to species richness (10 species) and density in the quantitative samples (Table 3.13). Four chironomid taxa were found in the profundal samples. *Tanytarsus* cf. *niger* dominated. A total of 10827 chironomids m^{-2} were found. The difference between the faunal composition of the lake and the river clearly illustrates the hydrophysical differences between these two habitats. Typical stream-dwelling species like stoneflies, Rhyacophilidae and *Heleniella* sp.were common in the outflow river, while coleopterans and Diptera were frequent in the lake samples. A conspicious feature of the lake was the high abundance of Sciaridae in one of the littoral kick

Figure 3.3.3. Occurrence of acid sensitive and tolerant species within invertebrate groups in Lac Noir, Lago Paione Superiore, Lago Paione Inferiore, Lago Lung9o, Lago di Latte and Schwarzsee ob Sölden.



samples. Little is known of the ecology of this dipteran group, but most species are known to be semiaquatic.

Only three moderate sensitive animal groups were found in the samples (Figure 3.3.3), giving an acidification index of 0.5.

Lago Paione Inferiore (5.2)

Despite being only 267 m lower than Lago Paione Superiore, the species richness was considerably higher. 54 different taxa were identified, of which 24 belonged to the group Chironomidae (Table 3.14). The littoral chironomid fauna was dominated by *Heterotrissocladius marcidus*, *Micropsectra* sp., *Psectrocladius* (*Psectrocladius*) *limbatellus*-group, and *Zavrelimyia* cf. *barbatipes*, while the outlet area was dominated by *Paratanytarsus* cf. *austriacus* and *Psectrocladius* (*Psectrocladius*) *limbatellus*-group. Further downstream *Zavrelimyia* cf. *barbatipes*, *Conchapelopia* sp. and *Tvetenia calvescens* were common chironomid species.

A total of six caddisfly and five stonefly species were found. These groups were most frequent in the inlet and outlet streams.

Eight sensitive invertebrates were recorded (Figure 3.3.3). The existence of *Baetis rhodani* populations in both the inlet and outflow river gives the locality an acidification index 1.0.

Lago Lungo (6.1)

The benthic samples from Lago Lungo consisted of 16 identified taxa, of which oligichaetes and chironimids dominated in the littoral sample and crustaceans and nematodes were most abundant in the quantitative profundal samples (Table 3.15). Only one chironomid larva was found in the profundal sample taken at 34 m depth. The species, *Corynoneura* cf. *arctica*, is a littoral dweller and is therefore allochthonous. Besides C. arctica, *Heterotrissocladius marcidus* was abundant in the littoral. The presence of *Pseudodiamesa* cf. *branickii* and *Pseudodiamesa* cf. *nivosa* shows that this is a highly oligotrophic site.

Three moderately sensitive taxa were found (Figure 3.3.3), giving an acidification index of 0.5.

Lago di Latte (6.2)

The total invertebrate fauna recorded in Lago di Latte consisted of 32 taxa (Table 3.16). Chironomids were the dominant group with 19 taxa followed by Crustacea. In the sample at 11 m, *Corynoneura* cf. *arctica*, *Eukiefferiella claripennis*, and *Micropsectra radialis* were found. Only the latter can be regarded as a true profundal species. *Corynoneura* cf. *arctica* and *Zavrelimyia* cf. *barbatipes* were the typical littoral species of the lake, while *Corynoneura* cf. *lobata* and *Eukiefferiella claripennis* was dominant in the outlet and downstream river, respectively.

The species richness of Lago di Latte was higher than Lago Lungo, which is situated further downstream. One of the reasons for this is that outflow samples were not taken in Lago Lungo. In 1991, when outflow river samples were included, the differences were much smaller.

In Lago di Latte five species/groups of invertebrates, moderately sensitive to acidification, were recorded (Figure 3.3.3) giving the locality an acidification index of 0.5.

Schwarzsee ob Sölden (11)

The invertebrate fauna of Schwarzsee ob S`lden was poor. Of a total of 9 recorded taxa, only one chironomid species, the moderately acid-sensitive *Micropsectra radialis*, was found (Figure 3.3.3,

Table 3.17). Crustaceans and oligochaetes dominated in the profundal samples. The flatworm *Crenobia alpina*, a moderate sensitive species which is typical for cold lakes, was high. Based on the faunal composition, Schwarzsee had an acidification index of 0.5.

Zgornje Krisko Jezero (19)

The lake littoral was sampled twice in 1994. Five species of chironomids and five species of Crustacea were found (Table 3.18). Three moderately sensitive taxa were identified (Figure 3.3.4). On three occasions during the summer of 1994 profundal material was sampled from the deepest point of the lake. The samples contained no living organisms; only the remains of Chironomidae and ephippia of Cladocera. It is therefore concluded that the profundal of Lake Zgornje Krisko Jezero is not permanently inhabited by benthic invertebrates.

Region summary - Alps

The highest diversity among the lakes of the Alps were found in the Paione lakes. Both inlet and outlet rivers of Lago Paione Inferiore hosted populations of the highly acid-sensitive mayfly *Baetis rhodani*, while only moderately sensitive animals were found in Lago Paione Superiore. Despite being only 267 m higher in altitude, Lago Paione Superiore had a considerably lower diversity. The macroinvertebrate diversity differences in the samples from the Alps were high, ranging from less the 10 taxa in The French and Austrian lakes to 54 and 32 taxa in Paione Inferiore and Lago di Latte, respectively. This may probably partly be explained by differences in the sampling programme.

Tatra

Starolesnianske Pleso (15.1)

The lake was sampled twice, in 1993 and 1994. A total of 17 invertebrate taxa were recorded in Starolesnianske Pleso (Table 3.19). Chironomids were the dominant group with five species, followed in order of abundance by Oligochaeta and Coleoptera. The fauna of Ephemeroptera, Plecoptera and Trichoptera was poor, with zero, one and one species respectively.

The quantitative samples were dominated by the oligochaete *Tubifex tubifex* and the chironomids *Procladius (Holocladius)* sp. and *Heterotrissocladius marcidus*.The sampling depth was only 3.5 meters, which means that the samples were not taken from the true profundal zone.

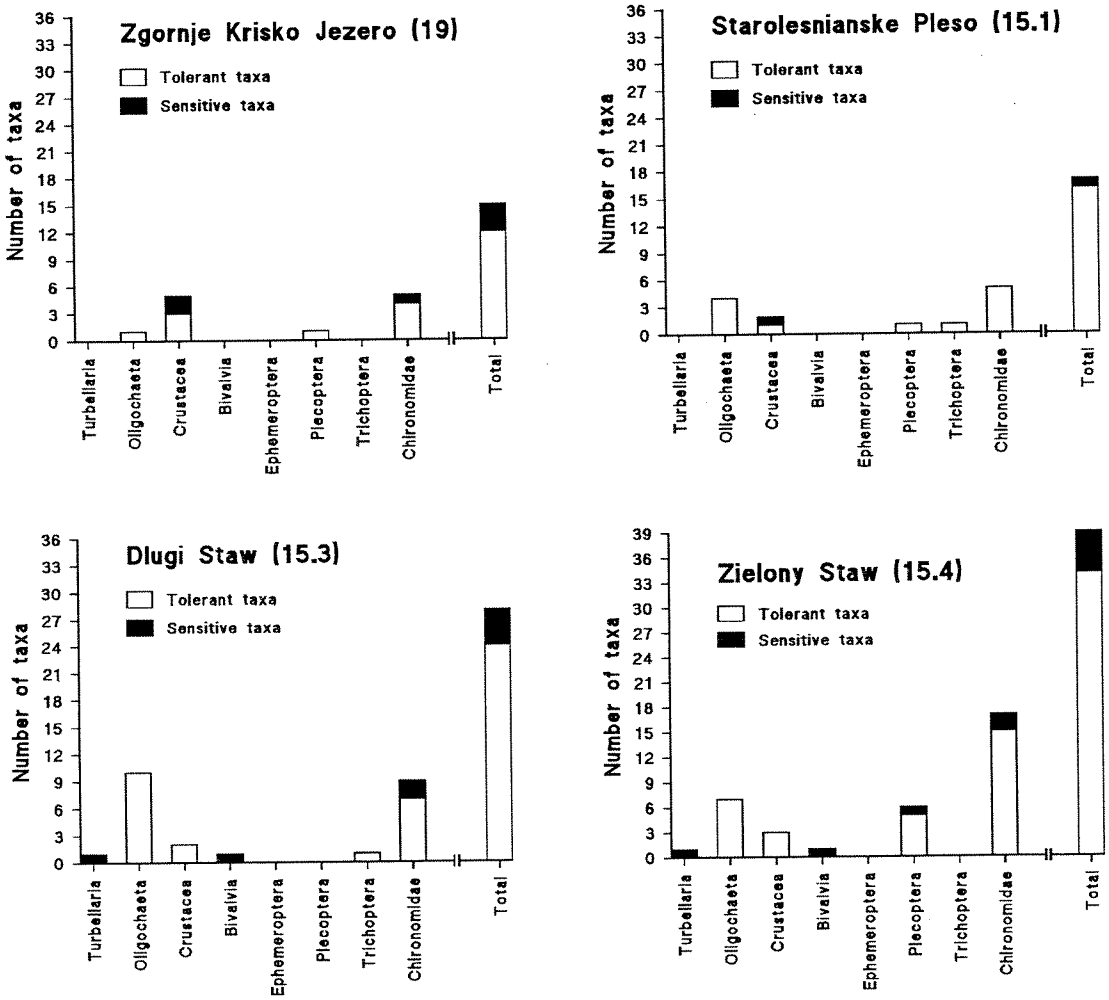
The total number of taxa in the lake system is probably higher than shown in Table 3.19, as no stream samples were taken. The crustacean *Cyclops* sp. was the only acid-sensitive species recorded in the samples (Figure 3.3.4).

Dlugi Staw (15.3)

The lake was sampled twice, in 1993 and 1994. A total of 28 different taxa were identified in Dlugi staw, of which oligochaetes comprised 11 taxa and chironomids 9 taxa (Figure 3.3.4, Table 3.20). The profundal community was relatively well developed and also dominated by the above mentioned groups. *Heterotrissocladius marcidus* and *Micropsectra radialis* were most abundant among the chironomids.Table 3.20 also includes obsevations made by diving. During this activity the flatworm *Crenobia alpina*, a characteristic species for cold mountain lakes, was found.

The record of four moderately sensitive taxa (Figure 3.3.4) places the lake in acidification category 0.5.

Figure 3.3.4: Occurrence of acid sensitive and tolerant species within inverterate groups in Zgornje Krisko Jezero, Starolesnianske Pleso, Dlugi Staw and Zielony Staw.



Zielony Staw (15.4)

A total of 39 taxa were identified in Zielony Staw (Figure 3.3.4, Table 3.21). Chironomidae was the largest group (17 taxa) followed by oligochaets (7 taxa). The profundal fauna was dominated by oligochaetes and chironomids.

Three littoral kick samples contained a total of 11 chironomid taxa. *Macropelopia* sp., *Heterotrissocladius marcidus*, *Corynoneura* sp., *Paratanytarsus austriacus*, and *Dicrotendipes* sp. dominated. In a kick sample from the outlet 14 taxa were found, the most important were *Heterotrissocladius marcidus*, *Corynoneura* sp., and *Micropsectra* sp.

Five of the identified taxa were known to be moderately acid sensitive, giving the lake an acidification index of 0.5.

Region summary - Tatra

Three lakes of the Tatra region were subjected to invertebrate studies. Zielony Staw had the richest fauna (39 taxa) followed by Dlugi Staw (28 taxa) and Starolesnianske Pleso (17 taxa). The proportion of acid- sensitive species was low, and only moderately sensitive animals were detected.

3.3.4 Discussion

Some of the lakes of this study were also sampled during the AL:PE 1 project (Wathne et al. 1995). The recorded fauna of these localities was generally very similar to the results of AL:PE 1. However, in some cases the station net was different from the previous sampling. In Norway this is illustrated in Lake Øvre Neådalsvatn. The recorded fauna was remarkably similar with a total number of taxa of 67 and 70 in 1991 and 1994, respectively. An important difference is the record of the mayfly *Baetis rhodani* in both the inlet (not sampled in 1991) and outlet stream. According to Raddum et al (1988) the presence of *Baetis rhodani*, which is highly acid-sensitive, places Lake Øvre Neådalsvatn in acidification category 1 (not acidified). In 1991, Lake Lille Hovvatn was considered the most acidic of all lakes in the study. This was also the case in the present dataset. In 1993 a single specimen of the moderately sensitive mayfly *Siphlonurus alternatus* was found in one of the samples. This species has recently colonized the nearby Lake Store Hovvatn due to liming (Fjellheim & Raddum 1993). The build-up of the population in this lake may have caused occasional colonisation in Lake Lille Hovvatn. However, the pH of the latter is too low to maintain stable populations of the species.

During the AL:PE 1 project, a sharp faunal gradient was demonstrated for the Italian lakes (Wathne et al. 1995). In spite of the relatively small difference in altitudine between the upper and lower Paione lakes (267 m), there is a difference in the total number of taxa, and more sensitive taxa were found in Lago Paione Inferiore. This also includes *Baetis rhodani*, which in 1994 was found in both the inlet and outlet stream. Besides geological differences, climatic differences are also an important factor at such high altitudes. Between relatively small differences in altitude, the length of the ice-free period may vary considerably and seems to be of great importance to the benthic community. This is in accordance with the results of the CCA-analysis made on the AL:PE 2 Crustacea dataset, where altitude and length of the ice-free season were considered the most important explanatory factors.

The samples from Spain and Portugal had the highest invertebrate diversity of the AL:PE 2 data, including a total of 123 taxa. The two Pyreneean lakes appeared to have the highest species richness. The low number of taxa in La Caldera (Sierra Nevada), can be related to the small area of the lake and its watershed, and the large lake-level fluctuations due to high evaporation and low summer precipitation. The number of species increases from south to north on the Iberian peninsula and no trend related to acidification of the lakes was evident. Most of the species collected in the present survey of high mountain lakes and lagoons in Spain and Portugal are cold stenothermal and are common in oligotrophic mountain lakes and streams.

Three of the plecopteran species are endemic to the Pyrenees: *Pachyleuctra benlocchi*, *P. bertrandi* and *Chloroperla breviata*. Most of the rest are known from central and southern Europe. The list of Ephemeroptera is short if we consider only the lake samples. Species known as highly resistant to acidification in high mountain lakes such as *Leptophlebia vespertina*, did not appear. However, biogeographical reasons are probably more important than water quality in this case. The Chironomid communities of the four lakes studied were composed mainly of species known from montane and northern lakes or streams in Europe. The species found in Lagoa Escura are known to inhabit a wide range of environments. Several species commonly found in northern remote lakes, which until the present study were not reported in Southern Europe, appeared in collections of chironomid exuvial pupae from the Iberian peninsula. This was the case of *Paratanytarsus setosimanus*, described from Greenland but suggested for the West Palearctic by Reiss & S@vedal (1981). Also *Pentaneurella katterjokki*, which has been described from springs and mountain springs above the tree line in North Scandinavia and was recently found in Sierra Nevada (Casas & Vilches 1993) was found at Lake Redo in this study. These two chironomid species must be considered as glacial relicts.

In Lake Aguilo another glacial relict was found: *Hygrobates foreli*, a water mite. The rest of the Hydracnellidae species are typical cold stenoterm species, except *Piona carnea*, which is known from lentic waters and temporary lagoons. This is in accordance with the results for the chironomids: this species was the only one found in Lagoa Escura, which confirms the idea of its poorly specialized fauna.

A total of 154 chironomid taxa were identified from the AL:PE 2 sites (Table 3.22 a-c). It is difficult to see any pattern in the occurence of the different taxa. Most are normal inhabitants of mountainous lakes and rivers all over Europe. The chironomid fauna at the Norwegian sites are very diverse, and this reflects the differences in the three habitats. Øvre Neådalsvatn has a typical undisturbed chironomid fauna both in the littoral and profundal zone. In Stavsvatn and Lille Hovvatn the littoral fauna is dominated by acid tolerant chironomid taxa, except from *Micropsectra insignilobus* in Stavsvatn and *Microtendipes pedellus* in Lille Hovvatn, which are regarded as acid sensitive. The chironomid fauna of Paione Superiore was similar in 1991 and 1994. The mostly terrestrial genus *Bryophaenocladius* dominated the kick samples in the littoral zone. Considering the altitude the lake has a very high number of chironomid larvae per m^2 in the profundal zone. Only 10 taxa were found, reflecting the high altitude. The chironomid fauna of Paione Inferiore was much richer, with 26 taxa found in the inlet, littoral zone, and outlet. Comparing the two lakes, the chironomid communities show few similarities. This is surprising, since the difference in altidude between the lakes is only 267 meters. The two other Italian sites, Lungo and Latte, both contained *Pseudodiamesa* cf. *branickii* and *Pseudodiamesa* cf. *nivosa*, indicating an ultraoligotrophic environment. *Corynoneura* cf. *arctica* were found in the profundal zone of both lakes. This is peculiar, since the members of the genus normally lives in the littoral zone of lakes and in rivers.

The profundal samples from Arresjren was dominated by *Micropsectra insignilobus*, indicating a moderately oligotrophic lake. Only 3 taxa were found in the bottom samples. The density of chironomid larvae was suprisingly high at all depths except for the samples taken at 31 meters, where no chironomids were found. There are nesting cliffs for birds surrounding the lake, and this probably results in a mild eutrophication, explaining the moderately oligotrophic chironomid community. The river samples from Arresjren were, as expected, dominated by the genus *Diamesa*. The chironomid community found in the samples from Lough Maam was very similar to the fauna found in Lille Hovvatn, indicating an acid, humic locality. This is shown particularly by the presence of *Tanytarsus buchonius* and the dominance of *Psectrocladius* (*Psectrocladius*) spp.

For unknown reasons, no chironomids were found in the kick samples from the littoral zone of Schwarzsee ob S`lden. Only *Micropsectra radialis* was found in the profundal samples. This indicates ultraoligotrophic conditions. The species is regarded as acid sensitive.The Spanish sites Llac Aguilo and Llac Redo are characterized by the highest species diversity found among the chironomids in the project. The fauna mostly consists of taxa normally found in mountain regions throughout Europe. By contrast, only 4 taxa were found in La Caldera in Southern Spain. Also in this lake *Corynoneura arctica* was found in the profundal zone. The presence of *Micropsectra radialis* shows that the lake is ultraoligotrophic, and is not severely influenced by acid rain. Lagoa Escura in Portugal has a chironomid fauna in the profundal zone indicating a moderately oligotrophic environment. *Cladopelma* sp. can be regarded as acid sensitive.

The bottom samples from Starolesnianske Pleso are taken in a too shallow area of the lake to be regarded as profundal samples. A typical member of the chironomid community in this part of Europe is *Zalutschia tatrica*, which was originally described from the area. In Dlugi Staw Gaisenkowy the dominance of *Micropsectra radialis* in the profundal samples indicates that this is an unacidified, ultraoligotrophic lake. The profundal samples from Zielony Staw Gaisenkowy are similar to the samples from Dlugi Staw Gaisenkowy, but more taxa were found in this lake. In Chibini the presence of two species of *Pseudodiamesa* shows that this is an ultraoligotrophic lake. These two taxa are most likely identical to the *Pseudodiamesa* taxa found in Lago Lungo and Lago Latte in Italy. The dominance in the profundal zone of *Diplocladius cultriger* is surprising, this species is normally found in brooks and the littoral zone of lakes. The littoral kick samples from Zgornje Krisko Jezero contained *Pseudodiamesa branickii*, showing the ultraoligotrophic nature of the lake.

Most of the data regarding the relationships between acidification of freshwater and benthic invertebrates refer to studies in nordic countries, while data for the Alps or the southern mountain environments are more scarce. In general, results show a decrease in species richness with the disappearance of gastropods, mayflies, stoneflies, caddisflies, crustaceans as well as other groups (Otto & Svensson 1983, Raddum & Fjellheim 1984, Fjellheim & Raddum 1990). The negative trend in species richness can be reversed by liming (Fjellheim & Raddum 1992, Henrikson & Brodin 1995). However, re-immigration of sensitive invertebrates to limed lake ecosystems are low in cases where there are long distances to the nearest population (Fjellheim & Raddum 1993).

Øvre Neådalsvatn had the richest fauna with respect to acid-sensitive species (Figure 3.3.5). A total of 17 different sensitive taxa was registered in this locality. This was more than double that found in Lago Paione Inferiore (8 taxa). Also two of the Spanish lakes, L. Redo and L. Aguilo, had a relatively high number of acid-sensitive species. All the above mentioned lakes hosted invertebrate species belonging to the most sensitive category according to the model of Raddum et al. (1988). Examples of such invertebrates are the mayfly *Baetis* spp. and gastropods. The other lakes can, with respect to the fauna, be considered more acidified. Colonization rates are, however, low in such remote systems. This can account for the low species diversity as well as absence of many sensitive species despite a water chemistry indicating that such sensitive species should be able to live there.

Some of the Ephemeroptera and Plecoptera registered in the localities in the Iberian peninsula, including some endemic stoneflies, were poorly known with respect to tolerance levels. With better knowledge of their tolerance to acidic water, the total number of sensitive species in L. Redo and L. Aguilo might have been higher.

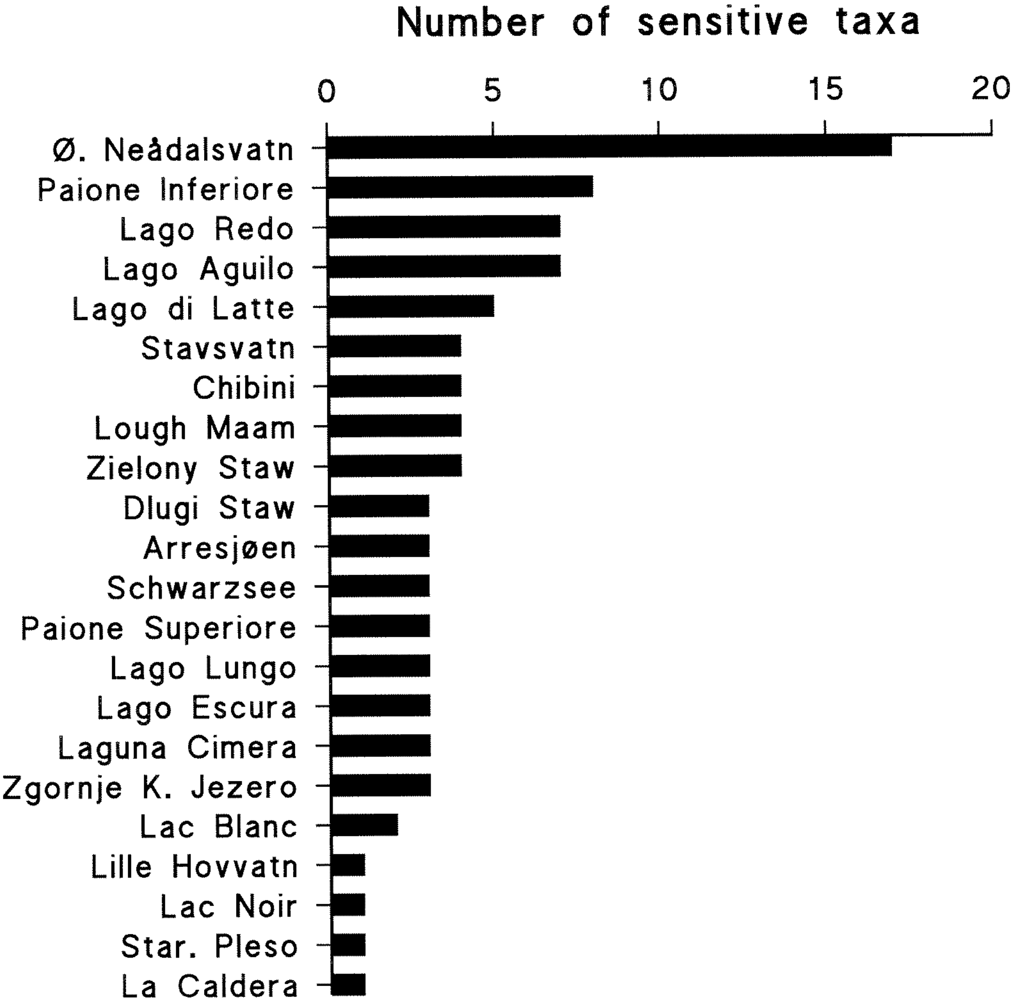


Figure 3.3.5. Number of sensitive invertebrate taxa recorded in the investigated lakes.

3.3.5 Summary

Benthic invertebrate sampling throughout the AL:PE 2 programme was standardized for all participating institutions and included qualitative and quantitative data from all sites as well as paleolimnological analyses from selected sites. All lakes were ranked according to the number of acid-sensitive species present. The Norwegian reference Lake Øvre Neådalsvatn, had the richest fauna with respect to acid-sensitive species. A total of 17 different sensitive taxa were recored in this locality. This was more than the double the number found in Lago Paione Inferiore (8 taxa). In addition, the two Spanish lakes, L. Red\ and L. Aguil\, had a relatively high number of acid-sensitive species. All of these lakes had invertebrate species belonging to the most sensitive category, such as the mayfly genus *Baetis* and gastropod species. The other lakes could, with respect to their faunas, be considered more acidified. Colonization rates are, however, low in such remote systems and this could account for the low species diversity as well as the absence of many sensitive species even though the water chemistry is suitable for their survival.

3.3.6 References

Casas J. J. & A.Vilchez-Quero. 1993. Altitudinal distribution of lotic chironomid (Diptera) in the Sierra Nevada mountains (Southern Spain). Annls. Limnol. 29(2): 175-187.
Fjellheim, A. & Raddum, G. G. 1990. Acid precipitation: Biological monitoring of streams and lakes. - The Science of the Total Environment 96: 57-66.
Fjellheim, A. & Raddum, G. G. 1992. Recovery of acid sensitive species of Ephemeroptera, Plecoptera and Trichoptera in River Audna after liming. - Environmental pollution 78: 173 - 178.
Fjellheim, A. & Raddum G. G. 1993. Changes in the mayfly community of Lake Hovvatn During the first 12 years of liming. - In: G.Giussani and C. Callieri (eds), Strategies for Lake Ecosystems Beyond 2000, Proceedings, Stresa, pp. 407-410.
Fjellheim, A. & Raddum G. G. 1995.Benthic animal response after liming of three South Norwegian rivers. -Water Air and Soil Pollution 85: 931 - 936.
Henrikson, L. & Brodin, Y. W. 1995. Liming of acidified surface waters. Springer Verlag, Berlin. 458 pp.
Frost, S., Huni, A. & Kershaw, W.E. 1971. Evaluation of a kicking technique for sampling stream bottom fauna. - Can. J. Zool. 49: 167-173.
Kajak, Z. 1971. Benthos of standing water. In: Edmondson, W.T. and Winberg, G.G. (eds.) A manual on methods for the assessment of secondary productivity in fresh waters. IBP Handbook no. 17. pp 25-65. Blackwell Scientific Publications, Oxford.
Otto, C. & Svensson, B. S. 1983. Properties of acid brown water streams in south Sweden. Arch Hydrobiol.99: 15-36.
Raddum, G.G. & Fjellheim, A. 1984. Acidification and early warning organisms in freshwater in western Norway. - Verh. Internat. Verein. Limnol. 22: 1973-1980.
Raddum, G.G., Fjellheim, A. & Hesthagen, T. 1988. Monitoring of acidification by the use of aquatic organisms. - Verh. Internat. Verein. Limnol. 23: 2291 -2297.
Reiss, F. & S@vedahl, L. 1981. Keys to males and pupae of the Palaearctic (excl Japan) *Paratanytarsus* Thinemann & Bause, 1913, n. comb., with descriptions of three new species (Diptera: Chironomidae). - Ent. Scand. Suppl. 15: 73-104.
Schnell, Ø. A. & Raddum G. G. 1993. Past and present fauna of chironomids in remote mountain lakes. Preliminary results from the AL:PE 1 Project. - In: G.Giussani and C. Callieri (eds), Strategies for Lake Ecosystems Beyond 2000, Proceedings, Stresa, pp. 444- 447.
Wathne, B. M., Patrick, S. T., Monteith, D. & Barth, H. 1995. AL:PE Project part 1. European commission, Ecosystem research report 9, 292pp. CEC-Environment, Bruxelles.

Legend to figures

Figure 3.3.1. Occurrence of acid sensitive and tolerant species within invertebrate groups in Arresjren, Lake Chibini, Øvre Neådalsvatn, Stavsvatn, Lille Hovvatn and Lough Maam.

Figure 3.3.2. Occurrence of acid sensitive and tolerant species within invertebrate groups in La Caldera, Lago Escura, Laguna Cimera, Lago Aguil\, Lago Red\ and Lac Blanc.

Figure 3.3.3. Occurrence of acid sensitive and tolerant species within invertebrate groups in Lac Noir, Lago Paione Superiore, Lago Paione Inferiore, Lago Lungo, Lago di Latte and Schwarzsee ob S`lden

Figure 3.3.4. Occurrence of acid sensitive and tolerant species within invertebrate groups in Zgornje Krisko Jezero, Starolesnianske Pleso, Dlugi Staw and Zielony Staw.

Figure 3.3.5. Number of sensitive invertebrate taxa recorded in the investigated lakes.

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

AL:PE 2 report for the period January 1993-June 1995.

Appendix 4. Contemporary Biology: Diatoms

Nigel G. Cameron[1] and H.John B. Birks[2]

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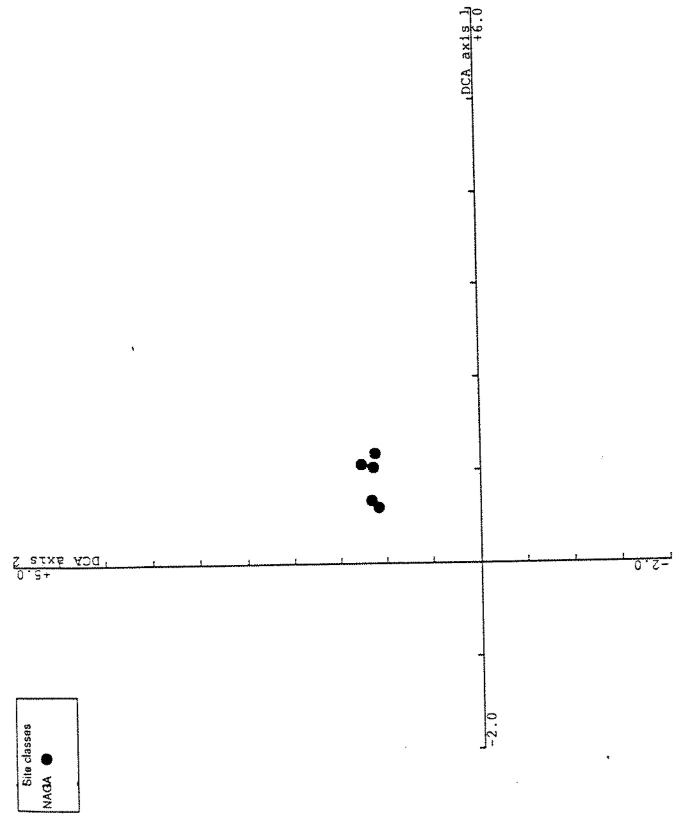
[2] University of Bergen, Botanical Institute (UIB-BI)

Appendix 4. Contemporary Biology: Diatoms

DCA plots of samples from each site

Diatom epilithon-based pH reconstruction using AL:PE diatom surface sediment - water chemistry calibration training set

Combined AL:PE 1 & AL:PE 2 diatom taxa and DIATCODES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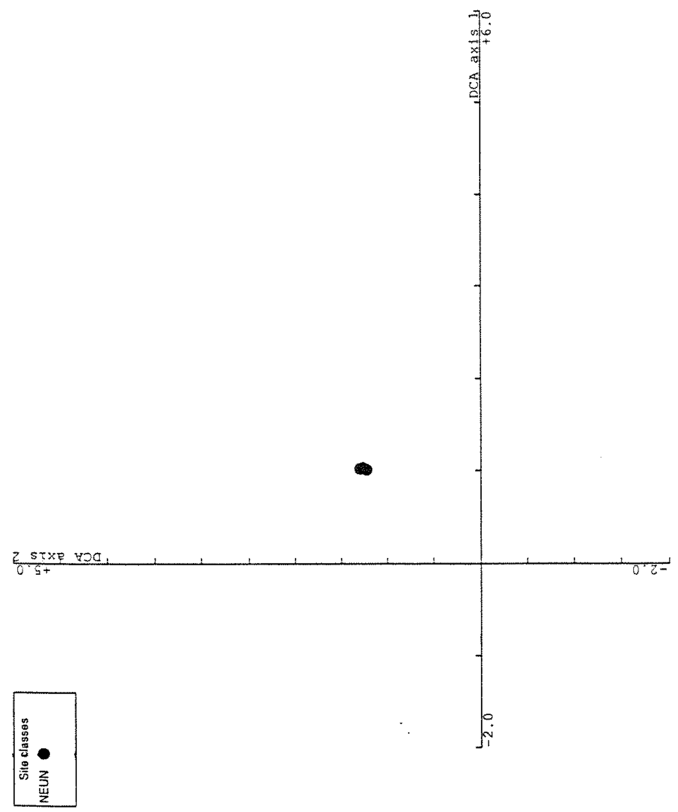
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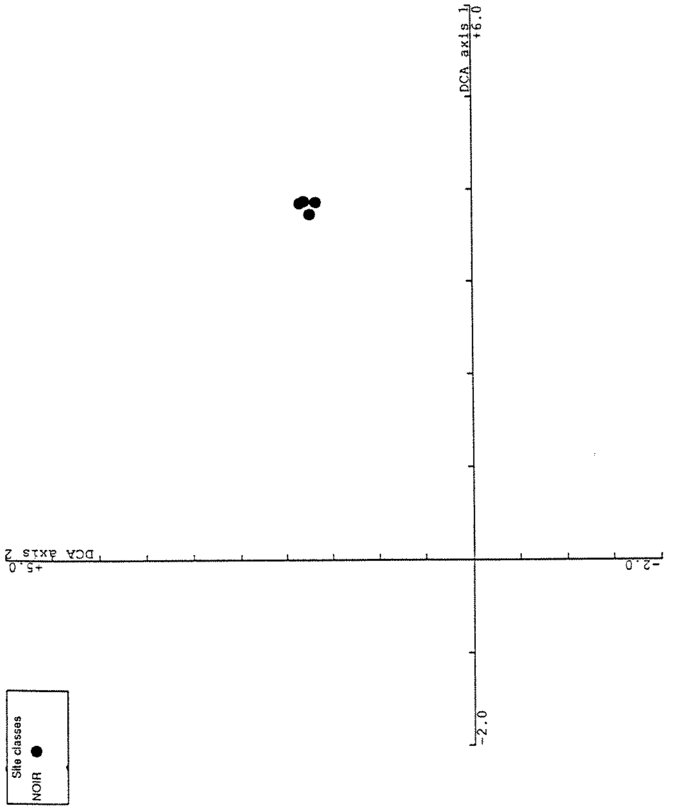
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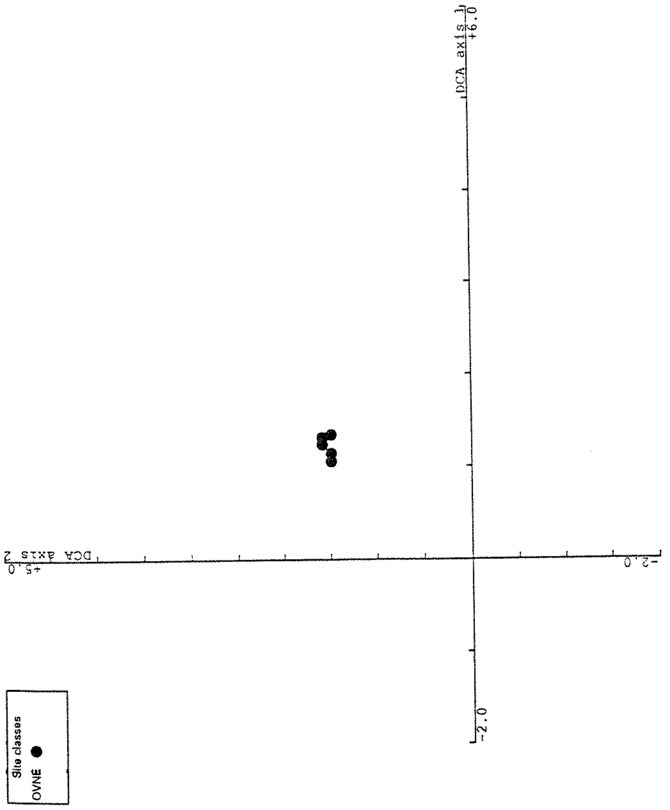
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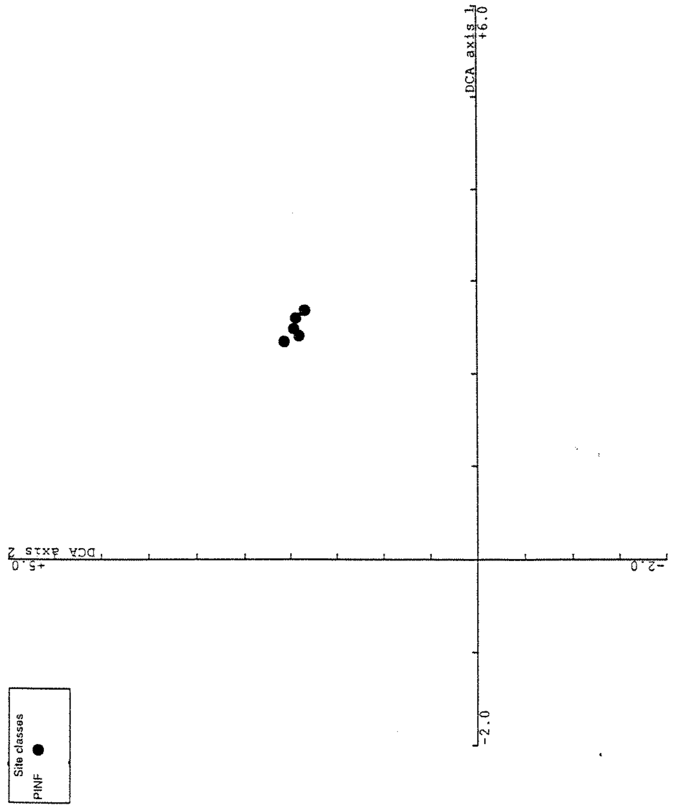
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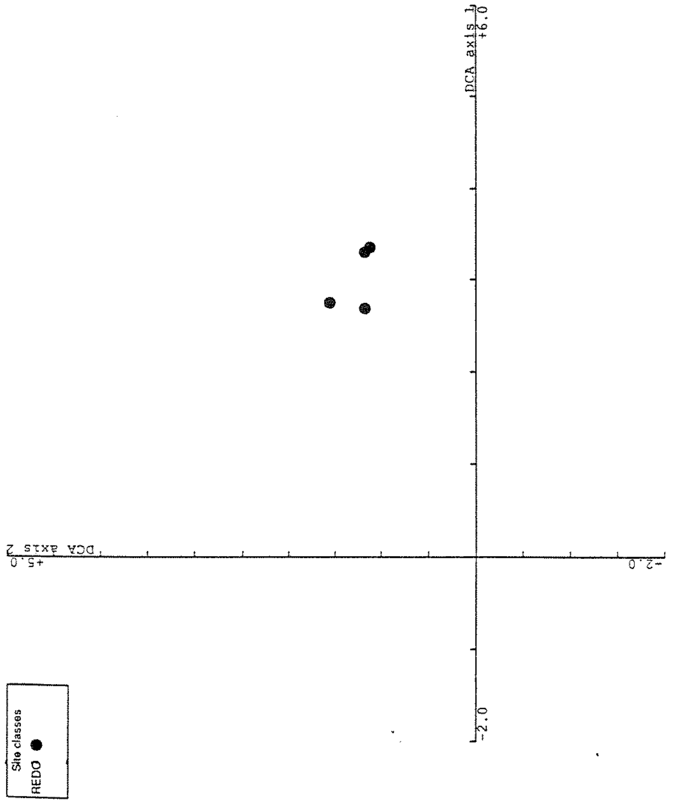
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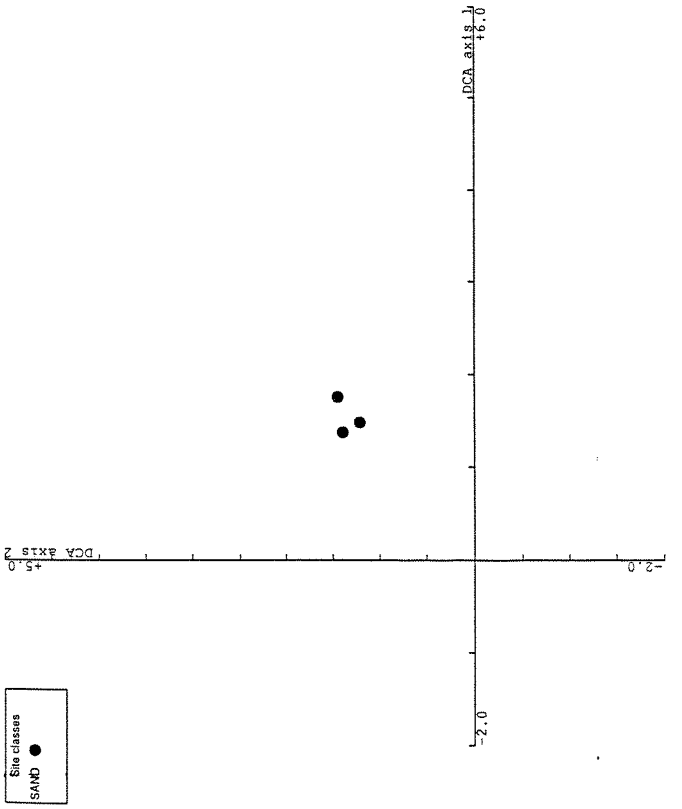
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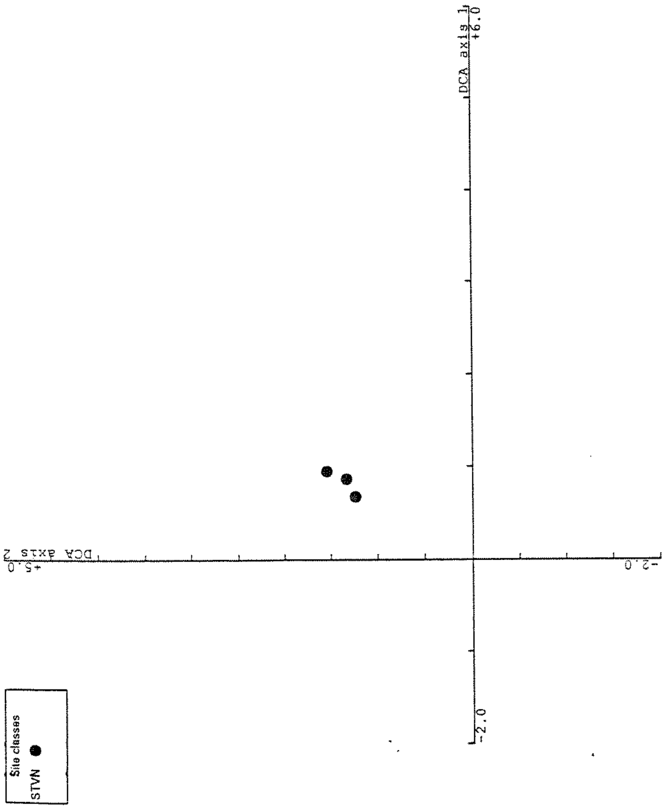
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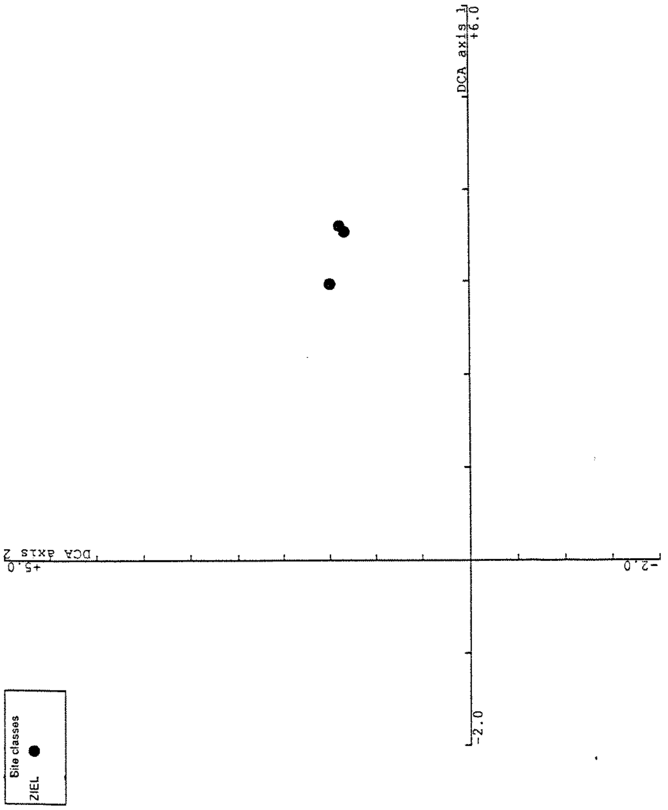
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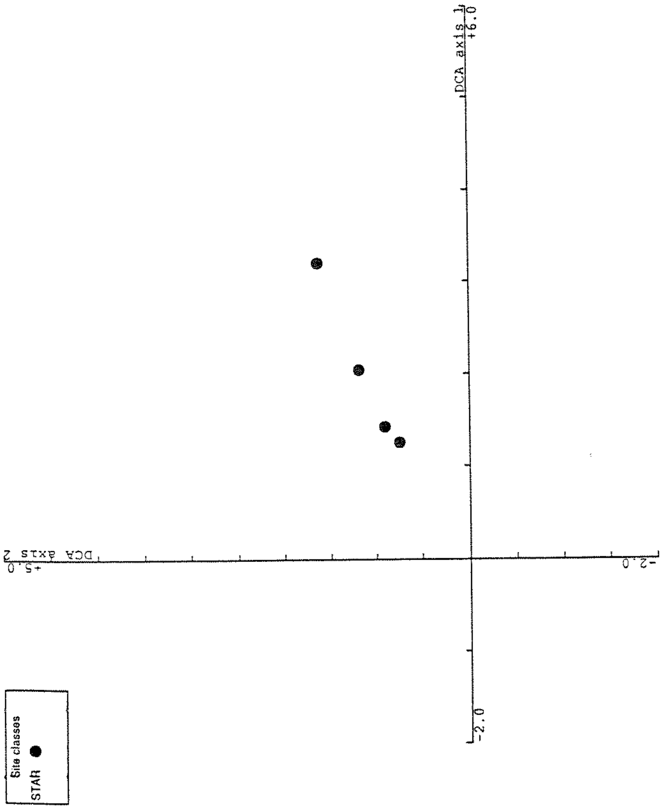
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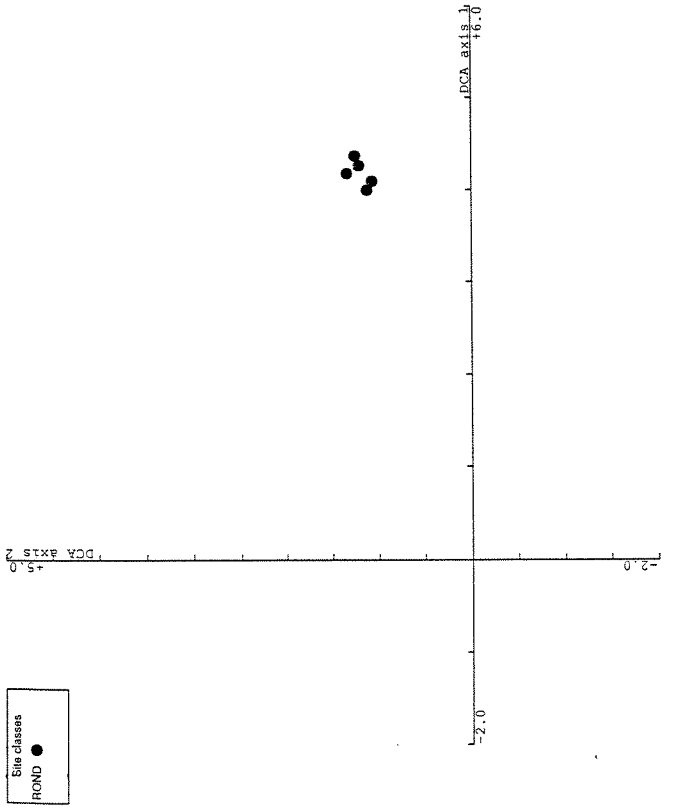
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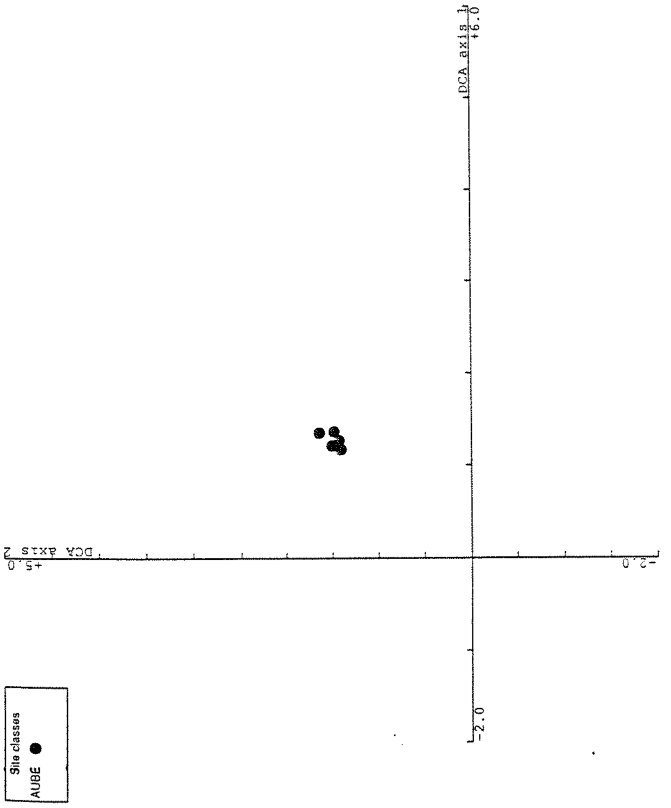
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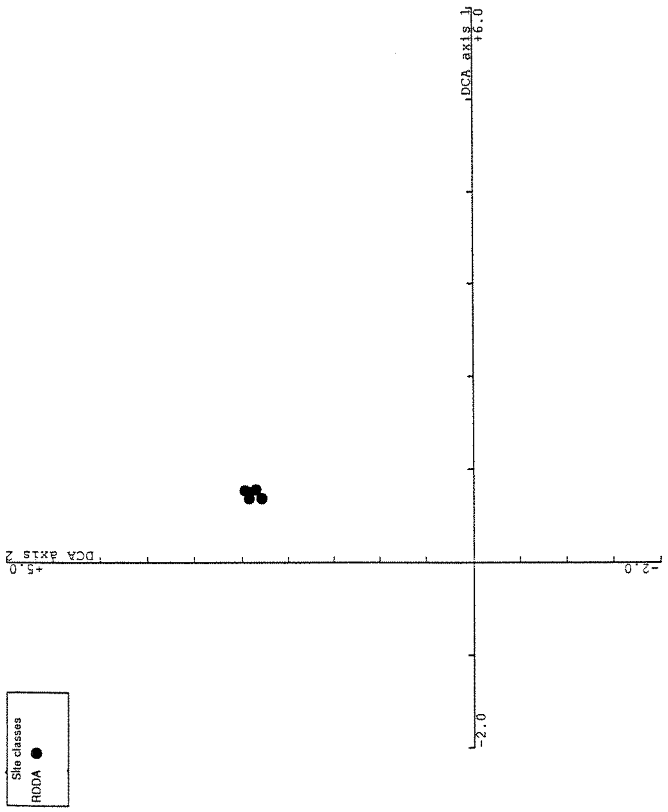
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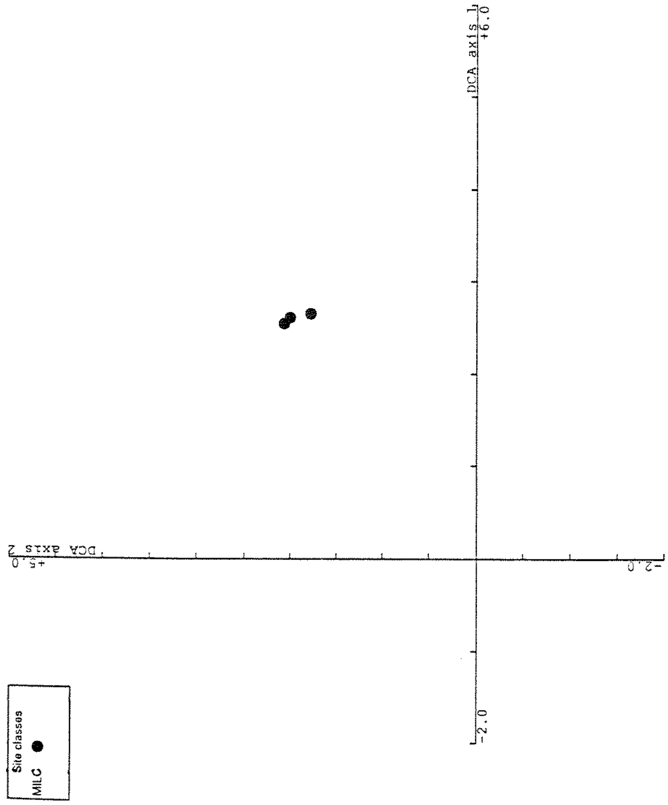
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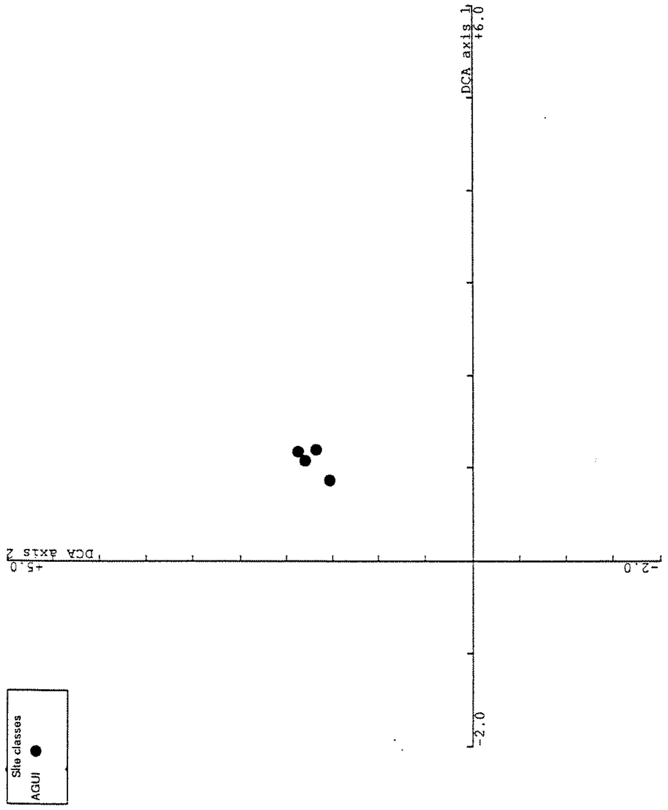
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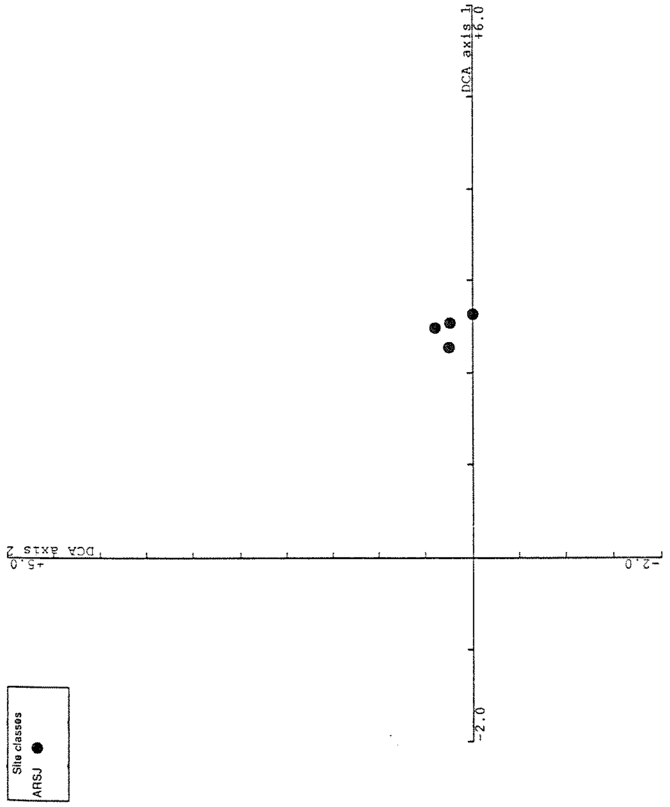
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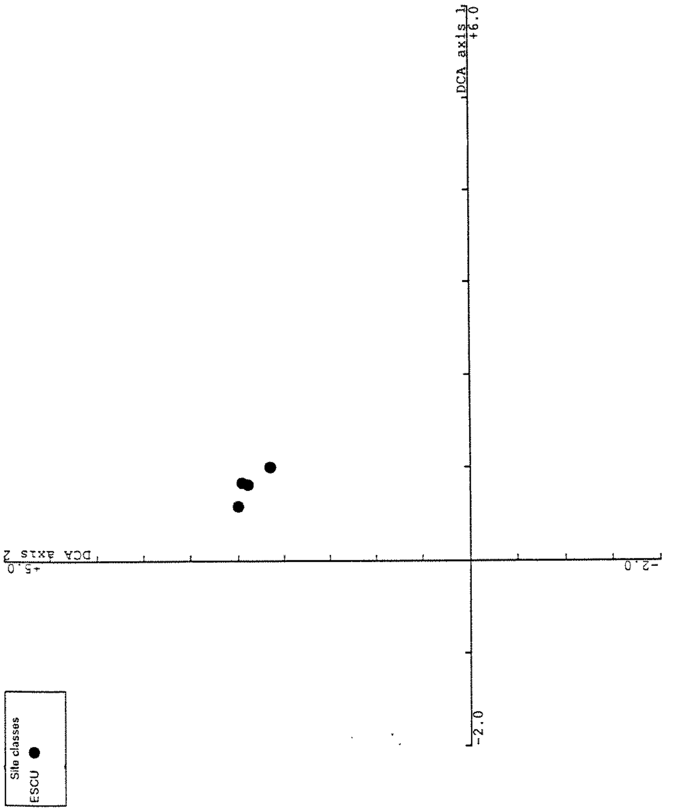
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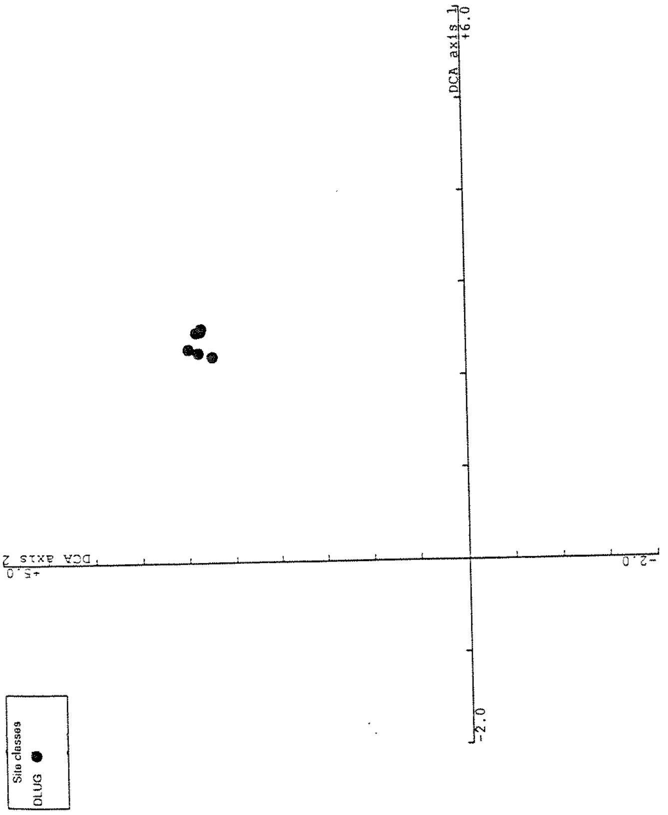
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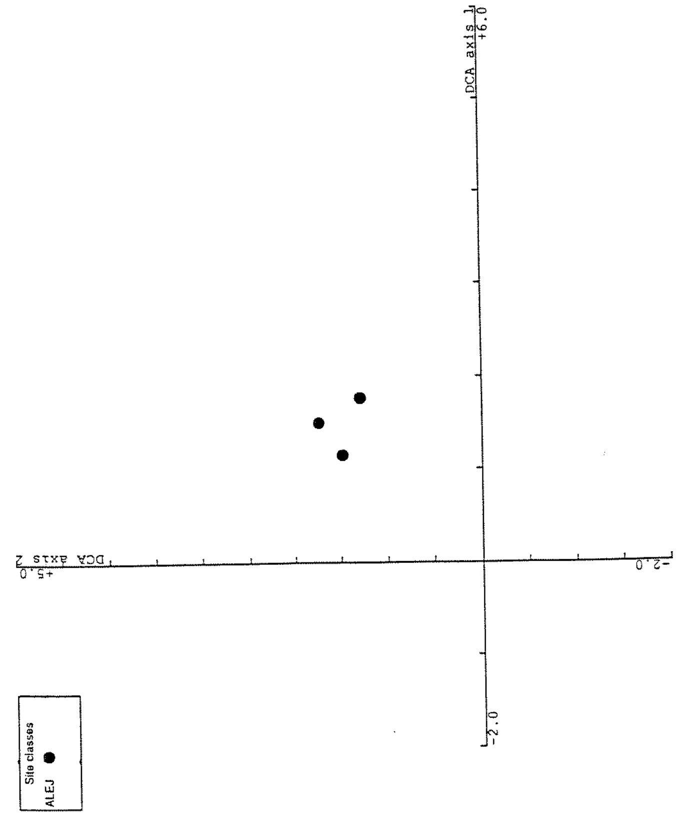
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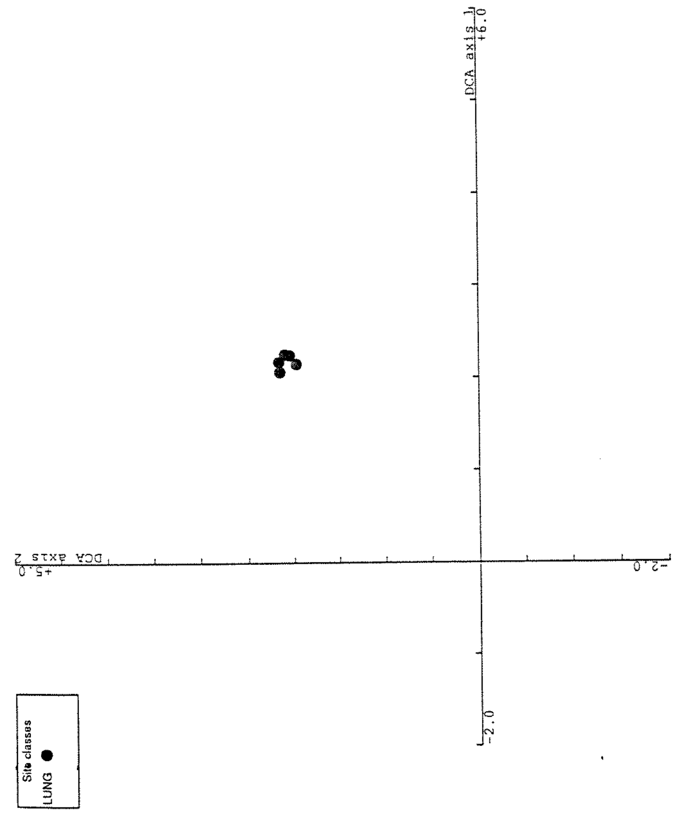
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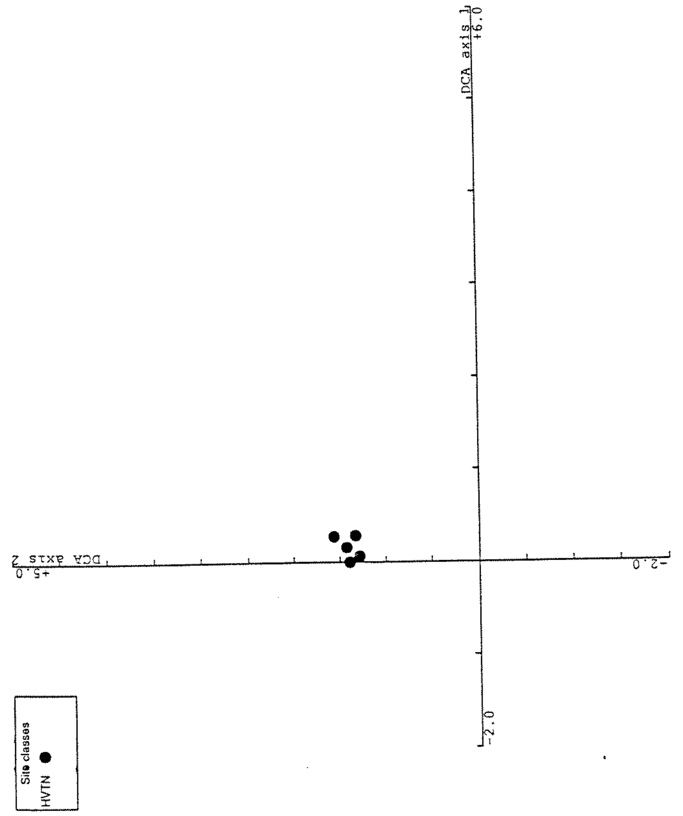
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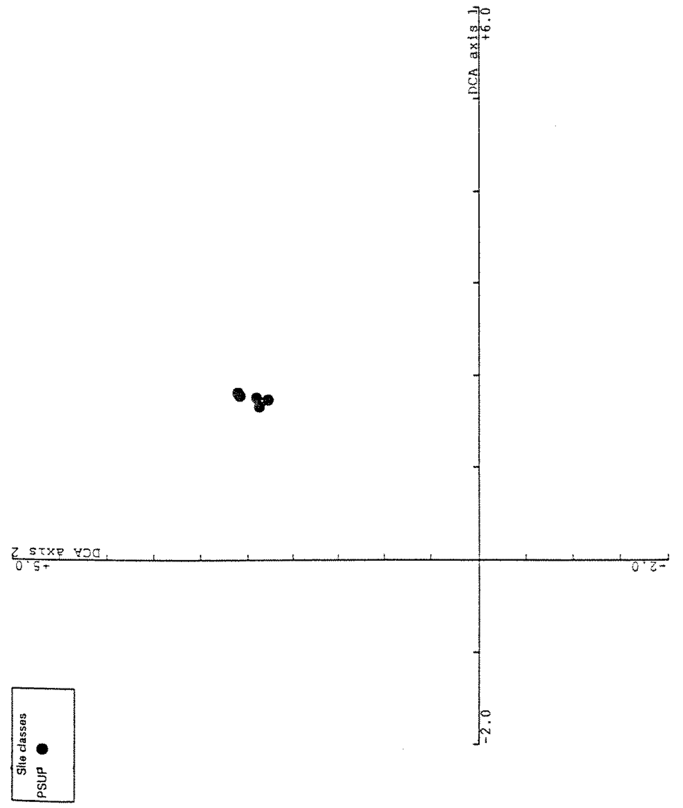
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Site classes
PSUP ●

```
Program WAPLS - Version 1.0

Results for environmental reconstruction of variable      pH
from fossil data epilsqrt.cep


Species comparison between WAPLS coefficient file and fossil data

           Taxon               Fossil                          Modern
                      N         Max       N2           N        Max       N2

   1   AC001A         2       0.6083     1.95          6      1.6310     4.68
   2   AC010A         1       0.8888     1.00          6      1.4697     4.67
   3   AC013A        54       8.5299    33.37         79      7.4202    53.40
   4   AC014B        58       3.3151    50.01         52      5.3852    37.55
   5   AC014C        72       6.1384    48.32         67      8.2462    44.78
   6   AC018A         2       0.8246     1.95          4      1.1747     3.57
   7   AC022A        80       7.5253    60.63         85      6.8498    60.14
   8   AC023A         2       1.0488     2.00          4      1.5652     3.48
   9   AC024A         6       1.9079     4.79          2      0.5831     1.97
  10   AC027A         6       0.6000     6.00          7      0.7141     6.74
  11   AC028A         2       0.6164     1.98          8      2.2361     5.80
  12   AC034A         3       0.6782     2.99         21      2.3431    15.58
  13   AC035A         5       1.0583     4.69          5      1.4142     3.80
  14   AC046A        20       3.8756    14.79         23      2.7386    16.22
  15   AC048A        61       5.5218    45.24         63      5.1624    48.17
  16   AC060A        30       4.3795    20.78         55      6.6030    40.16
  17   AC082A         9       1.4213     8.17          5      1.9468     4.47
  18   AC134A        10       2.1119     7.33         18      7.1400    12.42
  19   AC136A        37       4.1425    27.87          0      0.0000     0.00
  20   AC9968        25       4.3116    19.00         28      6.6317    17.75
  21   AC9975         7       3.4713     5.61          5      2.5652     3.49
  22   AC9996         1       0.8485     1.00          3      3.3166     2.22
  23   AC9999        40       1.6155    35.78         37      2.0857    29.01
  24   AM001A         1       0.5831     1.00          5      0.7937     4.81
  25   AM001B         7       1.1619     6.57          3      2.4779     1.95
  26   AM001C         2       0.5916     2.00          0      0.0000     0.00
  27   AM013A         1       0.6000     1.00          1      0.4472     1.00
  28   AM9999         2       0.6782     1.99          1      0.4123     1.00
  29   AU001A         2       0.5745     2.00          5      2.9967     3.77
  30   AU004D        47       6.3095    27.48         39      6.0349    27.16
  31   AU005A        15       3.2604    11.71         23      3.7376    17.63
  32   AU005E        37       7.3491    19.05         51      7.5835    37.07
  33   AU010A         2       0.6708     1.99          8      2.5120     5.38
  34   AU9999        30       2.7477    22.28         25      1.1747    22.71
  35   BR001A        30       4.3359    19.35         51      4.2907    32.95
  36   BR003A        14       1.8894    11.92         15      3.8013     8.19
  37   BR003B        15       1.6971    12.60          7      1.3038     5.89
  38   BR004A         1       0.5916     1.00          2      0.9539     1.77
  39   BR006A        54       7.7891    29.68         56      5.2383    41.02
  40   CA002A         5       0.8602     4.89         12      1.3711     9.76
  41   CA005A         3       0.8602     2.93          1      1.6703     1.00
  42   CA018A         1       0.6164     1.00          0      0.0000     0.00
  43   CM001A        10       1.1790     9.40          6      1.7804     4.44
  44   CM004A         6       0.9539     5.78         13      1.5264    10.82
  45   CM010A        35       2.4920    28.73         38      5.5678    25.25
  46   CM014A        24       2.6533    19.67         31      2.7074    25.65
  47   CM015A         2       0.6000     2.00          7      0.8124     6.55
  48   CM017A        29       1.5652    26.19         63      2.6306    49.98
  49   CM022A        10       2.4413     8.58          9      2.4372     5.59
  50   CM031A        38       8.0405    25.45         54      3.2696    43.68
  51   CM048A        15       2.5788    11.74         29      2.1633    22.69
  52   CM9999        16       1.3856    14.88         28      1.7000    23.11
  53   CY003A         2       0.6164     2.00          0      0.0000     0.00
  54   CY006A         7       2.0347     5.46          1      0.4899     1.00
  55   CY009A         1       0.6000     1.00          0      0.0000     0.00
  56   CY010A         5       2.0952     4.16          5      4.0988     2.69
  57   DE001A        16       5.7489    12.10         18      2.7785    11.42
  58   DP001A         1       0.5657     1.00          4      1.0344     3.45
  59   DT002B        20       2.1794    16.33         19      1.6401    15.56
  60   DT004B         4       0.8602     3.89          3      0.8660     2.79
  61   EU002A         8       1.3892     7.38         13      0.9000    11.97
  62   EU002B        31       4.0534    20.33         31      2.3664    22.27
  63   EU002C         2       0.6083     2.00          2      1.5556     1.69
  64   EU002E         2       0.8185     1.99          4      0.6164     3.92
  65   EU003A        12       1.8735    10.00          8      1.9235     5.43
  66   EU004A        44       3.0529    34.57         26      1.4353    22.77
  67   EU009A        46       6.3679    27.93         58      3.9243    40.95
  68   EU009C         3       1.3379     2.73          1      0.5000     1.00
  69   EU009D         1       0.6000     1.00          0      0.0000     0.00
  70   EU011A        26       2.7331    21.71         27      1.6613    20.87
  71   EU013A         2       0.6245     2.00         12      1.0149    10.84
  72   EU014A         5       1.3379     4.53          9      2.0785     6.60
  73   EU015A        13       3.7868    10.00         21      1.9875    16.59
  74   EU016A         2       0.9539     1.99          4      0.6403     3.90
  75   EU017A         2       0.6481     2.00          6      1.1000     5.06
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77	EU025A	8	1.1916	7.46	9	1.1045	8.01
78	EU026A	2	0.6000	2.00	3	0.7746	2.78
79	EU027A	2	0.7071	1.98	6	1.5875	4.70
80	EU028A	2	0.7000	1.99	7	1.9157	4.78
81	EU029A	6	1.2000	5.42	3	0.6481	2.93
82	EU032A	9	1.3748	8.34	7	0.7071	6.75
83	EU040A	7	0.8832	6.88	11	1.7833	8.09
84	EU042A	1	0.6164	1.00	4	0.8544	3.66
85	EU045A	2	0.9798	1.90	6	1.2042	5.00
86	EU047A	54	4.4452	42.39	49	5.3666	34.97
87	EU048A	31	5.2479	19.59	31	2.5768	23.26
88	EU049A	24	5.1078	13.82	13	1.5811	10.71
89	EU049B	17	4.4238	9.56	8	1.5748	6.73
90	EU049C	1	0.6000	1.00	0	0.0000	0.00
91	EU051A	12	1.1874	11.32	7	0.8544	6.56
92	EU051B	2	1.8439	1.60	6	2.8320	3.97
93	EU053A	1	0.8307	1.00	4	0.5745	3.93
94	EU056A	7	1.8358	5.73	8	1.5524	6.43
95	EU057A	2	0.5916	2.00	8	1.7607	5.67
96	EU060A	1	0.5657	1.00	0	0.0000	0.00
97	EU9960	2	0.8602	2.00	1	0.4359	1.00
98	EU9961	19	2.0273	15.95	5	2.9648	3.61
99	EU9963	9	1.5330	8.34	5	1.1747	4.38
100	EU9965	10	2.0785	8.50	6	1.0583	5.79
101	EU9999	64	2.5140	55.60	31	2.6571	23.81
102	FR001A	12	1.9313	10.27	41	9.3968	26.80
103	FR002A	6	1.6613	5.19	13	6.4000	8.12
104	FR002B	2	0.8307	1.98	8	2.7477	6.29
105	FR002C	12	1.9287	10.67	41	8.9777	22.59
106	FR005A	4	0.8544	3.91	7	1.1225	5.91
107	FR005D	14	1.5330	12.16	34	7.9404	18.55
108	FR006A	3	2.1703	2.56	32	8.7573	19.10
109	FR007A	11	4.5056	6.37	11	2.2000	8.41
110	FR009A	12	3.9306	7.86	15	1.7635	12.07
111	FR9999	12	1.5100	10.58	19	1.7521	15.18
112	FU002A	11	1.4629	9.37	40	1.9519	33.18
113	FU002B	44	3.6674	30.59	48	3.0447	36.59
114	FU002F	2	0.6325	2.00	12	2.3324	8.78
115	GO003B	2	0.9695	1.99	1	0.6325	1.00
116	GO004A	13	3.3407	8.72	23	2.2361	16.95
117	GO006C	2	0.9592	1.82	2	0.6000	1.96
118	GO9999	4	0.9950	3.76	10	0.9000	9.33
119	HA001A	14	1.2610	12.90	4	0.4359	4.00
120	HN001A	9	1.0817	8.37	12	1.1180	10.48
121	MR001A	5	1.2570	4.27	4	1.5427	2.71
122	NA003B	18	1.1619	16.93	22	2.8249	17.02
123	NA005A	10	1.0583	9.55	27	2.8373	20.03
124	NA006A	20	1.6401	18.20	39	2.8196	27.93
125	NA006B	5	1.2247	4.89	0	0.0000	0.00
126	NA013A	8	1.0583	7.51	31	2.3108	23.18
127	NA014A	3	0.8602	2.90	36	3.8066	24.38
128	NA025A	8	0.9899	7.79	1	0.6325	1.00
129	NA032A	4	1.0149	3.76	14	2.0000	11.34
130	NA033A	3	1.6217	2.55	9	0.9592	8.45
131	NA036A	16	3.3332	11.57	16	1.0000	14.43
132	NA037A	5	1.0000	4.83	15	1.1916	12.65
133	NA039A	1	0.6000	1.00	1	0.4123	1.00
134	NA044A	14	0.9849	13.41	23	4.3875	14.19
135	NA046A	8	1.2124	7.44	5	0.8185	4.70
136	NA099A	9	1.6553	8.18	5	0.7141	4.73
137	NA115A	1	0.5916	1.00	14	2.0000	10.04
138	NA129A	3	1.2649	2.77	20	3.5029	14.95
139	NA133A	17	1.9209	14.96	28	3.7683	19.96
140	NA135A	14	4.6690	8.48	17	3.6483	11.10
141	NA149A	12	1.6941	11.15	36	4.0460	25.30
142	NA156A	3	0.9798	2.88	9	2.2935	6.88
143	NA158A	2	1.0770	1.96	4	0.6325	3.92
144	NA160A	20	1.1045	18.85	42	1.7234	35.01
145	NA167A	15	7.0207	8.06	15	2.6721	10.70
146	NA322A	1	0.8246	1.00	4	0.6083	3.87
147	NA465A	1	0.8367	1.00	0	0.0000	0.00
148	NA9968	2	0.6000	2.00	1	0.6000	1.00
149	NA9999	26	2.3516	21.44	29	4.4340	17.33
150	NE003B	16	1.4000	14.74	8	1.2247	6.74
151	NE003C	3	0.8544	2.92	7	1.1446	6.09
152	NE004A	19	1.3379	17.08	20	1.6000	16.19
153	NE006A	13	1.1790	11.83	31	2.2361	24.72
154	NE9999	8	0.6782	7.95	17	0.8660	15.69
155	NI002A	3	0.9539	2.99	26	3.4088	19.51
156	NI005A	24	4.7497	13.76	25	1.8947	21.26
157	NI015A	1	0.5916	1.00	7	0.6856	6.71
158	NI017A	9	1.5264	7.97	20	4.4721	10.09
159	NI025A	1	0.6000	1.00	18	0.9849	16.30
160	NI9999	34	2.3195	28.34	17	1.6000	14.28
161	PE002A	27	3.1984	20.94	38	3.7974	26.88
162	PI005A	2	0.8660	1.95	8	0.5831	7.82

163	PI007A	7	0.7746	6.69	6	0.7616	5.68
164	PI007F	6	2.8213	5.35	0	0.0000	0.00
165	PI011A	35	3.2450	27.71	35	5.3852	18.43
166	PI011G	2	0.6782	2.00	0	0.0000	0.00
167	PI012A	15	1.3964	13.68	2	1.0000	1.69
168	PI015A	4	1.3115	3.46	12	1.4142	10.02
169	PI015C	1	2.6115	1.00	0	0.0000	0.00
170	PI016A	3	0.9592	2.91	3	1.2806	2.61
171	PI018A	5	0.6633	4.99	29	2.5788	22.93
172	PI022A	21	1.8166	17.57	9	0.9644	8.28
173	PI022B	21	5.2858	12.91	30	3.1623	20.86
174	PI023A	5	0.8888	4.85	9	1.0050	8.09
175	PI051A	1	0.5000	1.00	0	0.0000	0.00
176	PI9999	30	1.4000	27.72	33	2.3065	25.95
177	SA001A	7	0.9899	6.71	27	2.4495	18.83
178	SA001B	12	1.1747	11.11	24	2.0125	19.87
179	SA058A	3	0.8307	2.94	3	0.4359	3.00
180	SA9999	3	0.6928	2.99	5	1.2000	3.91
181	SE001A	7	1.7578	5.98	7	4.9749	3.55
182	SP002A	7	1.0677	6.55	16	1.5620	13.13
183	ST9999	1	0.6325	1.00	2	0.4359	2.00
184	SU005A	37	1.4731	33.44	47	2.7964	34.53
185	SU006A	31	3.3838	21.67	26	2.0000	20.23
186	SU9999	1	0.6164	1.00	3	1.0198	2.68
187	SY003A	12	1.3491	10.91	2	5.2593	1.24
188	SY010A	5	0.8485	4.81	4	3.2031	2.01
189	TA001A	54	7.1330	36.63	60	5.1942	38.91
190	TA003A	7	2.2782	5.58	9	1.5033	7.93
191	TA003B	6	1.1314	5.59	0	0.0000	0.00
192	TA004A	10	3.1512	7.49	12	2.4228	8.11
193	UN9998	36	1.5906	33.55	16	1.5199	13.58
194	UN9999	24	1.6155	21.92	32	4.2012	24.96
195	ZZZ794	4	2.1517	3.97	0	0.0000	0.00
196	ZZZ795	3	1.3675	2.55	0	0.0000	0.00
197	ZZZ796	19	2.1977	16.55	0	0.0000	0.00
198	ZZZ797	1	1.2124	1.00	0	0.0000	0.00
199	ZZZ940	1	0.9747	1.00	1	1.0344	1.00
200	ZZZ942	1	0.5916	1.00	1	0.5568	1.00
201	ZZZ943	1	0.5916	1.00	1	0.6856	1.00
202	ZZZ996	1	0.8602	1.00	26	6.5192	15.70
203	ZZZ997	9	1.5652	7.98	38	6.3246	22.64
204	NI020A	2	1.3565	1.94	2	0.6083	1.95
205	ZZZ979	4	3.4612	3.99	1	1.2649	1.00
206	AC044A	3	0.9592	2.94	36	3.5412	30.93
207	AC155A	3	0.6782	3.00	7	1.3304	6.30
208	CM003A	1	0.6481	1.00	6	1.1832	4.82
209	CM049A	2	0.9592	1.94	1	1.0954	1.00
210	OTI999	1	0.6782	1.00	0	0.0000	0.00
211	AC002A	2	1.0050	1.93	7	1.5199	5.25
212	AC025A	4	0.9592	3.71	2	0.4690	2.00
213	PI047A	1	0.6782	1.00	1	0.4472	1.00
214	CY9999	4	2.5826	3.21	2	0.9110	1.72
215	PI019A	1	0.9644	1.00	2	0.4359	2.00
216	AU004A	2	1.0630	1.90	21	4.2190	14.17
217	AS001A	1	0.6708	1.00	0	0.0000	0.00
218	EP9999	3	0.9539	2.73	0	0.0000	0.00
219	EU003B	1	0.9539	1.00	1	0.4359	1.00
220	RC001A	1	0.6708	1.00	0	0.0000	0.00
221	AU010B	8	7.1007	7.88	7	6.7875	3.70
222	AU014A	4	3.4103	3.77	9	3.7855	6.81
223	EU028B	4	1.5362	3.52	0	0.0000	0.00
224	FR015A	2	0.7000	2.00	5	0.6557	4.84
225	GO003A	9	1.5297	7.87	7	1.2570	5.93
226	NA9962	3	1.8385	2.70	3	1.9000	2.73
227	ZZZ798	1	0.6557	1.00	0	0.0000	0.00
228	EU058A	2	1.1874	1.79	0	0.0000	0.00
229	NI035A	1	1.2042	1.00	0	0.0000	0.00
230	NE003A	2	0.9000	1.80	30	4.3589	14.25
231	GO001A	1	0.9899	1.00	0	0.0000	0.00
232	SU004A	1	0.7000	1.00	12	2.0075	8.66
233	AC9965	1	0.7000	1.00	15	2.5100	10.95
234	AU003B	1	0.9899	1.00	1	0.6083	1.00
235	CY001A	5	0.8944	4.59	2	2.3622	1.80
236	NI014A	1	0.7000	1.00	0	0.0000	0.00
237	SY009A	1	0.6928	1.00	9	1.9339	6.62
238	AU001C	2	0.8888	1.94	8	2.3281	6.35
239	AU004C	4	0.8888	3.76	3	1.5811	2.70
240	CM052A	4	0.8944	3.76	7	1.0770	5.97
241	DT002A	5	2.1840	4.41	6	1.5556	4.67
242	DT003A	2	0.8888	1.80	1	0.7071	1.00
243	DT9999	2	0.4472	2.00	0	0.0000	0.00
244	EU024A	5	0.8888	4.49	9	1.8385	6.75
245	FR008A	4	2.1840	3.82	3	1.0296	2.69
246	GO029A	6	1.0724	5.31	1	0.4359	1.00
247	NA003A	4	0.8888	3.90	23	1.4697	19.11
248	NA007A	4	1.2570	3.57	26	1.2124	23.21
249	NA747A	2	0.8944	1.94	0	0.0000	0.00

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 250    NI197A          3      1.7861      2.47          0      0.0000      0.00
 251    TA001B          6      3.2156      5.45          0      0.0000      0.00
 252    AC043A          3      0.8944      2.77          4      0.7681      3.69
 253    AC9989          5      3.0952      4.51          0      0.0000      0.00
 254    CO005A          1      0.8888      1.00          0      0.0000      0.00
 255    NA011A          1      0.6325      1.00          0      0.0000      0.00
 256    GO023A          2      0.4472      2.00          1      0.4123      1.00
 257    MR001B          1      0.4472      1.00          0      0.0000      0.00
 258    NA015A          3      0.8944      2.92          5      1.1446      4.13
 259    CO001B          1      0.4359      1.00          1      0.4359      1.00
 260    NI034A          3      0.6164      2.94          7      1.2884      5.91
 261    CM006A          1      0.4359      1.00          0      0.0000      0.00
 262    CM009A          1      0.4359      1.00          7      1.7321      5.01
 263    GO006A          1      0.4359      1.00          7      0.7280      6.65
 264    NE007A          1      0.4359      1.00          0      0.0000      0.00
 265    SA006A          1      0.4359      1.00          7      1.7321      4.79
 266    AC9998          4      3.3586      3.99          0      0.0000      0.00
 267    PI055A          1      0.8485      1.00          2      1.1747      1.65
 268    SY9999          1      0.6000      1.00          3      0.5099      2.96
 269    CM020A          1      1.4318      1.00         29      2.8408     22.82
 270    GO013A          1      2.5456      1.00         20      2.7276     15.06
 271    NA045A          1      0.8246      1.00          7      0.8246      6.33
 272    AC014A          1      0.8718      1.00         11      3.2047      9.84
 273    FR9976          3      6.5977      2.99          1      6.1911      1.00

Fossil data has 273 taxa, 232 of which are present in calibration data


WAPLS Calibration for variable      pH for components 1 - 3

                          1            2            3

   1     AUBE01        5.6685       5.7945       5.7919
   2     AUBE02        5.7232       5.8737       5.9036
   3     AUBE03        5.6483       5.7920       5.8311
   4     AUBE08        5.5976       5.7408       5.7634
   5     AUBE09        5.6296       5.8219       5.8712
   6     HVTN01        5.3342       5.3094       5.3216
   7     HVTN02        5.2806       5.2240       5.2039
   8     HVTN03        5.1317       4.9069       4.8455
   9     HVTN04        5.2389       5.0974       5.0601
  10     HVTN05        5.1637       5.0366       5.0315
  11     LUNG01        5.8549       5.8283       5.7904
  12     LUNG02        5.6684       5.6649       5.6707
  13     LUNG03        5.8666       5.8430       5.8085
  14     LUNG04        5.9691       5.9891       5.9592
  15     LUNG05        5.8089       5.8453       5.8041
  16     MILC01        6.1458       6.2406       6.2591
  17     MILC02        6.2699       6.3437       6.3455
  18     MILC03        6.3619       6.4573       6.4921
  19     NAGA01        5.1975       4.9328       4.8065
  20     NAGA02        5.2311       5.0026       4.9263
  21     NAGA03        5.4758       5.3843       5.3467
  22     NAGA04        5.4799       5.3342       5.2773
  23     NAGA05        5.3602       5.2385       5.2042
  24     NEUN01        5.3353       5.1924       5.2014
  25     NEUN02        5.3695       5.2594       5.2516
  26     NEUN03        5.4005       5.3145       5.3108
  27     OVNE01        5.7178       5.8697       5.8726
  28     OVNE02        5.6149       5.7544       5.7248
  29     OVNE03        5.6195       5.8241       5.8784
  30     OVNE04        5.6638       5.8386       5.8757
  31     OVNE05        5.6246       5.8183       5.8060
  32     PINF01        6.2046       6.3352       6.3452
  33     PINF02        6.0759       6.1878       6.2206
  34     PINF03        6.2814       6.4434       6.4538
  35     PINF04        6.0688       6.1280       6.1279
  36     PINF05        6.2552       6.3685       6.3662
  37     PSUP01        5.6467       5.5968       5.5892
  38     PSUP02        5.5772       5.5260       5.4853
  39     PSUP03        5.6734       5.7116       5.7081
  40     PSUP04        5.4782       5.3202       5.2512
  41     PSUP05        5.5693       5.4982       5.4656
  42     ROND01        7.0293       7.1686       7.1394
  43     ROND02        7.0397       7.3283       7.3052
  44     ROND03        7.1076       7.3273       7.2837
  45     ROND04        7.1005       7.3008       7.2068
  46     ROND05        7.1942       7.3507       7.2942
  47     SAND01        5.6699       5.6993       5.6882
  48     SAND02        5.8598       5.9854       6.0225
  49     SAND03        5.8103       5.9309       5.9438
  50     STVN01        5.4633       5.5252       5.5541
  51     STVN02        5.3902       5.3084       5.2642
  52     STVN03        5.3657       5.3149       5.2420
  53     NOIR01        6.9972       7.3387       7.3206
  54     NOIR02        6.9790       7.2347       7.1952
  55     NOIR03        6.9813       7.3409       7.3385
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  56      NOIR04         7.0865        7.3657        7.3412
  57      REDO01         6.5514        6.7007        6.6480
  58      REDO02         6.6310        6.7403        6.6871
  59      REDO03         6.2519        6.3603        6.2913
  60      REDO04         6.4088        6.5981        6.5921
  61      RDDA01         5.6547        5.8119        5.7689
  62      RDDA02         5.5682        5.6578        5.6095
  63      RDDA03         5.5384        5.6299        5.5791
  64      RDDA04         5.5684        5.6034        5.5652
  65      AGUI01         5.4925        5.5998        5.6162
  66      AGUI02         5.4955        5.5614        5.5216
  67      AGUI03         5.5496        5.5490        5.5136
  68      AGUI04         5.5544        5.7164        5.7092
  69      ESCU01         5.5604        5.7132        5.6698
  70      ESCU02         5.4821        5.5928        5.4983
  71      ESCU04         5.5322        5.7306        5.6777
  72      ESCU03         5.4755        5.6743        5.6142
  73      ALET01         5.6836        5.7112        5.6547
  74      ALET02         5.7320        5.8494        5.8378
  75      ALET03         5.5439        5.5465        5.5161
  76      DLUG01         6.2958        6.3404        6.2777
  77      DLUG02         6.1937        6.2986        6.2518
  78      DLUG03         6.0588        6.1041        6.0405
  79      DLUG04         6.1726        6.3340        6.3405
  80      DLUG05         6.2620        6.2446        6.1461
  81      DLUG06         5.9942        6.0593        6.0283
  82      ARSJ01         6.1601        6.3995        6.3469
  83      ARSJ02         6.0529        6.2398        6.1795
  84      ARSJ03         6.1886        6.4170        6.3285
  85      ARSJ05         6.1925        6.3648        6.2908
  86      STAR02         5.3884        5.1712        5.0048
  87      STAR03         5.8720        5.7264        5.5904
  88      STAR04         6.5476        6.7037        6.6964
  89      STAR05         5.5131        5.4056        5.3153
  90      ZIEL01         6.9314        6.9061        6.7245
  91      ZIEL04         6.8662        6.9183        6.7549
  92      ZIEL05         6.5139        6.5741        6.4595

Sample specific error estimates for components 1 - 3

                              1             2             3

   1      AUBE01         0.3326        0.3444        0.3521
   2      AUBE02         0.3326        0.3431        0.3493
   3      AUBE03         0.3331        0.3520        0.3646
   4      AUBE08         0.3333        0.3503        0.3601
   5      AUBE09         0.3350        0.3590        0.3715
   6      HVTN01         0.3436        0.4008        0.4198
   7      HVTN02         0.3436        0.3979        0.4150
   8      HVTN03         0.3440        0.4065        0.4303
   9      HVTN04         0.3468        0.4135        0.4363
  10      HVTN05         0.3459        0.4110        0.4322
  11      LUNG01         0.3325        0.3433        0.3515
  12      LUNG02         0.3326        0.3451        0.3540
  13      LUNG03         0.3317        0.3400        0.3456
  14      LUNG04         0.3324        0.3444        0.3545
  15      LUNG05         0.3341        0.3477        0.3558
  16      MILC01         0.3329        0.3425        0.3467
  17      MILC02         0.3326        0.3444        0.3527
  18      MILC03         0.3329        0.3417        0.3461
  19      NAGA01         0.3335        0.3516        0.3622
  20      NAGA02         0.3327        0.3501        0.3624
  21      NAGA03         0.3331        0.3464        0.3531
  22      NAGA04         0.3317        0.3410        0.3482
  23      NAGA05         0.3328        0.3504        0.3627
  24      NEUN01         0.3330        0.3530        0.3676
  25      NEUN02         0.3332        0.3552        0.3713
  26      NEUN03         0.3350        0.3461        0.3518
  27      OVNE01         0.3320        0.3418        0.3473
  28      OVNE02         0.3326        0.3425        0.3468
  29      OVNE03         0.3320        0.3439        0.3527
  30      OVNE04         0.3316        0.3394        0.3455
  31      OVNE05         0.3331        0.3479        0.3553
  32      PINF01         0.3312        0.3364        0.3392
  33      PINF02         0.3309        0.3357        0.3401
  34      PINF03         0.3310        0.3375        0.3442
  35      PINF04         0.3310        0.3350        0.3378
  36      PINF05         0.3308        0.3348        0.3377
  37      PSUP01         0.3337        0.3406        0.3440
  38      PSUP02         0.3389        0.3693        0.3919
  39      PSUP03         0.3367        0.3561        0.3664
  40      PSUP04         0.3407        0.3892        0.4254
  41      PSUP05         0.3377        0.3708        0.3959
  42      ROND01         0.3356        0.3472        0.3710
  43      ROND02         0.3405        0.3612        0.3974
  44      ROND03         0.3344        0.3483        0.3736
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45	ROND04	0.3357	0.3541	0.3788
46	ROND05	0.3365	0.3541	0.3845
47	SAND01	0.3331	0.3455	0.3535
48	SAND02	0.3331	0.3460	0.3554
49	SAND03	0.3324	0.3421	0.3481
50	STVN01	0.3343	0.3531	0.3657
51	STVN02	0.3398	0.3855	0.4193
52	STVN03	0.3520	0.4481	0.5164
53	NOIR01	0.3967	0.5014	0.5019
54	NOIR02	0.3698	0.4402	0.4441
55	NOIR03	0.3749	0.4550	0.4615
56	NOIR04	0.3735	0.4572	0.4649
57	REDO01	0.3787	0.6628	0.8356
58	REDO02	0.3396	0.3998	0.4458
59	REDO03	0.3458	0.4510	0.5239
60	REDO04	0.3352	0.3589	0.3758
61	RDDA01	0.3383	0.3848	0.3866
62	RDDA02	0.3372	0.3962	0.4053
63	RDDA03	0.3398	0.4215	0.4161
64	RDDA04	0.3349	0.3695	0.3783
65	AGUI01	0.3357	0.3716	0.3965
66	AGUI02	0.3355	0.3633	0.3775
67	AGUI03	0.3327	0.3469	0.3551
68	AGUI04	0.3334	0.3506	0.3595
69	ESCU01	0.3341	0.3665	0.3670
70	ESCU02	0.3363	0.3828	0.3822
71	ESCU04	0.3359	0.3863	0.3818
72	ESCU03	0.3361	0.3869	0.3849
73	ALET01	0.3321	0.3414	0.3481
74	ALET02	0.3324	0.3368	0.3402
75	ALET03	0.3326	0.3450	0.3537
76	DLUG01	0.3345	0.3478	0.3633
77	DLUG02	0.3339	0.3574	0.3812
78	DLUG03	0.3354	0.3658	0.4021
79	DLUG04	0.3337	0.3555	0.3738
80	DLUG05	0.3351	0.3622	0.3856
81	DLUG06	0.3324	0.3481	0.3697
82	ARSJ01	0.3353	0.3667	0.3904
83	ARSJ02	0.3355	0.3622	0.3824
84	ARSJ03	0.3359	0.3673	0.3920
85	ARSJ05	0.3347	0.3607	0.3801
86	STAR02	0.3352	0.3596	0.3712
87	STAR03	0.3334	0.3517	0.3635
88	STAR04	0.3320	0.3375	0.3432
89	STAR05	0.3337	0.3513	0.3598
90	ZIEL01	0.4660	0.4873	0.4284
91	ZIEL04	0.4704	0.4971	0.4311
92	ZIEL05	0.3950	0.4079	0.3804

BB	A	Achnanthes [altaica var.	AC9975
BC	A	Achnanthes [minutissima agg.]	AC9989
AS	A	Achnanthes altaica (Poretzky)	AC046A
AZ	A	Achnanthes austriaca var.alpina	AC9965
AE	A	Achnanthes austriaca var.austriaca	AC014A
AG	A	Achnanthes austriaca var.helvetica	AC014C
AF	A	Achnanthes austriaca var.minor	AC014B
BD	A	Achnanthes cf. levanderi	AC9996
AJ	A	Achnanthes conspicua var.conspicua	AC023A
AU	A	Achnanthes curtissima J.R.	AC060A
AK	A	Achnanthes depressa (Cleve)	AC024A
AY	A	Achnanthes distincta Messikommer	AC155A
AL	A	Achnanthes flexella (Kutz.)	AC025A
AC	A	Achnanthes hauckiana Grun.	AC010A
AW	A	Achnanthes helvetica var.alpina	AC134A
AM	A	Achnanthes holstii Cleve	AC027A
AV	A	Achnanthes kriegeri Krasske	AC082A
AA	A	Achnanthes lanceolata (Breb.	AC001A
AQ	A	Achnanthes lapidosa Krasske	AC043A
AH	A	Achnanthes laterostrata Hust.	AC018A
AR	A	Achnanthes levanderi Hust.	AC044A
AB	A	Achnanthes linearis (W.	AC002A
AI	A	Achnanthes marginulata Grun.	AC022A
BA	A	Achnanthes marginulata f.major	AC9968
AD	A	Achnanthes minutissima var.minutissima	AC013A
AP	A	Achnanthes pusilla var.pusilla	AC035A
AN	A	Achnanthes saxonica Krasske	AC028A
AT	A	Achnanthes scotica Jones	AC048A
BF	A	Achnanthes sp.	AC9999
BE	A	Achnanthes sp. a	AC9998
AX	A	Achnanthes subatomoides (Hust.)	AC136A
AO	A	Achnanthes suchlandtii Hust.	AC034A
BJ	A	Amphora inariensis Krammer	AM013A
BI	A	Amphora ovalis var.libyca	AM001C
BG	A	Amphora ovalis var.ovalis	AM001A
BH	A	Amphora ovalis var.pediculus	AM001B
BK	A	Amphora sp.	AM9999
BL	A	Asterionella formosa var.formosa	AS001A
BS	A	Aulacoseira distans var.distans	AU005A
BT	A	Aulacoseira distans var.nivalis	AU005E
BO	A	Aulacoseira granulata var.angustissima	AU003B
BM	A	Aulacoseira italica ssp.italica	AU001A
BN	A	Aulacoseira italica var.valida	AU001C
BQ	A	Aulacoseira lirata f.biseriata	AU004C
BR	A	Aulacoseira lirata var.alpigena	AU004D
BP	A	Aulacoseira lirata var.lirata	AU004A
BW	A	Aulacoseira nygaardii Camburn	AU014A
BU	A	Aulacoseira perglabra	AU010A
BV	A	Aulacoseira perglabra var.floriniae	AU010B
BX	A	Aulacoseira sp.	AU9999
CC	A	Brachysira brebissonii f.brebissonii	BR006A
BZ	A	Brachysira serians (Breb.	BR003A
CA	A	Brachysira serians var.modesta	BR003B
CB	A	Brachysira styriaca (Grun.	BR004A
BY	A	Brachysira vitrea (Grun.)	BR001A
CE	A	Caloneis bacillaris var.bacillaris	CA005A
CD	A	Caloneis bacillum var.bacillum	CA002A
CF	A	Caloneis tenuis Gregory	CA018A

CX	A	Cocconeis pediculus Ehrenb.	CO005A
CW	A	Cocconeis placentula var.euglypta	CO001B
DC	A	Cyclotella comensis Grun.	CY010A
CY	A	Cyclotella comta var.comta	CY001A
DA	A	Cyclotella kuetzingiana var.kuetzingiana	CY006A
CZ	A	Cyclotella meneghiniana var.meneghiniana	CY003A
DB	A	Cyclotella ocellata Pant.	CY009A
DD	A	Cyclotella sp.	CY9999
CM	A	Cymbella aequalis W.	CM014A
CQ	A	Cymbella affinis Kutz.	CM022A
CN	A	Cymbella cesatii var.cesatii	CM015A
CJ	A	Cymbella cistula var.cistula	CM006A
CU	A	Cymbella descripta (Hust.)	CM052A
CT	A	Cymbella failaisensis (Grun.)	CM049A
CP	A	Cymbella gaeumannii Meister	CM020A
CO	A	Cymbella hebridica (Grun.	CM017A
CS	A	Cymbella lunata W.	CM048A
CI	A	Cymbella microcephala f.microcephala	CM004A
CR	A	Cymbella minuta var.minuta	CM031A
CK	A	Cymbella naviculiformis Auersw.	CM009A
CL	A	Cymbella perpusilla A.	CM010A
CH	A	Cymbella sinuata f.sinuata	CM003A
CV	A	Cymbella sp.	CM9999
CG	A	Cymbella ventricosa Kutz.	CM001A
DE	A	Denticula tenuis var.tenuis	DE001A
DG	A	Diatoma hyemale var.hyemale	DT002A
DH	A	Diatoma hyemale var.mesodon	DT002B
DK	A	Diatoma sp.	DT9999
DJ	A	Diatoma tenue var.elongatum	DT004B
DI	A	Diatoma vulgare var.vulgare	DT003A
DF	A	Diploneis ovalis (Hilse)	DP001A
DL	A	Epithemia sp.	EP9999
FD	A	Eunotia [sp. 10	EU9965
FC	A	Eunotia [sp. 13	EU9963
FA	A	Eunotia [tenella/paludosa] L.	EU9960
FB	A	Eunotia [vanheurckii var.	EU9961
DX	A	Eunotia arcus var.arcus	EU013A
DY	A	Eunotia bactriana Ehrenb.	EU014A
EC	A	Eunotia bigibba var.pumila	EU022B
ES	A	Eunotia curvata var.capitata	EU049C
EQ	A	Eunotia curvata var.curvata	EU049A
ER	A	Eunotia curvata var.subarcuata	EU049B
DZ	A	Eunotia denticulata var.denticulata	EU015A
EA	A	Eunotia diodon Ehrenb.	EU016A
EX	A	Eunotia exgracilis A.	EU057A
DV	A	Eunotia exigua var.bidens	EU009D
DT	A	Eunotia exigua var.exigua	EU009A
DU	A	Eunotia exigua var.tridentula	EU009C
EE	A	Eunotia fallax A.	EU025A
EB	A	Eunotia flexuosa var.flexuosa	EU017A
ED	A	Eunotia glacialis Meister	EU024A
EO	A	Eunotia incisa W.	EU047A
EM	A	Eunotia lapponica Grun.	EU042A
EH	A	Eunotia microcephala Krasske	EU028A
EI	A	Eunotia microcephala var.tridentata	EU028B
EW	A	Eunotia minutissima A.	EU056A
EP	A	Eunotia naegelii Migula	EU048A
EN	A	Eunotia nymanniana Grun.	EU045A

HM	A	Navicula detenta Hust.	NA322A
HD	A	Navicula difficillima Hust.	NA115A
HH	A	Navicula digitulus Hust.	NA149A
GP	A	Navicula exigua var.exigua	NA011A
GY	A	Navicula festiva Krasske	NA039A
HO	A	Navicula goeppertiana (Bleish)	NA747A
GS	A	Navicula hassiaca Krasske	NA015A
HL	A	Navicula hoefleri Sensu	NA167A
HN	A	Navicula kotschyi f.kotschyi	NA465A
GZ	A	Navicula krasskei Hust.	NA044A
HI	A	Navicula leptostriata Jorgensen	NA156A
GM	A	Navicula mediocris Krasske	NA006A
GN	A	Navicula mediocris var.atomus	NA006B
GT	A	Navicula mutica var.mutica	NA025A
GW	A	Navicula perpusilla (Kutz.)	NA036A
GQ	A	Navicula pseudoscutiformis Hust.	NA013A
GR	A	Navicula pupula var.pupula	NA014A
GJ	A	Navicula radiosa var.radiosa	NA003A
GK	A	Navicula radiosa var.tenella	NA003B
HF	A	Navicula schassmannii Hust.	NA133A
HE	A	Navicula seminuloides Hust.	NA129A
GL	A	Navicula seminulum Grun.	NA005A
HR	A	Navicula sp.	NA9999
HK	A	Navicula submolesta Hust.	NA160A
GV	A	Navicula subtilissima Cleve	NA033A
HG	A	Navicula tenuicephala Hust.	NA135A
HS	A	Neidium affine var.affine	NE003A
HU	A	Neidium affine var.amphirhynchus	NE003C
HT	A	Neidium affine var.longiceps	NE003B
HW	A	Neidium alpinum Hust.	NE006A
HV	A	Neidium bisulcatum var.bisulcatum	NE004A
HX	A	Neidium dubium f.dubium	NE007A
HY	A	Neidium sp.	NE9999
IB	A	Nitzschia amphibia var.amphibia	NI014A
IE	A	Nitzschia angustata var.angustata	NI020A
IC	A	Nitzschia dissipata (Kutz.)	NI015A
HZ	A	Nitzschia fonticola Grun.	NI002A
IH	A	Nitzschia gandersheimiensis Krasske	NI035A
ID	A	Nitzschia gracilis Hantzsch	NI017A
II	A	Nitzschia hamburgiensis Lange-Bertalot	NI197A
IG	A	Nitzschia hantzschiana Rabenh.	NI034A
IA	A	Nitzschia perminuta (Grun.	NI005A
IF	A	Nitzschia recta Hantzsch	NI025A
IJ	A	Nitzschia sp.	NI9999
IK	A	Orthosira sp.	OTI999
IL	A	Peronia fibula (Breb.	PE002A
IS	A	Pinnularia abaujensis var.abaujensis	PI015A
IT	A	Pinnularia abaujensis var.linearis	PI015C
JC	A	Pinnularia balfouriana Grun.	PI055A
IV	A	Pinnularia biceps var.biceps	PI018A
IR	A	Pinnularia borealis Ehrenb.	PI012A
IU	A	Pinnularia divergentissima var.divergent	PI016A
JA	A	Pinnularia intermedia (Lagerst.)	PI047A
IZ	A	Pinnularia irrorata (Grun.	PI023A
JB	A	Pinnularia lata var.lata	PI051A
IW	A	Pinnularia legumen var.legumen	PI019A
IM	A	Pinnularia major var.major	PI005A
IQ	A	Pinnularia microstauron var.brebissonii	PI011G

EL	A	Eunotia paludosa Grun.	EU040A
DN	A	Eunotia pectinalis var.minor	EU002B
DP	A	Eunotia pectinalis var.minor	EU002E
DM	A	Eunotia pectinalis var.pectinalis	EU002A
DO	A	Eunotia pectinalis var.ventralis	EU002C
EZ	A	Eunotia pirla Carter	EU060A
DR	A	Eunotia praerupta var.bidens	EU003B
DQ	A	Eunotia praerupta var.praerupta	EU003A
EF	A	Eunotia praerupta-nana Berg	EU026A
DW	A	Eunotia rhomboidea Hust.	EU011A
EY	A	Eunotia schwabei Krasske	EU058A
EK	A	Eunotia serra var.serra	EU032A
FE	A	Eunotia sp.	EU9999
DS	A	Eunotia tenella (Grun.	EU004A
EV	A	Eunotia tridentula Ehrenb.	EU053A
EG	A	Eunotia trinacria var.trinacria	EU027A
EJ	A	Eunotia valida Hust.	EU029A
EU	A	Eunotia vanheurckii var.intermedia	EU051B
ET	A	Eunotia vanheurckii var.vanheurckii	EU051A
FQ	A	Fragilaria [cf	FR9976
FL	A	Fragilaria brevistriata var.brevistriata	FR006A
FO	A	Fragilaria capucina var.capucina	FR009A
FH	A	Fragilaria construens var.binodis	FR002B
FG	A	Fragilaria construens var.construens	FR002A
FI	A	Fragilaria construens var.venter	FR002C
FN	A	Fragilaria crotonensis Kitton	FR008A
FP	A	Fragilaria lata Renberg	FR015A
FF	A	Fragilaria pinnata var.pinnata	FR001A
FR	A	Fragilaria sp.	FR9999
FM	A	Fragilaria vaucheriae var.vaucheriae	FR007A
FK	A	Fragilaria virescens var.exigua	FR005D
FJ	A	Fragilaria virescens var.virescens	FR005A
FS	A	Frustulia rhomboides var.rhomboides	FU002A
FT	A	Frustulia rhomboides var.saxonica	FU002B
FU	A	Frustulia rhomboides var.viridula	FU002F
FZ	A	Gomphonema acuminatum var.acuminatum	GO006A
GA	A	Gomphonema acuminatum var.coronatum	GO006C
FW	A	Gomphonema angustatum var.angustatum	GO003A
FX	A	Gomphonema angustatum var.productum	GO003B
GD	A	Gomphonema clavatum Ehr.	GO029A
FY	A	Gomphonema gracile Ehrenb.	GO004A
FV	A	Gomphonema olivaceum (Hornemann)	GO001A
GB	A	Gomphonema parvulum var.parvulum	GO013A
GE	A	Gomphonema sp.	GO9999
GC	A	Gomphonema truncatum var.truncatum	GO023A
GG	A	Hannaea arcus var.arcus	HN001A
GF	A	Hantzschia amphioxys var.amphioxys	HA001A
GH	A	Meridion circulare var.circulare	MR001A
GI	A	Meridion circulare var.constrictum	MR001B
HP	A	Navicula [sp. 2]	NA9962
HQ	A	Navicula [subtilissima var.	NA9968
GX	A	Navicula angusta Grun.	NA037A
HC	A	Navicula bremensis Hust.	NA099A
HA	A	Navicula bryophila var.bryophila	NA045A
GU	A	Navicula cocconeiformis var.cocconeiform	NA032A
HB	A	Navicula contenta f.contenta	NA046A
GO	A	Navicula cryptocephala var.cryptocephala	NA007A
HJ	A	Navicula cumbriensis Haworth	NA158A

IP	A	Pinnularia microstauron var.microstauron	PI011A
JD	A	Pinnularia sp.	PI9999
IY	A	Pinnularia subcapitata var.hilseana	PI022B
IX	A	Pinnularia subcapitata var.subcapitata	PI022A
IO	A	Pinnularia viridis var.rupestris	PI007F
IN	A	Pinnularia viridis var.viridis	PI007A
JE	A	Rhoicosphenia curvata (Kutz.)	RC001A
JK	A	Semiorbis hemicyclus (Ehrenb.)	SE001A
JG	A	Stauroneis anceps f.gracilis	SA001B
JF	A	Stauroneis anceps var.anceps	SA001A
JI	A	Stauroneis obtusa Lagerst.	SA058A
JH	A	Stauroneis phoenicenteron var.phoenicent	SA006A
JJ	A	Stauroneis sp.	SA9999
JL	A	Stenopterobia sigmatella (Greg.)	SP002A
JM	A	Stephanodiscus sp.	ST9999
JN	A	Surirella biseriata var.biseriata	SU004A
JP	A	Surirella delicatissima f.delicatissima	SU006A
JO	A	Surirella linearis var.linearis	SU005A
JQ	A	Surirella sp.	SU9999
JR	A	Synedra acus var.acus	SY003A
JT	A	Synedra minuscula Grun.	SY010A
JS	A	Synedra nana Meister	SY009A
JU	A	Synedra sp.	SY9999
JX	A	Tabellaria binalis (Ehrenb.)	TA003A
JY	A	Tabellaria binalis f.elliptica	TA003B
JW	A	Tabellaria flocculosa var.flocculosa	TA001B
JV	A	Tabellaria flocculosa var.flocculosa	TA001A
JZ	A	Tabellaria quadriseptata Knudson	TA004A
KK	A	Temporary sp. 21	ZZZ979
KM	A	Temporary sp. 3	ZZZ997
KL	A	Temporary sp. 4	ZZZ996
KJ	A	Temporary sp. 57	ZZZ943
KI	A	Temporary sp. 58	ZZZ942
KH	A	Temporary sp. 60	ZZZ940
KG	A	Temporary sp199	ZZZ798
KF	A	Temporary sp200	ZZZ797
KE	A	Temporary sp201	ZZZ796
KD	A	Temporary sp202	ZZZ795
KC	A	Temporary sp203	ZZZ794
KB	A	Unknown	UN9999
KA	A	Unknown naviculaceae	UN9998

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

AL:PE 2 report for the period January 1993-June 1995.

Appendix 5. Contemporary Biology: Zooplankton

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Tab. A5.1 continue..

LAKE	DATE	Byth long	Doma brac	Holo gibb	Ceri quad	Daph long	Daph puli	Bosm sp1	Bosm sp2	Bosm lina
Arresjoen	**930813**							**125000**		
Chibiny	**940713**								**21**	
Chuna	**940816**			**4160**						**37700**
Ovre Neadalsvatn	**940810**	88		**14900**						**6170**
Stavsvatn	**930923, 940928**			**22950**						**42250**
Lille Hovatn	**930819**			**45600**						**9260**
Lochnagar	**930707**			**95600**						**4110**
Lough Maam	**930910**		**4700**	**2940**	**273000**					**23500**
Zielony Staw	**931006, 940930**									
Nizne Terianske Pleso	**931005, 940926**									
Dlugi Staw	**931006, 940930**									
Starolesnianske pleso	**931004, 940927**									
Zgornje Krisko Jezero	**940829**						**34045**			
Schwarzsee o.s.	**930920,931020,940901**									
Milchsee	**940906**									
Langsee	**930920, 940905**									
Paione Superiore	**930810,930921,931109,940726,940926**					**11541**				
Paione Inferiore	**930727,930810,930921,931109,940726,940906**									
Aguilo	**931019, 941010**			**1055**		**15656**				
Redo	**931017, 941011**						**90300**			
Lagoa Escura	**930829,940917**		**1920**			**143213**				
Laguna Cimera	**930918**					**5715**				
La Caldera	**930907, 940913**						**19**			

Tab. A5.1 continue....

LAKE	Chyd spha	Acro harp	Alon affi	Alon eleg	Alon quad	Alla nana	Alis elon	Drep dent	Diap cyan	Eudi grac	Eudi vulg	Arct alpi	Mixo laci	Hete sali
Arresjoen	**1320**													
Chibiny	**85**													
Chuna	317						**212**						**64100**	
Ovre Neadalsvatn														**88**
Stavsvatn														**176**
Lille Hovatn										**19000**				**441**
Lochnagar			**196**							**125000**				
Lough Maam										**25000**				
Zielony Staw		**147**	**245**											
Nizne Terianske Pleso	**218**													
Dlugi Staw	**369**													
Starolesnianske pleso	**52300**													
Zgornje Krisko Jezero	**440**											**99385**		
Schwarzsee o.s.	**2417**													
Milchsee	**106**													
Langsee	**207**													
Paione Superiore	**46**	**160**			**51**							**3**		
Paione Inferiore		**103**			**8**							**5**		
Aguilo	**209**										**5244**			
Redo									**960**					
Lagoa Escura	**736**	**60**	**96**					**60**						
Laguna Cimera	**657**					**234**								
La Caldera	**7**			**57**									**73608**	

Tab. A5.1

LAKE	Cycl abys	Cycl scut	Cycl vici	Cycl sp1	Acan vern	Eucy serr	Tropo pras	Macr fusc	Macr albi	Meso leuc
Arresjoen			75500							
Chibiny						21				
Chuna									176	6980
Ovre Neadalsvatn		11300								
Stavsvatn				19350						
Lille Hovatn										
Lochnagar										
Lough Maam										
Zielony Staw	87850									
Nizne Terianske Pleso	5740					12				
Dlugi Staw					6					
Starolesnianske pleso					5410					
Zgornje Krisko Jezero	17765									
Schwarzsee o.s.	18373									
Milchsee	360									
Langsee	144550									
Paione Superiore	602									
Paione Inferiore	35									
Aguilo	4114									
Redo	138960									
Lagoa Escura							7769	60		
Laguna Cimera	63					1017	315			
La Caldera										

	I	II	III	IV	V	VI
Chibini	?F	Chibini				
Arresjoen	?T	@Arres				
Ovre Neadalsvatn			N		N1	OvreNead
Stavsvatn			N		N1	@Stav
Lochnagar			N		N2	@Lochn
Lille Hovvatn			N		N2	@@LHov
Lough Maam			N		N2	@LMaam
Chuna			N	N3 Chuna		
Caldera			Caldera			
Escura		S	S1		@Escura	
Cimera		S	S1			Cimera
Paione Superiore		S	S1			@PaiS
Aguilo		S	S1	Aguilo		
Paione Inferiore		S		?F	PaiInfer	
Langsee		S			S2	Langsee
Schwarzsee		S			S2	@Schw
Nizne Terianske		S			S2	NTeri
Zielony		S			S2	Zielony
Milchsee		S			S2	Milchsee
Redo		S		S3	Redo	
Zgornje Krisko		S		S3	ZKrisko	
No limnetic species in the lakes:						
Dlugi	TA	@Dlugi				
Starolesnianske	TA	@@Star				

Tab. A5.2. The dichotomy of lakes according to their zooplankton, only limnetic species included.

Columns: levels of dichotomy

?F .... high flowthrough
?T .... uncertain taxonomy
N...........northern lakes: latitude 54 - 68 N, altitude < 1100 m
S........... high mountain lakes: altitude > 1600 m, latitude < 50 N
TA.........acidified Tatra lakes
@ .... pH 6 - 5
@@....... pH < 5

	I	II	III	IV	V	VI
Ovre Neadalsvatn	N		N1	OvreNead		
Stavsvatn	N		N1	@Stav		
Lille Hovatn	N		N2		@@LHov	
Lochnagar	N		N2		@Lochng	
LoughMaam	N		N2	&LMaam		
Chuna	N	N3 Chuna				
Chibini					?F	Chibini
Cimera	S				S1	Cimera
Escura	S				S1	@Escura
Aguilo	S				S1	Aguilo
Paione Inferiore	S				?F	PaiInfer
Paione Superiore	S				S1	@PaiS
Zielony	S				S2	Zielony
Nizne Terianske	S				S2	NTeri
Langsee	S				S2	Langsee
Milchsee	S				S2	Milchsee
Schwarzsee	S				S2	@Schw
Zgornje Krisko	S				S3	ZKrisko
Redo	S				S3	Redo
Dlugi	S			TA	@Dlugi	
Starolesnianske	S			TA	@@Star	
Arresjoen			?T	@Arres		
Caldera	S	Caldera				

Tab. A5.3. The dichotomy of lakes according to their zooplankton, all species included.

Columns: levels of dichotomy

?F .... high flowthrough
?T .... uncertain taxonomy
N..........northern lakes: latitude 54 - 68 N, altitude < 1100 m
S...........high mountain lakes: altitude > 1600 m, latitude < 50 N
TA.........acidified Tatra lakes
@ .... pH 6 - 5
@@.......pH < 5

	Fryer '93	**Nilssen '80**	**Brett '89**	**Fott & al.**	**Fott & al.**
Species	pH range	lower pH limit	dominants	pH	labile mono-
			in acidic		meric Al
			lakes		mg/l
	(Yorkshire)	(Norway)	(Scand.)	(Sumava)	(Sumava)
Bosmina longispina	3.0 - 7.5	<4.5 very tolerant	xxx		
Bythotrephes longimanus s.lat.		4.8			
Ceriodaphnia quadrangula	3.9 - 10.2				
Daphnia longispina		5.0		4.6	0.3
Daphnia pulicaria					
Diaphanosoma brachyurum	5.0 - 10.2	4.5	xxx		
Holopedium gibberum		4.5	xxx		
Arctodiaptomus alpinus					
Diaptomus cyaneus					
Eudiaptomus gracilis	5.2 - 10.2	<4.5 very tolerant	xxx		
Eudiaptomus vulgaris					
Heterocope saliens		<4.5 very tolerant		4.6	0.9
Mixodiaptomus laciniatus					
Cyclops abyssorum		5.0		4.6	0.3
Cyclops scutifer		4.5			
Mesocyclops leuckarti		4.6			
Acroperus harpae	6.4 - 8.9			4.3	0.9
Alona affinis	4.0 - 10.2			4.3	0.9
Alona elegans					
Alona quadrangularis	4.8 - 8.6			4.6	0.3
Alonell nana	3.2 - 8.2				
Alonopsis elongata	3.6 - ?			4.3	0.9
Drepanothrix dentata	4.1 - ?				
Chydorus sphaericus s. lat.	3.0 - 10.2				
Acanthocyclops vernalis	3.3 - 8.5			4.3	0.9
Eucyclops serrulatus	4.8 - 10.2			4.5	0.8
Macrocyclops albidus	5.9 - 10.2				
Macrocyclops fuscus	6.4 - 9.1			4.3	0.9
Tropocyclops prasinus	4.7 - 9.1				

Tab. A5.4. List of the zooplankton species from ALPE lakes with notes on their tolerance to pH and labile monomeric aluminium. Lakes in Yorkshire (Fryer 1993), Norway (Nilssen 1980), Scandinavia (Brett 1989), Sumava (Fott et al. 1994 and unpublished results).

Precipitation data from the station Starolesnianske pleso, November 1994 - March 1995

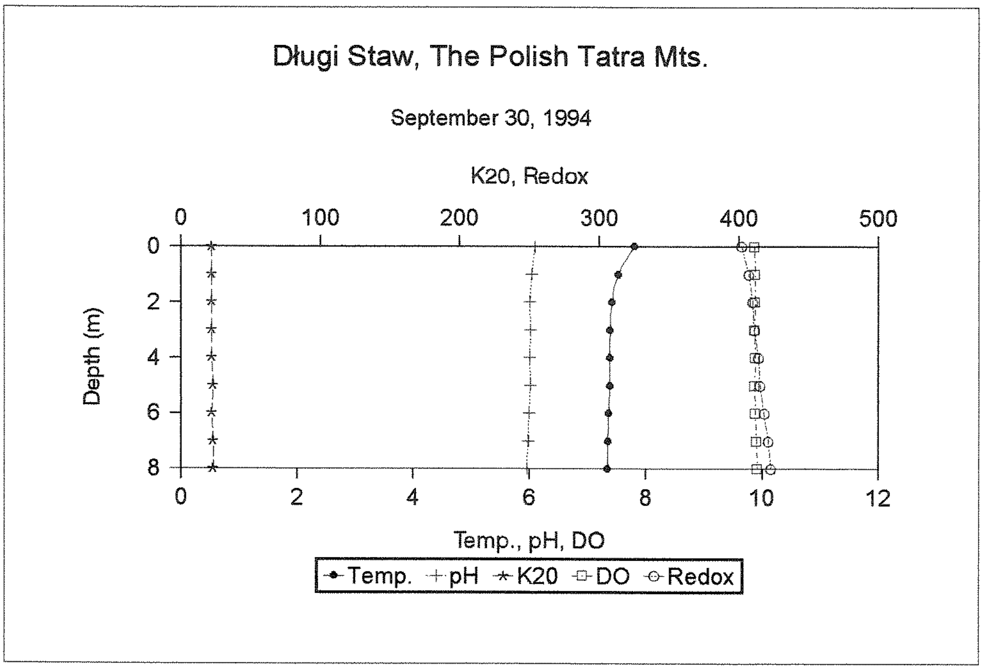
Chemistry of precipitation in weekly samples.

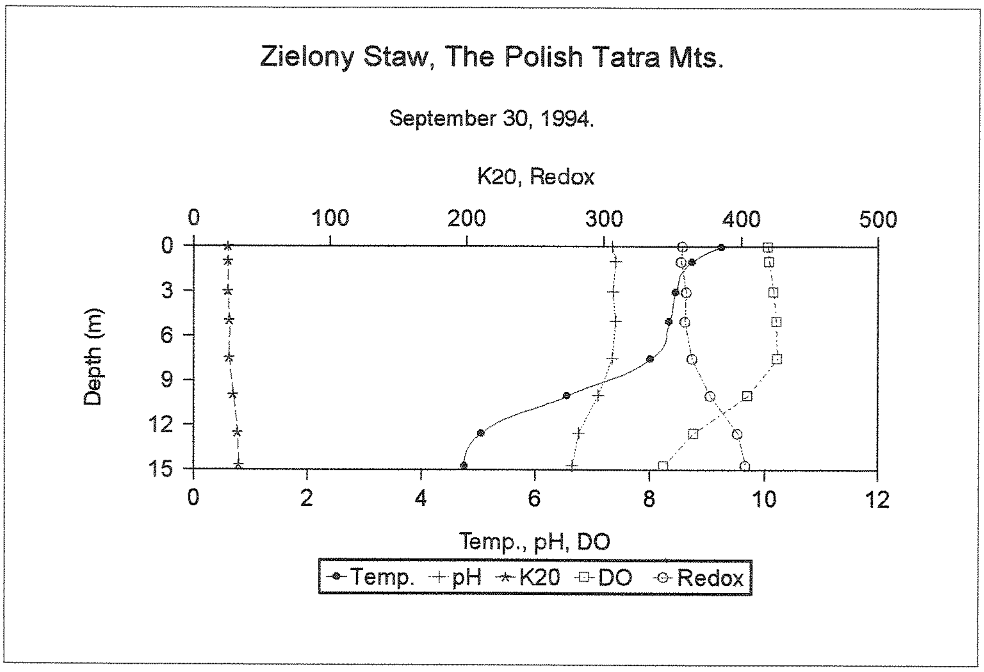
Date	K20	pH	Alk	Mg	Ca	Na	NH4	K	Cl	NO2	NO3	SO4	N-org	TP	SRP	COD	TOC	volume
			µeq/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	mg/l	mg/l	l
7.12.1994	9.2	4.59	-2.45	0.06	0.31	0.18	0.19	0.12	0.21		1.15	2.68						0.058
21.12.1994	6.8	4.51	-0.70	0.02	0.10	0.02	0.06	0.06	0.09		0.49	1.57	32	7.3	4.6	1.0	0.6	0.750
12.1.1995	5.8	4.59	1.90	0.01	0.02	0.03	0.00	0.06	0.19		1.07	0.54	87	6.4	4.3		1.2	0.196
23.2.1995	12	4.34	-8.35	0.02	0.10	0.03	0.38	0.05	0.04		0.93	2.83						0.064
2.3.1995	15	4.69		0.12	1.54	1.00	0.00	0.94	2.02	0.03	2.82	3.55						0.028
9.3.1995	7.7	4.70	-1.15										26	4.6	1.3	1.8	0.9	0.620

Precipitation (mm), weighted averages of concentrations and calculated deposition of sulphur and inorganic nitrogen.

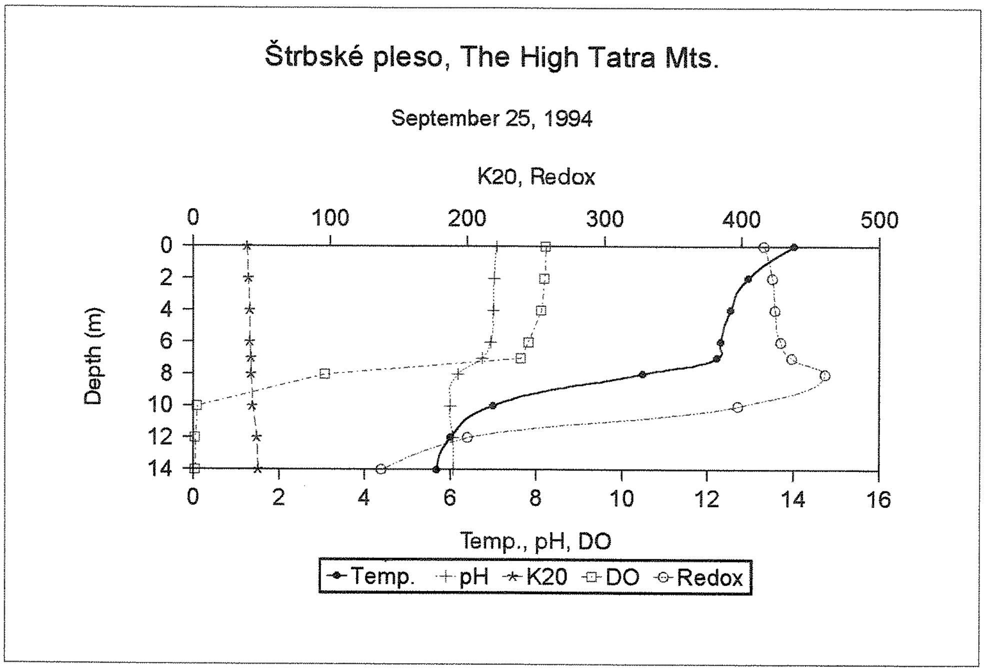
Month	Precip.	S conc.	IN conc.	S dep.	IN dep.
	mm	mg/l	mg/l	kg/ha	kg/ha
November	309				
December	393	0.54	0.18	2.12	0.69
January	257	0.18	0.24	0.45	0.62
February	117	1.00	0.55	1.17	0.65
March					

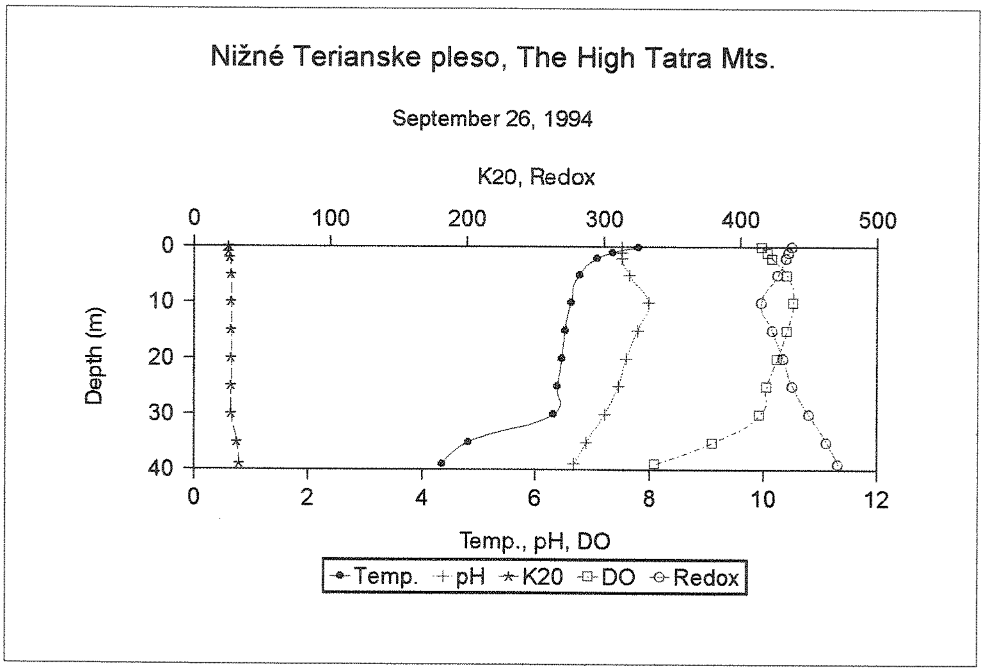
Hydrolab profiler: *in situ* data in two Tatra lakes. Temp - temperature (°C), K20 - specific conductance (µS/cm, 20 °C), DO - disolved oxygen (mg/l), Redox - redox potential (mV).





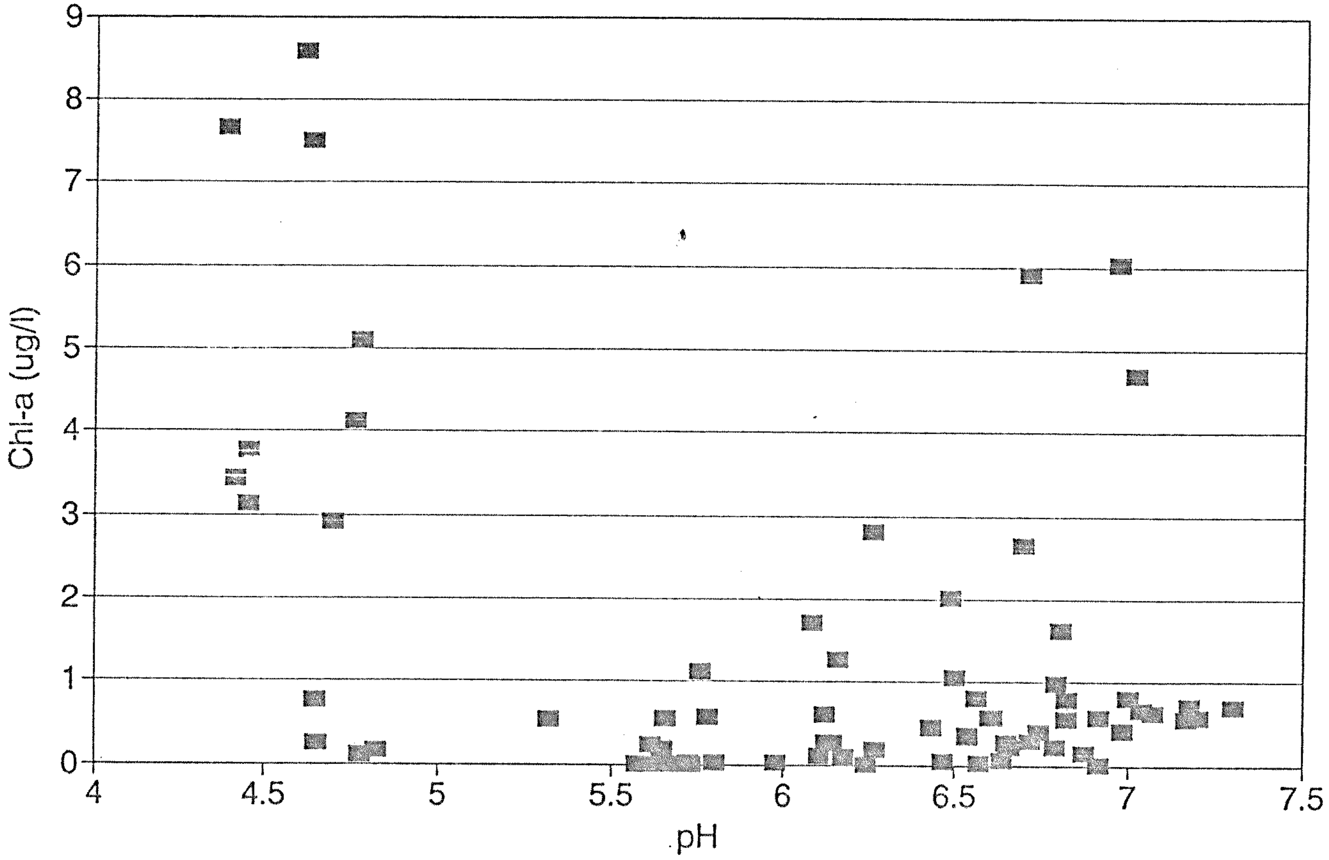
Hydrolab profiler: *in situ* data in two Tatra lakes. Temp - temperature (°C), K20 - specific conductance (µS/cm, 20 °C), DO - disolved oxygen (mg/l), Redox - redox potential (mV).





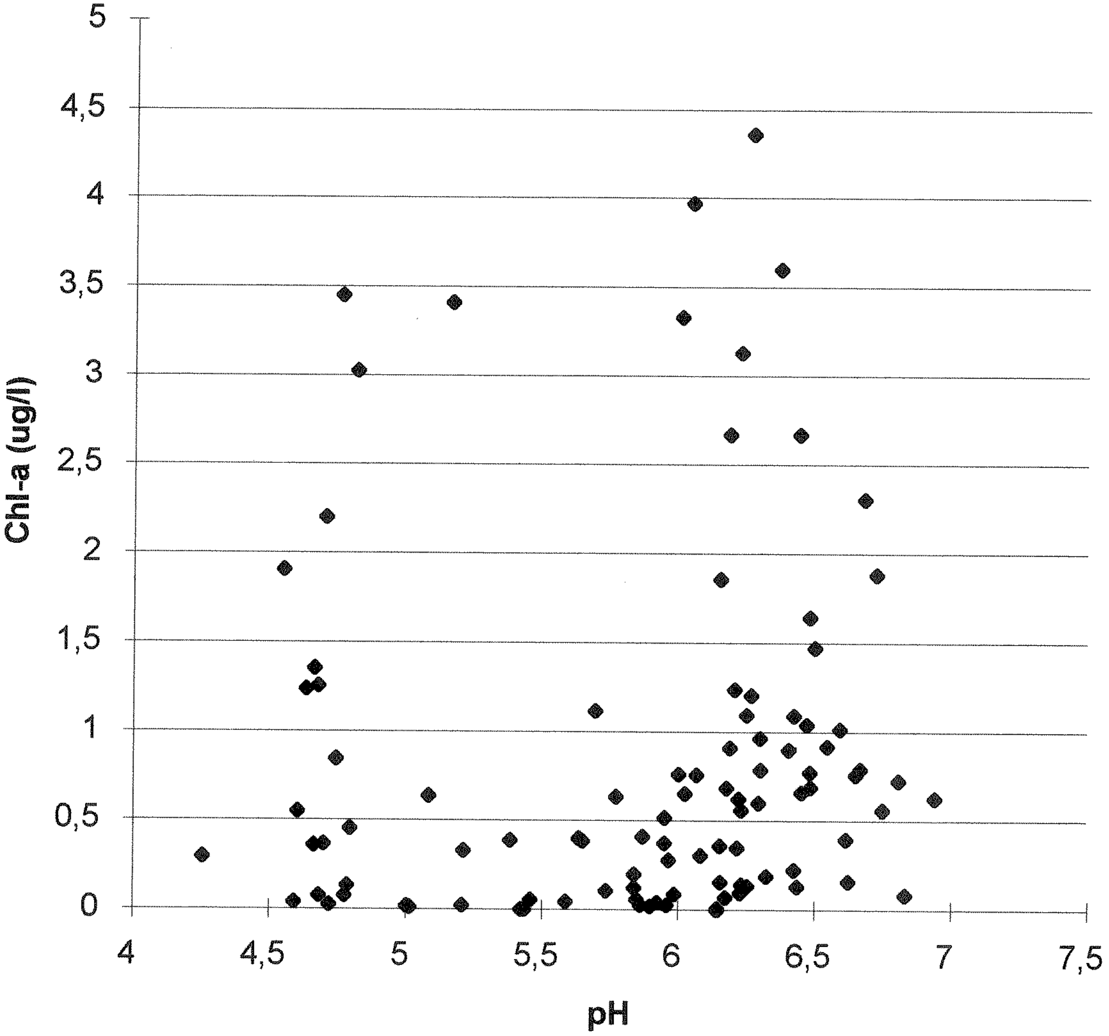
The Tatra Mts.-autumn 1993

Chl-a vs. pH



The Tatra Mts.-autumn 1994

Chl-a vs. pH



AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

AL:PE 2 report for the period January 1993-June 1995.

Appendix 6. Contemporary Biology: Invertebrates

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Table 3.1a. Recorded invertebrate taxa in the benthic samples from Arresjøen, Svalbard.

Sampled 23.09.1993	Inlet river	Inlet river pond	Littoral zone 1	Littoral zone 2	Outlet	Outlet river 1	Outlet river 2	Outlet river 3
Nematoda indet.	3	19	13	5	45	80	17	9
Oligochaeta:								
Enchytraeidae	1			1				1
Crustacea:			1					
Hydracarina indet.							1	1
Chironomidae:								
Chaetocladius sp.	1	1				1		
Cricotopus (C.) tibialis (Meigen)				28	7	1		
Diamesa aberrata (Lundbeck)	2					13	2	2
Diamesa arctica (Boheman)	1	2	1				1	1
Diamesa bohemani Goetghebuer		1						
Diamesa bertrami (Edwards)	2							
Diamesa hyperborea Holmgren	1							
Diamesa spp.	28	19	3	3	2	7	21	31
Hydrobaenus conformis (Holmgren)	11	1		16	68	3	2	4
Limnophyes sp. A	9	1	13				1	
Metriocnemus obscuripes (Holmgren)	9	10	4	15		1	3	
Pseudokiefferiella parva (Edwards)								1
Trissocladius n. sp.	3							3

Table 3.1b. Recorded invertebrate taxa in the quantitative profundal benthic samples from Arresjøen, Svalbard.

Sampled 13.08.93	Depth 5m	10m	15m	20m	25m	32m
Nematoda indet.	6896	14021	6401	5669	3086	76
Oligochaeta:						
Enchytraeidae	5410	7239	2705	1463	2438	7963
Crustacea:						
Bosmina sp.		191				114
Macrotrichidae	1943	4267	3124	2012	953	76
Cyclops sp.	2134	3239	1372	1280	953	953
Ostracoda	991	838	457	229	114	38
Chironomidae:						
Micropsectra insignilobus Kieffer	2019	1981	1905	1924	2019	
Micropsectra radialis Goetghebuer	76	114	38	0	191	
Oliveridia tricornis (Oliver)	533	495	495	504	152	

Table 3.2. Recorded invertebrate taxa in the benthic samples from Lake Chibini, Russia.

Sampled 26.07.93	Inlet kick	Littoral kick	Outlet kick	Outlet river kick	Profundal Kajak N m-2
Nematoda indet.					23
Oligochaeta:					
Tubificidae sp. juv					23
Hydracarina spp..		1	1	3	
Ephemeroptera:					
Ameletus inopinatus Eaton		10	7		
Plecoptera:					
Arcynopteryx compacta (Mc.L.)		2			
Isoperla obscura (Zett.)				1	
Trichoptera:					
Stenophylacini sp.			1		
Diptera:					
Dicranota sp.		1			
Simuliidae indet.	13			11	
Chironomidae:					
Arctodiamesa sp. (pupae)	1				
Diamesa spp.	74	15		11	211
Pseudodiamesa (Pachydiamesa) sp.		4			187
Pseudodiamesa (Pseudodiamesa) sp.	1	3			94
Diamesini spp.	1	3	48		
Coryoneura sp.	2	2			
Cricotopus sp.			1	10	
Diplocladius cultriger	1	83			235
Eukiefferella gracei gr. (pupae)					23
Eukiefferella sp.?				15	70
Heterotrissocladius sp					23
Zalutschia sp.					23
Orthocladiinae sp.		18	38	3	328
Paratanytarsus austriacus gr. (pupae)		1			

Table 3.3a. Recorded invertebrate taxa in the benthic samples from Lake Øvre Neådalsvatn, Norway.

Sampled 10-11.08.94	Inlet r. kick	Littoral kick A	Littoral kick B	Outlet kick	Outlet r. kick	Kajak 5m $N\ m^{-2}$	Kajak 17m $N\ m^{-2}$
Turbellaria:							
Crenobia alpina (Dana)				2			114
Nematoda indet.	30	8	32	5	6	1064	342
Oligochaeta:							
Lumbriculus variegatus (Müll.)							
Lumbricidae							
Stylodrilus heringianus Clap.		1					38
Eiseniella tetraedra (Savigny)							
Enchytraeidae	12	2	2		2	266	
Tubificidae			2	3		266	1026
Crustacea:							
Diaphanosoma brachyurum (Liév.)							76
Daphnia longispina (O.F.M.)						38	
Eurycercus lamellatus (O.F.M.)	1	10	10	11		1938	
Chydorus sphaericus (O.F.M.)		20	7	8		304	38
Bosmina longispina Leydig				8		38	1140
Bytotrephes longimanus Leydig				1			
Holopedium gibberum Zaddach			1	4		76	
Polyphemus pediculus L.		8					
Cyclops sp.		5	6	4		1368	304
Calanoida Copepoda							38
Ostracoda	24					114	114
Bivalvia:							
Pisidium sp.				26	18	228	266
Hydracarina indet.	28	33	1	18	29	494	418
Ephemeroptera:							
Baetis rhodani (Pictet)	7				3		
Siphlonurus lacustris Etn.		20	8	14		190	
Plecoptera:							
Taeniopteryx nebulosa (L.)					5		
Amphinemura standfussi (Ris)	4						
Nemoura cinerea (Retz.)	3						
Capnia sp.	28						
Leuctra sp. juv.	3	1					
Isoperla obscura (Zett.)				1	1		
Isoperla grammatica (Poda)	1						
Isoperla sp. juv.							
Diura bicaudata L.				2			
Diura nanseni Kempny	11						
Trichoptera:							
Rhyacophila nubila (Zett.)				1			
Rhyacophila nubila (Zett.) p.					1		
Plectrocnemia conspersa Curtis				1			
Polycentropus flavomaculatus Pictet					5		
Polycentropodidae indet. juv.						38	
Potamophylax latipennis (Curtis)							
Limnephilidae indet.		3					
Coleoptera:							
Dytiscidae l.		16	2				
Dytiscidae ad.		2					
Diptera:							
Limoniidae	6			1			
Tipulidae	3						
Simuliidae indet.	1			12	10		

Table 3.3b. Recorded invertebrate taxa in the benthic samples from Lake Øvre Neådalsvatn, Norway.

Sampled 10-11.08.94	Inlet r. kick	Littoral kick A	Littoral kick B	Outlet kick	Outlet r. kick	Kajak 5m $N\ m^{-2}$	Kajak 17m $N\ m^{-2}$
Chironomidae:							
Acamptocladius submontanus (Edwar	1						
Arctopelopia melanosoma (Goetghebuer)		15	0	10	6	1372	152
Bryophaenocladius sp.		1	2				
Corynoneura cf. *arctica* Kieffer	1	1	2				
Chaetocladius sp.	4			19	2		
Diamesa spp.	11						
Eukiefferiella minor (Edwards)	6						
Heterotanytarsus apicalis (Kieffer)							
Heterotrissocladius brundini Sæther & Schnell						152	1410
Heterotrissocladius indet.							76
Micropsectra insignilobus Kieffer						114	
Micropsectra radialis Goetghebuer		11	9				
Micropsectra spp.				1	8		
Mesocricotopus thienemanni (Goetghebuer)						229	610
Monodiamesa bathyphila (Kieffer)						38	38
Nanocladius cf. *rectinervis* (Kieffer)				1	0		
Orthocladius (*O*.) spp.	4	1		2	1		
Parakiefferiella bathophila (Kieffer)							38
Parakiefferiella fennica Tuiskunen							1029
Paratanytarsus hyperboreus Brundin						76	
Procladius sp.		2	5			76	38
Protanypus sp.							38
Psectrocladius (*P*.) *limbatellus* (Holmgren)		5					
Psectrocladius (*P*.) spp						495	191
Psectrocladius septentrionalis Chernovski				1			38
Rheocricotopus (*R*.) *effusus* (Walker)	1						
Rheosmittia spinicornis (Brundin)	1						
Sergentia coracina (Zetterstedt)	0	1					
Tanytarsus cf. *lugens* (Kieffer)						152	
Tanytarsini indet.						191	
Thienemanniella sp.	2			1	3		
Thienemannimyia fusciceps (Edwards)			22				
Tvetenia calvescens (Edwards)	3			4	31		
Zalutschia sp.			1				

Table 3.4. Recorded invertebrate taxa in the benthic samples from Stavsvatn, Norway.

Sampled 23.09.1993	Littoral kick	Outlet kick	Outlet river kick
Nematoda indet.	8	10	
Turbellaria:			
Crenobia alpina (Dana)	2	1	
Oligochaeta:			
Lumbriculus variegatus (Müll.)	5	2	
Enchytraeidae	5	9	1
Crustacea:			
Sida crystallina (O.F.M.)	1		
Eurycercus lamellatus (A.F.M.)	36		
Chydorus sphaericus (O.F.M.)			1
Holopedium gibberum Zaddach			1
Cyclops sp.	8	32	
Calanoida Copepoda	4	9	3
Hydracarina indet.	1	6	26
Ephemeroptera:			
Leptophlebia vespertina (L.)	3	2	1
Plecoptera:			
Leuctra hippopus Kmp.			3
Trichoptera:			
Polycentropus flavomaculatus (Pict.)		1	
Plectrocnemia conspersa Curtis		3	2
Oxyethira sp.			1
Potamophylax latipennis (Curtis)			1
Limnephilidae indet. juv.			9
Coleoptera			
Dytiscidae indet.		3	
Diptera:			
Empedidae	3		
Limoniidae			2
Simuliidae indet.			5
Chironomidae:			
Arctopelopia sp.	19	14	17
Heterotrissocladius marcidus (Walker)	1	2	
Orthocladius (O.) sp.			22
Psectrocladius (Monopsectrocladius) calcaratus (Edwards)	1	3	
Psectrocladius (Psectrocladius) limbatellus group	13	17	1
Psectrocladius (Psectrocladius) sordidellus (Zetterstedt)	18	4	
Psectrocladius (Psectrocladius) indet.		3	
Micropsectra insignilobus (Kieffer)		7	
Zalutschia torntraeskensis (Edwards)		1	
Zavrelimyia sp.		1	

Table 3.5. Recorded invertebrate taxa in the benthic samples from Lille Hovvatn, Norway.

Sampled 17.08.1993	Littoral kick	Outlet kick	Outlet river kick
Nematoda indet.	19	9	7
Oligochaeta:			
Lumbriculus variegatus (Müll.)	2		
Crustacea:			
Acantholeberis curvirostris (O.F.M.)		24	41
Chydorus sphaericus (O.F.M.)	3	1	
Iliocryptus sp.	1		1
Macrotrichidae indet.	26		
Cyclops sp.	5	3	
Calanoida Copepoda			1
Hydracarina indet.			2
Ephemeroptera:			
Siphlonurus armatus Etn.	1		
Leptophlebia vespertina (L.)	14	12	
Plecoptera:			
Leuctra hippopus Kmp.		1	
Trichoptera:			
Polycentropus irroratus (Curtis)		2	
Plectrocnemia conspersa Curtis			3
Cyrnus flavidus McL.	2	6	
Phryganea grandis L.	1		
Phryganeidae indet juv.	1		
Megaloptera:			
Sialis lutaria L.	1	5	1
Corixidae:			
Glaenocorisa propinqua (Fieb)	1	1	
Callicorixa wollastoni (Dgl. & Sc.)		1	
Anisoptera	1	2	11
Zygoptera			3
Coleoptera:			
Dytiscidae indet.	17	4	2
Haliplidae indet.		1	8
Diptera:			
Tipula sp.			2
Tabanidae indet.			1
Simuliidae indet.			10
Chironomidae:			
Ablabesmyia monilis (Linné)		2	
Arctopelopia barbitarsis (Zetterstedt)	3	9	
Chironomus anthracinus Zetterstedt	18	6	3
Cladopelma viridula Linné	6		
Cryptochironomus cf. *psittacinus* (Meigen)	1		
Dicrotendipes modestus (Say)		1	
Heterotanytarsus apicalis (Kieffer)	1		
Limnophyes asquamatus Andersen			2
Macropelopia adaucta (Kieffer)	13	22	17
Microtendipes pedellus (deGeer)		1	
Pagastiella orophila (Edwards)	2	2	
Procladius chorus (Meigen) & *signatus* (Zetterstedt)	19	13	8
Psectrocladius (Mesopsectrocladius) barbatipes ((Kieffer)			1
Psectrocladius (Psectrocladius) limbatellus (Holmgren)	1		
Psectrocladius (Psectrocladius) psilopterus Kieffer	2		2
Tanytarsus buchonius Reiss & Fittkau	10	2	
Tanytarsus cf. *gregarius* Kieffer	2	3	

Table 3.6 Recorded invertebrate taxa in the benthic samples from Lough Maam, Eire. Samples from 6 sites, pooled.

Sampled 17.08.1993	Littoral kick
Tricladida	12
Nematoda indet.	3
Oligochaeta:	
Naididae	128
Enchytraeidae	21
Tubificidae	6
Lumbriculidae	1
Bivalvia:	
Pisidium spp.	4
Hydracarina indet.	1
Ephemeroptera:	
Leptophlebia vespertina (L.)	12
Trichoptera:	
Hydropsyche siltalai Dohler	1
Tinodes waeneri (L.)	2
Polycentropus flavomaculatus (Pict.)	77
Plectrocnemia conspersa Curtis	5
Plectrocnemia geniculata McL.	4
Cyrnus flavidus McL.	11
Polycentropidae indet. juv.	8
Halesus digitatus Schrank	2
Limnephilidae indet juv.	1
Mystacides azurea (L.)	20
Coleoptera:	
Oreodytes septentrionalis (Gyll.)	2
Oulimnius tuberculatus Ph. Müll.	7
Chironomidae:	
Arctopelopia cf. griseipennis (Wulp)	54
Corynoneura scutellata Winnertz	8
Dicrotendipes modestus (Say)	27
Heterotanytarsus apicalis (Kieffer)	25
Heterotrissocladius marcidus (Walker)	2
Macropelopia cf. *adaucta* (Kieffer)	8
Micropsectra sp.	1
Microtendipes cf. *pedellus* (deGeer)	1
Psectrocladius (Mesopsectrocladius) barbatipes (Kieffer)	16
Psectrocladius (Monopsectrocladius) calcaratus (Edwards)	4
Psectrocladius (Psectrocladius) limbatellus (Holmgren)	12
Psectrocladius (Psectrocladius) psilopterus Kieffer	40
Psectrocladius (Psectrocladius) sordidellus (Zetterstedt)	20
Tanytarsus buchonius Reiss & Fittkau	4

Table 3.7. Recorded invertebrate taxa in the benthic samples from La Caldera, Sierra Nevada, Spain.

Sampled 28.07.93	Littoral Kick stones, gravel N/sample	Littoral Kick sand N/sample	Littoral exuviae N/sample	Profundal Kajak corer 6.3m N/m2	Profundal Ekman grab 5.5m N/m2
Nematoda indet.	26	42		113	45
Oligochaeta					
Tubificidae indet.	80	100		793	1644
Crustacea					
Chydoridae	92	88		838	378
Coleoptera					
Ilybius sp.	20			113	
Guignotus sp.	6				
Diptera					
Chironomidae					
Apsectrotanypus sp.	1				
Corynoneura arctica Kieffer	158	29	179	566	422
Micropsectra radialis G.	57	26	5	906	269
Tanytarsus sp.	7				

Table 3.8. Recorded invertebrate taxa in the benthic samples from Lagoa Escura, Serra de Estrela, Portugal.

Sampled 23.07.93	Littoral Kick macrophytes N/sample	Littoral Kick sand N/sample	Littoral Hand-net N/sample	Profundal Kajak corer 11.5m N/m2	Profundal Ekman grab 10.5m N/m2
Nematoda indet.	29	196	18		45
Oligochaeta					
Tubificidae indet.	7	48	1	1585	178
Naididae	11	4	1		
Hydracarina					
Piona carnea Koch				453	89
Crustacea					
Ilyocryptus sp.	224	20	17	226	
Chydoridae	4144	352	631	9285	
Copepoda	488	80	35	1132	
Ephemeroptera					
Thraulus bellus Eaton		2	5		
Habroleptoides confusa		2			
Odonata					
Ischnura pumilio (Charp.)	15	4	3		
Heteroptera					
Micronecta sp.			1		
Coleoptera					
Oulimnius sp.		76	3		
Trichoptera					
Plectrocnemia sp. (*P. ?geniculata* McL.)		20	4		
Beraeidae	4				
Diptera					
Empididae	15		4		
Chironomidae					
Ablabesmyia longistyla Fittkau	51	112	29		
Procladius (H.) choreus (Meigen)	48	5		3226	1224
?Trissopelopia sp.	1				
Corynoneura sp.	8		4		
Heterotrissocladius sp.		28		230	
Psectrocladius sp.	79	8	8		
Cladopelma sp.				8526	351
Pagastiella orophila (Edwards)				1152	485
Parachironomus sp.	1				
Polypedilum sp.	18		8		
Micropsectra sp.	15	32	38		
Tanytarsus chinyensis G.					89
Tanytarsus sp.		980			

Table 3.9. Recorded invertebrate taxa in the benthic samples from Laguna Cimera, Spain

Sampled 18.09.1993	Littoral kick
Nematoda indet.	15
Oligochaeta:	
Stylodrilus heringianus Clap.	25
Nais alpina	1
Enchytraeidae	3
Bivalvia:	
Pisidium casertanum Poli	3
Gastropoda:	
Ancylus fluviatilis Müller	1
Plecoptera:	
Protonemura meyeri (Pict.)	4
Trichoptera:	
Allogamus auricollis Pict.	2
Chaetopteryx villosa (Fabr.)	1
Plectrocnemia conspersa (Curtis)	3
Athripsodes cinereus (Curtis)	1
Coleoptera:	
Oulimnius tuberculatus perezi Scharp	3
Helophorus sp.	1
Agabus bipustulatus (L.)	1
Dytiscidae indet.	1
Diptera:	
Limoniidae	1
Ephydridae	1
Chironomidae:	
Heterotrissocladius marcidus (Walker)	29
Paracladopelma gr. *camptolabis*	1
Tanytarsus sp.	2
Thienemannimyia sp.	2
Macropelopia sp.	1
Micropsectra sp.	2
Cricotopus sp.	1
Ablabesmyia sp.	1

Table 3.10 a. Recorded invertebrate taxa in the benthic samples from Llac Aguiló, Pyrenees, Spain.

Sampled 20.07.93	Littoral exuviaes	Littoral Kick	Profundal Ekman 22m	Inlet Kick	Inlet Drift	Outlet kick
	N	N	ind/m2	N	N	N
Nematoda indet.		5		4		3
Oligochaeta						
Tubificidae indet.		64	22			
Hydrachnellae						
Hygrobates foreli Lebert		1				
Lebertia rufipes Koenike		7				
Sperchon thienemanni Koenike				2		
Tiphys group *torris*		1				
Crustacea						
Chydoridae		400				34
Copepoda		20		2		44
Colembola		1				1
Ephemeroptera						
Baetis gr. *vernus* (? *neglectus* Navas)		5		116	14	438
Cloeon praetextum Bengtsson	1					
Cloeon schoenemundi Bengtsson	7					
Plecoptera						
Xantoperla apicalis Newman		1				
Xantoperla apicalis Newman (e)				1		
Pachyleuctra benlocchi (Navas)						1
Isoperla sp. (Banks)						1
Isoperla sp. (Banks) (e)				4		
Protonemura risi Navas (e)				2		
Protonemura culmensis Vinçon &Zwick (e)				2		
Leuctra leptogaster Aubert (e)				4		
Protonemura beatensis Despax (e)				2		
Heteroptera						
Gerris sp.				4		
Micronecta scholtzi		4				
Coleoptera		21				
Guignotus sp.		9				
Ilybus sp.		3				
Megaloptera						
Sialis sp.	1	5				
Trichoptera						
Plectrocnemia sp. (P. ?*geniculata* McLachlan)				10		18
Allogamus (*A.* ? *auricollis* Pictet)		7				
Simulidae						
Prosimulium (P.) latimucro Enderlein					5	
Simulium (Eusimulium) gr. *aureum*						2
Simulium (Nevermannia) carthusiense G. & D.					1	
Simulium (Simulium) tuberosum Lundström						7

Table 3.10 b. Recorded invertebrate taxa in the benthic samples from
Llac Aguiló, Pyrenees, Spain.

Sampled 20.07.93	Littoral exuviaes	Littoral Kick	Profundal Ekman 22m	Inlet Kick	Inlet Drift	Outlet kick
	N	N	ind/m2	N	N	N
Chironomidae						
Conchapelopia melanops (Meigen)	1					
Macropelopia adaucta K.	14					1
Pentaneurella sp.				52	1	172
Procladius sagittalis (K.)	174	152	22			11
Trissopelopia longimana (Staeger)		1		6		19
Zavrelimyia melanura (Meigen)	6			2		
Tanypodinae indet.				2		
Corynoneura arctica Kieffer	25					1
Corynoneura coronata Edwards	16				2	1
Corynoneura lacustris Edwards	38			2	5	
Corynoneura spp.				6		
Cricotopus pulchripes Verrall.	1			2		1
Eukiefferiella coerulescens (K.)				2		
Eukiefferiella devonica (Edw.)					1	
Eukiefferiella spp.					9	
Heterotrissocladius marcidus (Walker)	24	116				4
Orthocladius sp.					36	
Psectrocladius octomaculatus Wülker	143					33
Psectrocladius sp.					8	
Rheocricotopus effusus (Walker)	1			25	2	
Synorthocladius semivirens (Kieffer)						1
Thienemanniella pe 2b, Langton 1991					2	
Thienemanniella sp.					1	
Tvetenia calvescens (Edwards)	1					9
Pagastiella orophila (Edwards)	210					
Polypedilum sp.		163		4		143
Micropsectra Pe 5. Langton ms.				2		
Micropsectra radialis G.						1
Micropsectra sp.				2		12
Paratanytarsus ?setosimanus G.	1					
Paratanytarsus laccophilus (Edwards)	707					53
Stempellinella brevis (Edwards)	1				1	
Tanytarsus bathophilus Kieffer	9	1				7
Tanytarsus debilis (Meigen)	3					
Tanytarsus Pe 9, Langton 1991	5					
Zavrelia sp1. Langton, 1991				2	2	

Table 3.11a. Recorded invertebrate taxa in the benthic samples from Llac Redo, Spain.

Sampled 18.07.93	Litt. 1	Litt. 2	Litt. 3	Inlet	Outl.	Outl.	Outl.	Kajak	Kajak
	Kick	Kick	Kick	Drift	Drift	Drift	kick	25 m	65 m
	N	N	N	N	N	N	N	N m^{-2}	N m^{-2}
Nematoda indet.								75	
Gastropoda									
Radix peregra (*glacialis* form)	22	3	7						
Bivalvia									
Pisidium hibernicum Westerlund								1212	
Pisidium spp.							2		
Oligochaeta									
Stylodrilus heringianus Clap.		1	8						175
Lumbriculus variegatus (Müller)			4						
Lumbriculidae indet.	2	3	16			1	4	1929	438
Tubificidae indet.									2894
Nais alpina					2				
Nais alpina imm.		4					88		
Nais variabilis/communis imm.		28	40				4		
Nais simplex Pig. imm.			16						
Vejdovskyella comata (Vej.)			4						
Achaeta sp. imm.			2						
Cernosvitella sp.	2		8						
Cernosvitella sp. imm.			2						
Cognettia glandulosa (Mich.)			2						
Cognettia glandulosa (Mich.) imm.	40	3	182						
Hydrachnellae									
Lebertia rufipes Koenike	4		22						
Sperchon thienemanni Koenike						2			
Crustacea									
Ilyocryptus sp.	72								
Chydoridae	2020	2076	5488		9	3			
Ostracoda								75	
Copepoda	128	148	264			1	4		
Colembola			2						
Ephemeroptera									
Baetis alpinus Pictet						113	36		
Ecdyonurus gr. *forcipula* Pictet						1	10		
Epeorus sp.						1	2		
Plecoptera									
Arcynopteryx compacta Mc.L. (e)	2								
Chloroperla breviata Navas		4							
Dinocras cephalotes Curtis							6		
F. Perlidae indet. (e)						2			
F. Perlodidae		2							
Leuctra leptogaster Aubert (e)						2			
Pachyleuctra bertrandi Aubert					1	1	8		
Protonemura intrincata Ris							2		
Siphonoperla torrentium Pictet	6		16						
Trichoptera									
Rhyacophila cf. septentrionis				1	3				
F. Psychomyidae					3	3	6		
Plectrocnemia sp. (*P. ?geniculata* Mc.L.)	6	1	28						
Diptera									
Simuliidae									
Prosimulium (P.) latimucro Enderlein					435	38			
Simulium (Nevermannia) brevidens Rubzov					1	9			
Simulium (Simulium) tuberosum Lundström						8			

Table 3.11b. Recorded invertebrate taxa in the benthic samples from Llac Redo, Spain.

Sampled 18.07.93	Litt. 1	Litt. 2	Litt. 3	Inlet	Outle	utlet	utlet	Kajak	Kajak
	Kick	Kick	Kick	Drift	Drift	Drift	kick	25 m	65 m
	N	N	N	N	N	N	N	N m^{-2}	N m^{-2}
Chironomidae									
Macropelopia adaucta Kieffer	66	2	210						
Pentaneurella katterjokki Fittkau & Murray			4			27	10		
Rheopelopia sp.					54				
Zavrelimyia melanura (Meigen)	272	43	77	18			1		
Pseudodiamesa sp.									
Corynoneura arctica Kieffer	30	5	23						
Corynoneura lacustris Edwards						21			
Corynoneura lobata Edwards				3	2	48			
Corynoneura sp.	14		2	18	56	3	1		
Cricotopus (C.) annulator Goetghebuer						1			
Cricotopus (C.) pulchripes Verrall.					2				
Cricotopus (I.) sp.						1			
Cricotopus curtus Hirvenoja						1			
Eukiefferiella coerulescens (K.)				1					
Eukiefferiella devonica (Edw.)						3			
Eukiefferiella lobifera G.						6			
Eukiefferiella minor (Edw.)						1			
Eukiefferiella spp.	2		12			2			
Eukiefferiella tirolensis G.					2	13			
Heterotrissocladius marcidus (Walker)	6	1				1			75
Krenosmittia boreoalpina (G.)						2	1		
Nanocladius parvulus K.					6	65	2		
Orthocladius (Euorthocladius) sp.						8			
Orthocladius (O.) rubicundus (Mg.)					228	15	32		
Paracricotopus niger (K.)						5			
Parametriocnemus boreoalpinus Gowin						4			
Psectrocladius octomaculatus Wülker	322	105	433						
Psectrocladius sp.							17		
Rheocricotopus effusus (Walker)						3			
Synorthocladius semivirens (K.)	22	8	20						
Tvetenia bavarica (G.)						1	7		
Tvetenia calvescens (Edwards)				1		3			
Polypedilum albicorne (Meigen)	72	4	77						
Micropsectra atrofasciata K.						1			
Micropsectra radialis G.	22	1	9						
Micropsectra sp.						6		906	604
Paratanytarsus austriacus Kieffer	236	57	92						
Paratanytarsus spp.	2		8		30				
Rheotanytarsus sp.					18				
Tanytarsus bathophilus Kieffer	84	31	52	1					

Table 3.12. Recorded invertebrate taxa in the benthic samples from Lac Noir and Lac Blanc, France

Sampled July1993	Lac Noir littoral kick	Lac Blanc littoral kick
Hirudinea:		
Glossiphonia sp.	+++	+++
Plecoptera:		
Perlodidae		2
Trichoptera:		
Sericostomatidae indet.	38	83
Coleoptera:		
Dytiscidae indet. larvae	1	1
Dytiscidae indet. adult	5	14
Diptera:		
Simuliidae indet.	30	

+++ Many individuals

Table 3.13 Recorded invertebrate taxa in the benthic samples from Lake Paione Superiore, Italy

	Littoral kick A	Littoral kick B	Outlet river kick	Profundal Kajak N m-2
Sampled	13.09.94	13.09.94	13.09.94	27.10.94
Turbellaria		1	1	
Nematoda indet.	3	4		677
Oligochaeta:				
Lumbriculidae indet.	1		2	
Enchytraeidae indet.	11	46	12	
Crustacea:				
Chydoridae indet.	13	13		
Daphnia sp.				1556
Ephippia indet.				303
Cyclops sp.		25		271
Copepoda	9			
Hydracarina indet.	3	3		68
Plecoptera:				
Leuctra sp.			39	
Dictyogenus fontium Ris			1	
Perlodidae indet. juv.			2	
Trichoptera:				
Pararhyacophila			3	
Metarhyacophila			3	
Limnephilidae indet.			5	
Limnephilidae indet. p.			1	
Potamophylax sp.	7			
Coleoptera				
Dytiscidae l.	1			
Dytiscidae ad.	10	5		
Hydrophilidae indet. l	1			
Diptera:				
Limoniidae indet.	1		1	
Sciaridae indet.	57	15		
Stratiomyidae indet.	1			
Tipulidae indet.	1			
Diptera pupae indet.	6			
Chironomidae:				
Bryophaenocladius sp.	11	32		
Corynoneura sp.			1	
Eukiefferiella brevicalcar (Kieffer)			1	
Heleniella sp.			53	
Heterotrissocladius marcidus (Walker)				1020
Micropsectra radialis Goetghegebuer				1496
Orthocladius (*Euorthocladius*) sp.			1	
Parorthocladius sp.			4	
Procladius sp.				2176
Orthocladiinae indet.	3			
Tanytarsus cf. *niger*				6188

Table 3.14a. Recorded invertebrate taxa in the benthic samples from Lake Paione Inferiore, Italy

Sampled 13.09.94	Inlet r. kick	Littoral kick A	Littoral kick B	Outlet kick	Outlet r. kick A	Outlet r. kick B
Turbellaria	1				3	5
Nematoda indet.	6	6		3	3	1
Oligochaeta:						
Lumbriculidae indet.			11			
Tubificidae indet.		9				
Enchytraeidae indet.	6	5	1	10	11	6
Bivalvia:						
Pisidium sp.		2	3			
Crustacea:						
Chydoridae indet.	1			5	1	
Cyclops sp.				4		
Ostracoda indet.	6					
Hydracarina indet.	2	1		1	5	
Ephemeroptera:						
Baetis rhodani (Pictet)	3					7
Plecoptera:						
Nemoura mortoni Ris					1	6
Nemoura sp. *(cinerea?)*	8	13		7	4	3
Nemouridae indet. juv.		7	1		2	
Protonemura sp.	1				7	12
Leuctra sp.	32					7
Dictyogenus fontium Ris	1					4
Trichoptera:						
Pararhyacophila indet.						3
Metarhyacophila indet.	1					
Rhyacophila sp.					3	1
Plectrocnemia conspersa (Curtis)	2					1
Limnephilidae indet.		5				5
Potamophylax sp.	1					
Odontocerum albicorne Scop.		2			4	1
Megaloptera:						
Sialis sp.		2	6			
Coleoptera						
Dytiscidae l.	1	2		2	3	
Diptera:						
Sciaridae indet.		2				
Limoniidae indet.	1				3	2
Dixidae indet.						1
Simuliidae indet.	4				10	26
Diptera indet.	1					

Table 3.14b. Recorded invertebrate taxa in the benthic samples from Lake Paione Inferiore, Italy

Sampled 13.09.94	Inlet r. kick	Littoral kick A	Littoral kick B	Outlet kick	Outlet r. kick A	Outlet r. kick B
Chironomidae:						
Apsectrotanypus trifascipennis (Zetterstedt)		1	1			
Arctopelopia sp.	2					
Chaetocladius sp.		1				
Cricotopus (*Cricotopus*) *tremulus*-group					9	6
Cricotopus (*Cricotopus*) sp.						1
Conchapelopia sp.						21
Corynoneura cf. *lobata* Edwards	6				3	3
Eukiefferiella brevicalcar (Kieffer)	6				1	1
Eukiefferiella claripennis (Lundbeck)					1	1
Eukiefferiella corulescens (Kieffer)					1	
Heterotanytarsus apicalis (Kieffer)					1	
Heterotrissocladius marcidus (Walker)		2	11		3	
Krenosmittia sp.	1					
Macropelopia sp.		2	6			
Micropsectra cf. *contracta* Reiss				1		1
Micropsectra sp.		2	13		3	
Orthocladius (*Orthocladius*) spp.					9	1
Paratanytarsus cf. *austriacus* (Kieffer)		1	3	29	7	2
Procladius sp.			2			
Prodiamesinae olivacea (Meigen)			6			
Psectrocladius (*Psectrocladius*) *limbatellus*-group		5	5	56	6	1
Tokunagaia sp.						1
Trissopelopia longimana (Staeger)						3
Tvetenia calvescens (Edwards)					1	17
Tvetenia bavarica (Goetghebuer)	8				9	2
Zavrelimyia cf. *barbatipes* (Kieffer)	1	31	40	7	22	2
Orthocladiinae indet.						1
Tanypodinae indet.					1	

Table 3.15. Recorded invertebrate taxa in the benthic samples from Lake Lungo, Italy

Sampled 05.09.94	Littoral kick A	Profundal Kajak N m-2
Turbellaria	1	1101
Nematoda indet.	35	7526
Oligochaeta:		
Lumbriculidae indet.	50	
Enchytraeidae indet.	12	
Crustacea:		
Chydoridae indet.	12	10463
Diaphanosoma brachyurum (Liév.)		184
Ephippia indet.		4589
Cyclops sp.	7	1652
Ostracoda indet.	32	6241
Hydracarina indet.	7	
Diptera:		
Limoniidae indet.	3	
Diptera indet.	1	
Chironomidae:		
Corynoneura cf. *arctica* Kieffer	34	184
Heterotrissocladius marcidus (Walker)	14	
Micropsectra radialis Goetghebuer	7	
Protanypus sp.	1	
Pseudodiamesa cf. *branickii* (Nowicki)	2	
Pseudodiamesa cf. *nivosa* (Goetghebuer)	3	

Table 3.16. Recorded invertebrate taxa in the benthic samples from Lake Latte, Italy

Sampled 06.09.94	Littoral kick	Outlet kick	Outlet r. kick A	Profundal Kajak N m-2
Turbellaria		9	1	367
Nematoda indet.	25	11	14	551
Oligochaeta:				
Tubificidae indet.	2			9362
Enchytraeidae indet.	4	2	120	2937
Crustacea:				
Chydoridae indet.	25	2		184
Ephippia indet.				5507
Cyclops sp.		33	1	551
Ostracoda indet.	30	1		35245
Hydracarina indet.	22	43	108	551
Plecoptera:				
Leuctra sp.			16	
Trichoptera:				
Limnephilidae indet.			33	
Potamophylax sp.	5		3	
Coleoptera				
Dytiscidae l.	4	4		
Dytiscidae ad.	1			
Diptera:				
Limoniidae indet.	22	6	2	
Tipulidae indet.		4	3	
Simuliidae indet.		7	25	184
Chironomidae:				
Chaetocladius cf. *laminatus* (Brundin)			1	
Chaetocladius sp.		1		
Corynoneura cf. *arctica* Kieffer	25			736
Corynoneura cf. *lobata* Edwards		85	1	
Corynoneura spp.			5	
Diamesa sp.			1	
Eukiefferiella brevicalcar (Kieffer)			5	
Eukiefferiella claripennis (Lundbeck)			14	184
Eukiefferiella minor (Edwards)			4	
Heterotrissocladius marcidus (Walker)	4			
Krenosmittia sp.	0		3	
Micropsectra radialis Goetghebuer	8			736
Orthocladius (*Eudactylocladius*) sp.		6		
Paratrichocladius sp.			1	
Parorthocladius sp.			1	
Pseudodiamesa cf. *branickii* (Nowicki)	1	6	1	
Pseudodiamesa cf. *nivosa* (Goetghebuer)	2			
Tvetenia bavarica (Goetghebuer)		4	9	
Zavrelimyia cf. *barbatipes* (Kieffer)	13			
Orthocladiinae indet.			17	
Tanypodinae indet.			1	

Table 3.17. Recorded invertebrate taxa in the benthic samples from Schwarzsee ob Sölden, Austria.

Sampled 18.08.93	Littoral kick A	Littoral kick B	Profundal Kajak n m-2
Turbellaria:			
Crenobia alpina (Dana)	34	14	60
Nematoda indet.			60
Oligochaeta:			
Tubificidae			965
Enchytraeidae			784
Crustacea:			
Chydorus sp.			121
Cyclops sp.			362
Copepodites			4945
Plecoptera:			
Nemouridae indet. juv.			60
Coleoptera:			
Dytiscidae indet.		1	
Chironomidae:			
Micropsectra radialis Goethghebuer			603

Table 3.18. Recorded invertebrate taxa in the benthic samples from Lake Zgornje Krisko Jezero, Slovenia. +: recorded in samples

	Littoral kick	Littoral kick	Profundal Kajak
Sampled	27.07.94	31.08.94	31.08.94
Nematoda:			
Merminthidae indet.		132	
Oligochaeta:			
Lumbriculidae indet.	+	175	
Crustacea:			
Daphnia pulicaria Forbes	+	900	+
Daphnia pulicaria Forbes ephippia		4000	
Chydorus sphaericus (O.F.M.)	+	7000	+
Chydorus sphaericus (O.F.M.) ephippia		700	
Arctodiaptomus alpinus (Imhof)		1100	+
Eucyclops serrulatus (Fish.)	+	4500	+
Cyclops abyssorum tatricus Kozm.	+	250	+
Plecoptera:			
Nemoura cinerea (Retz.)	+	5	
Coleoptera:			
Hydroporus sp.		41	
Hydroporus nigrita (Fabr.)		1	
Agabus bipustulatus (L.)		3	
Agabus sp.		4	
Chironomidae:			
Paratanytarsus austriacus Kieffer	+	+	
Pseudodiamesa cf. *branickii* (Nowicki)	+		
Tanytarsus gregarius Kieffer		+	
Tanytarsus lugens -group	+		
Tanypodinae indet.	+		
Tanytarsini indet.	+		

Table 3.19. Recorded invertebrate taxa in the benthic samples from Starolesnianske Pleso, Slovakia, 1993 and 1994.

	Litt. kick A	Litt. kick B	Litt. kick C	Litt. kick D	Prof. Kajak N m^{-2}	Litt. kick	Prof. Kajak N m^{-2}
Sampled	28.09.93	28.09.93	05.10.93	05.10.93	05.10.93	27.09.94	27.09.94
Nematoda indet.	4	35					
Oligochaeta:							
Tubifex tubifex (Müll.)					8437		17936
Tubificidae	2						
Cognettia sp.			38	65		40	
Cernosvitoviella atrata (Bretscher)			20	17		11	
Enchytraeidae	11	6					1416
Crustacea:							
Chydorus sp.	32	13					
Cyclops sp.	5	43					
Plecoptera:							
Nemurella picteti Klap.			9	6		39	
Trichoptera:							
Limnophilus coenosus Curtis			14	15		33	
Limnephilus sp.	5	2					
Coleoptera:							
Agabus solieri Aubé im.			1	1		4	
Agabus bipustulatus (L.) im.						3	
Agabus sp. larvae			5	7		20	
Hydroporus sp. larvae			5	2		2	
Dytiscidae indet.	2	7					
Chironomidae:							
Procladius (*Holocladius*) sp.					1612	1	1416
Heterotrissocladius marcidus (W	18	11	2	9	1054	47	1888
Tanytarsus cf. *gregarius* Kieffer	1	1				1	7021
Tanytarsus sp. (*gregarius* type)	3	4					
Tanytarsus sp.			1				
Zalutschia tatrica (Pagast)	154	30	67	87	124	299	944

Table 3.20. Recorded invertebrate taxa in the benthic samples from Dlugi Staw Gasienkowy, Poland 1993 and 1994.
X: present in samples collected by divers.

	Littoral	Profundal	Littoral	Littoral	Profundal
	kick	Kajak	kick 1	kick 2	Kajak
	N	N m^{-2}	N	N	N m^{-2}
Sampled	08.10.93	08.10.93	12.10.94	12.10.94	12.10.94
Turbellaria:					
Crenobia alpina (Dana)	x				
Nematoda indet.	5	1360	1		280
Oligochaeta:					
Enchytraeidae juv.			1		
Mesenchtraeus armatus (Lev.)	1				
Cernosvitoviella atrata (Bret.)	1	68	2		180
Cernosvitoviella carpatica Niel. & Christ.		68		1	
Cernosvitoviella tatrensis (Kow.)	15	612	4		680
Cernosvitoviella gen. spp. (juv.)	34	1156	3		3440
Cognettia sphagnetorum (Vejd.)	14		20	31	
Cognettia glandulosa (Mich.)	15		29	16	
Cognettia cognetti (Issel)	1				
Cognettia anomala			1	1	
Cognettia. lapponica	7		2		
Cognettia spp.	65		39	39	
Nais pseudobtusa Piguet	1				
Stylodrilus parvus (Hr. & Cern.)	1				
Stylodrilus spp.	14				160
Crustacea:					
Cladocera	x				
Copepoda	x		1		
Hydracarina indet.	1				
Trichoptera:					
Limnophilus coenosus Curtis	1				
Coleoptera:					
Hydraenidae larvae			2	3	
Diptera:					
Chironomidae:					
Zavrelimyia sp.	x				
Tanypodinae (juv.)		136			
Heterotrissocladius marcidus (Walker)		952	2	2	
Heterotrissocladius gr. *marcidus*	4				760
Psectrocladius (*P.*) sp.	x				
Smittia sp. (? *terrestris*)	1		1		
Orthocladinae (juv.)	6				
Micropsectra radialis G.	x	1904		1	2920
Tanytarsini (juv.)		68			
Chironomidae juv.			1		
Limoniidae:					
Antocha sp.		68			
Pedicia sp.	1				

Table 3.21. Recorded invertebrate taxa in the benthic samples from
Zielony Staw Gasienkowy, Poland 1993 and 1994
X: present in samples collected by divers.

Sampled	Littoral kick N 09.10.93	Outflow kick N 09.10.93	Profund. Kajak N m^{-2} 09.10.93	Littoral kick 1 N 13.10.94	Littoral kick 2 N 13.10.94	Profund. Kajak N m^{-2} 13.10.94
Turbellaria:						
Crenobia alpina (Dana)	0,5					
Hydrozoa						
Hydra sp.		18				
Nematoda indet.		5	2992	1	3	
Oligochaeta:						
Mesenchtraeus armatus (Lev.)			136		3	
Mesenchtraeus spp. juv	0,5					
Cernosvitoviella tatrensis (Kow.)		2				
Cernosvitoviella gen. spp. (juv.)			136	1		
Cognettia sphagnetorum (Vejd.)					1	
Nais variabilis Pig.	11,5		7616	13	7	1080
Tubifex montanus Kow.			136			
Stylodrilus parvus (Hr. & Cern.)		1				
Stylodrilus spp.	0,5	28	272			
Dero dorsalis Ferr.			816			
Tubificidae gen. spp. (juv.)			1904		1	1640
Crustacea:						
Ostracoda			3672			
Cladocera		67		5		40
Copepoda		85				80
Bivalvia:						
Pisidium sp.			544			
Hydracarina indet.	1,5	5				
Plecoptera:				1		
Nemuridae (? *Nemoura* sp.)	2,5					
Nemuridae (? *Nemurella picteti* Klap.)		1			2	
Leuctra sp.		1		7	1	
Diura bicaudata L.		1				
Perlodidae	0,5					
Chloroperla sp.		2				
Plecoptera juv.	2	2		1	3	
Coleoptera:						
Dytiscidae (l)					1	
Diptera:						
Chironomidae:						
Apsectrotanypus trifascipennis (Zett.)						80
Macropelopia sp.		11		30	20	
Macropelopini (juv.)				1		
Zavrelimyia sp.	7,5	1		9	28	40
Potthastia longimana K.		8				
Prodiamesa olivacea (Mg.)		x				
Heterotrissocladius marcidus (Walker)			272	7	81	160
Heterotrissocladius gr. *marcidus*	2,5	36				
Cricotopus (*Isocladius*) sp.	7,5	18		5	13	
Cricotopus + *Orthocladius*		21				
Rheocricotopus sp.		5				
Psectrocladius (*P*.) sp.	0,5	27		15	32	80
Corynoneura sp.	26	71	272	12	97	
Orthocladinae (juv.)	4,5	23		7		
Paratanytarsus austriacus (Kieffer)		5		11	72	
Tanytarsus (? "*lobatifrons*")		37			39	
Micropsectra radialis G.			272			160
Micropsectra sp.		67			2	120
Tanytarsini (juv.)	1	139	136	3	4	
Dicrotendipes sp.		4		16	21	200
Chironomini (juv.)				5	3	

Table 3.22a. Distribution of the different taxa of Chironomidae in the study areas.

Taxa	1 Øvre Neådalsvatn	2 Stavsvatn	3 Lille Hovvatn	5.1 Paione Superiore	5.2 Paione Inferiore	6.1 Lungo	6.2 Latte	7.3 Noir	7.4 Blanc	9 Arresjøen	10 Maam	11 Schwarzsee	12.1 Aguilo	12.2 Redo	13 Caldera	14 Escura	15.1 St. Pleso	15. 3 Dlugi Staw	15.4 Zielony Staw	16 Cimera	18 Chibini	19 Zgornje Krisko Jezero	**Sum localities**
Ablabesmyia longistyla Fittkau																X							1
Ablabesmyia monilis (Linné)			X																				1
Ablabesmyia sp.																				X			1
Acamptocladius submontanus (Edwards)	X																						1
Apsectrotanypus trifascipennis (Zetterstedt)					X										X				X				3
Arctopelopia barbitarsis (Zetterstedt)			X																				1
Arctopelopia melanosoma (Goetghebuer)	X																						1
Arctopelopia cf. *griseipennis* (Wulp)											X												1
Arctopelopia spp.		X			X																X		3
Bryophaenocladius spp.	X			X																			2
Chaetocladius cf. *laminatus* (Brundin)							X																1
Chaetocladius spp.	X				X		X			X													4
Chironomus anthracinus Zetterstedt			X																				1
Cladopelma viridula (Linné)			X																				1
Cladopelma sp.																X							1
Conchapelopia melanops (Meigen)													X										1
Conchapelopia sp.					X																		1
Corynoneura arctica Kieffer	X					X	X						X	X	X								6
Corynoneura coronata Edwards													X										1
Corynoneura lacustris Edwards													X	X									2
Corynoneura scutellata Winnertz											X												1
Corynoneura cf. *lobata* Edwards					X		X							X									3
Corynoneura spp.				X			X						X	X		X			X		X		7
Cricotopus (*Cric.*) *annulator* Goetghebuer														X									1
Cricotopus (*Cric.*) *curtus* Hirvenoja														X									1
Cricotopus (*Cric.*) *pulchripes* Verrall													X	X									2
Cricotopus (*Cric.*) *tibialis* (Meigen)										X													1
Cricotopus (*Cric.*) *tremulus*-group					X																		1
Cricotopus (*Cric.*) spp.					X															X	X		3
Cricotopus (*Isocl.*) spp.														X					X				2
Cricotopus + *Orthocladius* indet.																			X				1
Cryptochironomus cf. *psittacinus* (Meigen)			X																				1
Diamesa aberrata (Lundbeck)										X													1
Diamesa arctica (Boheman)										X													1
Diamesa bertrami (Edwards)										X													1
Diamesa bohemani Goetghebuer										X													1
Diamesa hyperborea Holmgren										X													1
Diamesa spp.	X						X			X											X		4
Dicrotendipes modestus (Say)			X								X												2
Dicrotendipes sp.																			X				1
Diplocladius cultriger Kieffer																					X		1
Eukiefferiella brevicalcar (Kieffer)				X	X		X																3
Eukiefferiella claripennis (Lundbeck)					X		X																2
Eukiefferiella corulescens (Kieffer)					X								X	X									3
Eukiefferiella devonica (Edwards)													X	X									2
Eukiefferiella lobifera Goetghebuer														X									1
Eukiefferiella minor (Edwards)	X						X							X									3
Eukiefferiella tirolensis Goetghebuer														X									1
Eukiefferella sp. (*gracei* group)																					X		1
Eukiefferiella spp.													X	X									2
Heleniella sp.				X																			1
Heterotanytarsus apicalis (Kieffer)	X		X		X						X												4
Heterotrissocladius brundini Sæther & Schnell	X																						1
Heterotrissocladius marcidus (Walker)		X		X	X	X	X				X		X	X				X	X	X			11

Table 3.22b. Distribution of the different taxa of Chironomidae in the study areas.

Taxa	1 Øvre Neådalsvatn	2 Stavsvatn	3 Lille Hovvatn	5.1 Paione Superiore	5.2 Paione Inferiore	6.1 Lungo	6.2 Latte	7.3 Noir	7.4 Blanc	9 Arresjøen	10 Maam	11 Schwarzsee	12.1 Aguilo	12.2 Redo	13 Caldera	14 Escura	15.1 St. Pleso	15. 3 Dlugi Staw	15.4 Zielony Staw	16 Cimera	18 Chibini	19 Zgornje Krisko Jezero	**Sum localities**
Heterotrissocladius spp.	X															X					X		3
Krenosmittia boreoalpina (Goetghebuer)														X									1
Krenosmittia spp.					X		X																2
Limnophyes asquamatus Andersen			X																				1
Limnophyes sp.										X													1
Macropelopia adaucta (Kieffer)			X								X		X	X									4
Macropelopia spp.					X														X	X			3
Mesocricotopus thienemanni (Goetghebuer)	X																						1
Metriocnemus obscuripes (Holmgren)										X													1
Micropsectra atrofasciata Kieffer														X									1
Micropsectra insignilobus Kieffer	X	X								X													3
Micropsectra radialis Goetghebuer	X			X		X	X			X		X	X	X	X			X	X				11
Micropsectra cf. *contracta* Reiss					X																		1
Micropsectra Pe 5 Langton 1991													X										1
Micropsectra spp.	X				X						X		X	X		X			X	X			8
Microtendipes pedellus (de Geer)			X								X												2
Monodiamesa bathyphila (Kieffer)	X																						1
Nanocladius parvulus K.														X									1
Nanocladius cf. *rectinervis* (Kieffer)	X																						1
Oliveridia tricornis (Oliver)										X													1
Orthocladius (*Eudactylocladius*) spp.				X			X																2
Orthocladius (*Euorthocladius*) sp.														X									1
Orthocladius (*Orth.*) *rubicundus* (Meigen)														X									1
Orthocladius (*Orth.*) spp.	X	X			X								X										4
Pagastiella orophila (Edwards)			X										X			X							3
Parachironomus sp.																X							1
Paracladopelma cf. *camptolabis* (Kieffer)																				X			1
Paracricotopus niger (Kieffer)														X									1
Parakiefferiella bathophila (Kieffer)	X																						1
Parakiefferiella fennica Tuiskunen	X																						1
Parametriocnemus boreoalpinus Gowin														X									1
Paratanytarsus austriacus (Kieffer)					X									X					X		X	X	5
Paratanytarsus hyperboreus Brundin	X																						1
Paratanytarsus laccophilus (Edwards)													X										1
Paratanytarsus cf. *setosimanus* Goetghebuer													X										1
Paratanytarsus spp.														X									1
Paratrichocladius sp.							X																1
Parorthocladius sp.				X			X																2
Pentaneurella katterjokki Fittkau & Murray														X									1
Pentaneurella sp.													X										1
Polypedilum (*Polyp.*) *albicorne* (Meigen)														X									1
Polypedilum spp.													X			X							2
Potthastia longimana Kieffer																			X				1
Procladius (*Holocl.*) *choreus* (Meigen)																X							1
Procladius (*Holocl.*) *sagittalis* (Kieffer)													X										1
Procladius chorus (Meigen)/*signatus* (Zetterstedt)			X																				1
Procladius (*Holocl.*) spp.	X			X	X												X						4
Prodiamesa olivacea (Meigen)					X														X				2
Protanypus spp.	X					X																	2
Psectrocladius (*Meso.*) *barbatipes* (Kieffer)			X								X												2
Psectrocladius (*Mono.*) *calcaratus* (Edwards)		X									X												2
Psectrocladius (*Mono.*) *septentrionalis* Chernov	X																						1
Psectrocladius (*Psectro.*) *limbatellus* (Holmgren	X		X								X												3
Psectrocladius (*Psectro.*) *octomaculatus* Wülker													X	X									2

Table 3.22c. Distribution of the different taxa of Chironomidae in the study areas.

Taxa	1 Øvre Neådalsvatn	2 Stavsvatn	3 Lille Hovvatn	5.1 Paione Superiore	5.2 Paione Inferiore	6.1 Lungo	6.2 Latte	7.3 Noir	7.4 Blanc	9 Arresjøen	10 Maam	11 Schwarzsee	12.1 Aguilo	12.2 Redo	13 Caldera	14 Escura	15.1 St. Pleso	15. 3 Dlugi Staw	15.4 Zielony Staw	16 Cimera	18 Chibini	19 Zgornje Krisko Jezero	**Sum localities**
Psectrocladius (Psectro.) psilopterus Kieffer			X								X												2
Psectrocladius (Psectro.) sordidellus (Zettetstedt)		X									X												2
Psectrocladius (Psectro.) spp	X	X											X	X		X		X	X				7
Pseudodiamesa cf. *branickii* (Nowicki)						X	X															X	3
Pseudodiamesa cf. *nivosa* (Goetghebuer)						X	X																2
Pseudodiamesa (Pachydiamesa) sp.																					X		1
Pseudodiamesa (Pseudodiamesa) sp.																					X		1
Pseudodiamesa sp.														X									1
Pseudokiefferiella parva (Edwards)										X													1
Rheocricotopus effusus (Walker)	X												X	X									3
Rheocricotopus sp.																			X				1
Rheopelopia sp.														X									1
Rheosmittia spinicornis (Brundin)	X																						1
Rheotanytarsus sp.														X									1
Sergentia coracina (Zetterstedt)	X																						1
Smittia sp.																		X					1
Stempellinella brevis (Edwards)													X										1
Synorthocladius semivirens (Kieffer)													X	X									2
Tanytarsus bathophilus Kieffer													X	X									2
Tanytarsus buchonius Reiss & Fittkau			X								X												2
Tanytarsus chinyensis Goetghebuer																X							1
Tanytarsus debilis (Meigen)													X										1
Tanytarsus cf. *gregarius* Kieffer			X														X					X	3
Tanytarsus cf. *lugens* (Kieffer)	X																					X	2
Tanytarsus cf. *niger* Andersen				X																			1
Tanytarsus Pe 9, Langton 1991													X										1
Tanytarsus sp. (*gregarius* group)																	X						1
Tanytarsus spp.															X	X	X		X	X			5
Thienemanniella Pe 2b Langton 1991													X										1
Thienemanniella sp.	X												X										2
Thienemannimyia fusciceps (Edwards)	X																						1
Thienemannimyia sp.																				X			1
Tokunagaia sp.					X																		1
Trissocladius n. sp.										X													1
Trissopelopia longimana (Staeger)					X								X										2
?Trissopelopia sp.																X							1
Tvetenia bavarica (Goetghebuer)					X		X							X									3
Tvetenia calvescens (Edwards)	X				X								X	X									4
Zalutschia tatrica (Pagast)																	X						1
Zalutschia tornetraeskensis (Edwards)		X																					1
Zalutschia spp.	X																				X		2
Zavrelia Pe1 Langton 1991													X										1
Zavrelimyia melanura (Meigen)													X	X									2
Zavrelimyia cf. *barbatipes* (Kieffer)					X		X																2
Zavrelimyia spp.		X																X	X				3
Chironomini indet.																			X				1
Orthocladiinae indet.				X	X		X											X	X		X		6
Tanypodinae indet.					X		X						X					X				X	5
Tanytarsini indet.	X																	X	X			X	4

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Chapter 4.

Fish

Population Structure and Concentrations of Heavy Metals and Organic Micropollutants

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EXECUTIVE SUMMARY FISH

Seventeen lakes with main populations of brown trout (*Salmo trutta*), Arctic charr (*Salvelinus alpinus*), brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) have been test fished in the AL:PE 1 and AL:PE 2 project to define the population structure. In addition, lakes that had been testfished during the AL:PE 1 project, as well as the new lakes in AL:PE 2, has been sampled for analyses of heavy metals and organic micropollutions in fillet and liver.

During resampling for analyses of heavy metals and organic micropollutants, new species were found in two lakes. In Étang d'Aubé, France, Arctic charr and minnow (*Phoxinus phoxinus*) was found for the first time, and in Zielony Staw, Poland, a population of brown trout was found. The outlet stream of Lochnagar, UK, is the only locality which annually has been testfished (by electrofishing) over the whole period.

NIVA has analysed the heavy metals in fish from all lakes, except Schwarzsee ob Sölden where the University of Innsbruck, Austria, has done the analyses. The concentrations of heavy metals were compared to the locality of capture and to the length, weight, age, sex, state of sexual maturity, and the condition factor of the fish. Organic micropollutants, organochlorinated compounds in tissue and lipids of fish (HCB, HCHs, DDTs and PCBs) have been analysed by CID-CSIC, Spain. As the fish which were sent to NIVA for heavy metals analyses also were age determined here, discrepancy between age determination was found between some institutes. Age determination in fish thus needs inter-calibration practices.

The lowest concentrations of Hg were registered in Øvre Neådalsvatn (Norway), Zielony Staw (Poland), Lago Paione Inferiore (Italy), Laguna Cimera (Spain) and Étang d'Aubé (France), while the highest concentrations of Hg were found in Arresjøen (Svalbard, Norway), and Lagoa Escura (Portugal).

The concentrations of Hg (in fillet) and Pb (in liver) were below the acceptable levels for human consumption in all of the AL:PE sites except for Schwarzsee Ob Sölden (Austria). Cd were too high for most of the sites, except the lakes Øvre Neådalsvatn, Lough Maam (UK), Lagoa Escura, Étang d'Aubé and Chibiny (Russia).

When the concentration of the metals Hg, Pb, and Cd are arranged according to geographical positions of the AL:PE sites and according to accumulations of the metals in the fish, the geographical distributions are quite pronounced. With reservation for differenses in age/size relationships, piscivorous/non- piscivorous populations and species differences, Hg seems to have the highest concentrations in the western localities close to the Atlantic ocean. The highest contaminations appeared in Arresjøen and Lagoa Escura, and also quite high value in the Irish Lough Maam.

Pb showed low concentrations in the northern sites, higher values in the western localities, and the highest figures in the central, south-east Europe. Cd shows more or less the same pattern as for Pb, but with generally higher concentrations, especially compared to acceptable limits for human consumption. Both for Pb and Cd, the concentrations in Lochnagar (Scotland) were higher than expected from its geographical position. Øvre Neådalsvatn showed the lowest or second lowest values for all three metals. This site is therefore also well suited as a reference locality concerning accumulation of heavy metals in fish.

For some of the lakes, correlation was seen between the size of the fish (length, age, weight) and the concentration of Cd and Pb. For the whole material (not separating between species), however, no significant correlation was identified between the measured fish parameters and concentration of Cd and Pb. For Hg, correlation was seen between the size (length, age) of the fish and the Hg concentrations for the whole material. However, site identity demonstrated the strongest controlling variable for the examined heavy metals in fish. Principal components analysis showed high covariance for Cd and Pb (e.g. high concentrations of Cd and Pb in the same lake), but no covariance with Hg.

The results of PCB and DDE/DDT in the fish analyses are in good agreement with the concentrations observed in the sediments. Thus, they exhibit approximately the same geographical distribution in terms of higher and lower polluted sites. The fish analyses also show a general good correspondence between PCB and DDE/DDT concentrations, usually the two compounds are observed to increase or decrease alike in the lakes.

The PCB distribution found in the fish tissues is similar to that present in the sediments although it shows a clear enrichment in the heavier congeners. This effect probably reflects the different bioaccumulation factor of each of these compounds. HCB and HCH seem to be distributed following the influence of local sources.

There is a group of lakes with very low levels (almost blanks): Lagoa Escura, Lough Maan, Lochnagar and Laguna Cimera. Some lakes with moderate pollution levels were Stavsvatn, Zielony Staw and Estany Redo, whereas lakes with relative high pollution were Arresjoen and Lago Lungo. The highest pollution was found in Schwarzsee ob Sölden.

This classification among low, moderate, high pollution corresponds to the concentrations of the major chlorinated compounds, the PCBs and DDTs. The concentrations of these compounds change alike. These results show a higher concentracion in Central Europe.

4. FISH

4.1 INTRODUCTION

Because of the good empirical relationship between water chemistry and fish population changes, information about fish populations, both the historical and present status, has been of great importance in the AL:PE projects. High mountain lakes represents some of the most extreme environments for fish; low ionic concentration, long ice-cover period, low annual mean temperature, short period with food abundance etc. In such areas, few changes toward a less favourable water quality might immediately be reflected in fish population characteristics. As fish are long lived, 20 to 40 years in some alpine areas, fish populations acts as integrators of pollutants, a.o. for heavy metal and organic micro pollutant contamination. Likewise will reproduction failure, found by missing yearclasses, pinpoint the years when extreme water quality no longer provided the environment for survival of the most sensitive life history stages. Such changes might therefore act as an early warning for environmental changes, or as a confirmation of the historical changes which have taken place in the environment.

4.2 METHODS

Both in the AL:PE 1 and 2 project, information about the historical changes and stocking programme in the lakes has been collected by interviews (see Wathne *et al.* 1995). In lakes where the fish population are undergoing negative changes due to acidification, such information about present status has in many cases been shown to underestimate the degree of damage (Hesthagen *et al.* 1993). Test fishing, using standard gill net series and sampling procedures to describe fish population size, age composition, growth pattern, food organisms etc., has since the start of the monitoring programme in Norway (Rosseland *et al.* 1980) demonstrated its relevance to give a true picture of the present fish status. These same methods have been used in the AL:PE 2.

4.2.1 Test fishing.

Gillnet series

In AL:PE 1 and 2, the gillnet series that was designed for the Norwegian monitoring programme (Rosseland *et al.* 1979) has been used (Wathne *et al.* 1995). Eight individual bottom gillnets of different mesh sizes (Table 1) or a set of three gillnets, each as a combination of these 8 mesh sizes (SFT 1983), has been used either alone or in combination. In cases where national laboratories have deviated from the standard (France, Austria and Russia), the used gillnets are given for the specific lakes.

Gillnet-setting.

The gillnets are set perpendicular to the shore, avoiding steep-slope shore to bottom areas.

Both in the AL:PE 1 and 2 projects, the period between August 15 to October 15 have been selected for testfishing, for reasons given in Wathne *et al.* (1995).

Table 4.1. The standardised gillnet series, containing 8 gillnets of given mesh size and thread thickness. (After: Rosseland *et al.* 1979). In the series of 8 single nets, each individual gillnet is 26 m long, 1.5 m deep, and have a dark red colour. In the series of 3 nets, each net contains a combination with 4 m of each mesh size, each of the 3 nets having the individual mesh sizes in different order. The catchability of the 8 single nets are 1.0, compared to 0.46 of the 3 net series. The gillnets are produced by Lundgrens Fiskredskapsfabrik AB, Stocholm, Sweden.

Mesh size mm.	10	12.5	16.5	22	25	30	38	46
Thread thickness mm.	.15	.15	.15	.15	.15	.15	.15	.17

Analytical program

Each fish have been given a specific number which follow all subsamples to be analysed. Data from individual fish has been sent to NIVA.

For each individual fish, the following parameters have been noted:

- lake
- date
- species
- length, in mm, measured from snout to lower part of tail.
- weight, in gram.
- sex and gonadal maturation, from stage I - VII
  - I - II juveniles
  - III - V recruit spawners
  - VI spawning
  - VII/.. postspawners
- flesh colour; white, pink or red.
- stomach fullness, classified from 0 - 4.
- stomach content (if possible), conserved in 70% alcohol and classified in main invertebrate groups (not fully analysed in AL:PE 2).
- scale samples for age determination, taken from the area between the sideline organ and dorsal and pectoral fin.
- otolith samples for age determination (all species), using the "burning technique" described by Christensen (1964). If age differ when determined by otolith and scales, otolith age is considered as the true age.
- growth, determined by:
  - length at catch as a function of true age.
  - back calculation of growth, using the methods of Dahl (1910) and Lee (1920).

Analytical programme for the electrofishing (Lochnagar, UK) includes length and age (by scales). Analytical work as well as testfishing at sites in Norway and Italy has been performed by NIVA. Lake In all other countries, practical and analytical work has been performed at the national laboratories. The results are processed in databases at NIVA

4.2.2 Heavy metals, Cd and Pb in fish liver, and Hg in fillet

Analyses

The liver and fillet were digested, and Pb and Cd were analysed by graphite furnace (Perkin-Elmer 2380), and Hg were determined by cold-vapour atomic absorption spectrometry (Perkin-Elmer 1100 B with gold trap used with helium as carrier gas). All methods are described in Green, 1993. Except for the fish from Schwarzsee ob Sölden, where the University of Innsbruck has done the metal analyses, NIVA has analysed the heavy metals in all other lakes.

Statistics

The concentrations of heavy metals were compared to the locality of capture and to the length, weight, age, sex, state of sexual maturity, and the condition factor of the fish. The statistical handling of the material (Principal component analysis, Analysis of variance, and Analysis of co-variance) was done by John Birks (UiB) and Eirik Fjeld (NIVA).

Multivariate numerical methods of data analysis have been applied to these data in an attempt to detect the major patterns of variation within the data-sets. Such patterns highlight the principal gradients of variation, help to generate hypotheses about the underlying causal processes, and define new research questions.

The Pb, Cd, and Hg concentrations in livers or muscle of arctic charr, brook trout, rainbow trout, and brown trout have been measured from 73 fish from 15 lakes in the AL:PE project. The lakes are Arresjøen (Spitsbergen), Lago Lungo (Italy), Lago di Latte (Italy), Schwarzsee ob Sölden (Austria), Lake Chibini (Kola), Étang d'Aubé (France), Laguna Cimera (Spain), Zieloni Staw (Poland), Lagoa Escura (Portugal), Lago Paione Inferiore (Italy), Stavsvatn (Norway), Estany Redo (Spain), Lochnagar (Scotland), Lugh Maam (Ireland), and Øvre Neådalsvatn (Norway).

Numerical analyses

The data have been analysed by principal components analysis (PCA) (ter Braak, 1987) using a correlation matrix between the three chemical variables. Because the chemical variables come from fish of different species, length, age, weight, sex, and growth stage, all of which could cause variations in the observed heavy metal concentrations, the effects of these variables were removed statistically by treating these variables as covariables and partialling out their effects in a partial PCA (ter Braak and Prentice, 1988).

The results of the PCA and of the partial PCA are presented as correlation biplots (ter Braak, 1983, 1994).

In an attempt to partition how much of the observed variation in the heavy-metal concentrations can be explained by all the potential predictor variables (site, fish species, sex, length, weight, age, and growth stage), and by site alone when the effects of different sets of biological variables are allowed for statistically, a series of (partial) redundancy analyses (RDA) were done using different sets of predictor variables and covariables. RDA is a constrained or canonical form of PCA (ter Braak, 1994) in which the patterns of variation in the response variables, in this case heavy-metal concentrations, are modelled as linear combinations of the predictor variables so as to give the lowest possible residual sum-of-squares (ter Braak, 1987, 1994). The statistical significance of each RDA model was assessed by a Monte Carlo permutation test (ter Braak, 1990) using 249 unrestricted permutations.

4.2.3 Organochlorinated compounds, PCBs PAH and DDT in fish fillet and lipid

The organochlorinated compounds, PCBs, PAH and DDT from fillet and lipid of fish has been analysed by CID-CSIC, Spain. In two Norwegian lakes, however, NIVA has in parallel analysed for total PCB.

The parameters analysed by CID-CSIC were:

- Water and lipid content in muscle tissue
- Organoclorinated pesticides compounds.
  Hexachlorobenzene
  Hexachlorocyclohexanes (α and γ isomers)
  DDTs (pp'-DDE, pp'-DDT)
- Industrial organochlorinated products:
  Polychlorobiphenyls (Congeners Nos. 28+31, 52, 101, 118, 153, 138 and 180)

The muscle tissues were freeze-dried and Soxhlet extracted with (4:1) *n*-hexane-dichloromethane for 18 hours. This extract was used to measure total extractable lipid weight after evaporation to dryness. The extract was then redissolved in 2 ml of *n*-hexane and cleaned up with agitation with sulphuric acid (three times). Instrumental analysis of the cleaned extracts was performed by gas chromatography with splitless injection and electron capture detection. The instrument was equipped with a 5% phenyl-95% methylpolysiloxane capillary column. Quantitation was performed with reference to authentic standards. Calibration curves were performed with each of these standards to ensure that all compounds were quantified within the linear range of the detector.

Results from the different lakes are shown in Appendix 7 (Table 7.2 - 7.16). These Tables report the concentrations per total wet weight and total extractable lipids. No significant covariation is observed between content of any of the chlorinated products and fish weight, length or lipid content. In these conditions the normalisation of the concentration to total extractable lipids is not necessary (Hebert and Keenleyside, 1995). The results referring to lipid weight are therefore only given for comparative purposes. In the present evaluation, only the concentrations per wet weight will be considered.

All the lakes considered in this study are oligotrophic (total N < 1000 µg/L and total P < 7 µg/L) and the concentration of humic materials in their waters is also low (TOC < 3.3 mg/L). Thus, the small influence of lake productivity and water concentration of humic substances in the uptake of organochlorinated pollutants by fishes observed in other studies (Larsson et al., 1992) is not probably significant in the context of the lakes selected for study.

4.3 RESULTS

Lakes not previously testfished in the AL:PE 1 project, was testfished and the population structure and contamination levels was determined. In lakes from AL:PE 1, a selective gillnet fishing for collecting tissue samples for determination of heavy metals and organic micropollutants have been performed. NIVA has analysed the metals (Cd and Pb in liver, and Hg in tissue) in five fish from all lakes, except the Austrian Lake Schwarzsee ob Sölden who was analysed by the University of Innsbruck (Hofer). The concentrations of HCB, HCH, DDT and PCBs was analysed from five other fish by CID-CSIC (Grimalt). The size of the fish and concentration of the different components are shown in Appendix 7.

4.3.1 SVALBARD

Arresjøen (9)

Arresjøen, Svalbard, was testfished by the University of Tromsø in 1990 (Svenning 1992, Svenning and Borgstrøm 1995) and by NIVA in 1993. The population of Arctic charr (*Salvelinus alpinus* L.) is typical for the arctic lakes at Svalbard being landlocked and isolated from sea migration. The fish has a slow growth the first 10-12 years, until they shift their feeding habits and becomes cannibals around the age of 12, Figure 4.1. This shift in feeding, is reflected in the bimodal growth curve, Fig 4.2. Charr up to the age of 31 years was found, Figure 4.3.

On August 16, 1993, NIVA performed a restricted testfishing to get data on micropollution in the charr population. Five fish, age from 17 to 31 years, were analysed. Cadmium and lead in liver ranged from 0.45 - 0.91 and 0.00 - 0.03 µg/g wet weight, respectively. Mercury in fillet ranged from 0.14 to 0.27 µg/g wet weight, se Table A7.1. As for Stavsvatn, total PCB concentration in the fish from Arresjøen has been analysed both by NIVA and CID-CSIC. The concentration was found by NIVA to be between 12 to 59.2 µg/kg wet weight (mean and SD = 24.7 ± 17.8) for the five fish, the oldest fish (31 years) having the highest concentration (Table A7.1).The body weight, length, tissue water, lipid content and concentrations of HCB, HCH, DDT and PCBs in the five charr analysed by CID-CSIC, are shown in Table A7.2.1-3. The body weight ranged from 27 to 440 g, ranging in total PCBs between 1.86 to 35.8, mean 17.0 ± 16.1 µg/kg wet weight (Table A7. 2.2).

Region summary - Svalbard

The fish population at Arresjøen is typical for a lake at Svalbard having a landlocked and isolated Arctic charr population. The old fish in these lakes make them ideal for studying pollutants concentrating as a function of exposure time (age dependant). Of the heavy metals, some of the highest concentrations of Hg in the AL:PE lakes were found in Arresjøen. Although not exceeding the acceptable limits for food consumption (>0.3 ppm Hg), the level for Cd in liver, however, was exceeded (> 0.5 ppm Cd). Pb, on the other hand, showed a low concentration (<0.1 ppm).

The concentrations of organochlorinated compounds in Arresjøen are low but they are not the lowest in the AL:PE series. This observation is a bit surprising taking into account large distance of this lake from the European continental sites were organochlorinated compounds are produced and/or used. Furthermore, the results from the sediment analyses show that the lower concentrations of these compounds are effectively found in this lake. One important feature of the fishes collected in this lake is that two specimens are among the largest collected in the whole study. They have been excluded from the average values described in Figures 4.18 - 4.21. The most abundant compounds are the PCB congeners. The DDT derivatives are also significant.

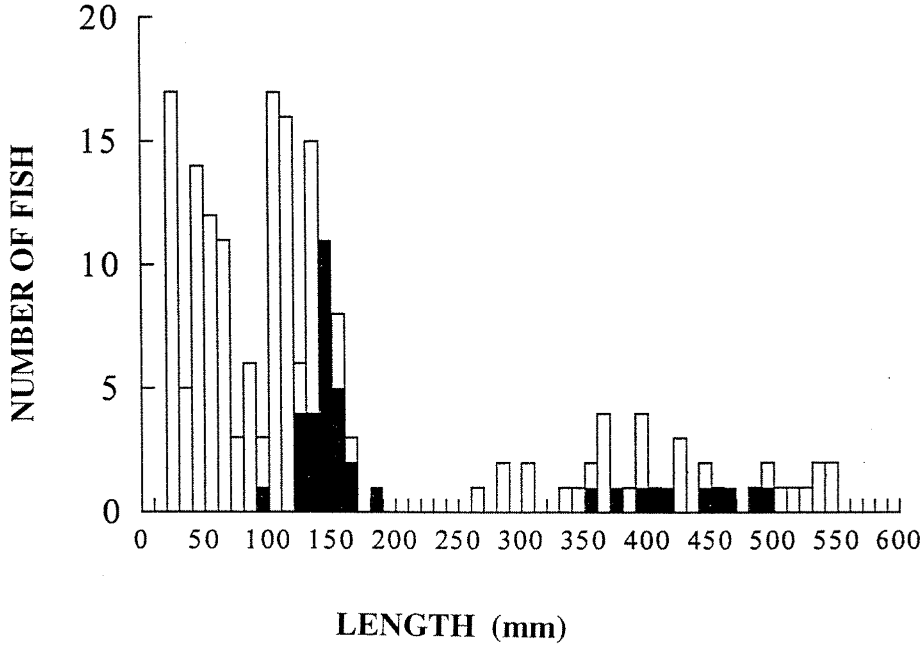


Figure 4.1. The length distribution of Arctic charr from Arresjøen in August 1990. Closed columns indicate spawners (stage IV-V or VII/IV-V). Data from Svenning (1992)

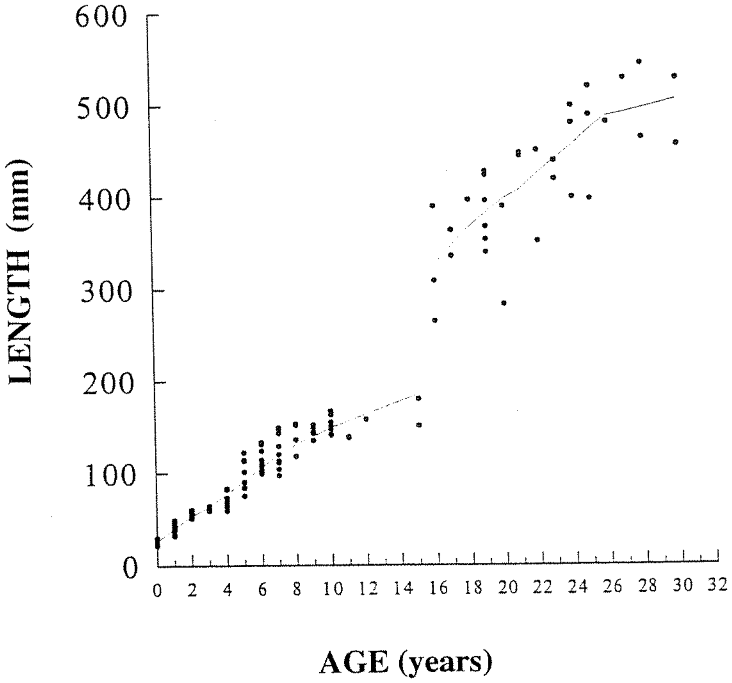


Figure 4.2. The bimodal growth curve of the Arctic charr from Arresjøen. Data from Svenning (1992).

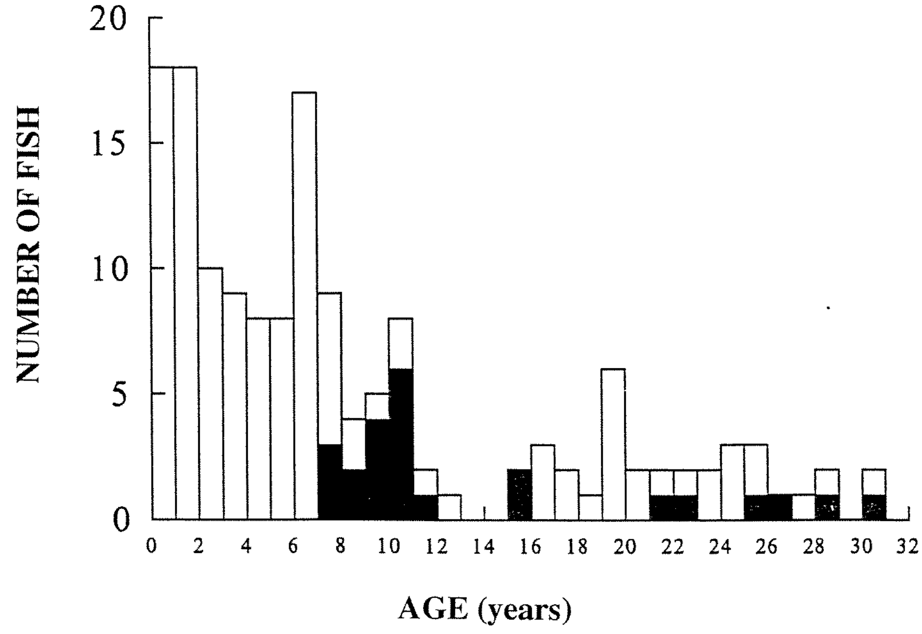


Figure 4.3. The age composition of the Arctic charr population in Arresjøen 1990. Closed columns indicate spawners (stage IV-V or VII/IV-V). Data from Svenning (1992).

4.3.2 KOLA

Chuna (17)

Chuna was testfished with one standard gillnet series on September 24, 1994. The lake contained a population of brown trout. Pathological and morphological examinations were performed, and symptoms of fish diseases and parasitic infections were examined visually. Detailed information on the results from Chuna is given by Moiseenko *et al.* (1995).

The 49 trout represented year classes between 1 to 7 years. The length and age distribution are shown in Figure 4.4. No signs of disease were found on the brown trout.

Based on the age determination, the length at age 1+ (mean 16.7 cm) seems extraordinary good, more comparable with a well grown 2+ fish. The brown trout population has a good growth up to the age of 5 years, and a marked growth reduction at higher age. Although the condition factor is good and around K = 1 even for the oldest fish, the data reflects a population of moderate to high density (Moiseenko *et al.* 1995).

No fish has been analysed for heavy metals and organic compounds.

Chibiny (18)

Chibiny was testfished with one standard gillnet series on September 30th, 1993, and 25 Arctic charr were captured. Detailed information on the results from Chibiny is given by Moiseenko *et al.* (1995).

Year classes between 1 to 7 years were found. The length, age distribution and condition factor are shown in Figure 4.5. The good growth and high condition factor (increasing with age), indicates a sparse fish population with abundance of food. The pathological studies showed some changes

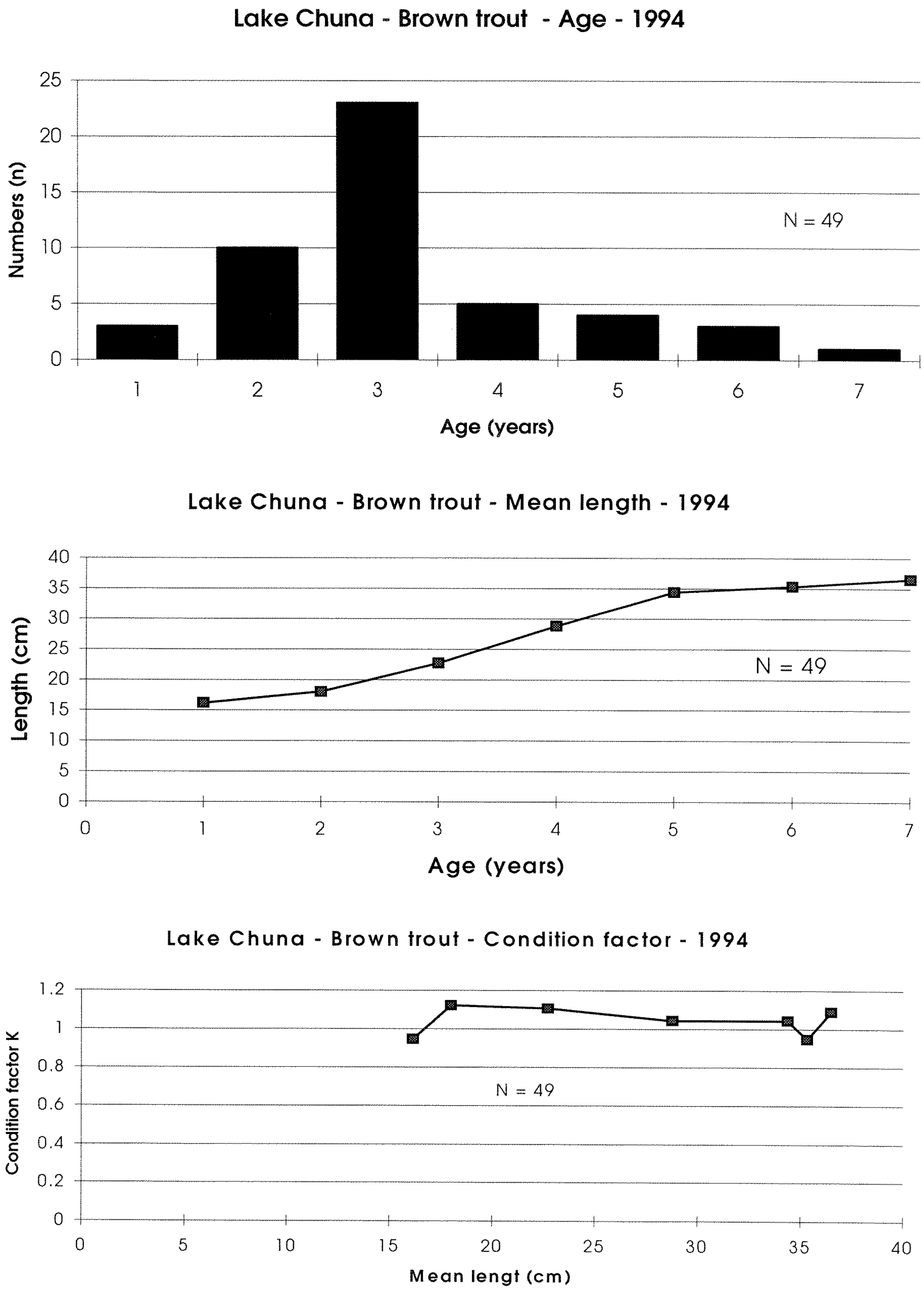


Figure 4.4. Chuna was testfished in September 1994. The length (upper), age (middle) and condition factor distribution (lower) for the brown trout are shown.

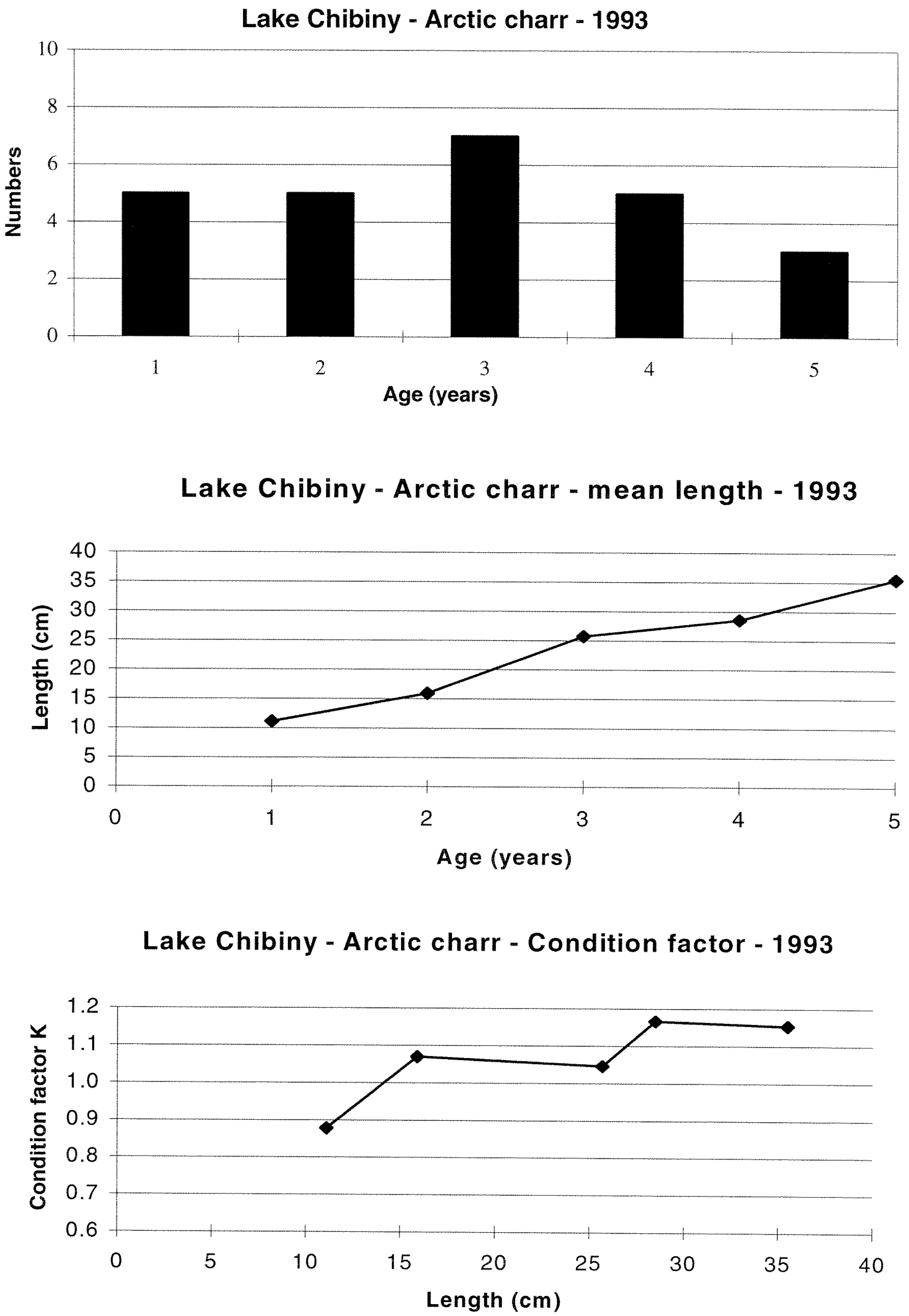


Figure 4.5. Chibiny was testfished in September 1993. The age (upper), length (middle) and condition factor distribution (lower) for the Arctic charr are shown.

relative to controls. Some unevenness colour of liver was observed in 24 % of the charr, and these livers were "flabby". Some charr (16%) had connective tissue expansions in kidney, and in most charr, initial stages of anaemic rings were found on gills.

Five fish between 5 and 8 years (weight 55 - 285), were sent to NIVA for analyses of heavy metals. Cadmium and lead in liver ranged from 0.024 - 0.042 and 0.03 - 0.07 µg/g wet weight, respectively. Mercury in fillet ranged from 0.031 to 0.062 µg/g wet weight, se Table A7.1 for comparison of levels between lakes. Metals in liver, muscle, gills, skeletal and kidney were also analysed by the Institute of the North Industrial Ecology problems (INEP). The concentrations of Cu, Ni, Co, Zn, Mn, Al and Sr (mg/g dry weight) are shown in Table A7.3.

Four fish were analysed by CID-CSIC (Table A7.4.1-3.), age between 5 and 8 years, body weight from 79 to 233 g, ranging in total PCBs between 0.76 to 2.83, mean 2.08 ± 1.06 µg/kg wet weight, and between 55.1 to 166, mean 120 ± 61 µg/kg lipid weight.

Region summary - Kola

The fish populations in Chuna and Chibiny seemed both to be naturally reproducing. The age structure and general growth are considered to be typically for the region.

Only fish from Chibiny were analysed for heavy metals and organic micropollutants. Heavy metal concentrations were generally low, and well below acceptable limits for food consumption. The concentrations are also very low for all organochlorinated compounds. The PCB congeners are those present in higher abundance although their concentrations range among the lowest of the whole AL:PE series.

4.3.3 NORWAY

Øvre Neådalsvatn (1)

Øvre Neådalsvatn was testfished in 1978 and in August 1991 in the AL:PE 1 project. The lake contain a healthy, self reproducing brown trout population, which are carefully but extensively exploited by the owners. In 1991, six year classes was found, and the fish demonstrated a rapid growth with a high condition factor (mean around K = 1.1), Wathne *et al.* (1995).

A minor testfishing was performed on August 12, 1994. One five year old and four 3 year old trout (weight 298 - 524 g) was analysed for metals (µg/g wet weight). Cadmium and lead in liver ranged from 0.063 - 0.084 and 0.03 - 0.05, respectively. Mercury in fillet ranged from 0.028 to 0.034 µg/g wet weight, see Table A7.1 for comparison of levels between lakes.

Six fish was analysed by CID-CSIC (age 3-5 years, body weight from 75 to 237 g) for HCB, HCH, DDT and PCBs, ranging in total PCBs between 0.69 to 3.29 mean 1.50 ± 1.08 µg/kg wet weight, and between 25.4 to 82.7 mean 51.2 ± 29.3 µg/kg lipid weight, respectively (Table A7.5.1-3).

In general, Øvre Neådalsvatn exhibits low concentrations of organochlorinated compounds, where the most abundant compounds correspond to the mixture of PCBs.

Stavsvatn (2)

Stavsvatn was testfished in August 1991, in the AL:PE 1 project. The population of brown trout suffered from reproduction failure due to acidification, and the sparse population has been kept by repeated stocking over 20 years (Wathne *et al.* 1995). In 1991, age classes between 2 and 6 years were represented, having a low condition factor (K < 1) and growth rate.

In September 1993, five trout from Stavsvatn, one at 5 and four at 7 years of age, was captured and analysed for micropollutants. Cadmium and lead in liver ranged from 0.67 - 1.84 and 0.12 - 0.30 µg/g wet weight, respectively. Mercury in fillet ranged from 0.05 to 0.11 µg/g wet weight, se Table A7.1. As for Arresjøen, PCB concentration in the trout from Stavsvatn has been analysed both by NIVA and CID-CSIC. The pooled total PCB concentration in the five fish from Table A7.1 (weight 374 - 768 g) was found by NIVA to be 14.6 µg/kg wet weight. Five fish analysed by CID-CSIC (weight between 258 to 675 g) had a concentration of total PCBs between 2.19 to 16.23, mean 6.57 ± 5.74 µg/kg wet weight, and between 176 to 896, mean 426 ± 302 µg/kg lipid weight Table A7.6.1-3.

The pollution level of major chlorinated compounds in Stavsvatn is considered to be low.
The most abundant compounds correspond to those included in the DDT mixtures (Table A7.6.2-3).

Region summary - Norway

The Norwegian lakes represents a reference lake with a healthy selfreproducing brown trout population (Øvre Neådalsvatn), and an acid lake dependant on repeated stockings to provide fishing (Stavsvatn). Øvre Neådalsvatn is a true reference lake for Europe, with very low values for the heavy metals. The concentrations of organochlorinated compounds in these lakes are also very low. The two lakes, however, exhibit significant differences in the concentrations of organic micro pollutants (less in Øvre Neådalsvatn) which probably reflect local influences or inhomogeneous deposition trends in this area.

4.3.4 BRITISH ISLES

Lochnagar (4.1)

Each autumn, the Freshwater Fisheries Laboratory, Pitlochry, has estimated the fish population in the outlet river of Lochnagar by electrofishing. The stream is divided into three stretches which are testfished three times. The pooled samples for all stretches and the three samples are used in Figure 4.6. The number of fish in the years 1991-94 has been 168, 140, 100 and 132, respectively.

The age composition in the stream is shown in Figure 4.6 (upper). The 0+ generation in 1993 was smaller than in the other years, being reflected as a small 1+ yearclass in the catches in 1994. The results thus seems to reflect the real situation in the outlet stream from Lochnagar, still providing recruitment in spite of a marginal water quality. The growth, represented by length at catch, is shown in Figure 4.6 (middle). Except for the size of the 3+ in 1991 (N= 5), no difference exist between the other yearclasses over the four year period. The condition factor for the fish sampled in 1991 (Figure 4.6 lower), illustrates good growth conditions.

In July 1993, a testfishing took place in the lake itself, and ten fish were sent to analyses; five for heavy metals and five for organic compounds. In the 2-4 year old fish, weighting from 41 to 296 g, the cadmium and lead in liver ranged from 1.33 - 2.58 and 0.52 - 0.77 µg/g wet weight, respectively. Mercury in fillet ranged from 0.04 to 0.08 µg/g wet weight, se Table A7.1.

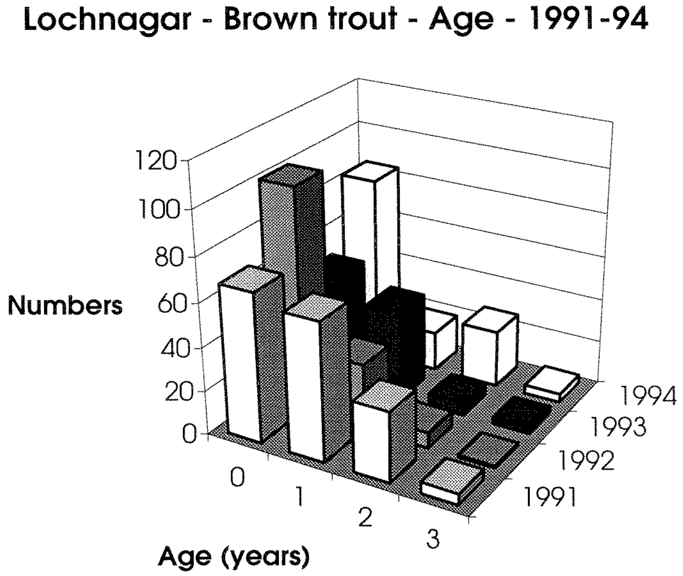


Figure 4.6. Results from electrofishing in the outlet stream of Lochnagar, pooled samples from three stations, each being electrofished three times. The age composition of the brown trout in the period 1991 to 1994 (upper), empirical length at testfishing (middle) and condition factor K for all three stations in 1991.

The concentrations of HCB, HCH, DDT and PCBs was analysed by CID-CSIC from five other fish, weight between 108 to 211 g. The fish size and concentration of the different components are shown in Table A7.7.1-3. The fish had a concentration of total PCBs between 2.01 to 5.77, mean 3.48 ± 1.84 µg/kg wet weight, and between 134.8 to 289, mean 187 ± 82 µg/kg lipid weight, Table A7.7.1-3.

The pollution level of major chlorinated compounds in Lochnagar is low. As in the previous cases the most abundant compounds are PCBs. The concentrations of total DDTs range among the lowest in the whole AL:PE series.

Lough Maam (10)

Lough Maam, Ireland, was testfished on September 10, 1993 by the Freshwater Fisheries Laboratory, Pitlochry. Out of 22 brown trout caught, ten fish were sent to analyses; five for heavy metals and five for organic compounds. In the 4 and 5 year old fish, weighting from 185 to 299 g, the cadmium and lead in liver ranged from 0.19 - 0.56 and 0.14 - 0.20 µg/g wet weight, respectively. Mercury in fillet ranged from 0.07 to 0.09 µg/g wet weight, se Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs was analysed from five other fish, weight between 187 to 270 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.8.1-3. The fish had a concentration of total PCBs between 1.20 to 6.88, mean 3.16 ± 2.72 µg/kg wet weight, and between 48.7 to 365, mean 198 ± 164 µg/kg lipid weight, Table A7.8.1-3.

The pollution level of major chlorinated compounds in Lough Maam is very low, and close to what can be considered to be "blanks".

Region summary - British Isles

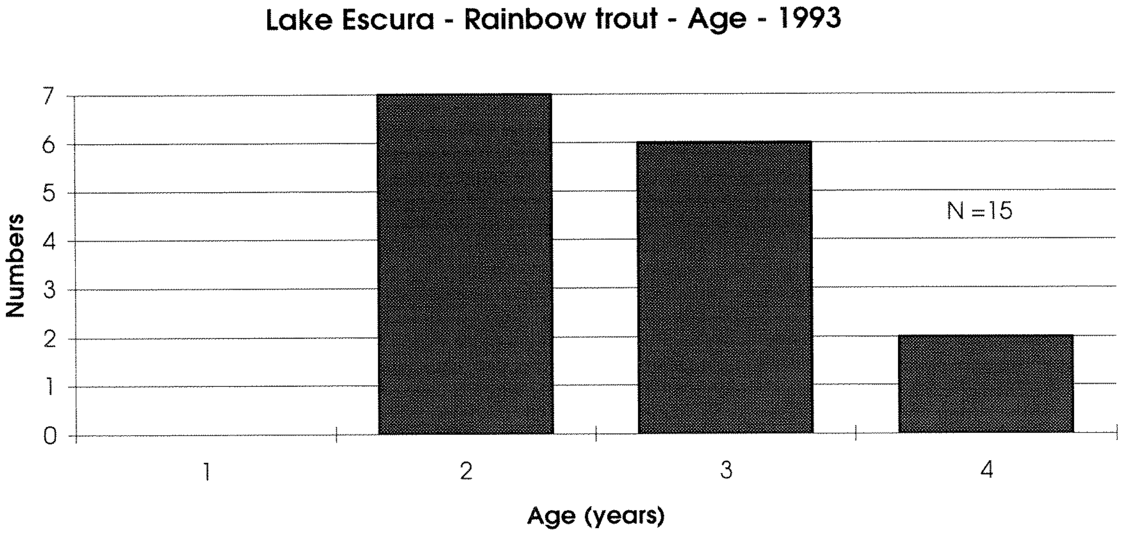
The brown trout population in the outlet stream of Lochnagar, Scotland, has not changed during the AL:PE 1 and 2 project period, demonstrating only small annual variations in yearclass composition, growth etc.

The levels of heavy metals are generally high, when compared to reference areas, both in Lochnagar and Lough Maam, Ireland. However, the geographical distributions of metals are quite pronounced, and Hg seems to have the highest concentrations in the western localities close to the Atlantic ocean. For this reason, there were quite high values of Hg in Lough Maam. Both for Pb and Cd, the concentrations in Lochnagar were higher than expected from its geographical position.
The concentrations of organochlorinated compounds are low and rather uniform between the two lakes. The most abundant products correspond to the PCB congeners. These lakes range among those showing lowest concentrations of total DDTs.

4.3.5 IBERIA

Lagoa Escura (14)

Lagoa Escura was testfished on October 7, 1993. A small population of rainbow trout was found, represented by 2 - 4 year old fish. This small population presented a good growth and a mean condition factor of 1.35, Figure 4.7.



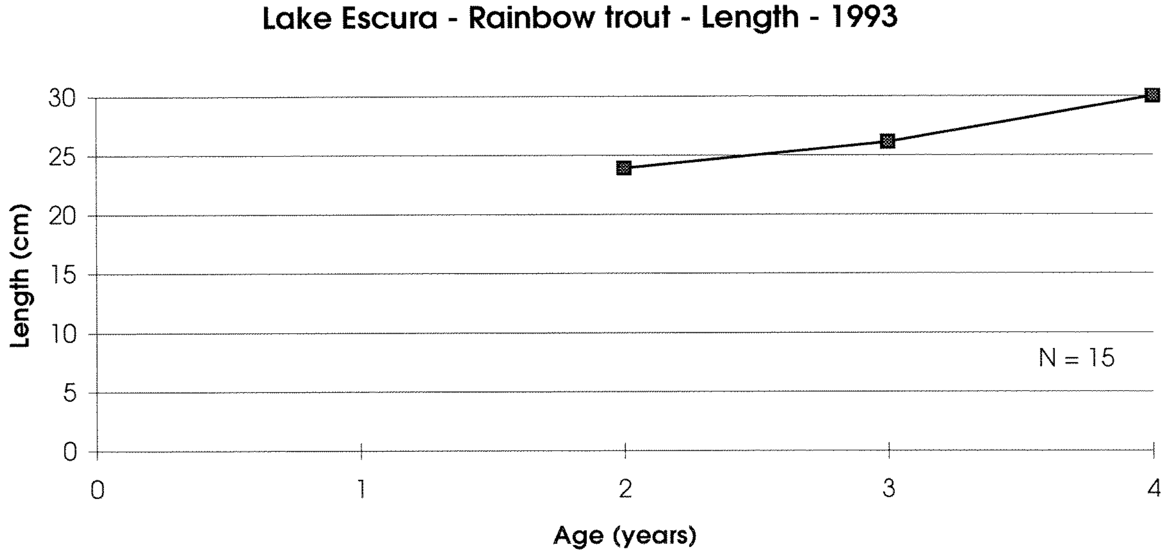


Figure 4.7 Lagoa Escura: Age of rainbow trout caught by testfishing in October 1993 (upper), and empirical length according to age (below).

Six rainbow trout were sent to analyses; three for heavy metals and three for organic compounds. In the 3 year old fish , weight between 185 to 277 g, the cadmium and lead in liver ranged from 0.07 - 0.09 and 0.22 - 0.39 µg/g wet weight, respectively. Mercury in fillet ranged from 0.09 to 0.13 µg/g wet weight, se Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs were analysed from three other fish, weight between 174 to 264 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.9.1-3. The fish had a concentration of total PCBs between 1.19 to 2.17, mean 1.76 ± 0.61 µg/kg wet weight, and between 91.6 to 142, mean 110 ± 35.6 µg/kg lipid weight, Table A7.9.1-3.

The pollution level of major chlorinated compounds in Lagoa Escura is very low, and considered to range among the lowest of the whole series of lakes studied. The dominant compounds are PCBs although their concentration, 1.8 µg/kg, is the lowest observed. This lake is also that showing lowest concentrations of total hexachlorocyclohexanes

Laguna Cimera (16)

Laguna Cimera was testfished on October 16, 1994, catching 48 brook trout. Age groups from one to six years was found, and the population had a relative good growth and condition factor, Figure 4.8.

Ten brook trout was sent to analyses; five for heavy metals and five for organic compounds. In the 2 to 3 year old fish , weight between 152 to 259 g, the cadmium and lead in liver ranged from 0.16 - 0.88 and 0.07 - 0.18 µg/g wet weight, respectively. Mercury in fillet ranged from 0.017 to 0.042 µg/g wet weight, see Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs were analysed from five other fish, weight between 140 to 230 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.10.1-3. The fish had a concentration of total PCBs between 2.37 to 4.90, mean 3.73 ± 1.65 µg/kg wet weight, and between 216 to 507, mean 354 ± 181 µg/kg lipid weight, Table A7.10.1-3.

Although the concentrations of PCBs are higher in Laguna Cimera than Lagoa Escura, the two lakes range among the lowest of the whole series of lakes studied. The only exception to this trend is the relatively high amount of DDT derivatives in Lake Cimera, 14 µg/kg, which is important when compared to other AL:PE lakes (see Table A7.10.1-3).

Region summary - Iberia

This region is represented by Lagoa Escura, Portugal, and Laguna Cimera, Spain. Both have introduced salmonid fish populations, rainbow trout and brook trout, respectively. The brook trout population seems to be self reproducing. Both populations have good growth conditions.

The levels of heavy metals differ in the region. Hg concentrations were among the highest of the AL:PE lakes in Lagoa Escura, while it was among the lowest in Laguna Cimera. Pb was low, and did not differ much, but Cd was highest in Laguna Cimera, exceeding the acceptable levels for human food consumption.

The concentrations of organic micropollutants in these two lakes range among the lowest of the whole series of lakes studied. The only exception to this trend is the relatively high amount of DDT derivatives in Laguna Cimera.

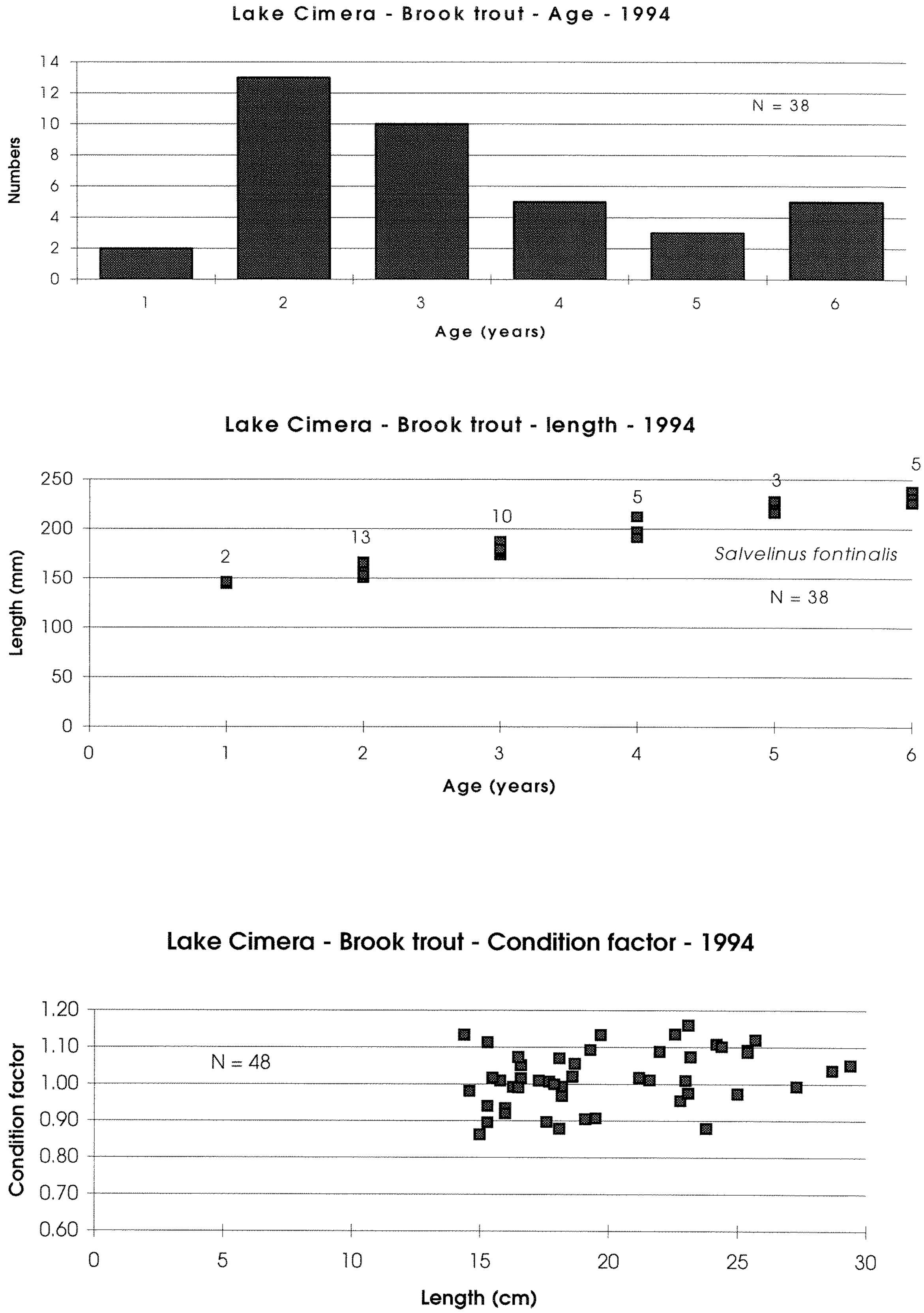


Figure 4.8 Laguna Cimera: Age of brook trout caught by testfishing in October 1994 (upper), empirical length according to age (middle), and the condition factor (below)

4.3.6 PYRENEES

Étang d'Aubé (8)

Étang d'Aubé was test fished in September 1991 as a part of AL:PE 1. Three species of fish were found; brown trout, lake trout (*Salvelinus namaycush*) and dace (*Leuciscus leuciscus*) (introduced as bait), see C.4.5. in Wathne *et al.* (1995). To sample for heavy metals and organic micropollutants, another test fishing took place between August 30 and September 2, 1994. Both floating nets and bottom gill nets were used (not standard SNSF-series), Table 4.1.

Table 4.1. Gillnets used in Étang d'Aubé in 1994.

Floating nets :

Mesh size(mm)	Length(m)	Height(m)
10	19	2
15	19	2.1
20	20	2.6
27	40	3.8
35	50	4

Bottom nets :

Mesh size(mm)	Length(m)	Height(m)
10	20	2
15	20	2
20	20	2
27	50	3
35	50	3

Three species were found, brown trout (n = 13), Arctic charr (n = 65) and minnow (*Phoxinus phoxinus*, (introduced as bait) n = 2), while only brown trout had been captured in 1991. The lake thus contains (or had contained) five species of fish. It was not possible to do proper age determination of the brown trout. Most of the Arctic charr had been stocked in 1992, as 1+, 5 - 7 cm long, and were therefore considered to be 3 years at catch in 1995. The five charr that were sent to NIVA for analyses, were determined as 5, 6, 6, 7 and 21 years of age, respectively (Table A 7.1). A re-determination of Arctic charr age by otoliths was performed by B. Riviera, CNRS, who confirmed 3 years as the correct age. The catch per unit effort (CPUE), converted from the used series to a comparative standard SNSF-series is shown in Table 4.2. In 1993, the CPUE for the three species was 8.6 (brown trout = 7.5, lake trout 1.0, dace 0.1), compared to a total of 8.38 for the three species caught in 1994. Although the CPUE was in the same range in the two years, Arctic charr was dominating in 1994, in contrast to the brown trout dominance in 1993. The condition factor (K) for the three species in 1994 were: 0.99, 1.06 and 1.35 for Arctic charr, brown trout and minnow, respectively. The comparative value for brown trout in 1993 was 1.14, slightly higher than in 1994.

Five old Arctic charr was sent to NIVA for heavy metal analyses. In the 5 to 21 year old fish, weight between 163 to 246 g, the cadmium and lead in liver ranged from 0.26 - 0.5 and 0.11 - 0.15 µg/g wet weight, respectively. Mercury in fillet ranged from 0.019 to 0.041 µg/g wet weight, se Table A7.1.

No fish was sent to CID-CSIC for analyses of organic micropollutants.

Table 4.2. The catch per unit effort, converted to a standard SNSF-series, for the three species caught in Étang d'Aubé in 1995.

Species	Number/UE	Weight/UE(g)
Salvelinus alpinus	6.81	1277.49
Salmo trutta	1.36	508.38
Phoxinus phoxinus	0.21	1.67
Total	8.38	1787.54

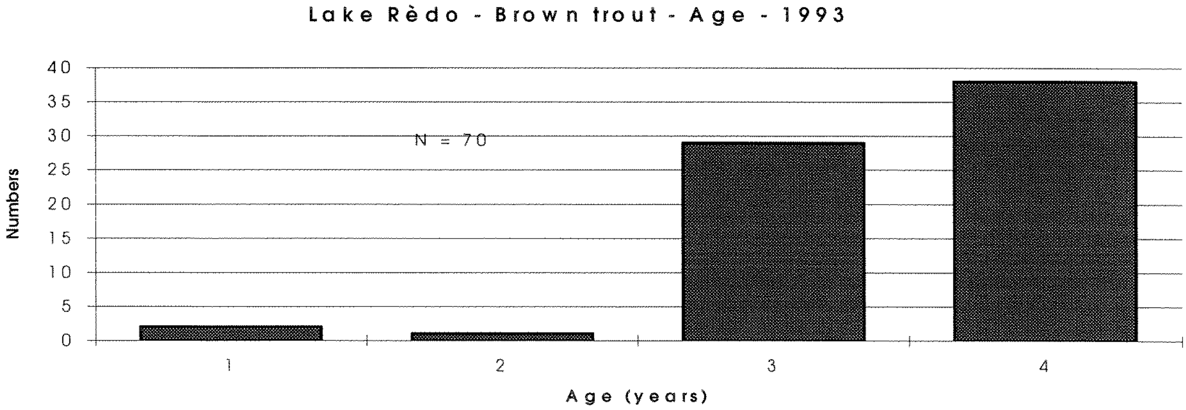
Estany Redo (12.2)

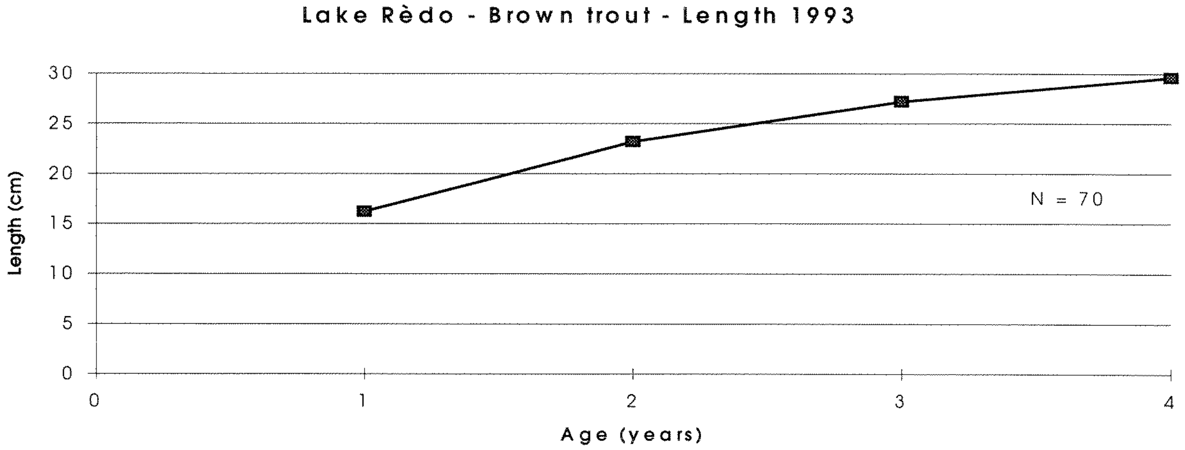
Estany Redo was testfished on October 17, 1993, and contained a population of brown trout. Fish from 1 to 4 years were represented in the material which was analysed in Spain. The five largest fish which were sent to NIVA for metal analyses, however, were six years old. The trout became recruit spawners at the age of three. The trout population showed a good growth, with a mean condition factor of 1.2 , Figure 4.9.

Ten brown trout, the largest captured, was sent to analyses; five for heavy metals and five for organic compounds. In the 6 year old trout (oldest found, not represented in the ordinary catch data, see Figure 4.9), weight between 240 to 351 g, the cadmium and lead in liver ranged from 0.57 - 0.82 and 0.10 - 0.16 µg/g wet weight, respectively. Mercury in fillet ranged from 0.05 to 0.16 µg/g wet weight, se Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs was analysed from five other fish, weight between 200 to 295 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.11.1-3. The fish had a concentration of total PCBs between 7.82 to 12.21, mean 9.91 ± 2.31 µg/kg wet weight, and between 104 to 306, mean 215 ± 101 µg/kg lipid weight, Table A7.11.1-3.

Estany Redo is the one lake showing highest concentrations of total hexachlorocyclohexanes and hexachlorobenzene. The concentration of the former is more than one order of magnitude higher than any other concentration observed in the AL:PE series. The concentration of hexachlorobenzene is also very high when compared with most AL:PE lakes. The other chlorinated products, total DDTs and PCBs, also exhibit important concentrations, the highest in the Iberian Peninsula, but they are found even in higher levels in the fishes from other European lakes.





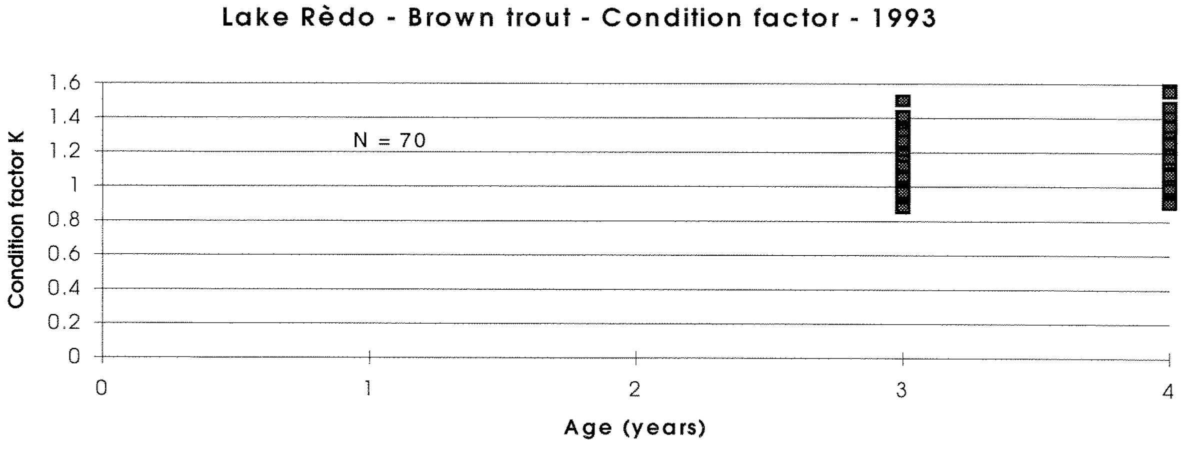


Figure 4.9 Estany Redo: Age of brown trout caught by testfishing in October 1993 (upper), empirical length according to age (middle), and the condition factor (below)

Region summary - Pyrenees

The two lakes, Étang d'Aubé, France and Estany Redo, Spain, have both brown trout populations which apparently are only selfreproducing in Estany Redo. In Ètang d'Aubè, five different species have been identified, the most abundant being the Arctic charr. Both the charr and the brown trout are dependant on stocking. However, there are clearly spawning places for charr in Étang d'Aubé. In 1994, the population of Arctic charr was 3 years old. With a natural maturation to spawners at age 5, reproduction capability will be studied in 1996. The Hg and Pb had generally low levels in both lakes. In contrast to Ètang d'Aubè, Estany Redo had higher concentrations of Cd, exceeding the acceptable limits for human food.

As for the organic micropollutants, this region is only represented by Estany Redo. The highest concentrations of total hexachlorocyclohexanes and hexachlorobenzene are found in this lake. The concentration of the former is more than one order of magnitude higher than any other concentration observed in the AL:PE series. The concentration of hexachlorobenzene is also very high when compared with most AL:PE lakes. The other chlorinated products, total DDTs and PCBs, also exhibit important concentrations but they are found even in higher levels in the fishes from other European Lakes.

4.3.7 ALPS

Lago Paione Inferiore (5.2)

Lago Paione Inferiore was testfished in August 1991 as a part of the AL:PE 1 project (Wathne et al. 1995). The lake contained a population of rainbow trout, which was kept by repeated stocking every five years. In 1991, the catches consisted of three yearclasses (1-3 years) showing good growth and a high condition factor.

In September 1994, a minor testfishing took place. Ten fish were sent for analyses; five for heavy metals and five for organic compounds. In the 3 to 5 year old rainbow trout, weighting from 185 - 313 g, the cadmium and lead in liver ranged from 0.22 - 2.37 and 0.16 - 0.42 µg/g wet weight, respectively. Mercury in fillet ranged from 0.018 to 0.045 µg/g wet weight, se Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs was analysed from five other fish, weight between 147 to 262 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.12.1-3. The fish had a concentration of total PCBs between 1.67 to 6.45, mean 4.67 ± 2.50 µg/kg wet weight, and between 201 to 1057, mean 585 ± 376 µg/kg lipid weight, Table A7.12.1-3.

The levels of organochlorinated compounds in this Lago Paione Inferiore are low in comparison with the mean of the AL:PE series. PCBs are the major compounds.

Lago Lungo (6.1)

Lago Lungo was testfished in October 1991 as a part of the AL:PE 1 project (Wathne *et al.* 1995). The lake contained a mixed population of Arctic charr (N = 76), brown trout (N = 7) and grayling (*Thymallus thymallus*) (N = 1). In 1991, the catches of Arctic charr, yearclasses from 6 up to 27, indicated a stunted population with no growth after 10 years and having a very low condition factor. The smaller population of brown trout had good condition and good growth.

In September 1993, a minor testfishing took place. Eleven arctic charr were sent for analyses; five for heavy metals and six for organic compounds. In the 11 to 15 year old charr, weighting from 95 to 175 g, the cadmium and lead in liver ranged from 0.97 - 4.38 and 0.38 - 1.84 µg/g wet weight, respectively. Mercury in fillet ranged from 0.01 to 0.06 µg/g wet weight, se Table A7.1.

The concentration of HCB, HCH, DDT and PCBs was analysed from six other fish, age 11-15 years, weighting from 69 to 123 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.13.1-3. The fish had a concentration of total PCBs between 15.1 to 37.8, mean 24.7 ± 12.2 µg/kg wet weight, and between 972 to 3183, mean 2204 ± 1096 µg/kg lipid weight, Table A7.13.1-3.

The fishes from Lago Lungo can also be grouped among those showing highest pollution for organochlorinated compounds. Total DDTs and PCBs are the most abundant compounds.

Lago di Latte (6.2)

Lago di Latte was testfished in September 1992 as apart of the AL:PE 1 project (Wathne et al. 1995). The population of Arctic charr contained yearclasses between 6 and 18 years of age, having a slow growth and a very low condition factor. In spite of good spawning conditions, occasional stockings have been practised over many years, last in 1986.

In September 1993, a minor testfishing took place. Eleven Arctic charr were sent to analyses; five for heavy metals and six for organic compounds. In the 11 to 15 year old charr, weighting from 32 to 50 g, the cadmium and lead in liver ranged from 0.91 - 5.66 and 0.44 - 2.26 µg/g wet weight, respectively. Mercury in fillet ranged from 0.03 to 0.07 µg/g wet weight, se Table A7.1.

The concentrations of HCB, HCH, DDT and PCBs was analysed from six fish, weight between 28 to 47 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.14.1-3. The fish had a concentration of total PCBs between 21.0 to 74.9, mean 45.7 ± 26.7 µg/kg wet weight, and between 442 to 2438, mean 1245 ± 846 µg/kg lipid weight, Table A7.14.1-3.

The fishes in Lago di Latte stand out for their high concentration of total DDTs, 200 µg/kg (Table A7.14.2-3). This levels are almost one order of magnitude higher than those observed in the lakes that are not from the Alpine sites. The PCBs also shows one of the highest concentrations, 46 µg/kg, in this lake. The concentration of hexachlorobenzene is also one of the highest in the AL:PE series.

Schwarzsee ob Sölden (11)

Schwarzsee ob Sölden is a new lake in the AL:PE 2 project. The only fish species in the lake is the Arctic charr, which have been introduced probably in the last century or even earlier. At least during the last 40 years no additional introduction and only scientific fishery activities have been performed. The exploitation rate has been recorded, showing catches like:

1968-1982: 460 specimens
1989-1994: 147 specimens

Until the beginning of the 1980's reproduction was normal but decreased around 1986. Since 1988, the reproduction has completely failed.

Due to the decreasing number of fish and their importance for a local project fishing, fishing activities performed by the University of Innsbruck could not follow the AL:PE standard. Fish where caught in July 1992, September 1992, July/August 1993 and September 1994 by gill nets and in April/May 1993 by angling. Gill nets with mesh sizes of 19 (3), 22 (3), and 25 mm (3) were exposed for 5-7 hours during daytime and checked each hour. For each sampling period 2-3 days were necessary to get at least 15 fish. In September 1992 and August 1993 also gill nets with 12, 16 and 30 mm were used and exposed over night. However, no size related fish could be caught with this trial of nets. The results from the three testfishings in 1992 are shown in Figure 4.10.

An Austrian research project on histology and physiology have been run as an additional project to AL:PE 2. Results from that special project shows that with increasing age the number of fish with severe, but sublethal pathological changes in liver and kidney, increased. This might be the main reason for the high variability of all parameters measured including growth rate.

A minor testfishing took place on September 29, 1994. Twelve fish from Schwarzsee ob Sölden were examined in Austria, five fish for Cd and Pb, and another seven fish for Hg. Another three charr were sent to CID-CSIC for analyses of organic compounds.

In five 8 to 12 year old charr, weighting from 96 - 147 g, the cadmium and lead in liver ranged from 6.27 - 21.02 and 1.02 - 3.55 µg/g wet weight, respectively (Table A7.1). Mercury in the fillet from the seven 11 to 18 year old charr, weight between 66 to 201 g, ranged from 0.0130 to 0.0477 µg/g wet weight.

The concentrations of HCB, HCH, DDT and PCBs was analysed from three fish, weighting from 79 - 123 g, by CID-CSIC. The fish size and concentration of the different components are shown in Table A7.15.1-3. The fish had a concentration of total PCBs between 14.7 to 95.6, mean 46.5 ± 43.1 µg/kg wet weight, and between 485 to 2212, mean 1061 ± 998 µg/kg lipid weight, Table A7.15.1-3.

Schwarzsee ob Sölden and Lago di Latte are those showing highest pollution within the AL:PE series. The highest concentrations of PCBs, 46.5 µg/kg, are observed here.

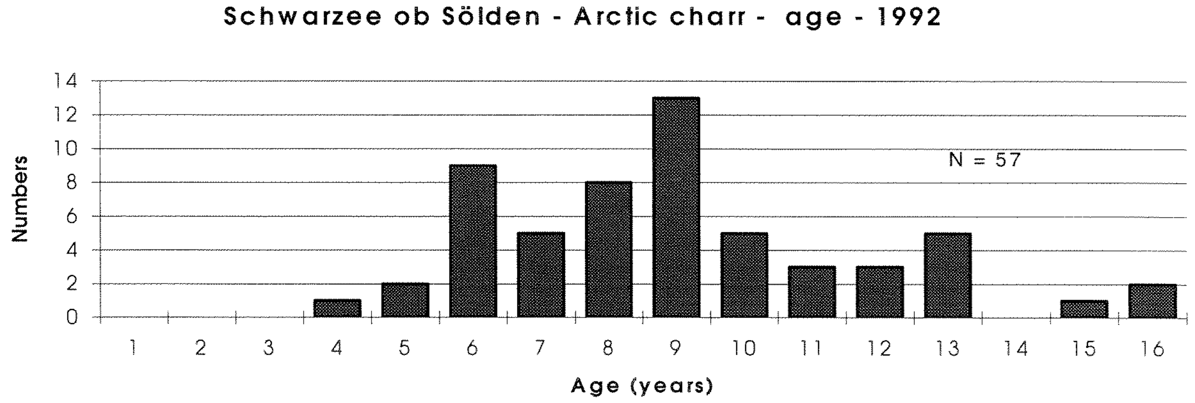
Furthermore, the lake also stands out by the high concentrations in total DDTs, 125 µg/kg, and hexachlorobenzene, 1.6 µg/kg.

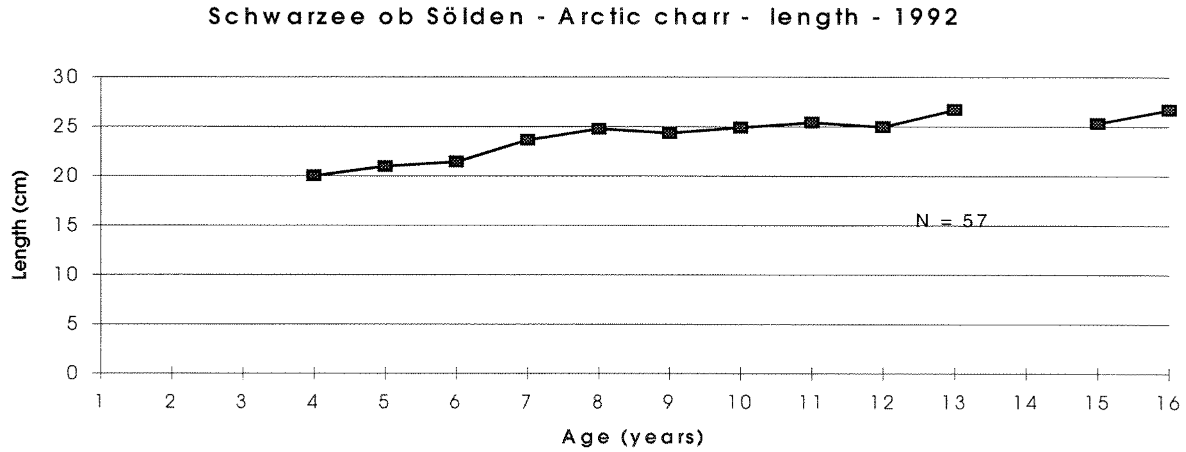
Region summary - Alps

The Alp region is represented by four lakes: Lago Paione Inferiore, Lago Lungo and Lago di Latte, Italy and Schwarzsee ob Sölden, Austria. In Lago Paione Inferiore, annual stocking of rainbow trout supply the existing fish population. In the three other lakes, Arctic charr is the main species, where Lago Lungo, as the only lake with more than one species, has a mixed population of brown trout and grayling. The fish populations in Italy are maintained by stocking, whereas the population in Schwarzsee ob Sölden is slowly depleted due to reproduction failure.

Of the heavy metals, Hg was found in low concentrations in all lakes, Lago di Latte having the highest values. Cd and Pb, on the other hand, was found in very high concentrations in all lakes, for Cd exceeding the acceptable limits for food consumption in all lakes. Schwarzsee ob Sölden had very high levels, and as the only AL:PE lake, even exceeding the acceptable limits for food consumption for Pb.

The four lakes in this region can be grouped in two parts: the western Alps (Lago Paione Inferiore) and the Tyrol (Lago di Latte, Lago Lungo, and Schwarzsee ob Sölden). A strong contrast is observed





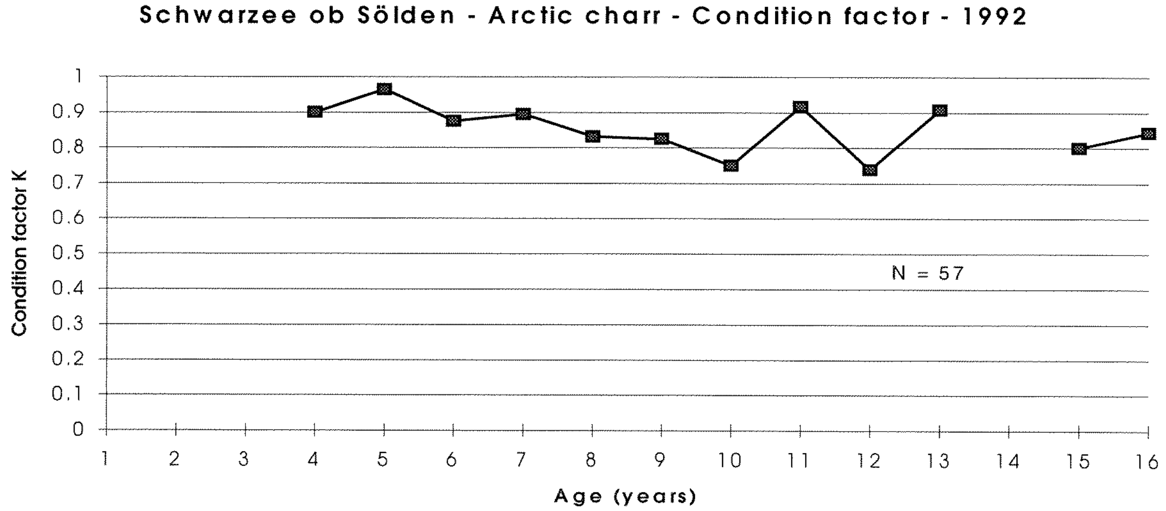


Figure 4.10 Schwarzsee ob Sölden: Age of Arctic charr caught by testfishing in July and September 1992 (upper), empirical length according to age (middle), and the condition factor (below)

between the two parts. Whereas the West Alps generally show low concentrations of organochlorinated compounds, the highest levels of PCB congeners and DDT derivatives are found in the Tyrol region. This difference is particularly important for the Tyrol area since the three lakesstudied consistently show a high pollution for these two groups of compounds. In addition, high levels of hexachlorobenzene are also found in some lakes of Tyrol (Lago di Latte and Schwarzsee ob Sölden).

4.3.8 TATRA MOUNTAINS

Dlugi Staw (15.3)

Dlugi Staw in the Polish Tatra National Park, was stocked with brook trout in 1960. No data on fish from earlier period exist. No fish management after the 1960-stocking, including test fishing, are known.

On the 9th of October, 1993, a testfishing was performed by the Karol Starmach Institute of Freshwater Biology. One standard SNSF-gillnet series was used. No fish was caught during testfishing.

Zielony Staw (15.4)

Zielony Staw in the Polish Tatra National Park has since 1948 been stocked with brook trout. After 1980, a stocking density of 600 fish/ha has been used (Dawidowicz and Gliwicz, 1983). As a management control, testfishing by the use of angling methods has been performed (Lysak and Ligaszewski, National Institute of Animal breeding, Cracow, Poland, unpublished). Whether reproduction has taken place in the lake is not known.

Zielony Staw was testfished by the Karol Starmach Institute of Freshwater Biology on October 9th, 1993 with one single net of the multimesh size SNSF-gillnet series. 23 brook trout was found, giving a CPUE of 150 fish. Of the 23 brook trout, only data from 12 fish exist. Age analyses by scales (not recommended age determination method for brook trout) demonstrated yearclasses between two and six years. The growth was good up to the age of 4, thereafter decreasing. In spite of a reduced growth for the older fish, a very good condition factor was found (K > 1.2), Figure 4.11.

To sample fish for heavy metals and organic micropollutants, another testfishing with the same fishing effort as in 1993 took place in October 1994. Three species of fish were found; twelve brook trout, eleven brown trout and two hybrids between brown and brook trout, giving, a total CPUE of 181. The previous stocking of brown trout was not known to the Park Management.

The brook trout consisted of the same age classes as the previous year (2-6 years), Figure 4.11. A better growth of the two and three year old charr was found, and a reduced condition factor was found in the oldest yearclasses, Figure 4.11.

The age determination of the brook trout have been performed in Poland by the use of scales. This method, however, is not recommended for age determination of charr in general, see sampling protocol for AL:PE 1, Wathne *et al.* (1995). The five brook trout which were sent to NIVA for heavy metal analyses, had an age, based on otoliths, between 6 and 12 years (Table A7.1). Data from Poland, however, are used in the following, including Figure 4.11 and 4.12, but the representativity of this data are thus questioned.

The population of brown trout consisted of three yearclasses (1-3 years). The growth and condition factor was very similar to the brook trout population caught in 1994 (Figure 4.12).

The two hybrids of brown and brook trout, were one and two years old, respectively. The length, weight and condition factor was 10.5 and 18.8 cm, 9 and 16.5 g and K = 1.04 and 0.98, respectively.

Five brook trout was analysed both for heavy metals and organic micropollutants. In the 6 to 12 year old charr, weighting from 119 - 201 g, the cadmium and lead in liver ranged from 0.63 - 2.14 and 0.11 - 0.31 µg/g wet weight, respectively, Table A7.1. Mercury in the fillet from the same charr ranged from 0.016 to 0.037 µg/g wet weight.

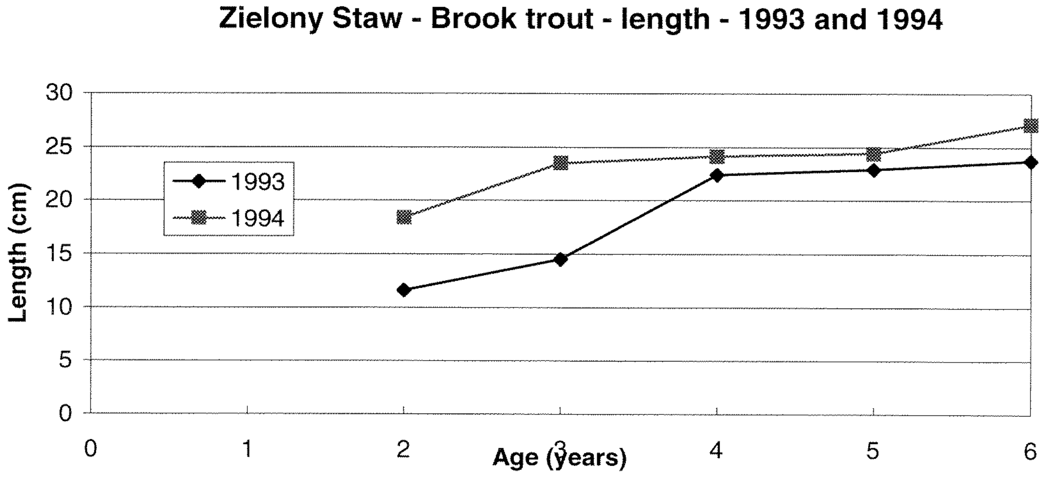
The concentrations of HCB, HCH, DDT and PCBs were analysed by CID-CSIC from the same five brook trout that were used for heavy metals, fish weight between 119 to 202 g. The fish size and concentration of the different components are shown in Table A7.16.1-3. The fish had a concentration of total PCBs between 5.86 to 12.26, mean 7.49 ± 3.58 µg/kg wet weight, and between 311 to 1077, mean 540 ± 342 µg/kg lipid weight, Table A7.16.1-3.

The concentrations of organochlorinated products in Zielowny Staw are relatively low. Total DDTs, 9.1 µg/kg, are the major products. The levels of PCBs are also significant, 7.5 µg/kg. This lake, however, has the lowest concentrations of hexachlorobenzene.

Regional summary - Tatra Mountains

Only one of the two studied lakes was found to contain fish, Zielony Staw. By a repeated testfishing (1993 and 1994), the lake was found to contain two species of salmonids, brook trout and brown trout. The latter was found for the first time in 1994. The brook trout population is old, having yearclasses up to 6 (determined in Poland) or 12 (determined in Norway) years.

Of the heavy metals, only Cd was found in high concentrations, exceeding the limits for human food consumption. The concentrations of organochlorinated products are relatively low. DDT derivatives are the major products. The levels of PCBs are also significant. This lake is, however, showing the lowest concentrations of hexachlorobenzene.



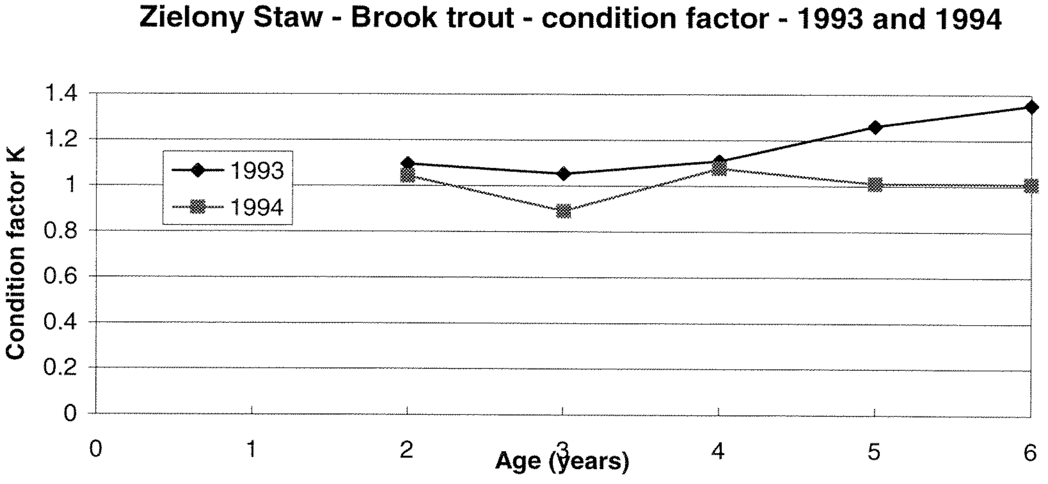


Figure 4.11. Zielony Staw: Results of testfishing in 1994 and 1993, showing the age of the population of brook trout (upper), empirical length according to age (middle), and the condition factor (below).

Figure 4.12. Zielony Staw: Results of testfishing in 1994, showing the age of the population of brown trout (upper), empirical length according to age (middle), and the condition factor (below).

4.4 REGIONAL HEAVY METAL CONCENTRATIONS IN FISH

4.4.1 Concentration levels

The 68 fish which were sent frozen to NIVA, and examined for Cd and Pb from liver and Hg from fillet, were caught in 15 AL:PE lakes. Five fish were analysed from each locality except Lagoa Escura (3). Fish from Schwarzsee ob Sölden were examined in Austria (five fish for Cd and Pb, and another seven fish for Hg). Four different species of fish were identified in the 15 lakes:

Brown trout:	Øvre Neådalsvatn, Stavsvatn, Lochnagar, Lough Maam, Estany Redo
Arctic charr:	Arresjøen, Lago Lungo, Lago di Latte, Ètang d'Aubè, Schwarzsee ob Sölden, Chibiny
Rainbow trout:	Lago Paione Inferiore, Lagoa Escura
Brook trout:	Zielony Staw, Laguna Cimera

The concentrations of Cd, Pb, and Hg in the fish from the different AL:PE sites are shown in Figure 4.13 - 4.16. The Figs. 4.13, 4.14 and 4.15 for Cd, Pb, and Hg respectively are given with no adjustments for differences in fish parameters. Fig 4.16 shows the concentrations of Hg adjusted for differences in fish length, and normalised to a fish length of 27 cm for all sites.

Significant differences were seen for Cd, Pb, and Hg between several lakes: low concentrations of Cd were observed in Lake Chibini, Øvre Neådalsvatn, and Lagoa Escura, and low concentrations were also observed of Pb in Øvre Neådalsvatn, Lake Chibini and Arresjøen.

The highest concentration of Cd were seen in Schwarzsee ob Sölden followed by Lago di Latte, Lago Lungo, and Lochnagar. The highest concentrations of Pb were also seen in the same sites and in the same sequence.

The lowest concentrations of Hg were registered in Øvre Neådalsvatn, Zielony Staw, Lago Paione Inferiore, Laguna Cimera and Étang d'Aubé, while the highest concentrations of Hg were found in Arresjøen, and Lagoa Escura. Regarding Hg concentrations, minor changes within classification of fish contamination was introduced by the use of fish length adjustment (compare Fig. 4.15 and 4.16).

Acceptable limits for Hg in fillet, and Cd and Pb in liver for human food consumption are set to 0.3, 0.5 and 2.0 µg/g wet weight respectively (JMG 1990 a, b, 1995). The concentrations of Hg and Pb were below these acceptable limits for human consumption in all of the AL:PE sites except for Schwarzsee Ob Sölden (Pb = 2.3 µg/g). Cd was too high for most of the sites, except in lakes Øvre Neådalsvatn, Lough Maam, Lagoa Escura, Étang d'Aubé and Lake Chibini.

The concentration of the metals Hg, Pb, and Cd are arranged according to geographical positions of the AL:PE sites and according to accumulations of the metals in the fish (Fig 4.17.). The geographical distributions are quite pronounced, and Hg seems to have the highest concentrations in the western localities close to the Atlantic ocean. The highest contamination's appeared in Arresjøen (Svalbard) and Lagoa Escura (Portugal). Values are also quite high in the Irish Lough Maam.

Pb showed low concentrations in the northern sites, higher values in the western localities, and the highest figures in the central, south-east Europe (Fig. 4.17). Cd shows more or less the same pattern as

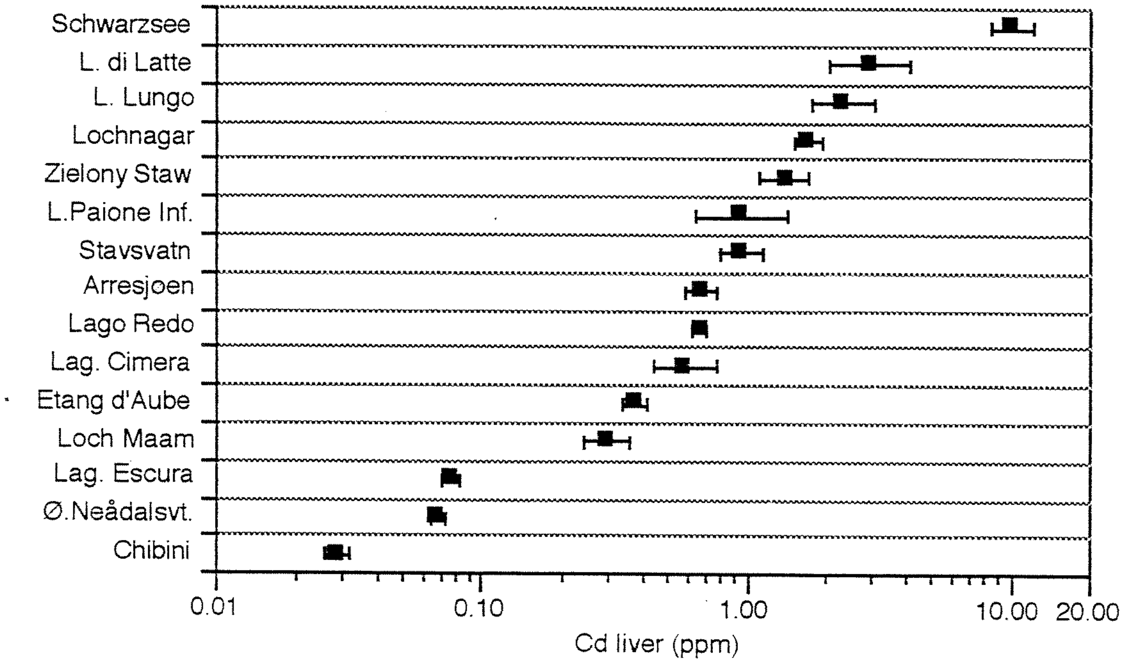


Figure 4.13. Concentrations, +/- std. error, of Cd in fish liver from the various AL:PE sites with no adjustment for differences in fish parameters or fish species.

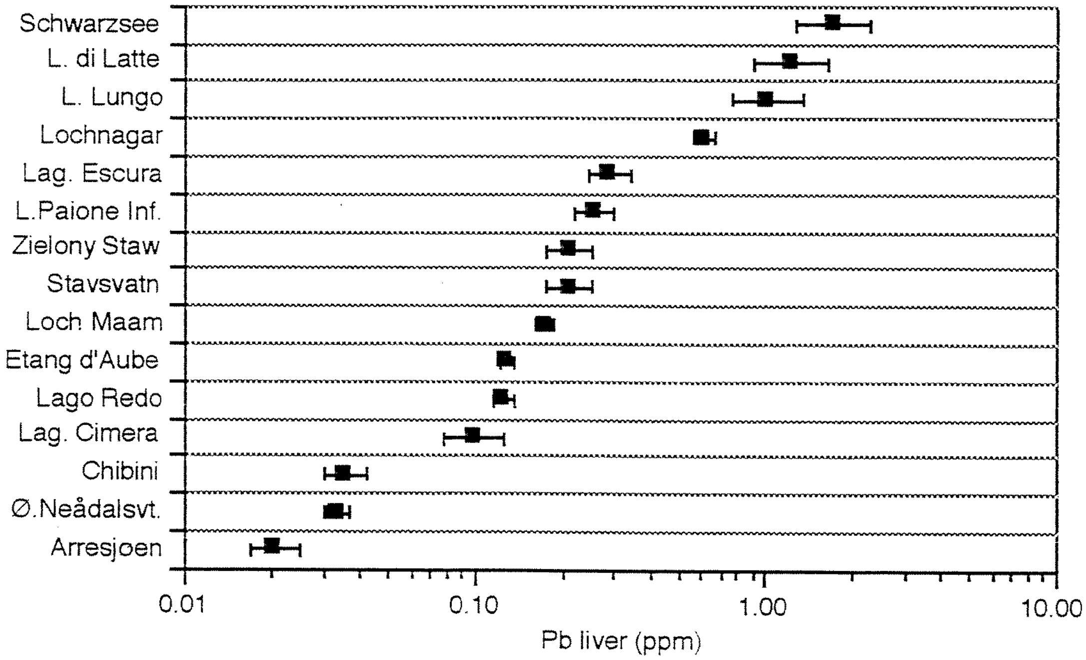


Figure 4.14. Concentrations, +/- std. error, of Pb in fish liver from the various AL:PE sites with no adjustment for differences in fish parameters or fish species.

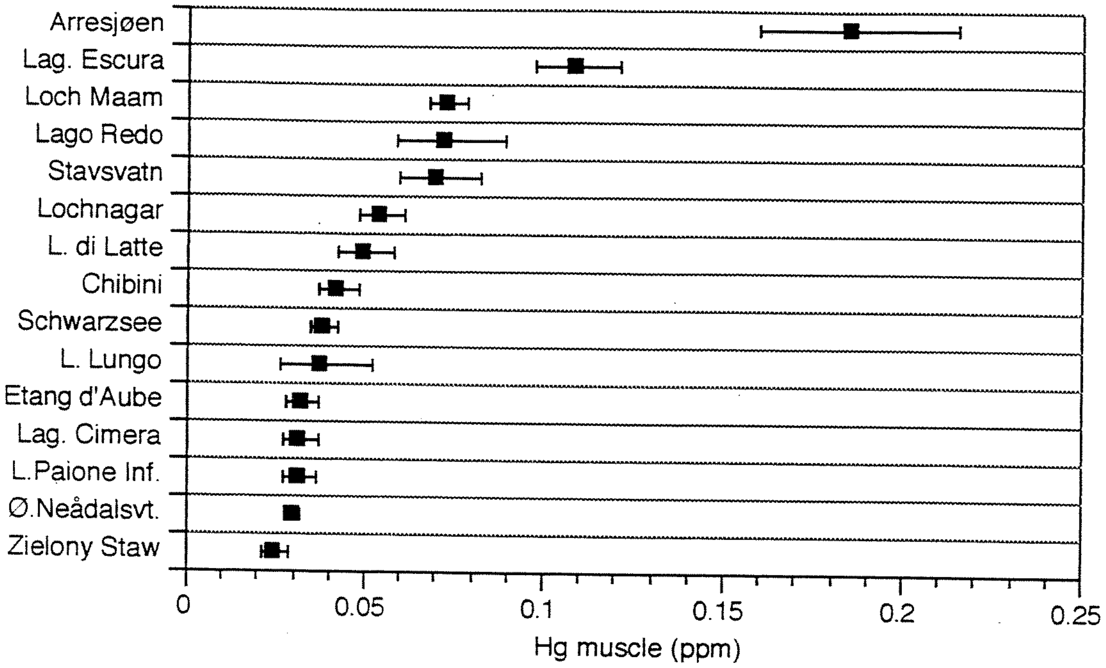


Figure 4.15. Concentrations, +/- std. error, of Hg in fish fillet from the various AL:PE sites with no adjustment for differences in fish parameters or fish species.

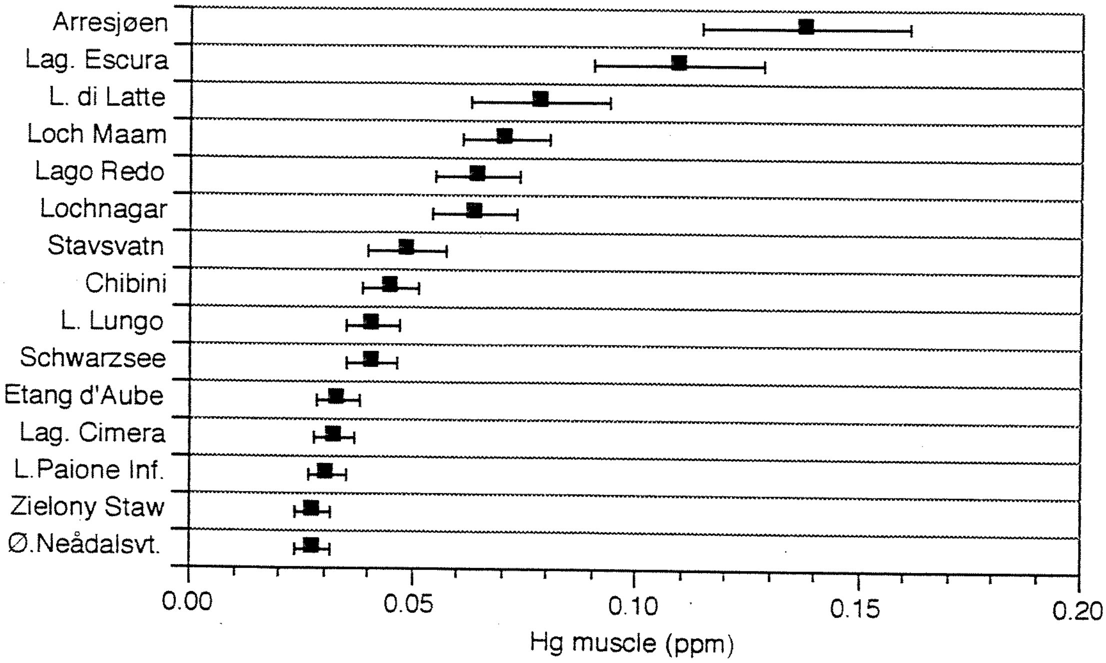
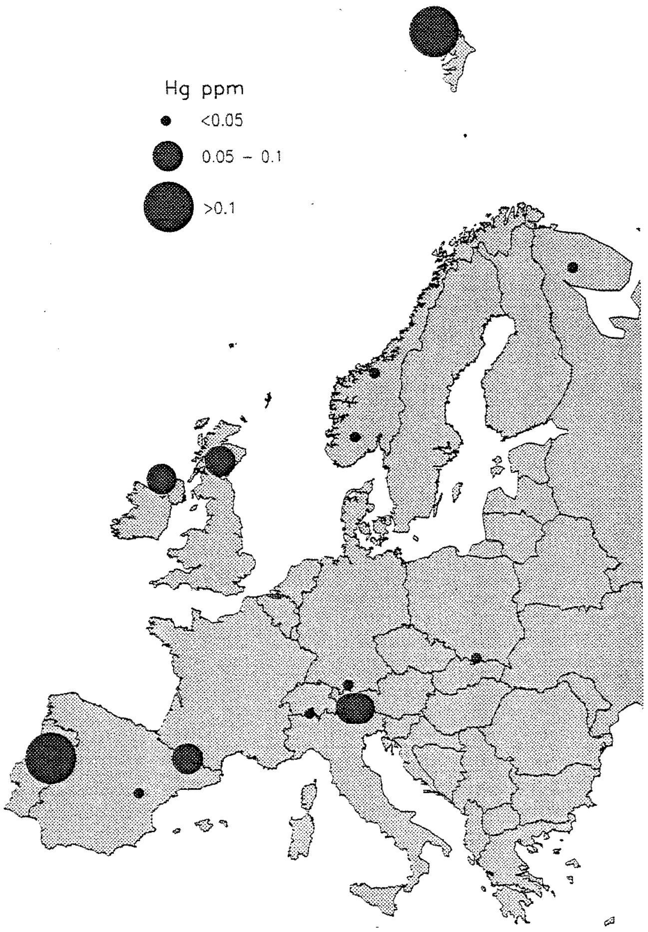
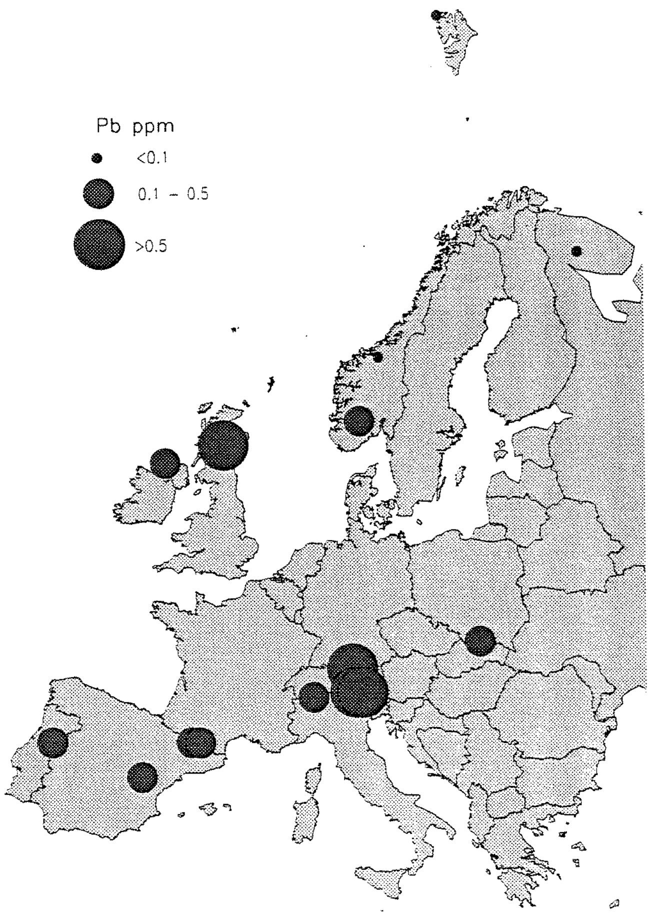


Figure 4.16. Concentrations, +/- std. error, of Hg in fish fillet from the various AL:PE sites with adjustment for differences in fish length (standard length 27 cm).





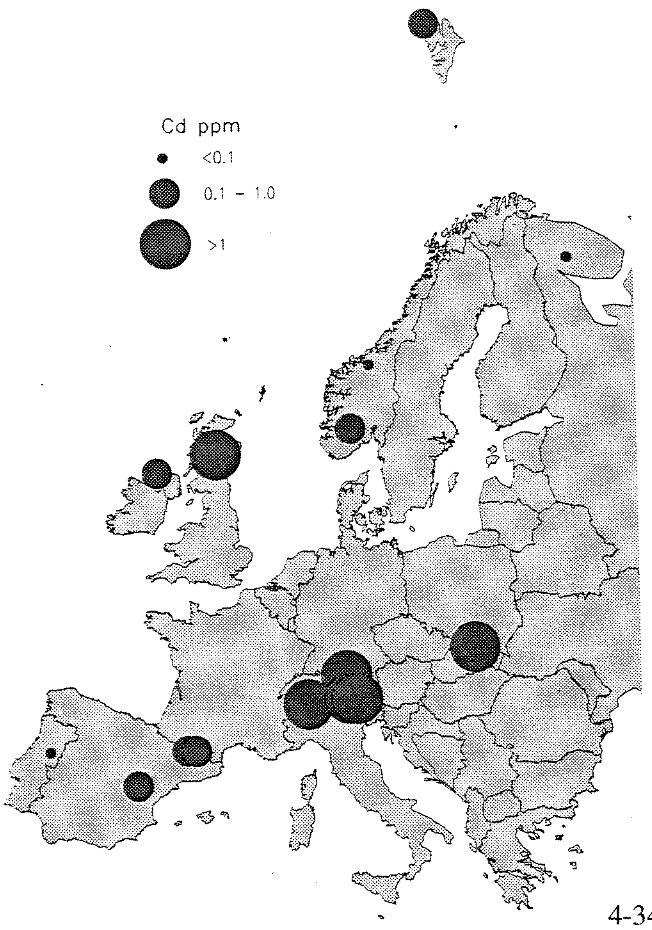


Fig. 4.17. AL:PE 2 sites examined for Hg, Pb and Cd in fish. The concentrations of metals are arranged according to geographical positions and according to accumulations of the metals. For Hg and Cd, the two largest circles represents values higher than expected background levels. For Pb, only half of the largest circles represents values exceeding background levels.

for Pb, but with generally higher concentrations, especially compared to acceptable limits for human consumption. Both for Pb and Cd, the concentrations in Lochnagar (Scotland) were higher than expected from its geographical position. Øvre Neådalsvatn showed the lowest or second lowest values for all three metals. This site is therefore also well suited as a reference locality concerning accumulation of heavy metals in fish.

4.4.2 Statistics

Statistical analyses demonstrated that for some of the lakes, correlation existed between fish size (length, age, weight) and concentrations of Cd and Pb. For the whole material, no significant correlation was identified between the measured fish parameters and concentration of Cd and Pb. For Hg, a correlation was seen between the size (length, age) of the fish and the Hg concentrations for the whole material. However, site identity demonstrated the strongest controlling variable for the examined heavy metals in fish.

Principal components analysis showed high covariance for Cd and Pb (e.g. high concentrations of Cd and Pb in the same lake), but no covariance with Hg.

The first principal component explains 64.9% of the total variance in the heavy-metal concentrations and the second component a further 32%. A total of 96.9% variance is captured by the two PCA axes. In Figure 33 the position of the individual fish samples are shown in relation to the three heavy-metal variables (biplot arrows) and the lakes from which the fish samples were collected. Figure 4.18 shows a clear contrast between PCA axis 1 with high correlations with Pb (0.97) and Cd (0.97) and PCA axis 2 with a high correlation (0.96) with Hg. These patterns are shown in Figures 4.19 - 4.21 where the concentrations of Pb, Cd, and Hg are plotted for the individual fish samples,with the size of the symbol being proportional to the concentration and the different type of symbol reflecting the different lakes as in Figure 4.18.

It is clear that above-average Pb and Cd values occur consistently in fish from Schwarzsee ob Sölden, Lago di Latte, and Lago Lungo, whereas above-average Hg concentrations are found in fish from Arresjøen, Estany Redo, Lagoa Escura, Stavsvatn, Lough Maam, and Lochnagar. All the lakes with above average Hg concentrations are along the western part of the AL:PE project (Portugal, Spain, Ireland, Scotland, southern Norway, Spitsbergen).

The results of the (partial) RDA are shown in Table A.7.17 in terms of the different predictor and covariables used in each analysis, the total variance in the heavy metals explained by the predictor variables, and the statistical significance of the overall model. All the predictor variables explain 83.8% of the total variance in the heavy-metal concentrations whereas locality by itself explains 78.2%. When the effects of the different fish species sampled are partialled out, the percentage variance explained by locality falls to 66.2%. This drops to 48.3% when the effects of fish species, sex, growth stage, and age are partialled out. The addition of fish length and weight as covariables reduces the percentage variance explained by locality very slightly to 44.6%. All the RDA and partial RDA are statistically significant with $p = 0.0004$.

These results indicate that although variables such as fish species, sex, age, length, weight, and growth stage explain, in a statistical sense, some of the observed variation in the heavy-metal concentrations, there is still a highly significant relationship between lake locality and heavy-metal concentrations, even when the effects of other variables are allowed for statistically.

Results of a partial PCA where the effects of fish species, sex, growth stage, age, length, and weight are removed statistically and a PCA done of the residual variation in the heavy-metal concentrations not explained by these biological variables show that 95.9% of this residual variation (0.61) is represented by two partial PCA axes (axis 1 = 69.7%, axis 2 = 26.2% of the total residual variance). The partial PCA results (Figures 4.18 - 4.21) with a major contrast between Pb and Cd and Hg on axes 1 and 2. The relationship between above-average Pb and Cd concentrations in fish from lakes in Austria and Italy and between above-average Hg concentrations in fish from lakes in western and northern areas persists. Interestingly one can now identify which lakes have fish with above-average Pb, Cd, and Hg concentrations after the effects of fish age, species, etc. have been partialled out (Figures 4.23 - 4.25). These are the lakes in the upper-right quadrant of Figure 4.22 and are Arresjøen, Lagoa Escura, Stavsvatn, Lochnagar, Lago di Latte, Zieloni Staw, and Schwarzsee ob Sölden.

4.4.3 Conclusions

The numerical analyses of heavy-metal concentrations in fish from 15 AL:PE lakes show the strong contrast in the type of heavy metals between lakes in Italy and Austria with high Pb and Cd values and lakes in northern and western Europe with high Hg concentrations.

There are several explanations to the observed accumulation of heavy metals in this fish. Some metals are partly taken up by the fish directly from the water, other elements enter the fish mainly by food uptake. The metals could be transported at long distance by air from industrial areas to these remote AL:PE localities. Some metals might also originally be present in the bedrock of these AL:PE catchments. The acid precipitation of the last century increase the solubility and the washing out of metals from the catchments into the lakes and their sediments. Analyses of metals through sediment cores would also confirm higher metal concentrations in the upper (recent) layers compared to lower (older) layers, stating the increasing contributions over the last decades. Elevated metal concentrations in lower (older) sediment layers may indicate local supply of metals. However, the direct airborne transport of metals into the catchment, or the washing out of metals from the catchments due to acid rain, are expected to be the main source for accumulation in fish in remote areas.

Without any air transport of Hg, Cd, or Pb, nor any marked leakage of these elements from the catchments of the AL:PE sites, the accumulations of these elements in the fish were expected to be: Hg (fillet) 0.01 - 0.05 ppm, Cd (liver) 0.03 - 0.3 ppm, and Pb (liver) 0.02 - 0.2 ppm (Grande 1979, Rognerud & Fjeld 1991). Six AL:PE lakes showed higher concentrations for Hg than expected (see Fig. 4.17 for Hg, filled and half filled circles). For Pb, one half of the lakes had higher accumulation than the expected background values, and only three of the lakes showed values below expected concentrations for Cd (see Fig. 4.17 for Cd, open circles). It is not likely that all of these contaminated sites release all these elements from their catchments, and certainly not without any acid precipitation. It is therefore reasonable to believe that many of these sites also receive air transported Hg, Cd, and Pb.

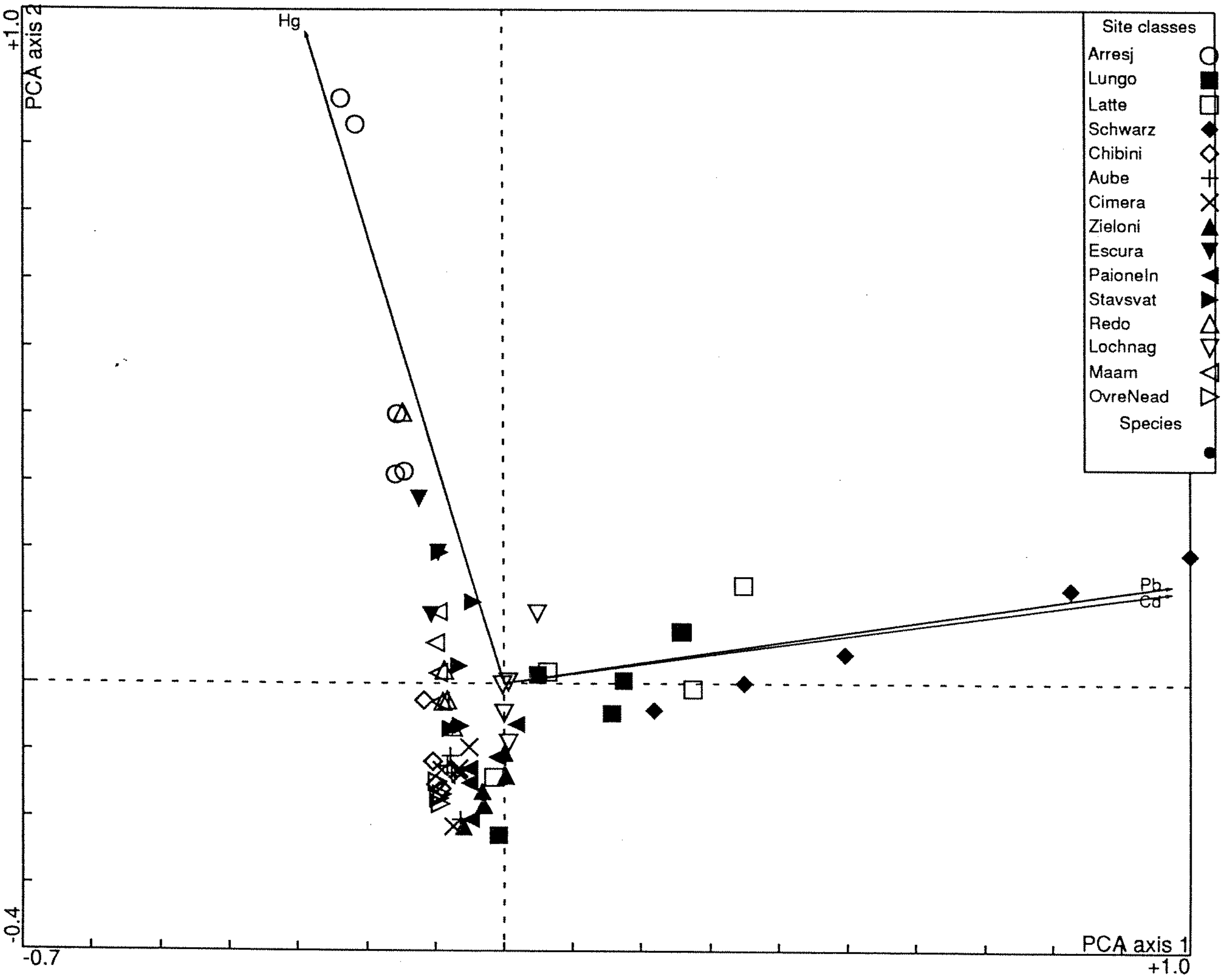


Figure 4.18. Position of individual fish samples on PCA axes 1 and 2 in relation to the correlation biplot arrows for Pb, Cd, and Hg. The 73 samples are coded by lake. The variable scores are variance adjusted.

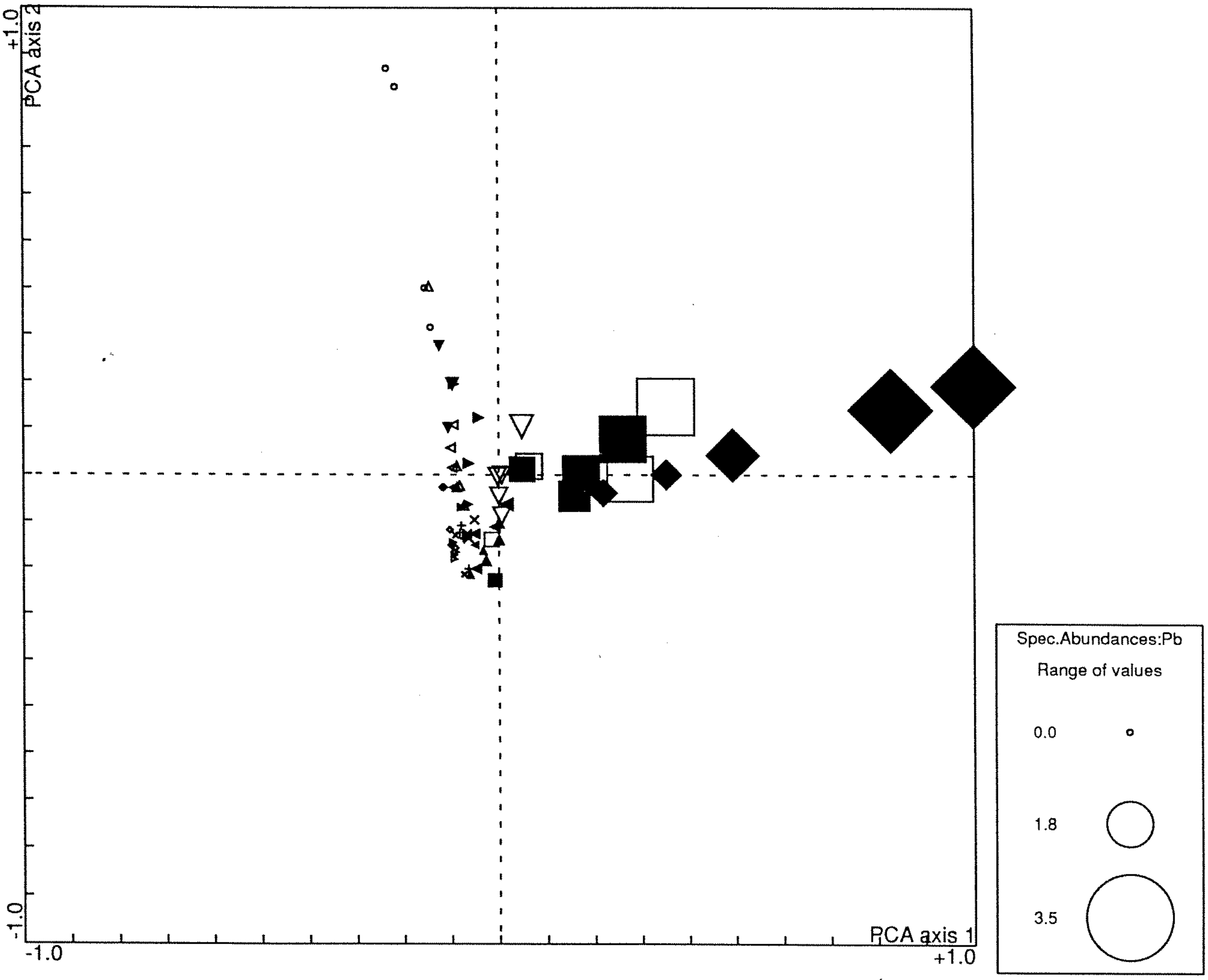


Figure 4.19. Pb concentrations in individual fish samples on PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.18).

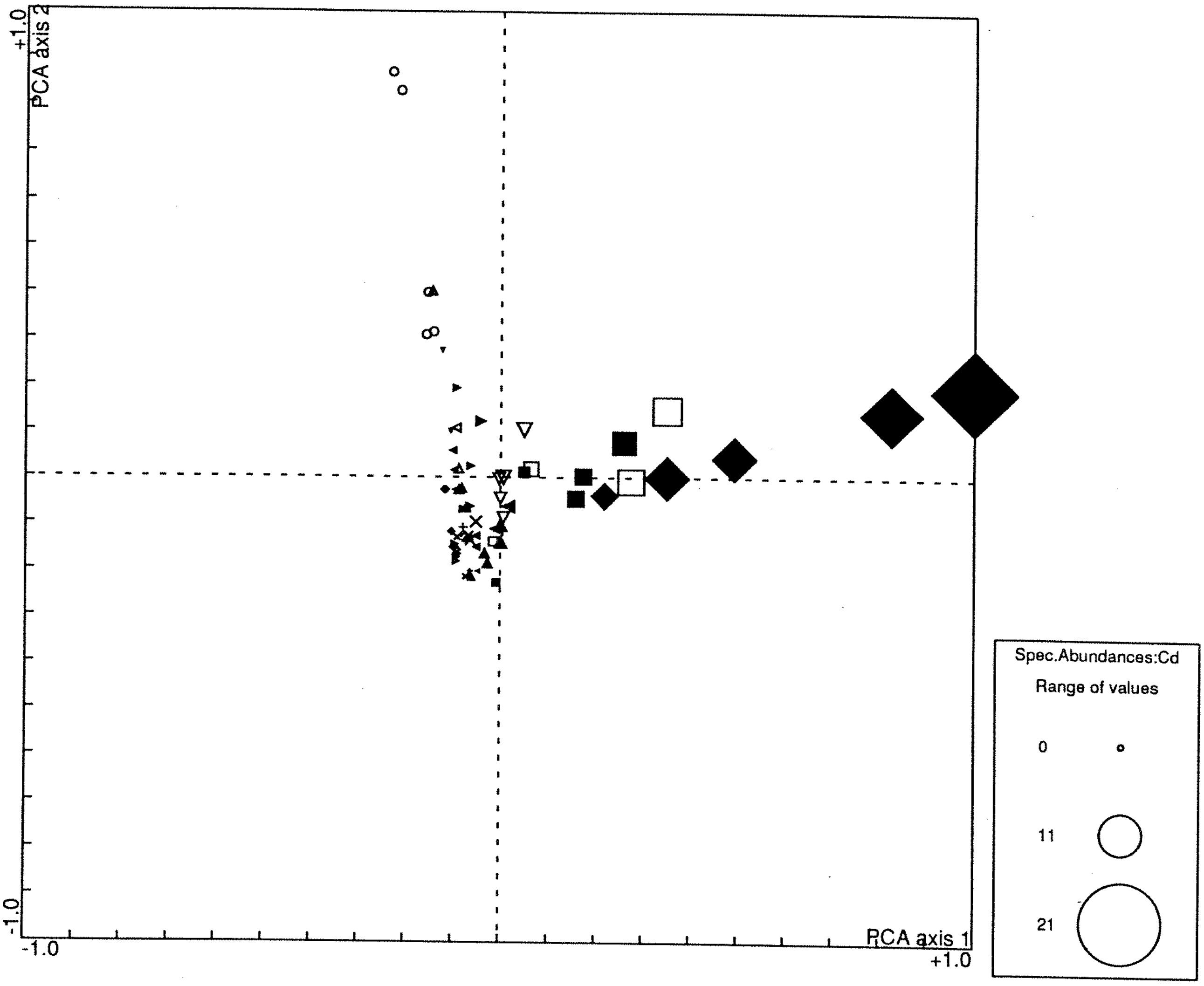


Figure 4.20. Cd concentrations in individual fish samples on PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.18)

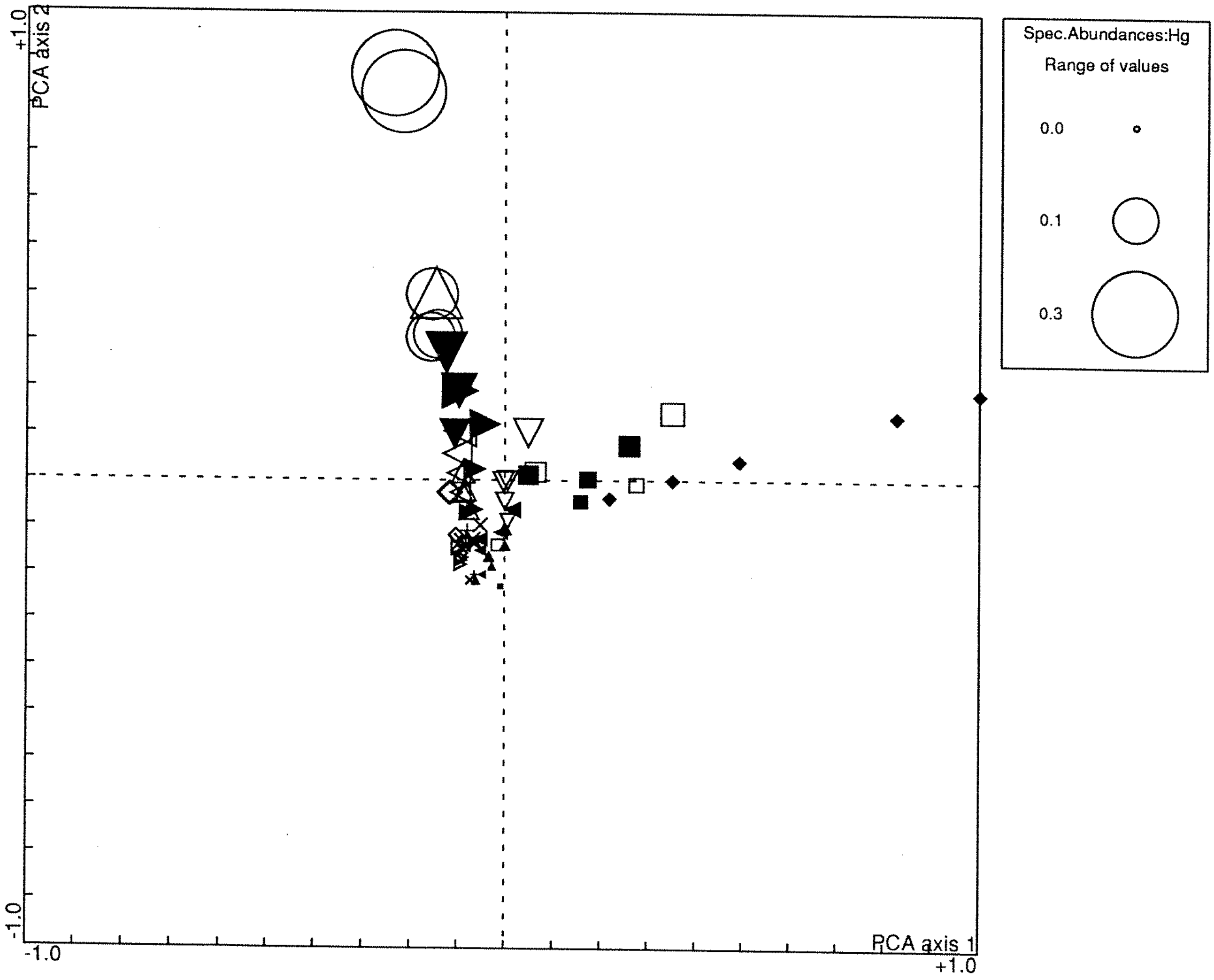


Figure 4.21. Hg concentrations in individual fish samples on PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.18).

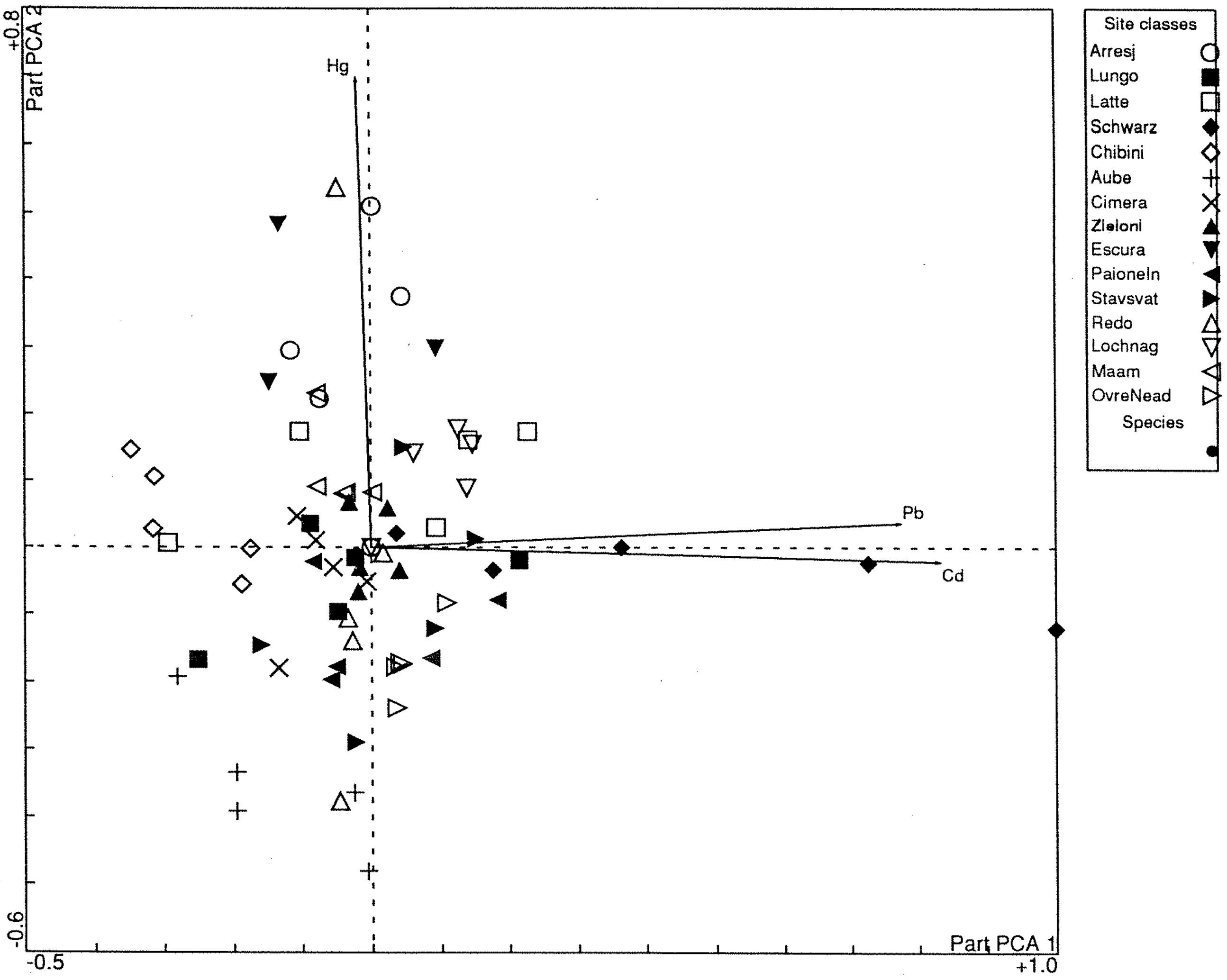


Figure 4.22. Position of individual fish samples on partial PCA axes 1 and 2 in relation to the biplot arrows for Pb, Cd, and Hg. The 73 samples are coded by lake. In the partial PCA the effects of fish sex, species, age, length, weight, and growth stage have been partialled out.

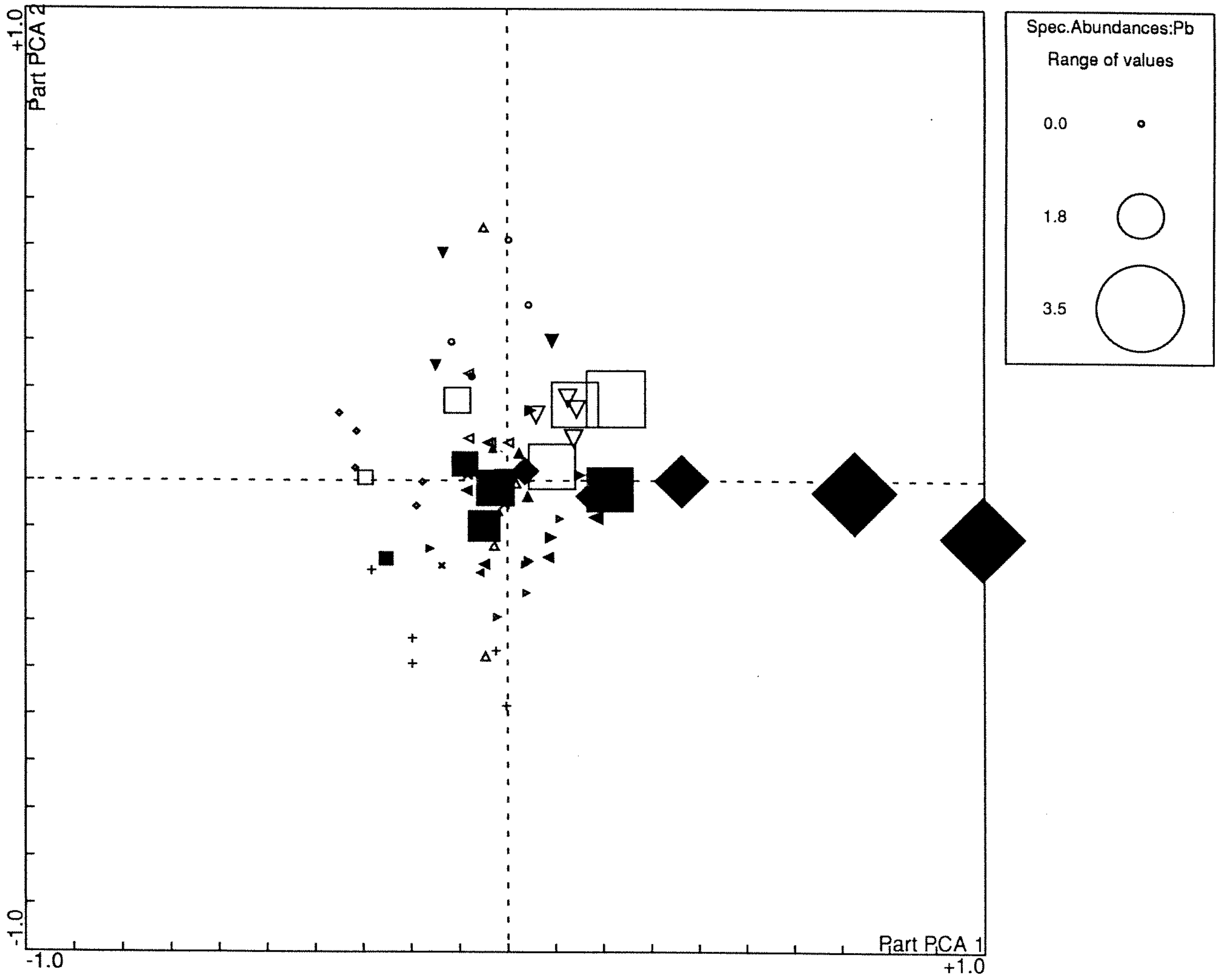


Figure 4.23. Pb concentrations in individual fish samples on partial PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.22).

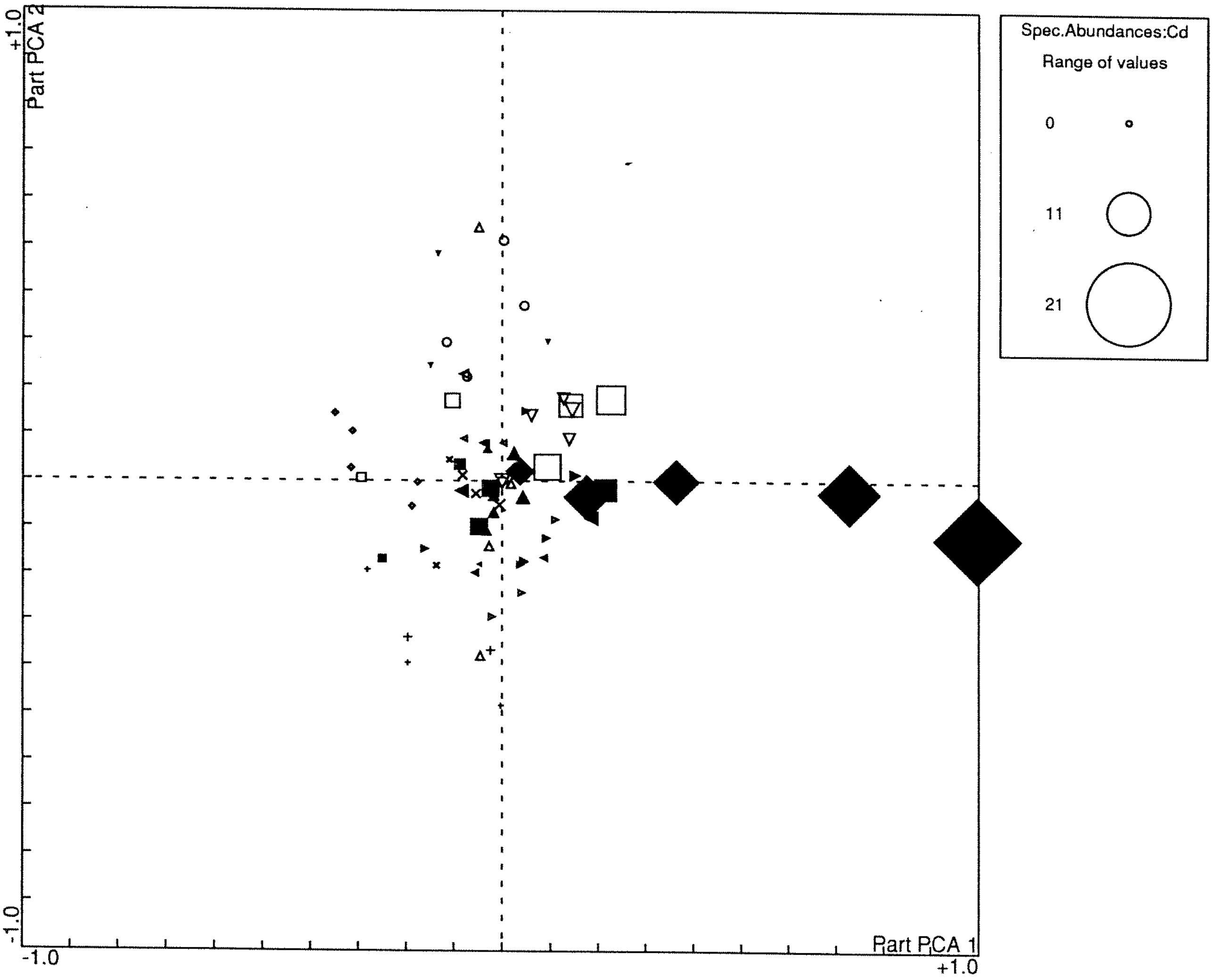


Figure 4.24. Cd concentrations in individual fish samples on partial PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.22).

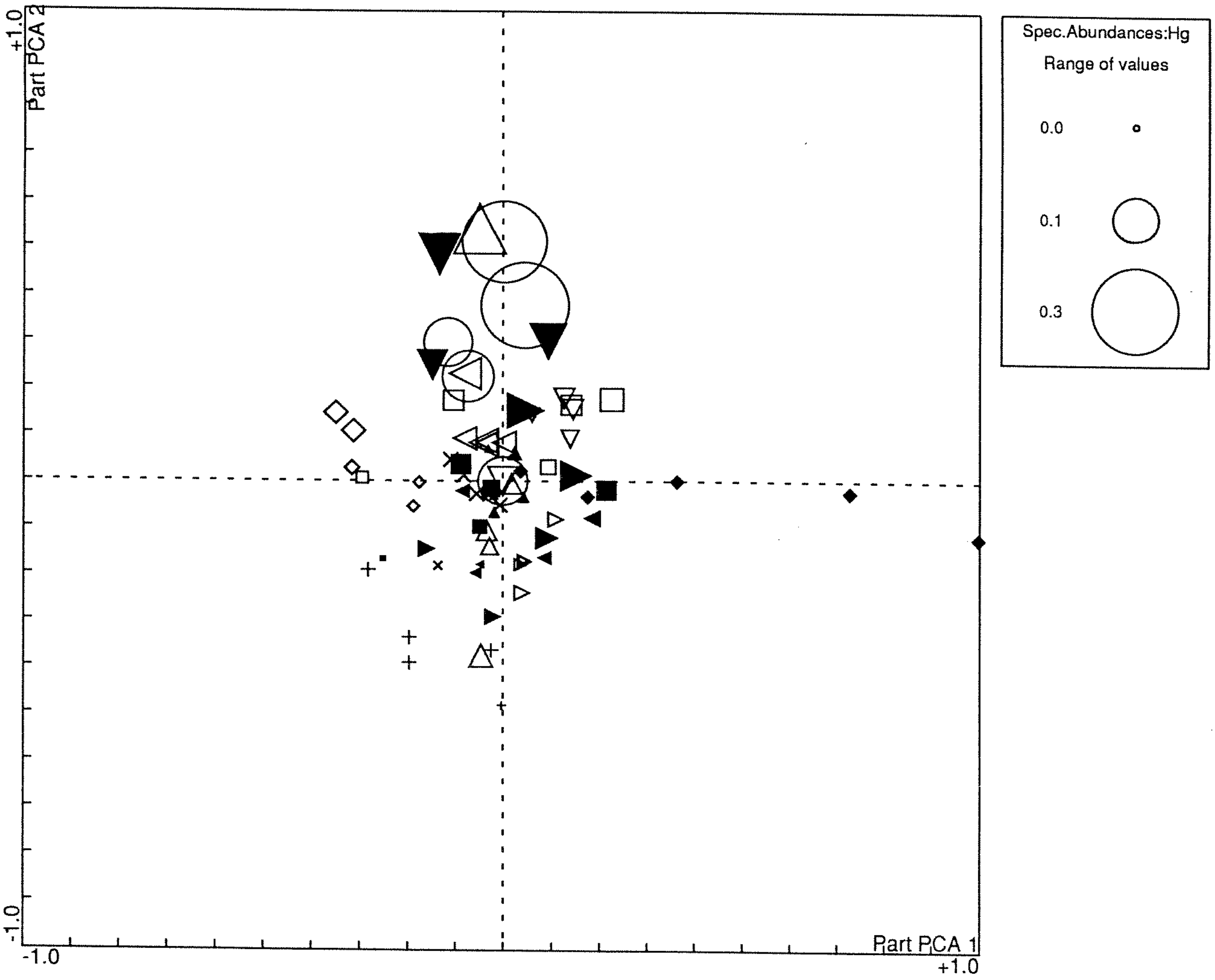


Figure 4.25. Hg concentrations in individual fish samples on partial PCA axes 1 and 2. The 73 samples are coded by lake (Figure 4.22).

4.5 ORGANIC MICROPOLLUTANTS IN FISH

4.5.1 INTRODUCTION

The organochlorinated compounds in the muscle tissue of fishes from 14 lakes of the AL:PE 2, Lagoa Escura, Laguna Cimera, Lago Redo, Lago Paione Inferiore, Lago di Latte, Lago Lungo, Schwarzsee ob Sölden, Zielony Staw, Loch Maam, Lochnagar, Øvre Neådalsvatn, Stavsvatn, Chibini and Arresjøen, have been analysed. Two main objectives were addressed:

a) To use the concentrations of these compounds in the fishes as an indication of the load of these compounds in the waters of each lake. This objective is supported by the fact that a substantial amount of these compounds is bioconcentrated (not or slowly degraded and depurated) and the concentration in the fish tissues are related to the concentration in the waters.

b) To ascertain whether the organochlorinated compounds are related with the health problems of the fishes in high altitude lakes, particularly those concerned with reproduction.

The analyses were limited to the muscle because this tissue is related with long term effects of pollutant accumulation. 3-6 individual fish per lake were analysed which resulted in a data set of 72 samples after analysis of the 15 lakes included in the study.

The results of PCB and DDE/DDT in the fish analyses are in good agreement with the concentrations observed in the sediments. Thus, they exhibit approximately the same geographical distribution in terms of higher and lower polluted sites. The fish analyses also show a general good correspondence between PCB and DDE/DDT concentrations. Usually the two compounds are observed to increase or decrease alike in the lakes.

The PCB distribution found in the fish tissues is similar to that present in the sediments although it shows a clear enrichment in the heavier congeners. This effect probably reflects the different bioaccumulation factor of each of these compounds.

HCB and HCH seem to be distributed following the influence of local sources. However, generally speaking there is a group of lakes with very low levels (almost blanks): Lagoa Escura, Loch Maan, Lochnagar and Laguna Cimera. Some lakes have a moderate pollution level: Stavsvatn, Zielony Staw and Estany Redo. Another with relative high pollution, Arresjøen and Lago Lungo, and the lake with the highest pollution level, Schwarzsee ob Sölden.

This classification among low, moderate, high pollution corresponds to the concentrations of the major chlorinated compounds, the PCBs and DDTs. The concentrations of these compounds change alike.

4.5.2 REGIONAL DESCRIPTIONS

The concentrations of summed polychlorobiphenyl congeners, DDT derivatives, hexachlorocyclohexanes and hexachlorobenzene are summarised in Figures 4.26 - 4.29. In the Figures, no corrections have been made for the mixtures of different important fish parametres like size (length/weight), age, feeding behaviour (piscivorous/non-piscivorous) or fish species.

a) Svalbard. This region is represented by Arresjøen. As indicated above, this region is characterised by low amounts of PCB congeners and DDT derivatives. The concentrations in the lake studied are low but they are not the lowest in the AL:PE series. This is in part in contrast with the very low amounts of organochlorinated pollutants found in the sediments of this lake.

b) Kola. This region is represented by Chibiny. The concentrations are very low for all organochlorinated compounds. The PCB congeners are those present in higher abundance although their concentrations range among the lowest of the whole AL:PE series.

c) Norway. This region is represented by Øvre Neådalsvatn and Stavsvatn. The concentrations of organochlorinated compounds in these lakes are low. The two lakes examined exhibit significant differences which probably reflect local influences or inhomogeneous deposition trends in this area.

d) British Isles. This region is represented by Lough Maam and Lochnagar. The concentrations of organochlorinated compounds are low and rather uniform between lakes. The most abundant products correspond to the PCB congeners. These lakes range among those showing lowest concentrations of total DDTs.

e) Iberia. This region is represented by Lagoa Escura and Laguna Cimera. The concentrations in these two lakes range among the lowest of the whole series of lakes studied. The only exception to this trend is the relatively high amount of DDT derivatives in Laguna Cimera.

f) Pyrenees. This region is represented by Lago Redo. The highest concentrations of total hexachlorocyclohexanes and hexachlorobenzene are found in this lake. The concentration of the former is more than one order of magnitude higher than any other concentration observed in the AL:PE series. The concentration of hexachlorobenzene is also very high when compared with most AL:PE lakes. The other chlorinated products, total DDTs and PCBs, also exhibit important concentrations but they are found even in higher levels in the fishes from other European Lakes.

g) Alps. This region is represented by Lago Paione Inferiore, Lago di Latte, Lago Lungo and Schwarzsee ob Sölden. These lakes can be grouped in two parts: the western Alps (Lago Paione Inferiore) and the Tyrol (Lago di Latte, Lago Lungo and Schwarzsee ob Sölden). A strong contrast is observed between the two. Whereas the West Alps generally show low concentrations of organochlorinated compounds, the highest levels of PCB congeners and DDT derivatives are found in the Tyrol region. This difference is particularly important for the Tyrol area since the three lakes studied consistently show a high pollution for these two groups of compounds. In addition, high levels of hexachlorobenzene are also found in some lakes of Tyrol (Lago di Latte and Schwarzsee ob Sölden).

h) Tatra Mountains. This area represented by Zielony Staw. The concentrations of organochlorinated products are relatively low. DDT derivatives are the major products. The levels of PCBs are also significant. However, Zielony Staw is the AL:PE 2 lake that shows the lowest concentrations of hexachlorobenzene.

Figure 4.26 Total polychlorobiphenils in the fish muscle from the AL:PE2 lakes considered in this study. Each value is the average of 3-6 individual determinations.

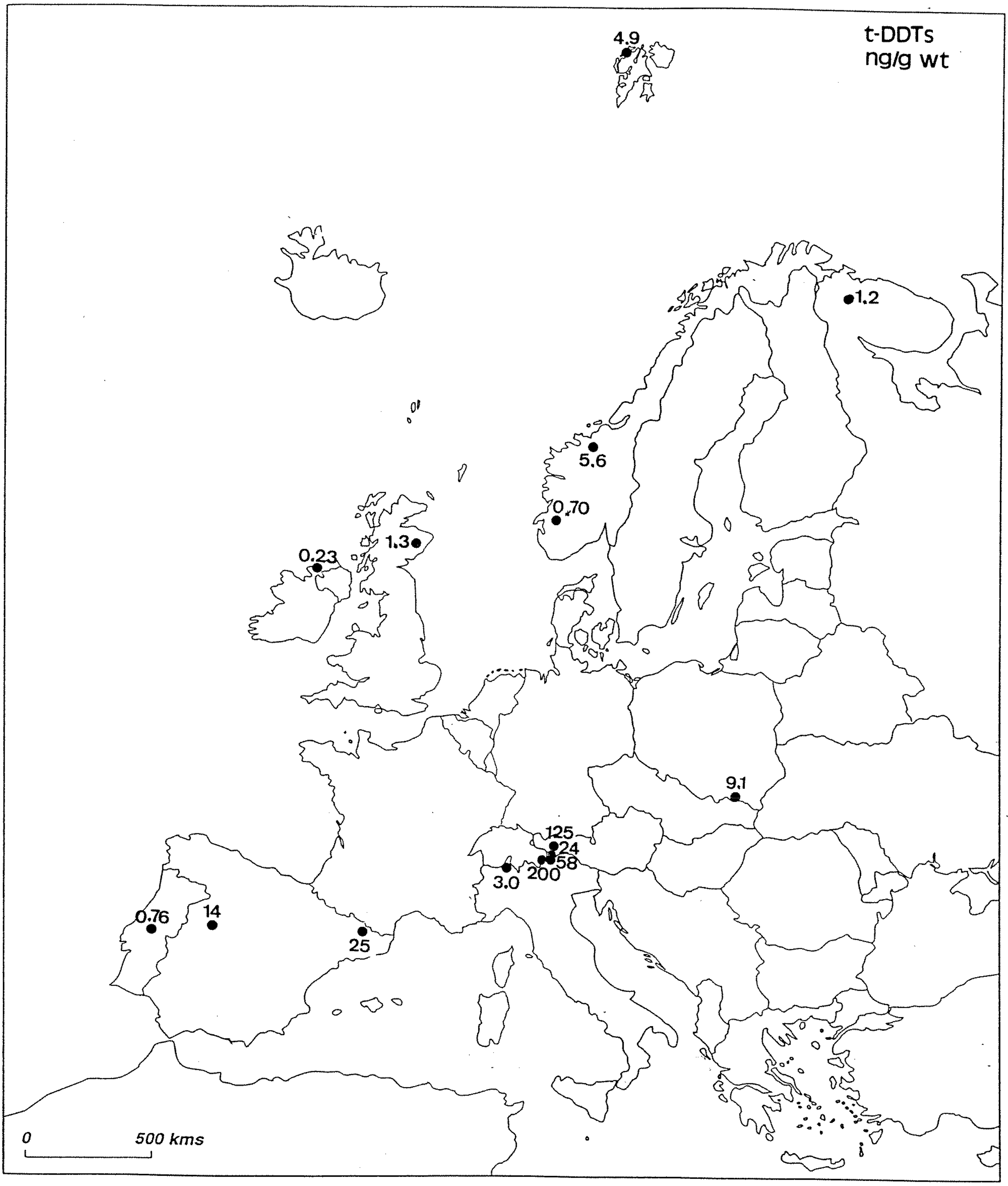


Figure 4.27 Total DDTs in the fish muscle from the AL:PE2 lakes considered in this study. Each value is the average of 3-6 individual determinations.

Figure 4.28 Total hexachlorocyclohexanes in the fish muscle from the AL:PE2 lakes considered in this study. Each value is the average of 3-6 individual determinations.

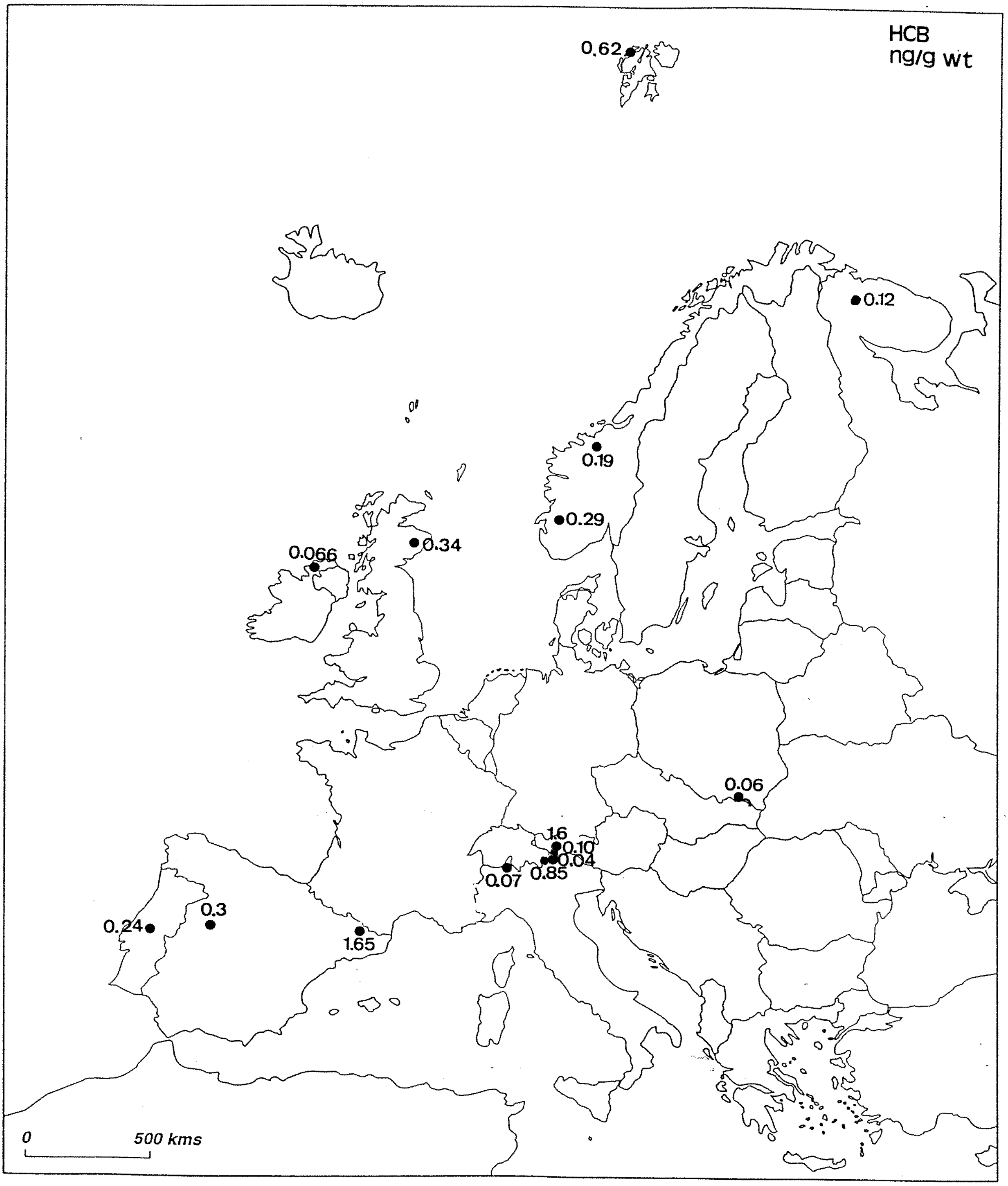


Figure 4.29 Hexachlorobenzene in the fish muscle from the AL:PE2 lakes considered in this study. Each value is the average of 3-6 individual determinations.

4.5.3 OVERALL SUMMARY AND CONCLUSIONS.

Distribution patterns.

The overall evaluation of the concentrations of hexachlorobenzene, total PCB congeners, DDT derivatives and hexachlorocyclohexane isomers show a major difference between the organochlorinated compounds of industrial origin and those used as pesticides.

Thus, total PCB congeners (mean 13 ng/g, standard deviation 16 ng/g) range between 1.8 and 46 ng/g (1.4 orders of magnitude) and their standard deviation is 120% of the mean. Hexachlorobenzene (mean 0.44 ng/g, standard deviation 0.53 ng/g) ranges between 0.06 and 1.65 ng/g which corresponds to the same order of magnitude than the PCBs (1.4) and to a standard deviation which is 120% of the mean. The similitude in the range of variation of these two products is remarkable in view of the different physico-chemical properties of hexachlorobenzene with respect the dominant PCB congeners in the lake (Nos. 118, 153, 138 and 180).

Conversely, the total DDT derivatives (mean 32 ng/g, standard deviation 57 ng/g) range between 0.23 and 200 (2.9 orders of magnitude) and the standard deviation is 180% of the mean. The hexachlorocyclohexanes (mean 0.06 ng/g, standard deviation 0.5 ng/g) also show a high dispersion (2.2 orders of magnitude) and their standard deviation is 270% of the mean.

This different dispersion pattern suggest that the concentrations of the industrial organochlorinated products in the fish population of the lakes reflect a more or less uniform distribution that has a maximum concentration near the Tyrol area and extends over all Europe. Conversely, the organochlorinated pesticides, in addition to a uniform distribution, are more affected by the influence of local sources.

Geographic patterns.

The first result evidenced by this study is the definition of a *hot spot* in the Tyrol area due to the high levels or organochlorinated compounds. This zone is characterised by having the highest concentrations of hexachlorobenzene, PCBs and DDTs among all the AL:PE lakes studied. The second most polluted region corresponds to the Pyrenees, where Lake Redo has the highest concentrations of hexachlorobenzene and hexachlorocyclohexane isomers and significant amounts of PCBs and DDTs. The Tatra Mountains also show similar concentrations of PCBs and DDTs but very low amounts of hexachlorobenzene and hexachlorocyclohexane isomers. The other areas, Kola, Norway, British Isles, Iberia, exhibit rather low concentrations of these four groups of compounds. These concentrations can be considered to represent the background atmospheric-pollution by these compounds and correspond to 1.4-3.5 ng/g t-PCBs, 0.23-5.6 ng/g t-DDTs, 0.06-0.38 ng/g t-HCHs and 0.06-0.34 ng/g HCB. There are, however some exceptions, such as the moderate but significant concentration of t-DDTs in Laguna Cimera or t-PCBs in Øvre Neådalsvatn.

Concentration ranges.

It is difficult to compare the present results with those obtained in other studies because of biases produced by differences in analytical criteria. In any case, the comparison with the aquatic systems considered in other studies gives a rough estimate of the differences with other ecosystems. Thus, in clean coastal areas of the Mediterranean Sea we have found concentrations of PCBs in the order of 10-55 ng/g and t-DDTs of 10-110 ng/g. The concentrations in several European Rivers and Lakes from areas that are not receiving pollution discharges are in the same order as those found in these lakes. For instance t-DDTs of 10-130 ng/g or <5-13 of t-HCHs in some Italian Rivers (Galassi *et al.*, 1981; Amodio *et al.*, 1988). These examples and other evidence support that there is not a major contrast between the low composition of organochlorinated compounds from the AL:PE Lakes and these other environments. This, in turn, also evidences the high mobility of these compounds between different ecosystems, including atmospheric transport.

4.7 REFERENCES:

Amodio-Cocchieri, R. and Arnese, A. 1988. Organochlorine pesticide residues in fish from Southern Italian Rivers. *Bull. Environ. Toxicol.* **40**: 233 - 239.

Christensen, J.M. 1964. Burning of otoliths, a technique for age determination of Soles and other fish. *J. Cons. perm. int. Explor. Mer.* **29**, 73-81.

Dahl, K. 1910. Alder og vekst av hos laks og Ørret belyst ved studiet av deres skjæl. (Age and growth of Atlantic salmon and brown trout by use of scales). Landbruksdepartementet Centraltrykkeriet, Kristiania. (In Norwegian).

Davidowicz, P. and Gliwicz, Z.M. 1983. Food of brook trout in extreme oligotrophic conditions of an alpine lake. *Env. Biol. Fish.* **8**: 55 - 60.

Galassi, S., Gandolfi, G. and Pacchetti, G. 1981. Chlorinated hydrocarbons in fish from the River Po (Italy). *The Science of the Total Environment* **20**: 231 - 240.

Grande, M.1979. "Bakgrunnsnivåer" av metaller i ferskvannsfisk. ("Background level of metals in freshwater fish"). Norwegian Institute for Water Research. Report. O-85167, (In Norwegian).

Green, N.,W. 1993. Overview of analytical methods employed by JMP (Joint Monitoring Group. Oslo. Paris Commissions) in Norway 1981-92. Norwegian Institute for Water Research. Report. O-80106.

Hebert C.E. and Keenleyside K.A. 1995. To normalize or not to normalize? fat is the question. *Environ. Toxicol. Chem.* **14**, 801-807.

Hesthagen, T., Rosseland, B.O.,Berger, H.M.& Larsen, B.M. 1993. Historical pattern of fish status in Norwegian lakes: comparison between fishermen's opinion and direct measurement. *Nordic Journal of Freshwater Research* **68**, 34 - 41.

JMG (Joint Monitoring Group. Oslo - Paris Commissions) 1990a. Document 15/3/12

JMG (Joint Monitoring Group. Oslo - Paris Commissions) 1990b. Document 15/7 Info 18-E

JMG (Joint Monitoring Group. Oslo - Paris Commissions) 1995. National comments to the Norwegian data for 1993. Norwegian Institute for Water Research. Report.O-80106.

Larsson P., Collvin L., Okla L. and Meyer G. 1992. Lake productivity and water chemistry as governors of the uptake of persistent pollutants in fish. *Environ. Sci. Technol.* **26**, 346-352.

Lee, R.M. 1920. A review of the methods of age and growth determination in fishes by means of scales. Fishery Invest. Lond. ser. II 4 (2), 1-32.

Moiseenko, T., Dauvalter, V., Kagan, L., Sharov, A., Landysh, O., Kashulin, N. and Yakolev, V. 1995. Air pollution effects on the Mountain Lakes of Northern Russia. Institute of Northern Industrial Problems INEP-Report 2/1995, 53 pp.

Rognerud, S. and Fjeld E. 1991. National survey of heavy metals in lake sediments and mercury in fish. Norwegian Institute for Water Research. Norwegian State Pollution Control Authority Report.426/90

Rosseland, B.O., Balstad, P., Mohn, E., Muniz, I.P., Sevaldrud, I. and Svalastog, D.. 1979. Bestandsundersøkelser DATAFISK-SNSF-77. Presentasjon av utvalgskriterier, innsamlingsmetodikk og anvendelse av programmet ved SNSF-prosjektets prøvefiske i perioden 1976-79. (Fish population studies, DATAFISH-SNSF-77. Presentation of criteria for lake selection, data collection and use of data program in the SNSF-projects test fishing program in the period 1976-79. SNSF-project, Technical Report TN 45/79, 63 pp. + appendix. (In Norwegian).

Rosseland, B.O., Sevaldrud, I., Svalastog, D. and Muniz, I.P. 1980. Studies of freshwater fish populations - effects of acidification on reproduction, population structure, growth and food selection. In : Drabløs, D. and Tollan A. (eds.) Ecological Impact of Acid Precipitation, p. 336-337, SNSF-project, FA 105/80, NISK, 1432 Aas-NLH, Norway.

SFT 1983. Overvåking av langtransportert forurenset luft og nedbør. Årsrapport 1982.(Monitoring of long range transported pollutants in air and precipitation. Annual report 1982). Statlig program for forurensningsovervåking. Rapp. 108/83, SFT, Oslo.

Svenning; M-A. 1992. Ecological studies in charr lakes on Svalbard (Spitsbergen), 1987 - 90. Report, Ministry of the Environment, 66p. (In Norwegian).

Svenning, M-A. and Borgstrøm, R. 1995. Population structure in landlocked Spitsbergen Arctic charr. Sustained by cannibalism? *Nordic J. Freshw. Res.* **71**: 424 - 431.

ter Braak,C.J.F. (1983) Principal components biplots and alpha and beta diversity. *Ecology* **64**, 454-462.

ter Braak, C.J.F. (1987) Ordination. In *Data analysis in community and landscape ecology* (eds. R.H.G. Jongman, C.J.F. ter Braak and O.F.R. van Tongeren), pp. 91-173. Pudoc, Wageningen.

ter Braak, C.J.F. (1990) Update notes: CANOCO version 3.10. Agricultural Mathematics Group, Wageningen, 35 pp.

ter Braak, C.J.F. (1994) Canonical community ordination. Part I: Basic theory and linear methods. *Écoscience* **1**, 127-140.

ter Braak, C.J.F. and Prentice, I.C. (1988) A theory of gradient analysis. *Advances in Ecological Research* **18**, 271-317.

Wathne, B.M., Patrick, S.T., Monteith, D and Barth, H. (eds.) 1995. AL:PE 1 Report for the period April 1991 - April 1993. Ecosystem Research Report 9, European Commision Report EUR 16129 EN, 296 p. ISBN 2-87267-129-1

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Appendix 7

Fish

Table A.7.1. Fish from AL:PE 2 lakes analysed at NIVA for heavy metals and total PCB.

J.no	Length	Weight	Age	Cd-Liver	Pb-Liver	Hg-Fillet	PCB-Fil.	Sex	Stage	Flesh-col.	Cond.fact.
Arctic charr Arresjøen											
1	34.4	311	19	0.84	0.02	0.16	24.3	M	2	Yellow	0.76
2	34.4	298	18	0.45	0.00	0.14	13.4	F	7.3	Y	0.73
3	29.6	166	17	0.77	0.03	0.14	14.5	F	2	Y	0.64
4	35.7	403	31	0.91	0.03	0.26	59.2	M	5	White	0.89
5	46.5	1050	20	0.5	0.02	0.27	12	M	7.2	Read	1.04
Arctic charr Lago Lungo											
11	23.1	112	15	1.59	0.89	0.06		F	5	Light Reac	0.91
12	23.8	112	12	2.98	1.46	0.05		M	5	W	0.83
13	27.9	175	11	4.38	1.84	0.06		M	2	LR	0.81
14	24.6	120	12	3.36	1.21	0.04		M	5	W	0.81
15	23.1	95	11	0.97	0.38	0.01		F	5	R	0.77
Arctic charr Lago di Latte											
16	17.1	39	11	0.91	0.44	0.03		M	5	W	0.78
17	17.1	40	13	4.97	1.73	0.04		M	5	W	0.80
18	18.5	50	14	4.61	1.78	0.06		F	5	LR	0.79
19	17.3	35	14	1.91	0.93	0.06		F	5	W	0.68
20	16.6	32	15	5.66	2.26	0.07		M	5	W	0.70
Arctic charr Schwarzsee ob Sölden											
139	24.8	96.22	9	15.1	3.55						0.63
140	27.8	147	8	10.19	2.19						0.68
141	25.1	123.8	12	21.02	3.55						0.78
142	24.6	127.3	9	6.27	1.02						0.86
143	22.3	108.9	10	10.37	1.10						0.98
						0.36 (kidney,mean 7 fish)					
Arctic charr Lake Chibini											
49	23.5	103	7	0.028	0.03	0.041		M	2	R	0.79
50	18.8	55	7	0.024	0.07	0.031		M	1	R	0.83
51	25	133	5	0.025	0.03	0.033		M	1	R	0.85
52	30.4	285	8	0.026	0.03	0.062		F	5	R	1.01
53	30.9	268	6	0.042	0.03	0.052		F	5	R	0.91
Arctic charr Étang d'Aubé											
54	24.5	181	7	0.35	0.15	0.019		F	2	LR	1.23
55	24.4	163	6	0.26	0.12	0.038		M	5	LR	1.12
56	26	201	5	0.43	0.14	0.034		F	2	R	1.14
57	27.5	239	6	0.5	0.11	0.041		M	5	LR	1.15
58	28.5	246	21	0.38	0.13	0.035		M	5	LR	1.06
Brook trout Laguna Cimera											
44	24.4	152	2	0.26	0.05	0.037		F	5	W	1.05
45	26.5	175	2	0.36	0.07	0.017		M	5	W	0.94
46	26	178	3	0.88	0.11	0.034		F	5	W	1.01
47	25.8	155	2	0.69	0.14	0.036		F	5	LR	0.90
48	30.1	259	3	1.16	0.18	0.042		F	5	LR	0.95

J.no	Length	Weight	Age	Cd-Liver	Pb-Liver	Hg-Fillet	PCB-Fil.	Sex	Stage	Flesh-col.	Cond.fact.
Brook trout Zieloni Staw											
64	26.5	150	10	1.35	0.20	0.026		M	5	R	0.81
65	23.5	121	10	2.14	0.31	0.037		M	5	W	0.93
66	24.5	143	12	2.13	0.29	0.029		M	5	R	0.97
67	21.5	119	6	0.63	0.11	0.016		F	5	R	1.20
68	26.5	201	8	1.31	0.21	0.021		M	5	W	1.08
Rainbow trout Lagoa Escura											
21	25.1	185	3	0.07	0.22	0.09		M	2	R	1.17
22	25.6	203	3	0.07	0.28	0.13		M	2	R	1.21
23	29.5	277	3	0.09	0.39	0.11		F	1	LR	1.08
Rainbow trout Lago Paione Inferiore											
59	28.4	260	3	2.37	0.42	0.045		F	1	LR	1.14
60	26.4	185	5	0.46	0.29	0.035		F	1	LR	1.01
61	27.1	246	4	0.33	0.26	0.018		F	2	LR	1.24
62	28.6	301	4	1	0.16	0.03		M	2	R	1.29
63	27.6	313	3	2.22	0.22	0.036		F	5	LR	1.49
Brown trout Stavsvatn											
6	32.4	374	5	0.67	0.12	0.05		M	5	LR	1.10
7	41	734	7	0.84	0.27	0.07		F	5	LR	1.06
8	40.7	768	7	1.84	0.30	0.09		F	5	LR	1.14
9	38.7	598	7	1	0.16	0.05		M	5	LR	1.03
10	38.8	650	7	0.75	0.26	0.11		F	5	LR	1.11
							14.6 (mean all 5 fish)				
Brown trout Lago Redo											
24	28.7	240	6	0.72	0.11	0.16		M	5	LR	1.02
25	29.6	264	6	0.82	0.12	0.05		M	5	LR	1.02
26	31.3	351	6	0.57	0.16	0.07		F	7.2	LR	1.14
27	31	284	6	0.6	0.10	0.06		M	5	LR	0.95
28	29.5	277	6	0.65	0.14	0.06		F	5	LR	1.08
Brown trout Lochnagar											
29	16	41	2	1.36	0.54	0.04		M	2	W	1.00
30	22.2	97	3	1.57	0.52	0.06		F	2	LR	0.89
31	23.4	119	3	1.91	0.74	0.05		F	2	LR	0.93
32	23.9	138	3	1.33	0.55	0.05		F	2	LR	1.01
33	32.2	296	4	2.58	0.77	0.08		F	3	LR	0.89
Brown trout Loch Maam											
34	25.5	185	4	0.56	0.20	0.09		M	5	LR	1.12
35	27.6	241	4	0.19	0.16	0.06		F	5	LR	1.15
36	26.7	223	4	0.38	0.14	0.07		M	5	LR	1.17
37	29.7	299	5	0.24	0.17	0.07		F	5	R	1.14
38	29.4	284	5	0.23	0.20	0.08		M	5	R	1.12
Brown trout Øvre Neådalsvatn											
39	28.2	314	3	0.067	0.03	0.028		M	2	LR	1.40
40	27.8	298	3	0.063	0.03	0.026		M	2	LR	1.39
41	28.6	315	3	0.084	0.05	0.029		M	2	LR	1.35
42	29.5	377	3	0.065	0.03	0.034		F	2	R	1.47
43	33.7	524	5	0.065	0.03	0.034		M	5	R	1.37

Table A.7.2.1 Body weights and lengths, tissue water and lipid contents in fish from Arresjoen Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	323.3	440.5	108.5	27.7	37.1	187.4	185.0
length (cm)	27.0	32.0	22.0	13.0	14.0	21.6	8.20
Tissue:							
water (%)	77.4	81.7	72.8	77.0	78.9	77.6	3.24
lipid (%)	(1)	0.83	0.58	1.22	0.83	0.87	0.26
Sex:	Female				Female		

(1) Not determined

Table A.7.2.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	1.80	1.21	0.63	0.62	0.61	0.97	0.53
HCHs							
a-HCH	0.14	0.07	0.05	0.14	0.10	0.10	0.04
g-HCH	0.15	0.08	0.11	0.06	0.26	0.13	0.08
DDTs							
pp'-DDE	12.7	15.6	6.29	6.07	1.48	8.42	5.65
pp'-DDT	2.36	2.04	0.11	0.70	0.06	1.05	1.08
PCB no.							
28+31	0.45	0.23	0.20	n.d.	n.d.	0.18	0.19
52	1.53	1.20	0.37	n.d.	n.d.	0.62	0.71
101	2.17	1.36	0.56	n.d.	n.d.	0.82	0.94
118	3.39	2.64	0.58	0.36	0.84	1.56	1.36
153	11.8	13.8	3.56	2.82	0.05	6.40	6.01
138	10.6	8.76	2.47	2.12	0.97	4.99	4.38
180	5.90	4.17	1.26	0.77	n.d.	2.42	2.50
PCBs TOTAL	35.8	32.2	9.00	6.07	1.86	17.0	16.1

Table A.7.2.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	2	3	4	5	Mean	s.d.
HCB	146	107	51.1	72.9	94.0	41.2
HCHs						
a-HCH	8.74	9.50	12.2	11.8	10.6	1.71
g-HCH	10.6	19.1	5.79	32.7	17.0	11.8
DDTs						
pp'-DDE	1874	1078	498	567	1004	635
pp'-DDT	245	19.0	57.2	7.74	82.3	111
PCB no.						
28+31	27.7	34.5	n.d.	n.d.	15.6	18.2
52	144	62.9	n.d.	n.d.	46.9	68.5
101	163	96.4	n.d.	n.d.	64.9	79.8
118	318	99.6	29.4	101	137	125
153	1660	610	231	5.77	627	733
138	1054	423	174	116	442	429
180	502	216	63.3	n.d.	195	224
PCBs TOTAL	3869	1542	498	223	1528	1677

Table A. 7.3. Concentration of some metals (mg/kg dry weight) in organs and tissue of Arctic charr from Chibiny

Organ	**Sample (n)**	**Cu**	**Ni**	**Co**	**Zn**	**Mn**	**Al**	**Sr**
Muscle	5	2.4	1.2	0.7	22	0.8	8	9
Skelleton	4	2.8	3.7	2.8	54	7.2	26	1230
Gills	5	4.3	2.3	1.7	83	9	46	1010
Liver	5	51	0.6	0.6	100	4.4	11	4.3
Kidney	5	11	1.2	3.7	106	8	26	24

Table A.7.4.1 Body weights and lengths,tissue water and lipid contents in fish from Chibini Lake.

	1(53)*	2(52)	3(51)	4(49)	Mean	s.d.
Body:						
weight (g)**	207	233	100	79	155	77
length (cm)	26.0	24.0	21.0	20.0	22.8	2.75
Tissue:						
water (%)	72.6	72.9	69.7	72.0	71.8	1.44
lipid (%)	1.16	1.38	2.66	1.86	1.77	0.66
Sex:	Female	Female				

*Original fish code between brackets

** Approximative fish weight (fish have been received partly dissecated).

Table A.7.4.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	Mean	s.d.
HCB	0.16	0.04	0.12	0.16	0.12	0.06
HCHs						
a-HCH	n.d.	n.d.	0.02	0.02	0.01	0.01
g-HCH	0.10	0.03	0.22	0.13	0.12	0.08
DDTs						
op'-DDE	0.05	n.d.	0.11	0.13	0.07	0.06
pp'-DDE	0.53	0.21	0.32	0.35	0.35	0.13
pp'-DDD	0.24	0.07	0.47	0.40	0.30	0.18
op'-DDT	0.09	0.06	0.31	0.17	0.16	0.11
pp'-DDT	0.30	0.11	0.63	0.34	0.35	0.21
PCB no.						
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	0.00
52	0.11	n.d.	0.52	0.62	0.31	0.30
101	0.16	0.19	0.25	0.31	0.23	0.07
118	0.47	0.28	0.56	0.57	0.47	0.13
153	0.43	0.14	0.72	0.57	0.47	0.25
138	0.49	0.11	0.47	0.46	0.38	0.18
180	0.26	0.04	0.30	0.30	0.23	0.12
PCBs TOTAL	1.92	0.76	2.82	2.83	2.08	1.06

Table A.7.4.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	Mean	s.d.
HCB	13.88	2.83	4.40	8.76	7.47	4.96
HCHs						
a-HCH	0.00	0.00	0.75	1.08	0.46	0.54
g-HCH	8.6	2.2	8.3	7.0	6.5	2.98
DDTs						
op'DDE	4.31	0.00	4.14	6.99	3.86	2.89
pp'-DDE	45.7	15.2	12.0	18.8	22.9	15.4
pp'-DDD	20.7	5.07	17.7	21.5	16.2	7.62
op'DDT	7.76	4.35	11.7	9.14	8.23	3.05
pp'-DDT	25.9	8.0	23.7	18.3	18.9	7.98
PCB no.						
28+31	0.00	0.00	0.00	0.00	0.0	0.0
52	9.48	0.00	19.5	33.3	15.6	14.3
101	13.8	13.8	9.40	16.7	13.4	3.00
118	40.5	20.3	21.1	30.6	28.1	9.51
153	37.1	10.1	27.1	30.6	26.2	11.5
138	42.2	7.97	17.7	24.7	23.2	14.5
180	22.4	2.90	11.3	16.1	13.2	8.2
PCBs TOTAL	166	55.1	106	152	120	61

Table A.7.5.1 Body weights and lengths,tissue water and lipid contents in fish from Ovre Neadalsvatn Lake

	1	2	3	4	5	6	Mean	s.d.
Body:								
weight (g)	237.0	236.0	74.7	90.4	101.0	237.0	162.7	81.5
length (cm)	22.5	22.0	15.0	17.0	18.0	22.0	19.4	3.17
Tissue:								
water (%)	71.9	74.8	72.1	71.6	74.3	74.3	73.2	1.44
lipid (%)	3.02	3.98	2.54	2.49	1.30	4.48	2.97	1.14
Sex:								

Table A.7.5.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	0.54	0.60	0.34	0.17	0.02	0.08	0.29	0.24
HCHs								
a-HCH	0.39	0.090	n.d.	0.020	n.d.	0.01	0.09	0.15
g-HCH	0.36	0.30	0.34	0.46	0.09	0.18	0.29	0.13
DDTs								
op'-DDE	0.03	n.d.	0.03	0.08	0.03	n.d.	0.03	0.03
pp'-DDE	0.31	1.17	0.11	0.18	0.09	0.13	0.33	0.42
pp'-DDD	n.d.	0.62	n.d.	0.06	0.04	0.04	0.13	0.24
op'-DDT	0.05	0.08	n.d.	0.09	n.d.	n.d.	0.04	0.04
pp'-DDT	0.15	0.45	n.d.	0.13	0.08	0.18	0.17	0.15
PCB no.								
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00
52	0.35	0.21	n.d.	0.26	n.d.	n.d.	0.14	0.16
101	0.02	0.41	0.19	0.16	0.03	0.06	0.15	0.15
118	0.15	0.27	0.11	0.18	0.09	0.13	0.16	0.06
153	0.17	0.99	0.25	0.43	0.33	0.39	0.43	0.29
138	0.22	0.92	0.32	0.34	0.17	0.36	0.39	0.27
180	0.20	0.49	0.36	0.15	0.07	0.20	0.25	0.15
PCBs TOTAL	1.11	3.29	1.23	1.52	0.69	1.14	1.50	1.08

Table A.7.5.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	17.72	15.0	13.46	6.9	1.38	1.85	9.4	7.0
HCHs								
a-HCH	12.91	2.26	n.d.	0.80	n.d.	0.22	2.70	5.08
g-HCH	11.92	7.54	13.39	18.47	6.92	4.02	10.4	5.24
DDTs								
op'-DDE	0.93	0.00	1.02	3.37	n.d.	n.d.	0.89	1.31
pp'-DDE	10.3	29.4	4.33	7.23	6.92	2.90	10.2	9.76
pp'-DDD	0.00	15.7	n.d.	2.29	2.85	0.89	3.61	6.01
op'-DDT	1.79	1.88	n.d.	3.49	0.00	0.00	1.19	1.44
pp'-DDT	4.97	11.3	n.d.	5.22	6.15	4.02	5.28	3.65
PCB no.								
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
52	11.6	5.28	n.d.	10.4	n.d.	n.d.	4.55	5.42
101	0.66	10.3	7.48	6.43	2.31	1.34	4.75	3.88
118	4.97	6.78	4.33	7.23	6.92	2.90	5.52	1.74
153	5.63	24.9	9.84	17.3	25.4	8.71	15.3	8.53
138	7.28	23.1	12.6	13.7	13.1	8.04	13.0	5.66
180	6.62	12.3	14.2	6.02	5.38	4.46	8.16	4.04
PCBs TOTAL	36.8	82.7	48.4	61.0	53.1	25.4	51.2	29.3

Table A.7.6.1 Body weights and lengths, tissue water and lipid contents in fish from Stavsvatn Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	675.3	594.5	341.2	258.3	296.6	433.2	188.6
length (cm)	35.5	35.0	33.0	25.0	26.5	31.0	4.91
Tissue:							
water (%)							
lipid (%)	1.60	1.24	1.69	1.04	1.81	1.48	0.32
Sex:	Female	Female					

Table A.7.6.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	0.10	0.06	0.09	0.10	0.58	0.19	0.22
HCHs							
a-HCH	0.04	0.02	0.03	0.04	n.d.	0.03	0.02
g-HCH	0.06	0.03	0.08	0.12	n.d.	0.06	0.05
DDTs							
pp'-DDE	6.15	2.07	4.15	3.04	9.86	5.05	3.09
pp'-DDT	0.17	0.06	0.12	0.60	1.93	0.58	0.79
PCB no.							
28+31		0.10	0.22	0.22	0.06	0.15	0.08
52	0.12	0.09	0.08	0.46	0.92	0.33	0.36
101	0.25	0.10	0.16	0.19	0.54	0.25	0.17
118	0.69	0.28	0.49	0.62	2.08	0.83	0.71
153	1.58	0.61	0.94	1.06	4.18	1.67	1.44
138	1.52	0.51	0.91	1.12	4.23	1.66	1.48
180	1.53	0.50	0.86	1.24	4.22	1.67	1.48
PCBs TOTAL	5.69	2.19	3.66	4.91	16.23	6.57	5.74

Table A.7.6.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	6.41	5.05	5.09	9.30	32.21	11.6	11.6
HCHs							
a-HCH	2.30	1.50	1.73	3.41	n.d.	1.79	1.24
g-HCH	3.95	2.29	4.64	11.53	n.d.	4.48	4.33
DDTs							
pp'-DDE	385	166	246	292	544	327	145
pp'-DDT	10.6	4.69	7.32	57.3	106.7	37.3	44.4
PCB no.							
28+31		8.18	13.0	21.4	3.53	11.5	7.62
52	7.76	6.89	5.01	44.6	50.6	23.0	22.6
101	15.5	8.14	9.48	18.2	29.6	16.2	8.57
118	43.3	22.7	28.91	59.8	115.1	54.0	37.0
153	99.0	48.7	55.83	102.0	230.6	107.2	73.11
138	94.9	40.9	54.28	107.1	233.6	106.2	76.36
180	95.5	40.30	50.9	119.16	232.9	107.7	77.01
PCBs TOTAL	356	176	217.4	472	896	426	302

Table A.7.7.1 Body weights and lengths,tissue water and lipid contents in fish from Nagar Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	110.3	108.4	139.4	175.3	211.3	148.9	44.2
length (cm)	21.0	19.5	21.0	23.0	25.0	21.9	2.13
Tissue:							
water (%)							
lipid (%)	1.22	2.62	2.46	1.45	1.11	1.77	0.71
Sex:					Female		

Table A.7.7.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	1.12	0.11	0.14	0.25	0.07	0.34	0.44
HCHs							
a-HCH	0.01	0.05	0.04	0.05	0.02	0.03	0.02
g-HCH	0.09	0.61	0.29	0.54	0.11	0.33	0.24
d-HCH	0.004	0.017	0.009	n.d.	0.016	0.009	0.007
DDTs							
pp'-DDE	0.49	0.96	1.49	1.84	0.58	1.07	0.58
pp'-DDT	0.06	0.35	0.24	0.54	0.10	0.26	0.20
PCB no.							
28+31	0.29	0.36	0.43	0.61	0.84	0.51	0.22
52	0.27	0.40	0.28	0.45	0.17	0.31	0.11
101	0.16	0.23	0.19	1.84	0.58	0.60	0.71
118	0.24	0.44	0.45	0.56	0.30	0.40	0.13
153	0.38	0.86	0.73	0.80	0.35	0.62	0.24
138	0.36	0.63	0.63	0.80	0.27	0.54	0.22
180	0.31	0.62	0.61	0.71	0.25	0.50	0.21
PCBs TOTAL	2.01	3.54	3.32	5.77	2.76	3.48	1.84

Table A.7.7.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	92.0	4.34	5.76	17.2	6.51	25.2	37.7
HCHs							
a-HCH	1.14	1.81	1.59	3.22	1.93	1.94	0.78
g-HCH	7.44	23.1	11.75	37.2	10.2	17.9	12.3
d-HCH	0.35	0.64	0.37	n.d.	1.46	0.56	0.55
DDTs							
pp'-DDE	40.4	36.5	60.5	127.0	52.0	63.3	36.9
pp'-DDT	5.15	13.5	9.66	37.2	9.1	14.9	12.8
PCB no.							
28+31	24.2	13.7	17.6	41.8	75.8	34.6	25.4
52	22.6	15.4	11.3	30.9	15.0	19.1	7.79
101	13.0	8.71	7.55	18.9	15.1	12.7	4.7
118	19.3	16.7	18.2	38.5	27.2	24.0	9.08
153	31.0	32.9	29.6	55.1	31.6	36.1	10.73
138	29.3	23.9	25.6	54.9	24.2	31.6	13.23
180	25.2	23.5	25.0	49.1	22.5	29.0	11.24
PCBs TOTAL	165	135	134.8	289	211	187	82

Table A.7.8.1 Body weights and lengths,tissue water and lipid contents in fish from Maan Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	199.1	270.1	210.5	194.7	187.5	212.4	33.3
length (cm)	23.0	26.0	25.0	24.0	23.5	24.3	1.20
Tissue:							
water (%)							
lipid (%)	1.33	2.07	2.47	1.89	0.88	1.73	0.63
Sex:	Female			Female			

Table A.7.8.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	0.078	0.067	0.065	0.061	0.058	0.066	0.008
HCHs							
a-HCH	0.04	0.02	0.03	0.03	0.02	0.03	0.01
g-HCH	0.11	0.10	0.07	0.11	0.07	0.09	0.02
d-HCH	0.04	n.d.	n.d.	n.d.	0.02	0.01	0.02
DDTs							
pp'-DDE	0.14	0.21	0.12	0.32	0.11	0.18	0.09
pp'-DDT	0.09	0.04	0.04	0.08	n.d.	0.05	0.04
PCB no.							
28+31	1.92	0.43	0.28	1.65	0.28	0.91	0.80
52	0.76	0.36	0.31	2.37	0.34	0.83	0.88
101	0.48	0.08	0.04	0.90	n.d.	0.30	0.39
118	0.59	0.31	0.18	1.03	0.16	0.45	0.36
153	0.27	0.36	0.21	0.43	0.21	0.30	0.10
138	0.33	0.32	0.18	0.35	0.17	0.27	0.09
180	n.d.	0.21	n.d.	0.15	0.12	0.10	0.09
PCBs TOTAL	4.35	2.07	1.20	6.88	1.28	3.16	2.72

Table A.7.8.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	5.87	3.27	2.63	3.23	6.60	4.3	1.8
HCHs							
a-HCH	3.16	1.08	1.12	1.34	2.11	1.76	0.88
g-HCH	8.31	4.93	2.84	5.70	7.71	5.9	2.20
d-HCH	2.88	n.d.	n.d.	n.d.	2.11	1.0	1.39
DDTs							
pp'-DDE	10.6	5.16	2.53	8.79	6.34	6.69	3.15
pp'-DDT	6.43	3.91	1.70	4.11	n.d.	3.23	2.46
PCB no.							
28+31	145	20.8	11.4	87.6	32.1	59.3	56.2
52	57.5	17.2	12.5	125.8	38.9	50.4	45.8
101	35.9	4.06	1.80	47.9	n.d.	17.9	22.3
118	44.5	14.9	7.42	54.7	18.7	28.0	20.4
153	20.4	17.7	8.34	22.9	24.2	18.7	6.31
138	24.7	15.6	7.17	18.5	19.2	17.0	6.40
180	n.d.	9.94	n.d.	8.07	14.2	6.4	6.29
PCBs TOTAL	328	100	48.7	365	147	198	164

Table 7.9.1 Body weights and lengths,tissue water and lipid contents in fish from Escura Lake.

	1(25)*	2(30)	3(38)	Mean	s.d.
Body:					
weight (g)	202.4	174.6	264.2	213.7	45.9
length (cm)	23.7	21.3	25.4	23.5	2.06
Tissue:					
water (%)	73.7	77.1	76.4	75.7	1.78
lipid (%)	1.99	1.53	1.30	1.61	0.35
Sex:					

* Original fish code between brackets

Table 7.9.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	Mean	s.d.
HCB	0.032	0.017	0.023	0.024	0.008
HCHs					
a-HCH	0.022	0.014	0.011	0.016	0.006
g-HCH	0.048	0.051	0.042	0.047	0.005
DDTs					
pp'-DDE	0.51	0.48	0.63	0.54	0.08
pp'-DDT	0.15	0.41	0.10	0.22	0.17
PCB no.					
28+31	0.09	0.25	0.07	0.14	0.10
52	n.d.	n.d.	n.d.	n.d.	
101	n.d.	0.07	n.d.	0.02	
118	0.39	0.43	0.29	0.37	0.07
153	0.40	0.47	0.28	0.39	0.09
138	0.78	0.82	0.31	0.64	0.28
180	0.26	0.13	0.23	0.21	0.07
PCBs TOTAL	1.92	2.17	1.19	1.76	0.61

Table 7.9.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	Mean	s.d.
HCB	1.65	1.15	1.78	1.53	0.33
HCHs					
a-HCH	1.08	0.89	0.87	0.95	0.12
g-HCH	2.44	3.36	3.20	3.00	0.49
DDTs					
pp'-DDE	25.4	31.6	48.2	35.1	11.8
pp'-DDT	7.44	27.0	7.38	13.9	11.3
PCB no.					
28+31	4.59	16.4	5.71	8.89	6.51
52	n.d.	n.d.	n.d.	n.d.	
101	n.d	4.35	n.d.	1.45	
118	19.6	27.8	22.3	23.3	4.1
153	20.3	30.7	21.8	24.3	5.6
138	39.1	53.8	24.0	39.0	14.9
180	13.2	8.76	17.7	13.2	4.5
PCBs TOTAL	96.8	142	91.6	110	35.6

Table A.7.10.1 Body weights and lengths,tissue water and lipid contents in fish from Cimera Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	181.3	230.7	157.9	197.5	140.6	181.6	35.0
length (cm)	23.0	25.0	22.0	24.0	20.5	22.9	1.75
Tissue:							
water (%)	79.4	81.0	79.8	80.9	80.4	80.3	0.68
lipid (%)	1.00	0.90	1.10	1.10	1.10	1.04	0.09
Sex:		Female	Female	Female	Female		

Table A.7.10.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	0.46	0.31	0.19	0.35	0.17	0.30	0.12
HCHs							
a-HCH	0.03	0.02	0.03	0.02	0.03	0.03	0.01
g-HCH	0.14	0.09	0.14	0.12	0.11	0.12	0.02
DDTs							
pp'-DDE	8.18	22.9	7.03	16.6	6.39	12.2	7.26
pp'-DDT	1.53	1.94	0.83	1.49	0.74	1.31	0.51
PCB no.							
28+31	0.37	0.11	0.03	0.16	0.05	0.14	0.14
52	0.68	0.37	0.59	0.42	0.41	0.49	0.13
101	0.88	0.50	0.24	0.48	0.39	0.50	0.24
118	0.61	0.39	0.21	0.35	0.23	0.36	0.16
153	0.81	1.13	0.33	0.87	0.38	0.70	0.34
138	0.89	1.69	0.89	1.25	0.79	1.10	0.37
180	0.62	0.71	0.16	0.53	0.12	0.43	0.27
PCBs TOTAL	4.86	4.90	2.45	4.06	2.37	3.73	1.65

Table A.7.10.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	46.1	32.6	17.7	31.2	15.4	28.6	12.5
HCHs							
a-HCH	2.89	2.36	2.46	2.14	2.43	2.46	0.27
g-HCH	14.5	10.9	13.0	10.0	10.6	11.8	1.90
DDTs							
pp'-DDE	817	2430	639	1463	788	1228	743
pp'-DDT	152	206	75.3	131.3	68.8	126.7	56.9
PCB no.							
28+31	37.2	0.047	0.013	0.069	0.017	7.47	16.6
52	67.7	38.7	53.7	36.7	37.7	46.9	13.6
101	88.1	52.5	21.9	42.1	36.6	48.2	24.9
118	61.4	41.3	19.3	30.9	21.8	34.9	17.1
153	81.0	120	29.8	76.3	35.5	68.4	36.8
138	88.6	180	80.5	110	73.2	106	43.2
180	61.9	75.0	14.8	46.9	10.9	41.9	28.4
PCBs TOTAL	486	507	220	343	216	354	181

Table A.7.11.1 Body weights and lengths, tissue water and lipid contents in fish from Redo Lake.

	1	2	3	4	5	Mean	s.d.
Body:							
weight (g)	204.0	200.7	295.0	236.5	219.5	231.1	38.4
length (cm)	25.0	25.0	26.5	23.5	25.0	25.0	1.06
Tissue:							
water (%)	75.2	75.0	74.4	71.7	75.0	74.3	1.46
lipid (%)	4.20	3.08	7.66	7.39	3.86	5.24	2.13
Sex:			Female	Female			

Table A.7.11.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	1.26	1.08	2.41	1.87	1.62	1.65	0.52
HCHs							
a-HCH	1.80	1.57	4.16	3.67	2.05	2.65	1.18
g-HCH	4.79	3.43	9.67	10.23	6.12	6.85	2.99
DDTs							
pp'-DDE	19.6	25.0	21.3	12.1	30.4	21.7	6.79
pp'-DDT	3.48	2.32	3.51	3.57	4.16	3.41	0.67
PCB no.							
28+31	0.07	0.11	0.19	0.13	0.40	0.18	0.13
52	0.29	0.50	0.44	0.56	0.24	0.41	0.14
101	0.88	1.17	1.24	0.89	1.57	1.15	0.29
118	0.51	0.54	0.63	0.33	0.64	0.53	0.13
153	3.56	2.57	4.16	2.61	3.81	3.34	0.72
138	2.49	3.03	2.52	2.38	3.25	2.73	0.38
180	1.60	1.79	1.24	0.92	2.30	1.57	0.53
PCBs TOTAL	9.40	9.71	10.42	7.82	12.21	9.91	2.31

Table A.7.11.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	29.6	35.0	31.5	25.4	42.0	32.7	6.2
HCHs							
a-HCH	42.3	51.3	54.4	49.8	53.2	50.2	4.7
g-HCH	113	111	126	138	159	129	19.7
DDTs							
pp'-DDE	462	812	278	163	788	501	294
pp'-DDT	81.8	75.4	45.9	48.3	108	71.8	25.6
PCB no.							
28+31	0.002	0.001	0.001	0.004	0.038	0.009	0.016
52	6.72	16.3	5.69	7.62	6.15	8.49	4.42
101	20.7	37.9	16.2	12.0	40.8	25.5	13.0
118	12.0	17.6	8.22	4.42	16.6	11.8	5.57
153	83.8	83.7	54.3	35.3	98.7	71.2	25.7
138	58.7	98.5	32.9	32.2	84.3	61.3	29.9
180	37.7	58.2	16.2	12.5	59.7	36.8	22.4
PCBs TOTAL	220	312	134	104	306	215	101

Table A.7.12.1 Body weights and lengths,tissue water and lipid contents in fish from Paione Inferiore Lake.

	1(59)*	2(60)	3(61)	4(62)	5(63)	Mean	s.d.
Body:							
weight (g)	212.6	146.9	167.8	261.9	216.6	201.2	45.0
length (cm)	22.0	24.5	23.0	24.0	24.0	23.5	1.00
Tissue:							
water (%)	75.0	76.3	82.7	74.5	75.5	76.8	3.37
lipid (%)	0.94	0.61	0.83	0.94	1.16	0.90	0.20
Sex:					Female		

*Original fish code between brackets

Table A.7.12.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	0.13	n.d.	n.d.	0.10	0.14	0.07	0.07
HCHs							
a-HCH	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00
g-HCH	0.17	0.19	0.10	0.16	0.24	0.17	0.05
DDTs							
pp'-DDE	2.88	3.45	0.90	1.89	2.61	2.35	0.98
pp'DDD	0.87	n.d.	0.06	0.13	0.50	0.31	0.37
op'-DDT	n.d.	0.12	0.04	0.07	0.24	0.09	0.09
pp'-DDT	0.34	0.33	0.12	0.38	0.17	0.27	0.12
PCB no.							
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00
52	n.d.	n.d.	n.d.	n.d.	0.82	0.16	0.37
101	0.35	0.39	0.12	0.10	0.32	0.26	0.14
118	1.03	0.47	0.17	0.40	0.71	0.56	0.33
153	1.56	1.90	0.47	0.85	1.56	1.27	0.59
138	1.64	2.03	0.40	1.01	1.22	1.26	0.62
180	1.43	1.66	0.51	0.91	1.33	1.17	0.46
PCBs TOTAL	6.01	6.45	1.67	3.27	5.96	4.67	2.50

Table A.7.12.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	13.6	n.d.	n.d.	10.5	11.6	7.16	6.63
HCHs							
a-HCH	0.00	0.00	0.00	0.00	0.00	0.0	0.0
g-HCH	18.1	31.1	12.0	17.0	20.7	19.8	7.08
DDTs							
pp'-DDE	306	566	108	201	225	281	174
pp'-DDD	92.8	0.00	6.87	14.3	42.7	31.3	38.0
op'-DDT	0.00	19.2	5.18	6.91	20.8	10.4	9.11
pp'-DDT	36.2	54.1	14.5	40.4	14.7	32.0	17.2
PCB no.							
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.0
52	n.d.	n.d.	n.d.	n.d.	70.7	46.9	31.6
101	37.2	63.9	14.5	10.6	27.6	30.8	21.3
118	110	77.0	20.5	42.6	61.2	62.2	33.9
153	166	311	56.6	90.4	134	152	98.5
138	174	333	48.2	107	105	154	110
180	152	272	61.4	97	115	139	81.1
PCBs TOTAL	639	1057	201	348	514	585	376

Table A.7.13.1 Body weights and lengths,tissue water and lipid contents in fish from Lungo Lake.

	1	2	3	4	5	6	Mean	s.d.
Body:								
weight (g)	69.6	78.6	69.5	123.5	120.6	124.1	97.7	27.7
length (cm)	16.5	17.5	17.0	22.0	20.4	21.5	19.2	2.43
Tissue:								
water (%)	78.3	69.9	78.1	75.3	79.1	78.2	76.5	3.47
lipid (%)	0.80	1.56	1.72	1.54	0.74	0.87	1.21	0.45
Sex:					Female	Female		

Table A.7.13.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	0.033	0.051	0.036	0.036	0.041	0.033	0.038	0.007
HCHs								
a-HCH	0.010	0.030	0.020	0.040	0.020	0.040	0.027	0.012
g-HCH	0.10	0.15	0.15	0.44	0.21	0.17	0.20	0.12
DDTs								
pp'-DDE	43.2	27.1	86.1	67.7	53.3	41.5	53.1	21.0
pp'-DDT	1.86	2.63	2.22	5.24	11.75	4.32	4.67	3.70
PCB no.								
28+31	0.43	0.65	0.87	4.13	1.82	2.79	1.78	1.45
52	2.61	1.80	2.24	5.56	2.52	5.21	3.32	1.63
101	0.43	0.66	0.74	4.02	1.03	1.49	1.40	1.34
118	1.59	5.44	9.08	6.30	7.77	4.59	5.80	2.62
153	4.85	2.69	7.97	7.51	4.37	4.32	5.29	2.04
138	3.88	2.51	5.97	5.86	3.45	3.43	4.18	1.41
180	3.39	1.38	5.19	4.43	2.47	0.81	2.95	1.71
PCBs TOTAL	17.2	15.1	32.1	37.8	23.4	22.6	24.7	12.2

Table A.7.13.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	4.08	3.25	2.10	2.33	5.52	3.80	3.51	1.26
HCHs								
a-HCH	1.81	2.07	1.20	2.39	3.02	4.14	2.44	1.03
g-HCH	12.4	10.2	9.4	29.3	26.8	17.1	17.5	8.60
d-HCH	2.90	2.38	0.86	2.83	3.84	5.57	3.06	1.57
DDTs								
pp'-DDE	5390	1739	5011	4401	7237	4746	4754	1780
pp'-DDT	233	169	129	341	1596	494	494	556
PCB no.								
28+31	54.0	42.1	50.6	269	247	320	164	128
52	326	115	130	361	342	596	312	177
101	54.0	42.2	43.0	261	140	170	119	89
118	199	350	529	410	1056	526	512	294
153	606	173	464	489	594	495	470	157
138	485	161	348	381	468	393	373	116
180	424	88.5	302	288	336	92.4	255	136
PCBs TOTAL	2148	972	1867	2459	3183	2593	2204	1096

Table A.7.14.1 Body weights and lengths,tissue water and lipid contents in fish from Di Latte Lake.

	1	2	3	4	5	6	Mean	s.d.
Body:								
weight (g)	47.0	28.2	30.2	29.3	38.5	38.2	35.2	7.3
length (cm)	14.5	13.0	13.5	13.5	15.0	15.5	14.2	0.98
Tissue:								
water (%)	73.9	73.9	78.4	79.1	77.2	78.9	76.9	2.41
lipid (%)	2.78	5.75	3.07	4.75	4.11	3.83	4.05	1.10
Sex:	Female					Female		

Table A.7.14.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	0.27	0.59	n.d .	3.82	0.06	0.35	0.849	1.469
HCHs								
a-HCH	0.09	0.11	n.d.	n.d.	0.10	0.24	0.09	0.09
g-HCH	0.57	0.38	0.15	0.93	0.30	2.36	0.78	0.82
DDTs								
op'-DDE	0.67	1.67	0.78	0.57	n.d.	n.d.	0.61	0.62
pp'-DDE	86.8	125	274	104	208	206	167	73.2
pp'-DDD	13.5	41.9	34.5	11.5	19.5	26.2	24.5	12.0
pp'-DDT	3.69	19.7	7.88	6.85	7.74	7.09	8.83	5.54
PCB no.								
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00
52	3.07	1.09	1.45	0.54	0.65	3.92	1.79	1.39
101	1.36	1.85	2.39	0.76	2.70	4.38	2.24	1.26
118	2.41	2.59	4.22	1.52	n.d.	n.d.	1.79	1.64
153	9.38	9.52	29.8	5.34	28.7	23.3	17.7	10.8
138	6.73	6.22	23.1	6.74	21.2	15.2	13.2	7.72
180	5.61	5.27	13.9	6.10	12.5	10.8	9.03	3.82
PCBs TOTAL	28.6	26.5	74.9	21.0	65.7	57.6	45.7	26.7

Table A.7.14.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	6	Mean	s.d.
HCB	9.86	10.3	0.00	80.3	1.48	9.22	18.5	30.6
HCHs								
a-HCH	3.24	1.91	0.00	0.00	2.43	6.27	2.31	2.34
g-HCH	20.50	6.61	4.89	19.58	7.30	61.62	20.1	21.45
DDTs								
op'-DDE	24.0	29.1	25.3	11.9	n.d.	n.d.	15.1	13.0
pp'-DDE	3123	2180	8932	2194	5061	5366	4476	2581
pp'-DDD	487	728	1124	242	474	684	623	300
pp'-DDT	133	343	257	144	188	185	208	79
PCB no.								
28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
52	110	19.0	47.2	11.4	15.8	102	51.0	44.8
101	48.9	32.2	77.9	16.0	65.7	114	59.2	35.0
118	86.7	45.0	137	32.0	0.0	0.0	50.2	53.6
153	337	166	971	112	698	609	482	335
138	242	108	753	142	515	396	360	247
180	202	91.7	451	128	305	283	243	131
PCBs TOTAL	1027	462	2438	442	1599	1504	1245	846

Table A.7.15.1 Body weights and lengths,tissue water and lipid contents in fish from Schwarzee ob Sölden Lake.

	1	2	3	Mean	s.d.
Body:					
weight (g)	78.8	122.6	78.8	93.4	25.3
length (cm)	20.3	22.0	20.4	20.9	0.95
Tissue:					
water (%)	68.3	71.5	72.5	70.8	2.19
lipid (%)	6.00	3.00	4.30	4.43	1.50
Sex:	Female	Female	Female		

Table A.7.15.2 Concentration of organochlorinated compounds (ng/g wet weight)

	1	2	3	Mean	s.d.
HCB	2.10	0.97	1.63	1.57	0.57
HCHs					
a-HCH	0.13	0.05	0.11	0.10	0.04
g-HCH	0.26	0.09	0.26	0.20	0.10
DDTs					
pp'-DDE	58.3	184	111	118	63.1
pp'-DDT	4.37	1.62	14.2	6.73	6.61
PCB no.					
28+31	0.40	0.32	0.44	0.39	0.06
52	0.21	0.07	0.47	0.25	0.20
101	0.56	0.40	1.64	0.87	0.67
118	1.76	0.73	4.88	2.46	2.16
153	10.9	4.95	35.7	17.2	16.3
138	9.68	4.93	33.7	16.1	15.4
180	5.69	3.34	18.8	9.26	8.31
PCBs TOTAL	29.2	14.7	95.6	46.5	43.1

Table A.7.15.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	Mean	s.d.
HCB	34.9	32.0	37.7	34.9	2.86
HCHs					
a-HCH	2.24	1.67	2.60	2.17	0.47
g-HCH	4.31	3.09	6.11	4.50	1.52
DDTs					
pp'-DDE	971	1039	2576	1529	908
pp'-DDT	72.8	53.4	329	152	154
PCB no.					
28+31	6.70	10.4	10.2	9.08	2.07
52	3.51	2.14	10.9	5.52	4.71
101	9.36	13.3	38.1	20.2	15.5
118	29.4	24.0	113	55.4	49.8
153	182	163	825	390	377
138	161	162	780	368	357
180	94.8	110	434	213	192
PCBs TOTAL	487	485	2212	1061	998

Table A.7.16.1 Body weights and lengths,tissue water and lipid contents in fish from Zielony Staw Lake.

	1(64)*	2(65)	3(66)	4(67)	5(68)	Mean	s.d.
Body:							
weight (g)**							
length (cm)	20.5	19.0	20.5	19.0	21.5	20.1	1.08
Tissue:							
water (%)							
lipid (%)	0.55	1.77	2.35	1.89	1.64	1.64	0.67
Sex:				Female			

* Original fish code between brackets

** Fish weight has not been measured since these fish have been received partly dissecated.

Table A.7.16.2 Concentration of organochlorinatedcompounds (ng/g wet weight)

	1	2	3	4	5	Mean	s.d.
HCB	0.04	0.05	0.05	0.10	0.06	0.06	0.02
HCHs							
a-HCH	0.01	0.01	0.01	0.02	0.02	0.01	0.01
g-HCH	0.10	0.05	0.16	0.16	0.15	0.12	0.05
d-HCH	0.012	0.005	0.015	0.017	n.d.	0.01	0.01
DDTs							
pp'-DDE	4.62	7.34	12.34	6.6	10.54	8.29	3.11
pp'-DDT	0.15	1.24	0.21	1.76	0.84	0.84	0.69
PCB no.							
28+31	1.31	0.50	1.05	1.25	0.58	0.94	0.38
52	1.55	1.21	2.07	0.74	0.56	1.23	0.61
101	0.14	0.24	0.36	0.31	0.38	0.29	0.10
118	0.45	0.22	1.37	0.73	1.10	0.77	0.47
153	0.77	1.24	2.64	1.09	1.76	1.50	0.73
138	0.55	0.99	2.16	0.87	1.53	1.22	0.63
180	1.12	1.46	2.61	0.90	1.64	1.55	0.66
PCBs TOTAL	5.89	5.86	12.26	5.89	7.55	7.49	3.58

Table A.7.16.3 Concentration of organochlorinated compounds (ng/g lipid weight)

	1	2	3	4	5	Mean	s.d.
HCB	6.96	2.76	1.96	5.15	3.42	4.1	2.0
HCHs							
a-HCH	2.59	0.55	0.51	1.31	1.00	1.19	0.85
g-HCH	18.3	2.83	6.86	8.51	9.45	9.20	5.70
d-HCH	2.14	0.28	0.64	0.91	n.d.	0.79	0.83
DDTs							
pp'-DDE	845	414	525	350	643	555	197
pp'-DDT	26.5	69.7	9.00	93.1	51.1	49.9	33.4
PCB no.							
28+31	240	28.2	44.9	66.1	35.7	83.0	88.9
52	283	68.0	88.1	39.1	33.9	102	103
101	25.9	13.8	15.5	16.3	23.4	19.0	5.3
118	82.9	12.1	58.3	38.5	67.1	51.8	27.3
153	140	69.9	112	57.5	108	97.5	33.5
138	100	55.6	91.9	46.3	93.4	77.5	24.7
180	205	82.3	111	47.7	100	109	58.7
PCBs TOTAL	1077	330	522	311	461	540	342

Table A.7.17. Statistics. Results of (partial) RDA of the fish-heavy metal concentrations in 73 fish from 15 lakes using different sets of predictor variables and covariables.

Predictors	**Covariables**	**% Variance Explained**	**p**
Length + weight + age + sex + stage +species + locality	-	83.8	0.0004
Locality	-	78.2	0.0004
Locality	Species	66.2	0.0004
Locality	Species + sex	66.4	0.0004
Locality	Species + sex + stage + age	48.3	0.0004
Locality	Species + sex + stage + length + weight + age	44.6	0.0004

p = probability, as estimated by an exact Monte Carlo probability based on 249 unrestricted permutations.

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Chapter 5.

Sediments

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5.1 Introduction

The study of remote mountain lake ecosystems and their response to varying levels of acid deposition requires accurate historical information. The scarcity of historical chemical and biological data for the last 200 years or so means that the reconstruction of lake histories from the sediment record is an important facet of the study of these environments.

Central to the AL:PE 1 project was the use of a range of palaeolimnological methods (Cameron *et.al.* 1993). These techniques have now been applied at the AL:PE 2 lakes with the addition of analyses of major and trace element chemistry, analyses of persistent organic compounds and cladoceran analysis on selected sediment cores. Consistent with the main objectives of the AL:PE 2 project, physical analyses (SCP, major and trace element chemistry, POC) were used to compare the levels and histories of deposition of pollutants at each of the lakes. An independent sediment chronology was established using radiometric dating, and analyses of diatom, chironomid and cladoceran remains in sediment cores were used to assess the impacts of environmental change on the lake ecosystems.

The parallel analyses of both pollutants or pollution markers along with the remains of living organisms has allowed us to examine the timing, extent and causes of acidification. In addition the analysis of a wider range of long range transported air pollutants has enabled us to assess the level of contamination by non-acidifying anthropogenic compounds. It is now possible to identify remote lakes and regions within Europe with relatively high, moderate and low levels of atmospheric pollution. The next stage of the work will be to concentrate research on selected lakes suitable for the study of climatic change and for the evaluation of contemporary sedimentary and pollution processes.

5.2 Methods

The analytical methods for lithostratigraphic, radiometric, SCP, diatom and chironomid analyses are detailed in earlier reports (Cameron *et.al.* 1993, Wathne *et.al.* 1995). The sediment coring technique was modified only to use a wide diameter (7.4 cm) Glew corer in order to retrieve a greater volume of sediment per sediment slice and provide enough sediment from a single core for all analyses. The development of the surface sediment diatom/lakewater chemistry training set is discussed the chapter by H.J.B. Birks on statistical analysis.

Cladoceran remains from the lakes Starolesnianske and Terianske were identified and counted by Miroslava Prazakova (Prague). The method of handling the sediment samples, producing stained remains in permanent mounts, is described by Prazakova & Fott (1994). Anton Brancelj (Ljubljana) analysed Cladocera in the core from Zgornje Krisko Jezero. The counts are expressed per gram wet weight of the sediment. In addition in the AL:PE 2 programme cladoceran analysis was carried out (Frey 1976, 1988, Nilssen & Sandoy 1990, Uimonen-Simola & Tolonen 1987, Whiteside & Swindoll 1988). An attempt was made to compare the contemporary cladoceran fauna with the sediment record, in order to look for evidence for very recent changes in the community that may have been caused by anthropogenic acidification or other transport of pollutants. Remains of Cladocera in sediment cores of three lakes (Starolesnianske pleso, Terianske pleso and Zgorne Krisko jezero were analysed.

5.3 Analytical Summary

i) Spheroidal Carbonaceous Particles (SCPs). Analyses on 31 AL:PE 1 and 2 lake sediment cores including back-up sites (see Figure 1).

ii) Major and trace element chemistry. Analyses of Al, Fe, Mn, Mg, Ca, Na, K, Ti, Cd, Cr, Co, Cu, Ni, Pb, V and Zn on 12 AL:PE 2 lake sediment cores. Also, dry weight and loss-on-ignition analysis.

iii) Persistent organic compounds (POC). Analyses of the following organic species on 10 AL:PE 2 lake sediment cores.

- Total organic carbon
- n-alkanes: from n-tetradecane to n-tritriacontane, pristane and phytane
- Polycyclic aromatic hydrocarbons (PAH): fluorene, phenanthrene, anthracene, fluoranthene, acephenanthrylene, pyrene, benzo[a]fluorene, benzo[ghi]fluoranthene, cyclopenta[cd]pyrene, benz[a]anthracene, chrysene + triphenylene, benzo[b+j]fluoranthene, benzo[k]fluoranthene, benzo[a]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, indeno[7,1,2,3-cdef]chrysene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, dibenz[aj]anthracene, dibenz[ah]anthracene, dibenz[ac]anthracene, benzo[b]chrysene, coronene.
- Methyl-PAH derivatives: 4-methylphenanthrene, 3-methylphenanthrene, 2-methylphenanthrene, 1-methylphenanthrene, 4H-cyclopenta[def]phenanthrene, dimethylphenanthrenes (10 individual isomers), retene, methylfluoranthene/pyrenes (7 individual isomers).
- Sulphur PAH (S-PAH) derivatives: naphto[1,2-b]thiophene, dibenzothiophene, naphto[2,1-b]thiophene, 4-methyldibenzothiophene, 3+2-methyldibenzothiophene, 1-methyldibenzothiophene, benzo(b)naphto[2,1-d]thiophene, benzo(b)naphto[1,2-d]thiophene, benzo(b)naphto[2,3-d]thiophene.
- Organochlorinated compounds: Hexachlorobenzene, pp'-DDE, polychlorobiphenyls (Congener Nos. 28+31, 52, 101, 118, 153, 138 and 180).

iv) Radiometric dating on 19 AL:PE 1 and 2 sediment cores. Analysis for $^{210}\mathrm{Pb}$, $^{137}\mathrm{Cs}$, $^{134}\mathrm{Cs}$ and $^{241}\mathrm{Am}$.

v) Diatom analysis & pH reconstruction

vi) Chironomid head capsule analysis on selected cores

vii) Cladoceran analysis on selected cores

viii) Lithological analyses: wet density, percentage dry weight (%DW), percentage loss on ignition (%LOI)

5.4 Site and Regional summaries

a) Svalbard

Sediment cores were taken from 3 sites in the north-west of Svalbard in 1993 (Figure 2). Arresjøen (79°40'N, 10°45'E) on the island of Danskøya and Birgervatnen (79°48'N, 11°38'E) and Scurvy Pond

Table 5.1. Summary of AL:PE 2 study lakes, their records of atmospheric contamination and pH changes.

Lake	Ca μeq^{l-1}	S dep. gm^{-2}a^{-1}	max SCP flux cm^{-2}a^{-1}	ϰpH meas	ΔpH recon. [SWAP]	Onset of change
Arresjoen	35	0.17	1.3	5.81	6.7-6.0	pre-industrial
Chuna	70	0.4	-	6.56	stable, varies from 6.1-6.3	no dates available, but stable
Øvre Neadalsvatn	19	0.24	12	6.20	stable, varies from 6.0-6.1 [5.2-5.1]	stable
Stavsvatn	44	0.55	17	5.94	5.9-5.6 [6.0-5.0]	1860
Lochnagar	30	0.47	700	5.40	5.8-5.4 [5.5-5.0]	1850
Lough Maam	37	0.50	119	5.04	5.8-5.2	1900
La Caldera	197	-	65	8.04	7.5-7.3-8.0	gradual pH decline pre 20th century to c. 1990. Sharp pH increase to present
Laguna Cimera	30	-	190	6.18	6.1-6.2	stable
Lagoa Escura	15	-	165	5.32	5.6-5.5 decline at surface 5.3	stable, decline in 1990s may not be real
Etang d'Aube	30	-	125	6.10	6.0-5.9 [5.3-5.2]	stable
Laguna Redo	77	1.12	73	5.54	6.8-6.6, 6.6-6.4	pre 1850, mid 19th century
Paione Superiore	47	0.50	4000	5.65	5.8-6.0-5.6 [5.1-5.2]	1940s
Lac Noir	142	-	-	7.18	7.0-7.2/7.3	stable but slight increase since c.1900
Zgornje Krisko Jezero	524	0.04	4031	7.86	7.5-7.3	slight decline since 1960s, not related to atmospheric deposition
Milchsee (Lago di Latte)	94	0.53	350	6.55	variable 6.5-7.0 [minimum 5.7, maximum 6.8]	not related to atmospheric deposition
Schwarzee ob Solden	51	-	low, 2 levels only	5.56	5.9-5.7	1920
Starolesnianske Pleso	39	3.69	-	4.79	variable 5.1-5.2, decline to 5.0 at surface	pH decline since 1970s
Terianske Pleso	159	2.65	178	6.86	6.9-6.6-6.8	decline in 1950s
Dlugi Staw	109	2.60	248	5.78	very variable 6.9-5.4	no trends apparent
Zielowny Staw	154	2.60	607	6.88	6.7-6.8, 6.9 at sediment surface	slight increase to sediment surface from 1950s

(79°43'N, 12°20'E) on the main island. Spheroidal carbonaceous particle (SCP) analyses were undertaken on all primary cores, major and trace element chemistry and analyses for persistent organic compounds (POC) were undertaken on the Arresjøen core only. A summary diagram is shown in Figure 2. Full analytical diagrams for chemistry and organics are given in Annex Figures 1-6. Diatom analysis and pH reconstruction was carried out on the Arresjoen core only (Figure 2a) Lithostratigraphic analyses for Arresjoen, Birgervatn, and Scurvy Pond are shown in Annex B Figures 1-7.

The Svalbard sites are by far the furthest north and most remote from any pollution source in the dataset. They show the lowest SCP, trace metal and POC concentrations.

Arresjøen

The lake was found to have a simple single basin and four cores ARSJ93/1 - ARSJ93/4 were taken from the deepest area (28 - 31 m), the recovery of sediment ranged from 15-36 cm. The results (Annex Figures 1-4) show that these cores share similar lithostratigraphic features, with an increase in percentage loss on ignition (%LOI) from about 10% to 20% towards the sediment surface. This change is accompanied by a decrease in the % dry weight (%DW) and the wet density (WD). Other features are shared by some of the cores eg. a sub-surface peak in %DW is seen in cores ARSJ93/2 (2.25 cm), ARSJ93/3 (5.25 cm) and in ARSJ93/4 (4.25 cm), this peak, and others lower down the cores probably reflect synchronous events. On the basis of its undisturbed core top with chironomid tubes present, overall length, and compatible lithostratigraphic features core ARSJ93/4 (taken in 29 m of water) was chosen as the 'mastercore' for palaeolimnological analyses.

The Arresjøen ARSJ93/4 core is the only one in the Svalbard group with ^{210}Pb dating and the core shows a very low SCP surface flux (1.3 cm^{-2} yr^{-1}). It is also the only Svalbard site with a surface decline in SCP concentration but this may be due to the low sediment weight available. An undated core from Arresjøen was also analysed for SCP using higher sediment weights and showed no surface decline. Instead, the concentrations levelled off towards the surface at 1060 - 1070 SCP per gram dry mass sediment (gDM^{-1}).

The results from the major and trace element chemistry are not easy to interpret. While the ^{210}Pb results preclude major changes in sedimentation rate, the concentrations are so low, and the relative noise is so great that the interpretation is questionable. Over the 300 year period covered by the core, there is a steady increase in organic content (shown as loss-on-ignition (LOI)) and corresponding fall in mineral matter (Annex Figure 1a). In the top 1 - 2 cm there is a sharp, probably diagenetic, increase in Fe and Mn, and in the top sample there is elevated Pb, Cu, Cd and Zn. The increase is not entirely confined to the top sample however, Pb and Zn fluxes show some evidence of elevated values down to a depth of 1.5 - 2 cm (1900-1920). This is not obvious for any of the other metals. Elevated Cd concentrations occur at a depth suggesting the middle of the last century, and there is no sign of any other metal enrichments at the same depth.

The POC results are summarized in Tables 1-5 (Annex). Total organic carbon (TOC) values are 4-6%. The n-alkane concentrations are low with a maximum concentration of 80 µg/g (Annex Figure 2). The ΣPAH concentrations are relatively low with a maximum of 300 ng/g at the surface. The PAH profile shows a regular increase starting at about 1910 (as do SCP and Pb) and the profile of PAH especially sulphur containing PAH (S-PAH) is similar to that of SCP suggesting the influence of deposition from fossil-fuel combustion. PAH are related to sub-micron particles and show a low concentration `tail' on the profile below the lowest depths of the SCP profile. This suggests that fossil-fuel combustion emissions were being deposited at the lake before the start of the SCP record. (See General Discussion). The POC results for Arresjøen are the lowest of the whole AL:PE dataset. The PAH concentrations are

Figure 2 Svalbard, summary of atmospheric contamination

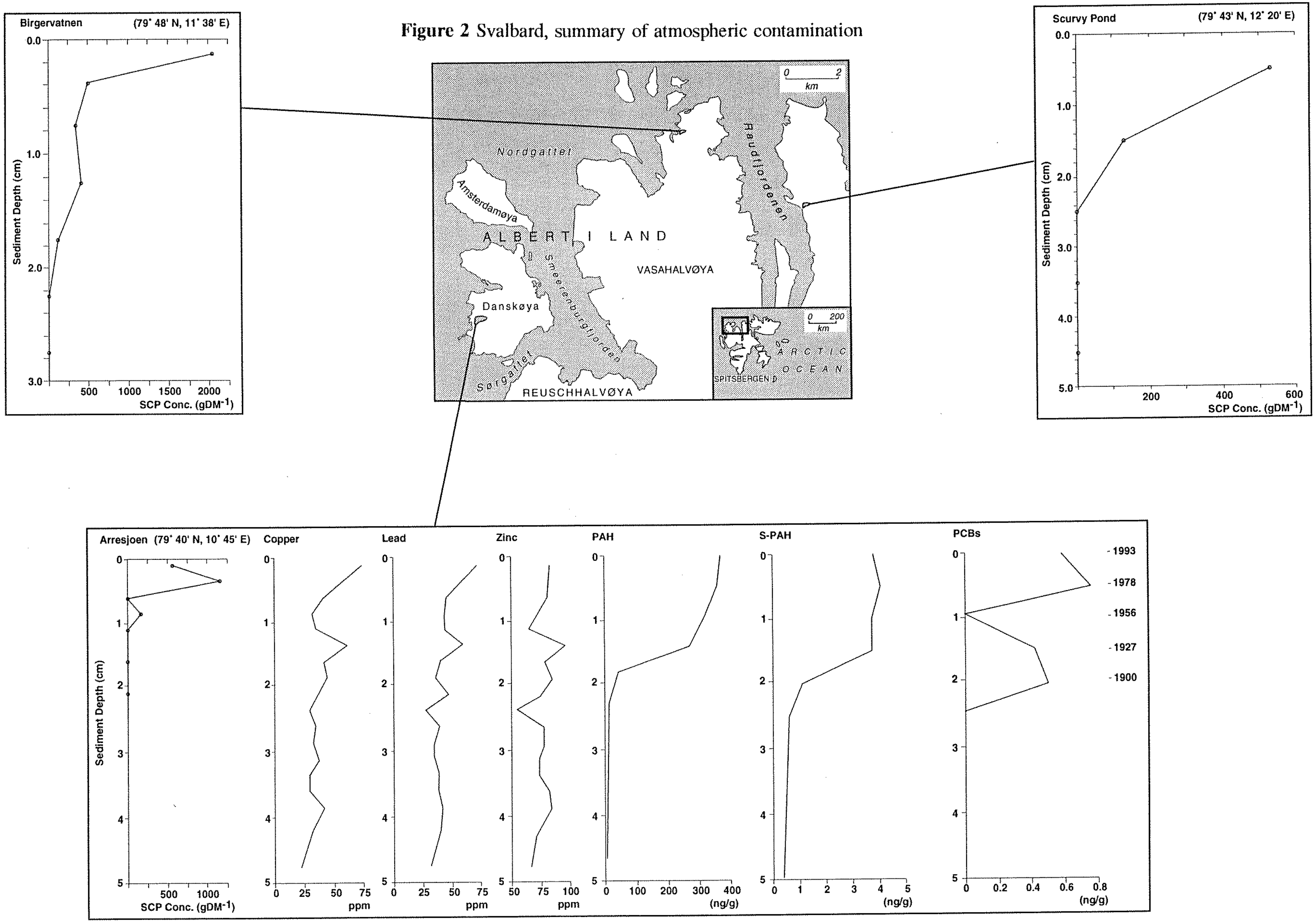
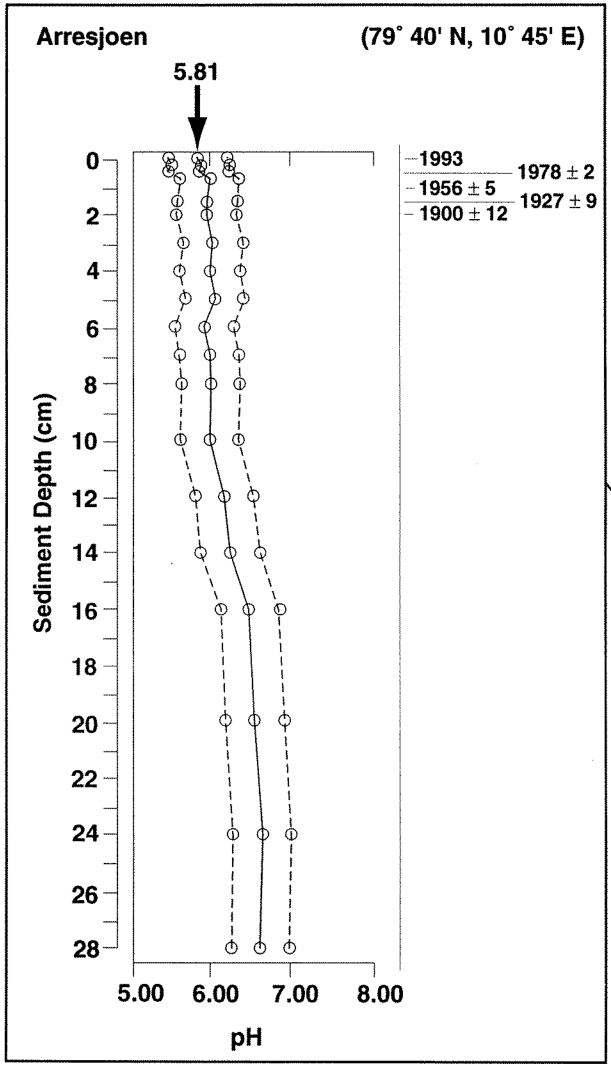
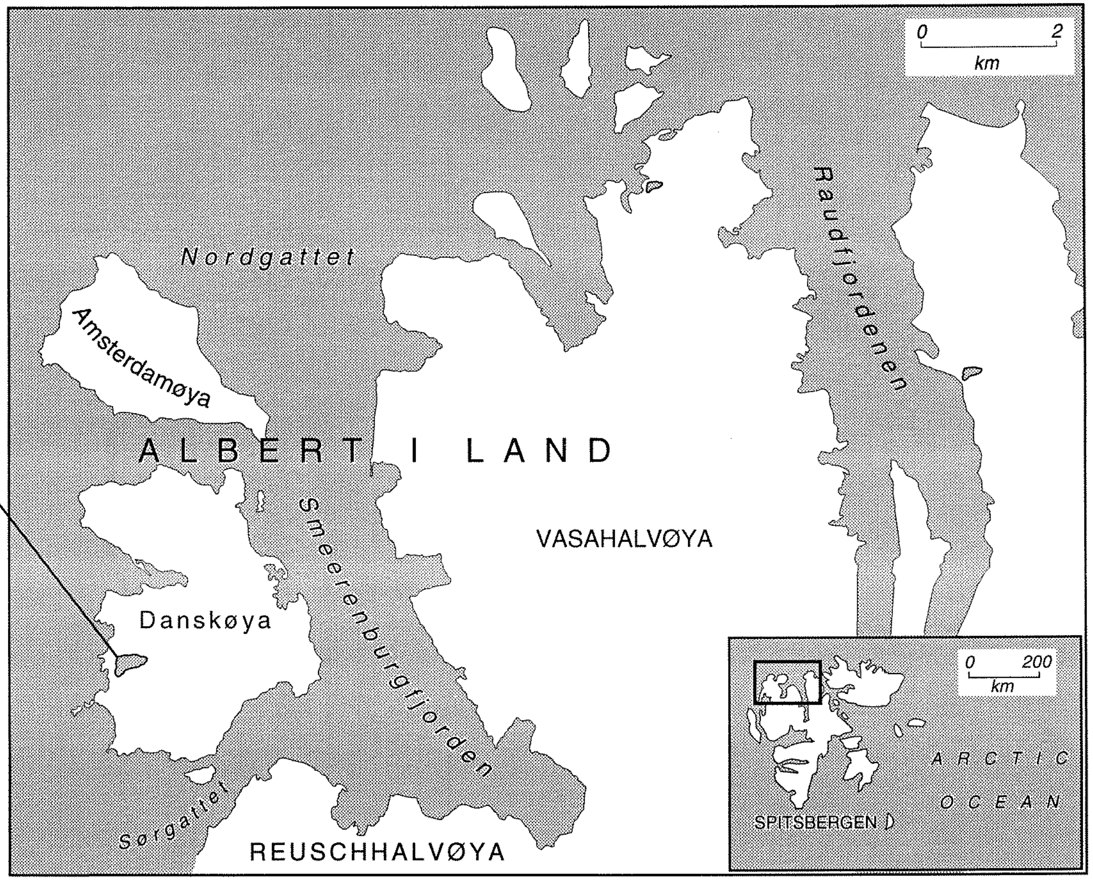


Figure 2a Arresjoen, reconstructed pH





5.4c

among the lowest (maximum concentration 380 ng/g) but when these concentrations are transformed into deposition fluxes (0.72 ng/cm^2/yr) they are the lowest of all the studied lakes. This is exactly the same as for the SCP data (see Spatial Patterns below).

The concentrations of organochlorinated hydrocarbons are rather low, particularly the PCB (< 1 ng/g) and this is close to the limit of detection (Annex Figure 4). The most abundant organochlorinated compound is HCB with maximum concentration of 1.7 ng/g (1920's) (Annex Figure 6). PCB and pp'DDE also show a peak at this time but both show a higher peak at 0.5cm (ca. 1978). The concentrations of organochlorinated compounds are already the lowest of the whole lake dataset even without transformation into fluxes.

A summary diagram illustrating the most important changes in the diatom assemblages of the mastercore ARSJ93/4 is shown in Annex B Figure 8. A number of clear changes occur, the most marked of which is at about 5 cm. Below this level the centric species *Cyclotella tripartita* is important making up about 15% of the assemblage, but above 5 cm it disappears and *Aulacoseira lirata* var. *alpigena* also decreases in abundance. Above 5 cm *Achnanthes* species such as *A. curtissima*, *A. subatomoides*, *A. altaica*, *A. marginulata* and *A. scotica* increase in abundance. *Navicula* species # 1 also increases together with these *Achnanthes* species. The date of this change is unknown since it lies beyond the period covered by ^{210}Pb dating, however, if dates are extrapolated, 5 cm would date to the early 18th century. The changes which occur in the diatom flora at around 5 cm are therefore unlikely to be related to atmospheric pollution and are more likely be to be caused by local catchment effects. This hypothesis is supported by changes in the %LOI and %DW which occur at this point, there is a peak in %DW at 4.25 cm with a corresponding trough in the %LOI (Figure 4), and above 4.25 cm %DW falls to the surface sediment whilst %LOI rises from <10% to >20%. Such a dramatic change in the %LOI appears to be unique in the history of the lake represented by this core, and could be caused by a number of factors. These could include the increased erosion of organic material from the catchment, or the increased *in situ* production of organic material. *Cyclotella* species are known to be sensitive to changes in water turbidity, and catchment erosion events can lead to increases in turbidity which has a detrimental effect on planktonic diatom species such as *Cyclotella*. Changes in the diatom assemblage are also evident further down the profile, one of the most marked of which is the increase in abundance of *Aulacoseira distans* var. *nivalis* above 12 cm. Below 16 cm a number of species are more important than in levels above 16 cm, these include *Navicula schassmannii*, *Fragilaria pinnata*, *Fragilaria pseudoconstruens*, *Pinnularia balfouriana* and *Achnanthes suchlandtii*, below 16 cm *A. lirata* var. *alpigena* is less abundant. However, some species maintain very stable abundances throughout the profile eg. *Stauroneis anceps* f. *gracilis* and *Pinnularia biceps*. The diatom-based pH reconstruction for Arresjoen (Figure 2a) reflects the changes in diatom assemblages in the middle part of the core. pH declines steadily from 6.7 to 6.6 in the basal levels of the core (28-16 cm) to 6.0 at the surface. Total diatom concentrations (Annex B Figure 9) show a relatively steady decline from the base of the core to the surface sediment. This appears to be largely a consequence of the higher water content in the top of the core (Annex B Figure 4), but it may also be associated with higher sediment accumulation rates at the top of the core. These changes pre-date the initiation of the background levels of atmospheric deposition

Annex B Figure 10 shows the numbers of chironomid head capsules and taxa found in the core from Arresjøen. A total of 6 taxa were found. Most taxa were present at all levels in the core. There is a trend up-core where the relative abundance of *Micropsectra insignilobus* decreases, while *Micropsectra radialis* increases (Annex B Figure 11). *Oliveridia tricornis* was not found in the bottom sample, while *Orthocladius* (*Pogonocladius*) *consobrinus* was found only in the bottom sample. The core was taken at the deepest point of the lake, where no chironomid larvae were found in the surface mud samples. The replacement of *Micropsectra insignilobus* by *Micropsectra radialis* up-core probably indicates that the lake has become more oligotrophic during the investigated time period. In the samples of the recent fauna, however, *Micropsectra insignilobus* was much more numerous than *Micropsectra radialis*. This might be due to hatching of *Micropsectra radialis* at the time of sampling.

Birgervatnen and Scurvy Pond

The surface SCP concentrations of Birgervatnen (2040 gDM^{-1}) and Scurvy Pond (530 gDM^{-1}) compare well with the peak concentration of both the dated and undated Arresjøen cores (1060 & 1170 gDM^{-1} respectively). The particle sizes in all the cores are small with a diameter of <10 µm and it is well known that particles in this size range can travel thousands of kilometres (e.g. Parkin et al., 1970). It is therefore quite possible that the source of these particulates is on the Kola Peninsula if not still further afield. At 1-1.5cm in the Birgervatnen core and 1-1.25cm in the undated Arresjøen core however, SCP occur with larger diameters (25-35 µm). Unfortunately, as these large SCP do not occur in dated cores it is not possible to state whether or not this is a single 'event' occurring at the same time at both sites or if the two are unrelated. If the date for the start of both Arresjøen profiles were 1950, then this `event' would date to the late 1960's.

Regional Discussion (Atmospheric Contamination)

The SCP results for all Svalbard sites are similar both in profile and in surface concentration suggesting that contamination is real and comparable over the region. The SCP and POC, especially S-PAH agree well. Pb, Cd and Cu fluxes also compare but other metals do not. The short profiles (and possible recent metal enrichment) suggest that the low concentrations are due to low deposition rather than dilution due to rapid sediment accumulation rate at the sites.

In the dated Arresjøen core the SCP profile only extends back to 1950 but significant concentrations only exist after 1960. This date corresponds to the commissioning of the large nickel smelters at Nikel and Zapoljarnyj on the Kola Peninsula and it is known that this is one pathway for pollutants to the Arctic (Rahn & Shaw, 1982) and therefore maybe the source of fossil-fuel related pollutants (SCP, PAH) in the Svalbard sediments (Rose, 1995). EMEP budgets for airborne acidifying components in Europe suggest that the impact from the Kola Peninsula does not reach this far north and all SO_x depositions in Svalbard are "inattributable" or from biogenic emissions from the North Atlantic Ocean (Sandnes, 1993). This could not explain the results obtained here however, and the Kola Peninsula must remain the most likely source for pollutants impacting this region. It is interesting to note that Ni does not show a significant enrichment from the time of the commissioning of the Kola smelters, which might be expected, although Cu and Pb do.

b) Kola

SCP, major and trace element chemistry and POC results are not available for either Chuna and Chibini. Diatom analysis has been carried out on a single core from Chuna Lake (Annex B Figure 12). The diatom assemblages throughout the core are similar, with only minor variations in species abundances. The flora is dominated by *Brachysira brebisonii, Brachysira vitrea, Achnanthes marginulata, Frustulia rhomboides* var. *saxonica* and *Pinnularia biceps*. There are minor peaks in the abundance of *Brachysira vitrea* at 14.5 cm and 8.0 cm. and an overall increase in *Pinnularia biceps* towards the surface of the core. At present no radiometric chronology is available for the Lake Chuna core and neither is there any stratigraphic evidence of the atmospheric deposition history. There is, however, little variation in the reconstructed pH at this site, values varying from 6.3 to 6.0 pH units.

Lake Chuna.

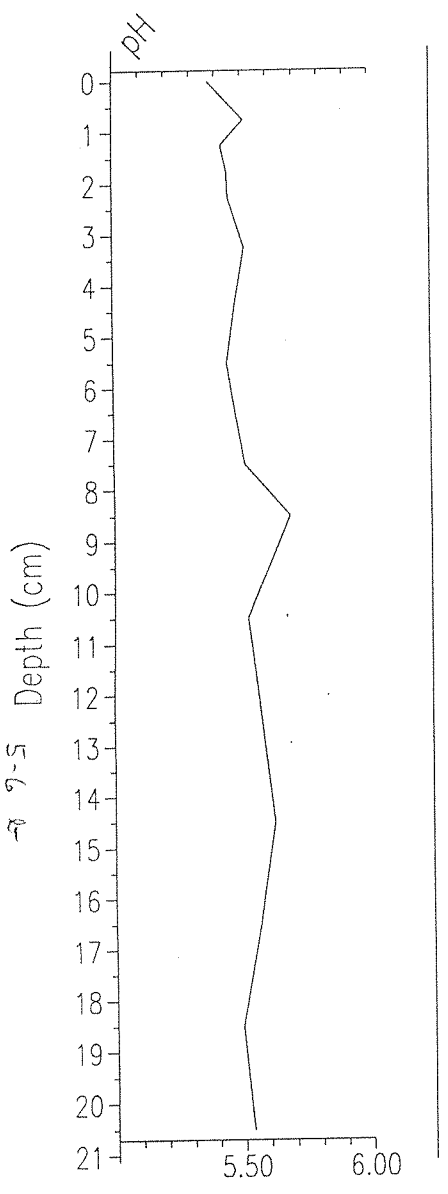


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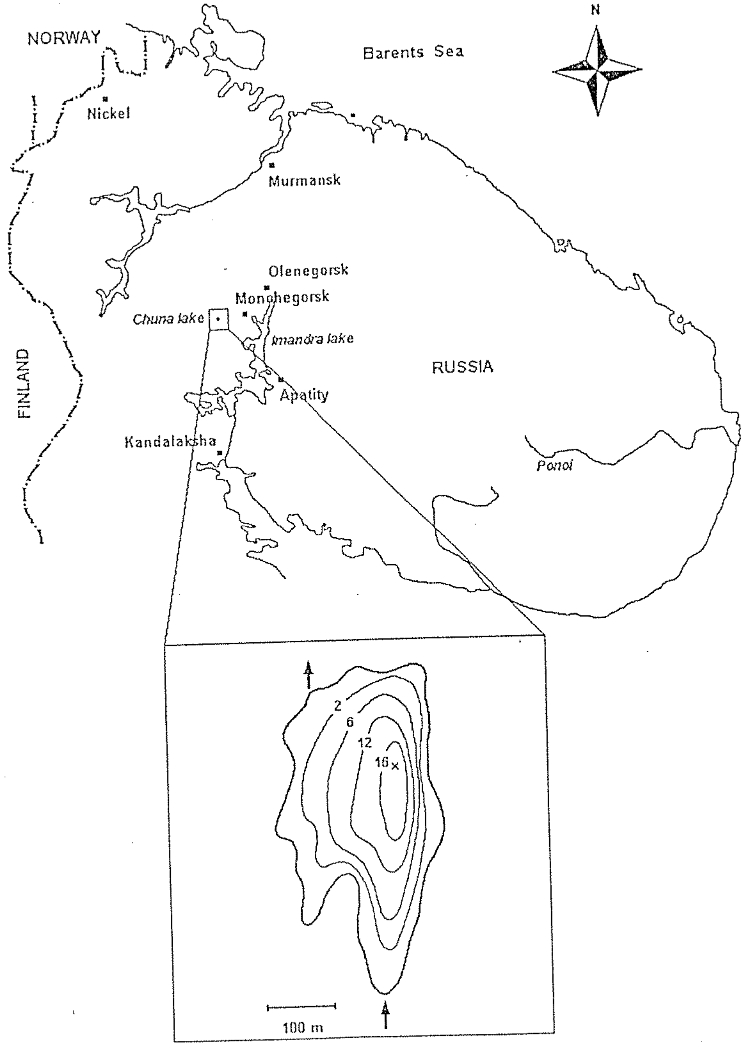
Figure 2b Lake Chuna, reconstructed pH



c) Norway

Three Norwegian sites were cored in 1991 as part of AL:PE 1 (Figure 3). Stavsvatn (59°38'N, 8°07'E) and Lille Hovvatn (58°36'N, 8°02'E) in the south and Øvre Neådalsvatn (62°46'N, 9°00'E) in mid-Norway. Evidence for atmospheric contamination was provided by SCP analysis only. No major and trace element chemistry and POC data are available for the Norwegian sites. Details of lake sediment, radiometric, diatom and chironomid analyses for Stavsvatan and Øvre Neådalsvatn are given in the AL:PE 1 report and sediment working paper (Wathne *et.al.* 1995, Cameron *et.al.*1993), together with pH reconstructions based on the SWAP dataset (Stevenson et.al. 1991).

Sites

Both Stavsvatn and Øvre Neådalsvatn sediment cores were ^{210}Pb dated and show SCP surface fluxes of 14 and 12 (cm^{-2} yr^{-1}) respectively. The Øvre Neådalsvatn profile is the shortest of the three starting in the 1930's and as might be expected from the furthest north (and AL:PE 1 reference) site, has the lowest surface SCP concentration (1,300 gDM^{-1}). It is also the only profile of the Norwegian set to show no surface decline. Other SCP profiles from mid-Norway have been produced, although these are from low altitude sites in the Høylandet area. Wik & Natkanski (1990) produced a SCP profile from Røyrtjørna showing a peak of 1,600 gDM^{-1} dated at 1969, and Rose (1991) analysed 3 cores from this area including Røyrtjørna and found that this to be the only core to show a surface decline. However, all cores showed similar surface concentrations of 1,000 - 1,500 gDM^{-1}.

The sediment diatom assemblages of Øvre Neådalsvatn show little change through time (Cameron *et.al.*1993) and reconstructed pH varies only slightly using both the SWAP (Stevenson *et.al.* 1991) and ALPE calibration sets. However, using the ALPE calibration set the estimate of present day pH is considerably improved (measured 6.20, reconstructed 6.02), compared with that derived from the SWAP dataset (5.12), (Figure 3a). The results of chironomid head capsule analysis support the evidence of diatom analysis that Øvre Neådalsvatn is not acidified.

Stavsvatn has a longer SCP record, starting in the latter half of the 19th century and increasing steadily to a peak of over 4,000 gDM^{-1} in the mid-1980's. Lille Hovvatn has a similar length profile but SCP concentrations increase rapidly at 2-3cm to a peak of nearly 50,000 gDM^{-1} at 1-1.5cm. Both cores show a surface decline. Wik & Natkanski (1990) also produced SCP profiles from sites in southern Norway, Verevatn, with a peak of 59,000 gDM^{-1} in 1970 and Åbuvatnet, only 8km away having a peak of half this concentration in the late-1960's.

There are significant changes in the diatom assemblages of Stavsvatn (Cameron *et.al.*1993), however, the differences between the reconstructed pH values and trends derived from the SWAP and ALPE training sets are large. Using the SWAP dataset, the onset of atmospheric deposition in the late 1800 s, is accompanied by a significant pH decline of 0.8 pH units, from 5.9 to 5.1 in the period to 1930. pH continues to decline from 1930 until the present resulting in a decline of about 1 pH unit. Chironomid analysis supports the diatom evidence for a significant acidification. The measured pH of Stavsvatn (5.94) is significantly different from the reconstructed pH of the surface sediment, 0 - 0.25 cm (5.00) according to the SWAP training set. Surface reconstructed pH is improved using the ALPE training set (5.60), but the overall reconstructed-pH decline is reduced to 0.3 units (5.86-5.60) (Figure 3a) and is not related to the period of atmospheric deposition. This feature is probably the result of the poor representation of the dominant species of the lower part of the core, *Cyclotella kuetzingiana*, in the ALPE training set. This planktonic species does not occur commonly in alpine lakes. Its appearance at low percentages in acid lakes probably causes an underestimation of its pH optimum and results in lower reconstructed pH values.

Figure 3 Norway, summary of atmospheric contamination

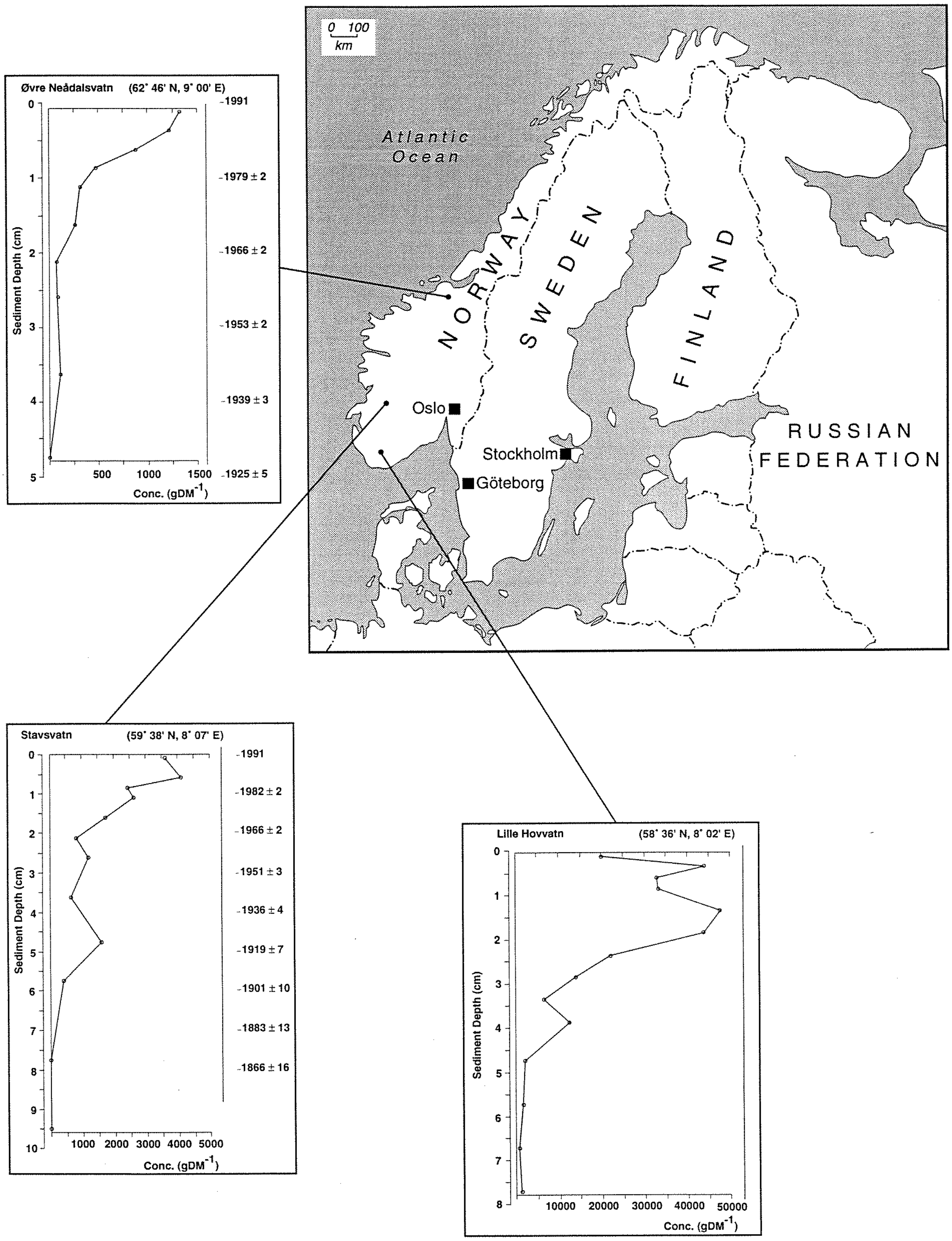
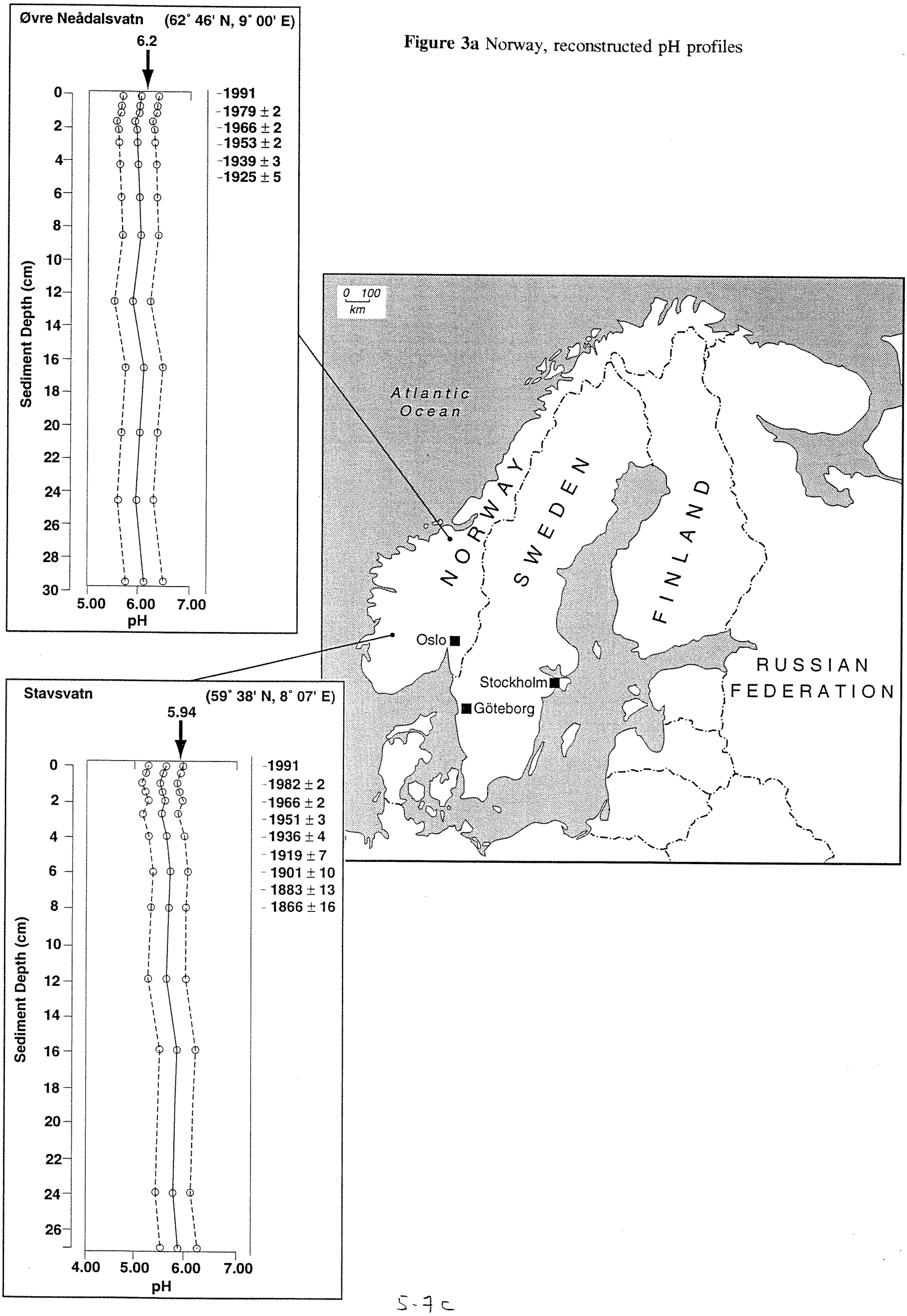


Figure 3a Norway, reconstructed pH profiles



Regional Discussion

Despite the variability in the south there is a clear south to north decrease in SCP concentration in Norway and this is consistent with expected sources of pollutants from other countries. Diatom and chironomid analyses are consistent with the north to south increase in atmospheric contamination. The EMEP model (Sandnes, 1993) predicts that for 1992 the UK was the source of 21.1% of the oxidised sulphur (SO_x as S) received by Norway, Germany 11.9% and Norway itself only 4.8%. The 3 Norwegian sites fall into different EMEP grid squares (150 km x 150 km) and the main countries impacting on each square have also been modelled. These confirm that U.K. and Germany are the main sources of atmospheric deposition at all three sites with minor inputs from a number of other European countries (including Norway). The fraction of acidifying deposition from the U.K. increases from north to south being approximately 30% in the Øvre Neådalsvatn EMEP square and 41-42% in the Stavsvatn and Hovvatn squares. The German influence remains similar (20-25%) at all sites, but is the second highest source in each case.

It might therefore be expected that Norwegian SCP profiles would follow the same trends as those from U.K. and this is clearly not the case. Although the start of the SCP record appears to be at approximately the same time in both countries (as indeed does much of Europe - see spatial patterns) the peak in Norwegian cores occurs earlier at 1969 or 1970 rather than mid-late 1970's in the U.K. (Rose et al., in press). The timing of the Norwegian SCP peak agrees with that of Norwegian SO_2 emissions even though these are low, but is later than the peak in the much larger emissions of U.K. and East Germany (mid-1960's). The peak in emissions from West Germany are of similar magnitude to those of U.K. and East Germany but occur later, in the mid-1980's. The reason for the timing of the Norwegian peak is therefore uncertain although it is likely to be a combination of the two sources.

Meteorological stations are located close to both Stavsvatn (Dalen i Telemark - 59°27'N, 8°00'E) and Øvre Neådalsvatn (Gjermundes - 62°37'N, 7°10'E) and long term wind direction data support transboundary origins for pollutants. The dominant wind direction all year for Stavsvatn is north of west and to a lesser extent west. Winds from the south-east are more frequent between March and August but never dominate the westerlies. At Øvre Neådalsvatn the prevailing wind direction is west of south between September and April and north of west between May and August. These suggest that airborne pollutants are probably carried mainly from the west i.e. U.K. and to a lesser extent from the south i.e. central Europe. Further work (e.g. SCP characterisation) would be needed to determine to what extent changes in the proportions of pollutant source have occurred at these sites.

Diatom and chironomid analyses from the Norwegian cores therefore accord with the levels of atmospheric deposition at the northern and southern sites. Despite the sensitivity of Øvre Neådalsvatn, the lake remains non-acidified as a result of the relatively low levels of deposition. The acidification of Stavsvatn is apparent from the pH profile reconstructed using the SWAP training set. Using the ALPE training set reconstructed pH at the base of the core is underestimated and the magnitude of pH change is also underestimated as a result. This inconsistency with lake sensitivity and level of atmospheric deposition probably results from the poor representation in the ALPE training set of the dominant taxon of the basal part of the core.

d) British Isles

Two lake sites were studied, Lochnagar (56°57'N, 3°13'W) in the Cairngorm mountains of Scotland and Lough Maam (55°00'N, 8°07'W) in Co. Donegal in the north-west of the Republic of Ireland (Figure 4). Cores from both sites were ^{210}Pb dated. Both were analysed for SCP, but neither was analysed for either major and trace element chemistry or POC. Diatom analysis, radiometric dating and lithological analyses are reported fully in Cameron *et.al.* 1993

In the past, many sediment cores have been analysed for SCP in the UK and in Ireland and generally the trends in the profiles of Lochnagar and Lough Maam reflect those seen in other cores in these countries. The SCP record in Lochnagar begins in the mid-19th century and a peak concentration of 3,500 gDM^{-1} occurs in 1978 at the same time as the peak seen throughout Scotland (Rose et al., in press). The rapid increase, however, occurs slightly later than is usual, in the late 1960's. The EMEP model predicts that the majority (>80%) of the pollutants deposited in this EMEP square are of U.K. origin with small contributions from other European countries including some from eastern Europe (Poland, Czech Republic). The HARM model (S. Metcalfe pers. comm.) suggests a larger non-UK component to the deposition at Lochnagar and predicts that the largest sources of U.K. deposition are the coal fired power stations in Yorkshire, England (Drax, Ferrybridge, Eggborough, West Burton) and on the Firth of Forth in southern Scotland (Longannet).

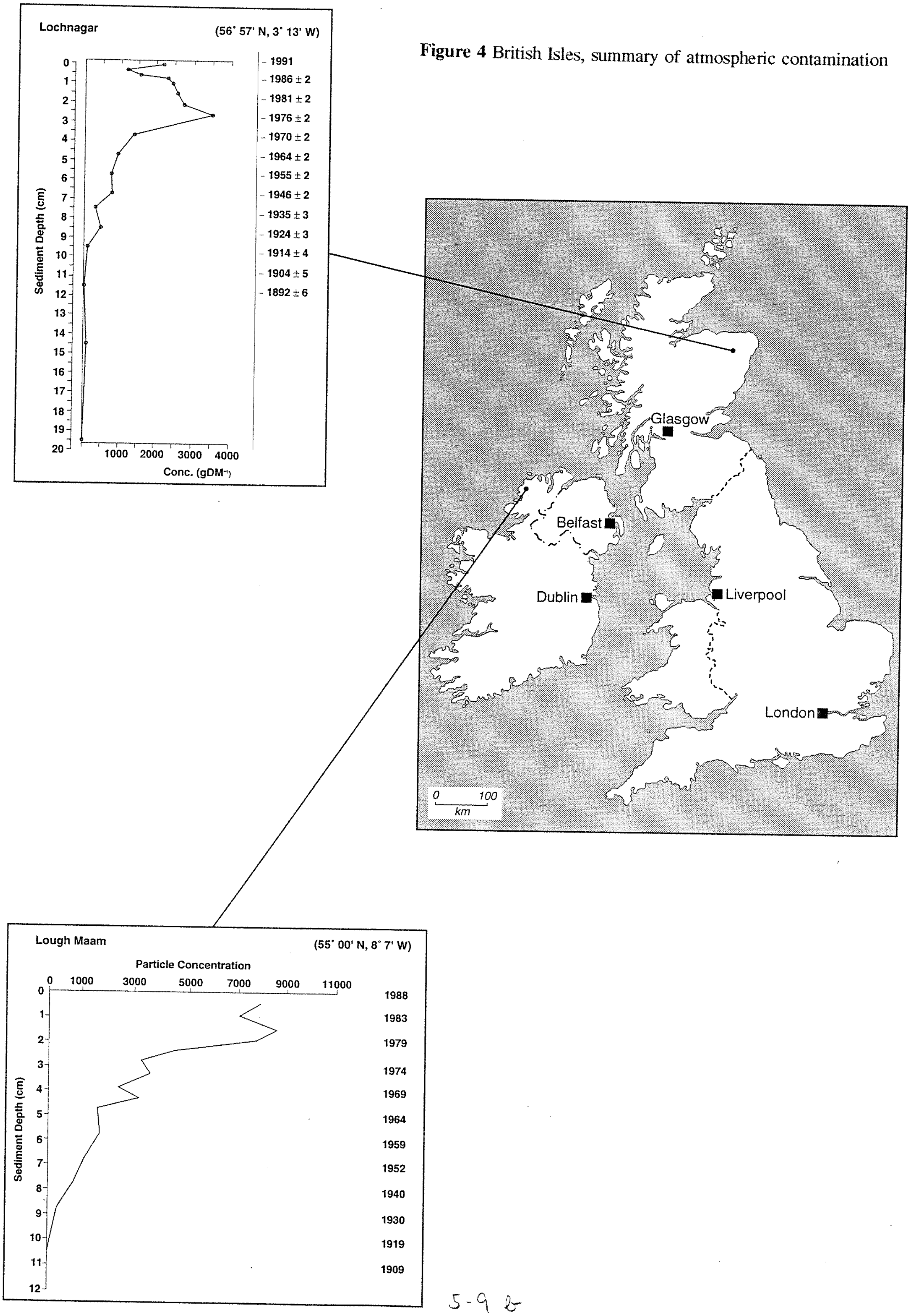
The SCP profile for Lough Maam closely follows trends seen in other sediment cores in Ireland. All the features usually ascribed to SCP profiles are found to be later in sediment cores from Ireland than for the U.K. (Rose *et al.*, in press). The start of the SCP record is in the late 19th or early 20th century, the rapid increase in SCP concentration is in the 1970's and a peak of 8,800 gDM^{-1} occurs in the early 1980's. Although the U.K. is known to be a major contributor of pollutants to the Republic of Ireland and about half of the SO$_x$ deposited in the Lough Maam EMEP square is from U.K. sources (Sandnes, 1993), differences between Irish and U.K. SCP profiles are likely to be due to Irish emissions (Rose *et al.*, in press).

Using the SWAP training set to reconstruct pH, values fall from 5.5 at the base of the Lochnagar core (16.5 - 14.5 cm) to 5.0 at 6.75 cm, declining to a minimum of 4.9 at 0.625 cm. Reconstructed pH therefore declines by 0.5 units between the mid-19 th century and 1950 declining to a minimum of 4.9 just below the surface. There is an increase in reconstructed pH of about 0.1 unit at the surface perhaps corresponding with the overall decrease in atmospheric deposition since the late-1970s. The reconstructed pH of the surface sediment (5.0) is somewhat lower than the mean measured value of 5.4. Using the ALPE training set to reconstruct pH (Figure 4a), the magnitude of the pH decline is similar, with an overall decline from 5.7/5.8 at the base of the core to 5.4 at the sediment surface. The reconstructed pH at the sediment surface is very close to the measured pH of Lochnagar at the present time.

Two cores were taken from Lough Maam in October 1993, Maam 93/1 was 29.5 cm long and a shorter core of Maam 93/2 was 11.5 cm long. %LOI was relatively high throughout both cores Annex B Figures 13 & 14, varying from 40-70%. Both cores had increasing LOI trends towards the surface where maximum values were reached. Maam 93/1 also had and LOI peak at 17-18 cm. A sediment core was also taken from Lough Maam in June 1988 using a Mackereth corer. The amount of organic matter was found to be lowest in the basal section of this core and increased to a subsurface peak of >80% at 18 cm depth (Flower *et.al.* 1994).

Diatom analysis was carried out on the Maam 93/1. However, it was apparent by comparison of the diatom record with the 1988 core and from radiometric analyses that this sequence was truncated, the upper part of the sequence was missing. It was therefore necessary to use the core collected in June 1988 (Flower *et.al.* 1994). The sequence described here (Annex B Figure 15) was analysed by Roger Flower and is described in Flower *et.al.* (1994).

Figure 4 British Isles, summary of atmospheric contamination



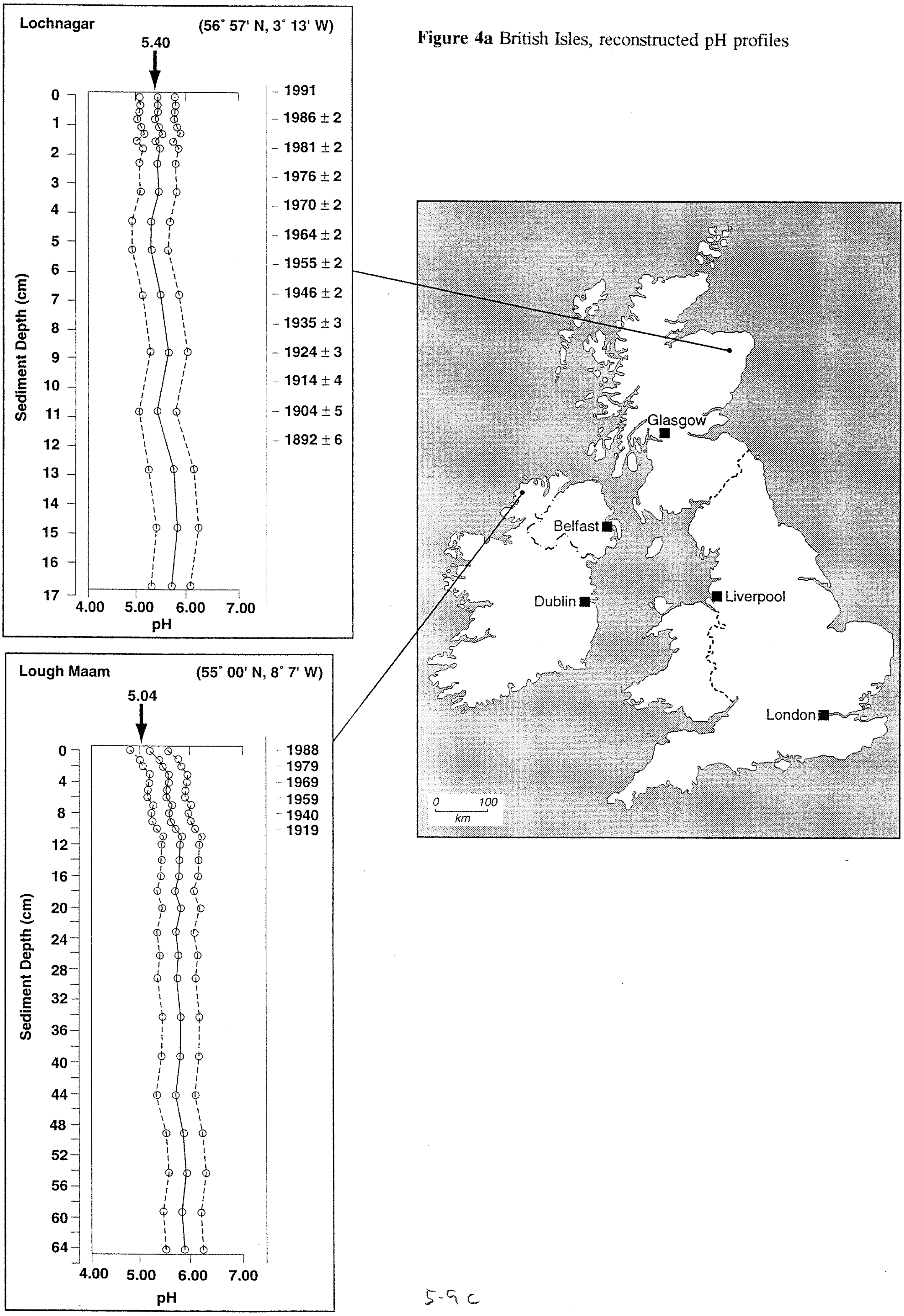


Figure 4a British Isles, reconstructed pH profiles

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Using the ALPE training set, reconstructed pre-20th Century pH values are stable at approximately pH 5.8 (Figure 4a). Like the previously published work from this site (Flower *et.al.* 1994), which used the SWAP training set, the reconstructed pH shows a consistent trend to lower values in the most recent period. The pH declines from 5.8 at 11.25 cm depth dated to about 1900 to 5.2 at the surface. In accordance with the regional trends described above, the steepest pH decline (5.6-5.2) occurs during the period from about 1970 to the present, at the time of maximum atmospheric deposition. The surface reconstructed pH of 5.2 is the same as that obtained by Flower *et.al.* (1994) using the weighted average method and the SWAP training set (Stevenson *et.al.* 1991). Both methods slightly over-estimate the lakewater pH when compared with the mean measured value of 5.04.

e) Iberia

The Iberian region includes Spain and Portugal but not the Spanish Pyrenean sites. These are dealt with below (Section f). Two lakes Spanish lakes were cored, Laguna Cimera in the Gredos Mountains (40°16'N, 5°20'W) and Laguna Caldera in the Sierra Nevada (37°03'N, 3°20'W). In Portugal three lakes were cored in the Sierra de Estrela, Lagoa Escura (40°21'N, 7°38'W), Lagoa Redonda (40°20'N, 7°35'W) and Lagoa Peixao (40°20'N, 7°40'W) (Figure 5). Of these, Cimera, Caldera and Escura were ^{210}Pb dated. All sites were analysed for SCP. Caldera, Cimera and Escura were analysed for major and trace element chemistry (Annex Figures 7-9), while Cimera and Escura only were analysed for POC (Annex Figures 2-6). Diatom analysis was carried out on the cores from Lagoa Escura, Laguna Caldera and Laguna Cimera.

Laguna Caldera

Sediment from an 11 cm core taken from Laguna Caldera in 1991 had an exceptionally low organic content Annex B Figure 16. %LOI values of approximately 5% increased to about 9% at the surface. Maxima in %DW and minima in %LOI 2-7 cm depth correspond with mineral rich bands within the core.

Laguna Caldera has a short SCP profile (<3cm) and the record starts in the 1950's. Concentrations are low throughout, however and so it maybe that SCP have not been detected below this point due to the dilution of particle numbers by a massive increase in sediment accumulation at this time. The slow increase in concentration becomes more rapid in the 1980's (top 1cm) and reaches a peak of just over 2,500 gDM^{-1} in 1989. A maximum flux of 62.7 cm^{-2} yr^{-1} occurs at the same time and drops slightly to a surface flux of 54.3 cm^{-2} yr^{-1}.

The major and trace element chemistry (Annex Figure 7a & b) for this site is very difficult to interpret. A sixteen fold increase in accumulation rate during the period 1930 to 1945 dominates the twentieth century patterns for Pb and Cd. The position of this depositional event in the core also makes it difficult to evaluate any pattern elsewhere in the profile. Experimental correction for the accumulation rate suggests that the high levels of Pb in the base are simply due to the low accumulation rate. However, the magnitude of the disturbance means that it will probably not be possible to reliably reconstruct the middle of the profile. The accumulation rate approach as illustrated in Annex Figure 7b, is clearly overcompensating. However, increasing Pb, Cu and Zn concentrations in the upper undisturbed 2 cm of the core, provides clear evidence of atmospheric contamination. Both metals and SCP show increases in atmospheric contamination above the sediment accumulation increase.

The base of the core from La Caldera is dominated by *Fragilaria pinnata* and *Fragilaria pseudoconstruens* (Annex B Figure 17). The percentages of these species decline slightly in the middle part of the core as *Achnanthes minutissima* and *Navicula radiosa* var. *tenella* increase in abundance.

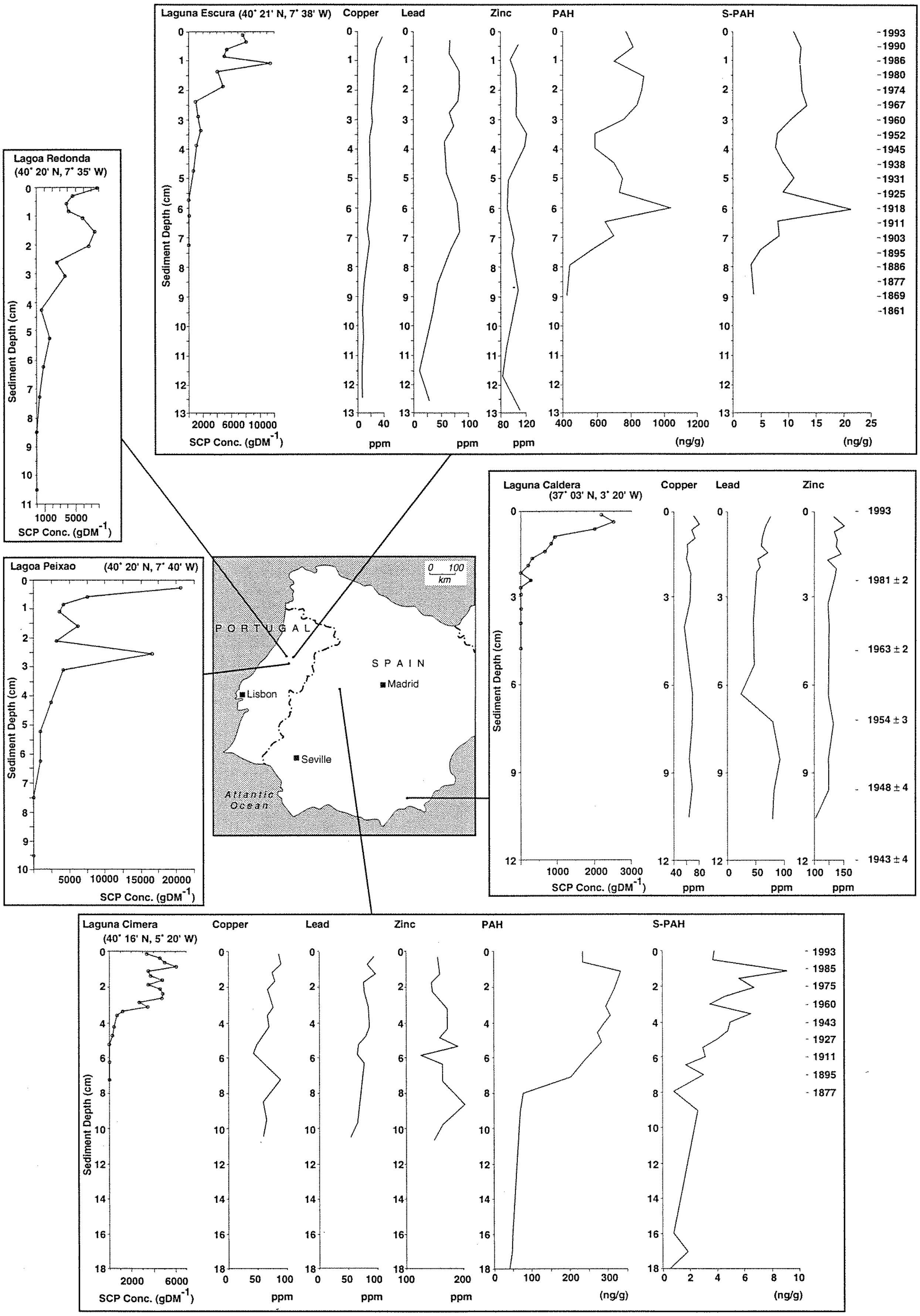


Figure 5 Iberia, summary of atmospheric contamination

From a depth of approximately 2 cm the abundance of *Fragilaria brevistriata* increases and this species becomes the dominant taxon in the surface sediment, along with *F. pseudoconstruens* and *F. pinnata*. There are also increased percentages of *Pinnularia* cf. *microstauron* sp.2 (Schmidt), *Achnanthes curtissima* and slightly increased abundances of *Fragilaria construens* var. *venter*.

The base of the core is dated to 1861 and the maximum %DW value at 6 cm is dated to 1940 where there is a corresponding dilution of ^{210}Pb. The basal section of the diatom record discussed above therefore corresponds to this period and the middle section of the core (c.6-2 cm) to a period of catchment disturbance c.1940-1960. The pH reconstruction for the basal and middle sections of the core indicates a gradual decline from pH 7.5 at the base to 7.3 at 2 cm (Figure 5a). There is then a sharp increase in reconstructed pH in the period from 1960 to the present (7.3 to 8.0). The surface sediment reconstructed pH is in close agreement with the mean measured pH of the lakewater of 8.04. The high alkalinity of Caldera precludes sensitivity to acid deposition, which is in any case low.

Laguna Cimera

The primary core taken from Laguna Cimera has relatively low %LOI values, varying between 5-14% (Annex B Figure 18). %LOI declines from 10% at the base of the core to 5% at 11 cm depth, increases to a maximum of 14% at 3 cm depth and declines to about 12% at the surface. %DW values show an approximately inverse trend with minimum values at the base and at the surface and a maximum at 11 cm.

Laguna Cimera in the Gredos mountains west of Madrid also has a short SCP profile, but in this core the SCP record starts in the 1920's, concentrations increase in the 1950's and, after many peaks and troughs, reaches a peak of 6,000 gDM^{-1} in 1986. Converting concentrations to fluxes makes this a more definite peak (190 cm^{-2} yr^{-1}) and both concentrations and fluxes decrease from this point to the surface.

This site is one of the least disturbed, showing only small perturbations in the accumulation rate. However, it is also one of the least polluted sites, so interpretation of the major and trace element profiles is not straightforward. There are very small increases in Pb, Cu and Cd in the upper part of the core, which are slightly strengthened when transformed to accumulation rate (Annex Figure 8b) (a reasonable procedure with changes of this magnitude). This increase takes place above 3cm (1960's) the same time as the increase in SCP concentration. There appears to be no increase in Zn, but there is a high base line for this element and any effect may have been masked.

The POC results for Laguna Cimera are summarized in Tables 6-10 (Annex). The core shows high TOC (3-5%) although these values are among the lower concentrations in the AL:PE dataset. The concentrations in higher plant n-alkanes are low (40-50 fg/g) and the absence of changes in the profile indicates a constant input from higher plant vegetation over the period covered by the core (1993-1869). Conversely, the PAH show a well defined change with a sharp increase at the end of last century (1877-1895; Annex Figure 3). The PAH concentrations are relatively low with a maximum concentration of 340 ng/g in the mid-1980's. The PAH and in particular the S-PAH agree well with the SCP temporal patterns and peak date (1979). Retene (from wood combustion e.g. forest fires) falls to 0 ng/g at the surface suggesting that the most recent ΣPAH are fossil-fuel related. pp'-DDE is the main organochlorinated compound with a maximum concentration of 9 ng/g in 1965 (Annex Figure 4). The depth profiles of both pp'-DDE and PCB show two peaks corresponding to 1985 and 1965. The earlier maximum is not observed for HCB and the peak concentration in 1985 is 5.5 ng/g.

There is a diverse diatom flora in the lake, composed entirely of non-planktonic species. The diatom diagram (Annex B Figure 19) shows a relatively stable flora dominated by various *Achnanthes* spp. such as *Achnanthes austriaca* var. *minor* and *Achnanthes austriaca* var. *helvetica*, with *Pinnularia microstauron* dominant at the base of the core. At the surface there are significant increases in the abundances of *Fragilaria construens*, *Achnanthes* cf. *levanderi* and an unknown *Navicula* species (sp. 89).

Laguna Cimera is sensitive to acid deposition, having a low buffering capacity (Ca 30 ueql-1), but is subject to a low level of deposition. ^{210}Pb dating places 8 cm depth at 1877, but there is no indication of any impact of atmospheric deposition on the reconstructed lakewater pH. Reconstructed pH is exceptionally stable at 6.1 - 6.2 and the surface reconstructed pH of 6.2 is close to the mean measured pH of 6.18 (Figure 5a). It should however be noted that there are changes visible in the diatom assemblages in the upper part of the core, c.8.5-0 cm and in particular in the uppermost 4 cm of the core. The significance of these recent species changes is unclear since the most common taxon was identified only in Laguna Cimera. The increased abundance of *Fragilaria construens* at this level may indicate increasing lakewater pH. It is perhaps more likely that the increased importance of these taxa in the last century may be associated with drier summer or colder winter conditions resulting in exceptional variation in lake levels, or accelerated erosion of material from the lakes catchment.

Lagoa Escura

Three sediment cores were taken from Lagoa Escura on 26/7/93. The cores were taken at the deepest point of the lake in 11.5 m water depth. %LOI values vary from approximately 25-35%, with 2 maxima of about 40-45% at around 15-25 cm depth in all three cores (Annex B Figures 20-22). %LOI increases to a maximum at the surface of 93/1 and 93/2. Escu 93/2 was selected as the mastercore, being a longer core than 93/1, a third core, 93/3, was extruded at 2 cm intervals.

The Escura SCP profile starts in the 1920's and increases slowly and steadily until a more rapid increase in the early-1970's. A peak concentration of 11,400 gDM^{-1} occurs in 1984 and corresponds to a maximum flux of 165 cm^{-2} yr^{-1}. This peak is followed by a trough and an increase again in the surface samples.

Escura has one of the simplest sedimentation rate curves and the effect of the near-surface accumulation rate increase can be predicted reliably. Pb, Zn, Cu and Cd all increase from approximately the same depth (corresponding to a date around 1800-1840) (Figure 5 and Annex Figure 9a & b). Ni also increases, with a similar pattern. Pb, Zn, Cd and Ni show a further increase at about 1940, this time accompanied by V. It is noteworthy that none of the concentrations are particularly high, the changes are simply well defined.

The POC results are summarized in Tables 11-15 (Annex). The TOC (11%) is among the highest of the AL:PE dataset. The concentration of n-alkanes of higher plant origin is also high (ca. 200 µg/g; Annex Figure 2) and PAH concentrations are moderate 800-1000 ng/g. One distinct feature of this lake is that the PAH profile is rather uniform not showing a significant temporal change. The organochlorinated compound of highest abundance is pp'-DDE (maximum concentration 3.3 ng/g in the mid 1970's). Polychlorobiphenyls (PCB) and hexachlorobenzene (HCB) are present in minor amounts (< 1 ng/g) but despite these low concentrations there appears to be an increase in concentration from the late-19th century to the peak in 1990 (Annex Figure 5).

There is little similarity between the temporal profiles of the atmospheric contaminants in this core.

A total of 91 diatom taxa were identified in the sediment core (Annex B Figure 23). Sediment diatom assemblages are dominated by non-planktonic species including many benthic *Aulacoseira* spp. At

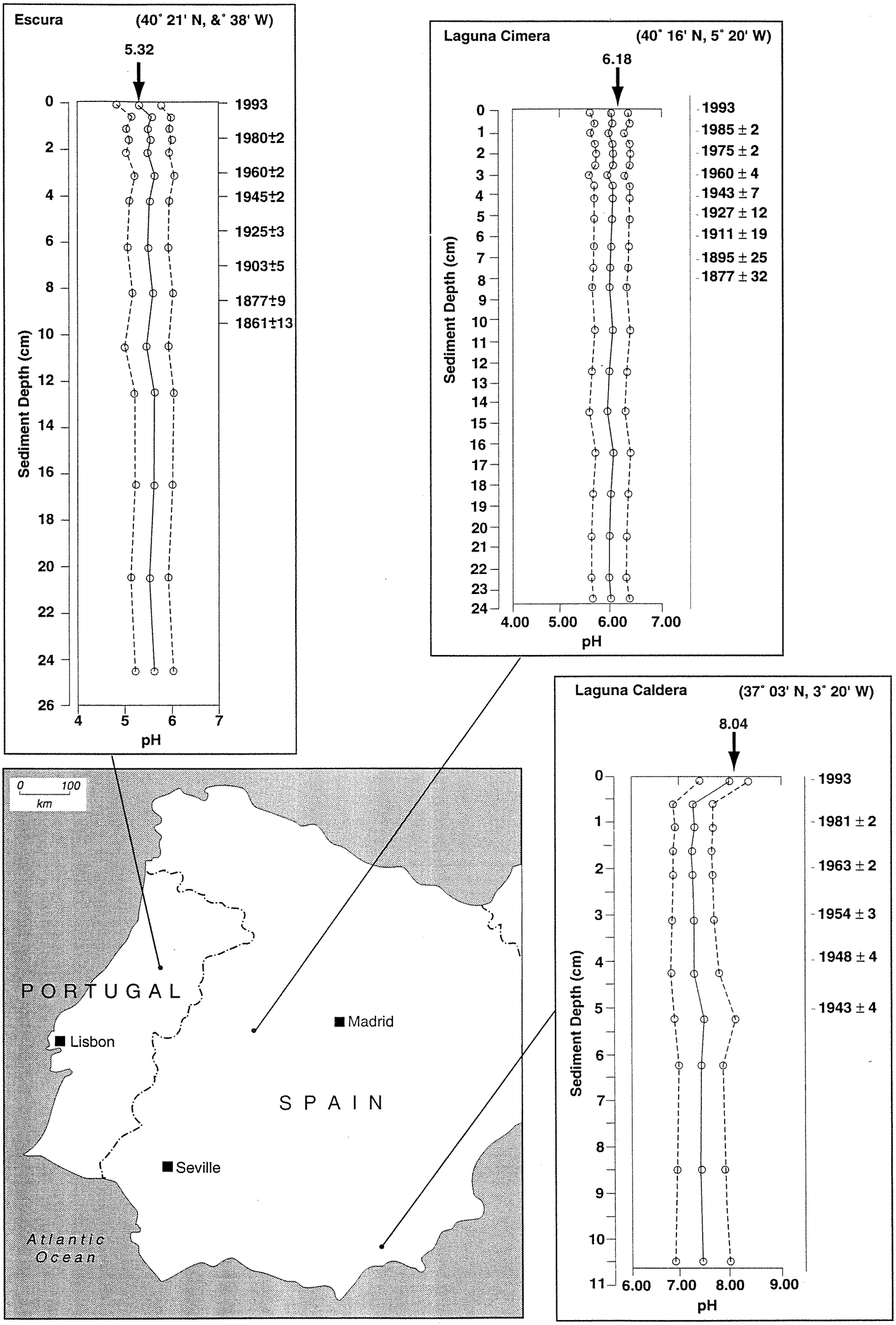


Figure 5a Iberia, reconstructed pH profiles

present several common diatom species in the Lagoa Escura core cannot be assigned to published diatom taxa, they have therefore been given temporary species codes within the ALPE project. Inspection of the summary stratigraphic diatom diagram shows some variation in the percentages of the dominant species. *Aulacoseira* sp.29 and Sp. 247 are generally more abundant at the base of the core and *Aulacoseira* sp. 27 is more abundant above 12 cm. *Aulacoseira* sp. 29 increases in abundance in the top 3 cm, reaching over 40% at the surface, whilst *Aulacoseira* sp. 27 declines to 20% at the surface. Some taxa, present throughout the profile are absent in the surface sediment sample, these include *Aulacoseira lirata* var. *alpigena* and Sp. 247.

The pH profile for Lagoa Escura is stable with reconstructed pH values of 5.5 - 5.6 throughout (Figure 5a). The exception is the surface sediment sample where the reconstructed pH declines significantly to 5.3. The top 8 cm of the core represents a period of approximately 100 years and atmospheric contamination is of relatively low magnitude. It appears, therefore, that the decline in reconstructed pH, driven only by the diatom composition of the uppermost sediment sample, may result from within core inconsistencies in diatom taxonomy. Clearly further taxonomic work is required, especially on the *Aulacoseira* taxa found in this lake and in other lakes in the region.

(Annex B Figure 24) shows the number of chironomid taxa and specimens found in the four samples analysed from the Lagoa Escura sediment core. A total of 18 chironomid taxa were recorded. In addition remains of the phantom midge *Chaoborus flavicans* were found. In the bottom sample *Micropsectra* cf. *insignilobus* dominated together with *Procladius* spp. No *Tanytarsus* spp. were observed in this sample. Up-core *Micropsectra* cf. *insignilobus* decreases in relative abundance at the same time as *Tanytarsus* spp. increase (Annex B Figure 25).

Lagoa Peixao and Redonda

The SCP pattern for Escura is repeated in Peixao and Redonda. Peixao has a peak of 17,000 gDM^{-1} at 2.5cm followed by a trough and a surface increase to a maximum of just over 21,000 gDM^{-1} in the surface sample, and Redonda has a peak of 7,600 gDM^{-1} at 1.75cm followed by a trough and an increase to a surface maximum of 8,000 gDM^{-1}.

Regional Discussion

Given the locations of the two Spanish lakes it is likely that the depositions they receive are almost solely of Spanish origin. The higher levels in Laguna Cimera (SCP, metals) may be due to its proximity to Madrid and CP peak concentrations similar to those seen here are found in other cores taken from the Gredos (Toro *et al.*, 1993). However, this is not reflected in the POC results where Escura concentrations are often higher than those of Cimera. In general the concentrations of PAH and organochlorinated compounds in the Iberian lake cores are moderately low with PAH deposition fluxes between 10-13 $ng/cm^2/yr$. However, pp'-DDE concentrations in Laguna Cimera are high (7 ng/g). The diatom-based pH reconstruction of Laguna Cimera shows no sign of acidification. The same is probably true of Lagoa Escura. However, there is an apparent acidification as a result of species changes in the uppermost sample of the core. This is probably related to difficulties with species taxonomy

The EMEP model confirms that Spanish emissions are the dominant source for both the EMEP squares of the Spanish sites, 85% for the Caldera square and 73% for the Gredos square. Portugal is the only other significant contributor with 8% and 18% respectively, and France and the U.K. both contribute minor amounts. The EMEP model for the Portuguese sites shows that 63% of the received SO_x is from Portugal and 32% is from Spain. The prevailing wind direction is from the west, although the main source of Portuguese pollutants appears to be from further south, around Lisbon (Sandnes, 1993). The SCP concentrations in the Portuguese sediments are higher than for the Spanish sites (e.g. Gredos lakes near Madrid) suggesting they have a Portuguese source.

f) Pyrenees

Four sites were cored in the Pyrenees, two on the French side, Etang d'Aube (42°44'N, 1°20'E) and Etang d'Alet (42°44'N, 1°16'E) and two in Spain, Laguna Redo (42°38'N, 0°46'E) and Laguna Aguilo (42°43'N, 1°20'E) (Figure 6). The mastercores from Etang d'Aube, Laguna Redo and Laguna Aguilo were ^{210}Pb dated. All the cores were analysed for SCP. Aguilo and Redo were analysed for major and trace element chemistry and Redo was also analysed for POC. A summary diagram is shown in Figure 6, full metal and POC results are given in Annex Figures 2-6 & 10a-11b. Details of radiometric dating, lithostratigraphic, diatom and chironomid analyses of the Etang d'Aube core are presented in Cameron *et.al.* 1993.

Etang d'Aube and Etang d'Alet

Etang d'Aube has a short SCP profile (5cm) starting in the 1930's and increasing slowly until a rapid increase in the 1980's (top 1cm). The maximum concentration of 15,400 gDM^{-1} is at the surface representing a SCP flux of 128 cm^{-2} yr^{-1}. This profile probably reflects the slow sediment accumulation rate. Etang d'Alet has a longer SCP profile and lower concentrations than Aube and shows a surface decrease in the top 1cm. These differences are probably due to different sedimentation rates and may therefore represent the same SCP deposition. A similar situation is observed between the two Paione sites in the Italian Alps (see below).

Diatom-based pH reconstruction, using the AL:PE training set, shows a stable pH profile with maximum values of 6.0 at the base of the core decreasing only slightly to 5.9 at the surface (Figure 6a). Using the SWAP diatom training set, the reconstructed pH curve also shows a stable pH, varying between 5.32 and 5.20. The measured pH of Lake Aube is 6.1, so the reconstruction using the AL:PE training set appears to be the better estimate. The carbonaceous particle record of the core AUBE1 indicates that the lake has been subject to significant atmospheric deposition beginning approximately 50 years ago and rising sharply from about 1980 to a maximum at the present time. However, the sediment diatom record indicates that there has been only a small decline in pH, of the order of 0.1 pH units which is not significant.

Laguna Redo

Lake Redo is an exceptionally deep mountain lake with a maximum depth of 73 m. Persistent attempts to retrieve cores, suitable for analysis, from the deepest part of the lake basin were unsuccessful as a result of the accumulation of coarse-grained, mineral rich sediment in the deepest part of the basin. However, Core 1 was taken from this part of the basin and has %LOI values of approximately 5-15% from the base at 11.5 cm to 1 cm depth (Annex B Figure 26). There is a pronounced peak in %LOI of 60% above 1 cm and a decline to less than 20% at the surface. There are also pronounced peaks in %DW accompanied by minima in LOI at 8 cm and 6 cm. Cores 2 & 3 were taken from a shallower basin where it was possible to take cores of c.30-40 cm length as a result of the consistently finer grained sediment (Annex B Figures 27 & 28). %LOI values were less than 20% with 2 significant minima in %LOI of just over 5% and corresponding maxima in %DW values in both cores. The position of the upper %DW maximum/%LOI minimum below 5 cm depth in Core 2 suggests that there is faster accumulation of sediment in the upper part of this core. Core 2 was therefore selected as the primary core for analysis.

The Spanish sites show different SCP profiles to the French sites and it is difficult to determine the reasons for this when they are geographically so close. The SCP profile for Redo is 6 cm long, the same as for Aube but here it represents a pre-1850 ^{210}Pb date. There appears to be no rapid increase and a peak concentration of 5,800 gDM^{-1} is reached at 0.25-0.5cm (1989) representing a maximum flux of 72.6 cm^{-2} yr^{-1}. There is a near surface decrease and the surface flux is only 22.9 cm^{-2} yr^{-1}. Even given that Redo was cored two years after Aube these fluxes are both significantly lower than for the French lake.

The sedimentation in Laguna Redo accelerated uniformly after 1940, and increased at a constant rate until recently. This has had the effect of flattening off the concentration profiles, which would otherwise have been much steeper (Annex Figure 10a). After compensation for rate changes a sharp rise in concentrations of Zn, Pb, Cu and Cd is observed after 1940. Lower in the core we see the initial rise in Pb, Cd and Zn after 1840-1850. Cd, and especially Cu , fluxes show similar patterns to that of the SCP.

The POC results are summarized in Tables 16-20 (Annex). TOC is 4-6%. Higher plant n-alkane concentrations are moderate (60-110 µg/g; Annex Figure 2). Again the regular downcore profile indicates a constant input from higher plant vegetation over the period of study.

ΣPAH concentrations are moderately high with a maximum concentration of 1100 ng/g in 1970 followed by a decrease in recent years (1981-1993; Annex Figure 3). This is a similar pattern to the SCP although the peak concentration for PAH occurs slightly earlier. The S-PAH results compare more favourably with the SCP with coincident peaks, although the S-PAH surface decline is less marked than that of SCP. The concentrations of PAH started to rise at the beginning of the century (1889-1900), slightly later than for SCP. The ΣPAH and retene maxima are coincident suggesting that in part at least, PAH in Redo are related to forest-fires. One important feature of this lake is the relatively high concentration of pp'-DDE (10 ng/g) showing an increasing concentration since 1926 to recent times. PCB and HCB are also important with maximum concentrations of 6 and 2.5 ng/g, in the late-1960's and 1981 respectively. (Annex Figures 5 and 6).

A summary diatom diagram illustrating the most important species changes in the Lake Redo core is shown in Annex B Figure 29. The diatom assemblages from this lake are diverse and dominated by non-planktonic taxa. The lower part of the core is dominated by *Fragilaria brevistriata, Achnanthes minutissima, Navicula digitulus,* and *Aulacoseira lirata. F.brevistriata, N.digitulus* and *A.minutissima* decline in abundance from the base of the core to c. 20 cm and there are increases in the percentages of *A. lirata* and *A.lirata var. alpigena* at the same depths. Between approximately 20 cm depth and 8 cm depth the percentage of *A.lirata* declines and *N. digitulus* reaches maximum percentages. From 8 cm depth to 0 cm the percentages of *Aulacoseira* spp. increase, along with a range of *Achnanthes* taxa (shown on the left hand side of the diagram), *Pinnularia caudata, Stauroneis anceps* fo. *gracilis, Nitzschia recta* and *Navicula pseudoscutiformis.* Radiometric dating places 5.25 cm depth at 1843+/-27 with a sedimentation rate of approximately 0.25 mm per year at this level increasing to almost 1 mm per year at the surface. The reconstructed pH shows a steady decline from pH 6.8 at the base of the core to pH 6.6 at 8 cm. There is a sharp decline in pH from 8 cm to 6 cm depth where the pH decreases to c. 6.3 and approximately stable pH values are maintained to the sediment surface. The pH of 6.35 reconstructed from the surface sediment diatom assemblage matches well with the mean measured lakewater pH during 1993 (6.32). However, this differs considerably from the mean pH recorded during the period of the AL:PE study (5.54). The decline in pH from 8-6 cm predates the onset of the SCP record just below 6 cm. The causes of this pH decline are other than atmospheric deposition. The same reasoning also applies to the gradual pH decline from the base of the core to c. 8 cm.

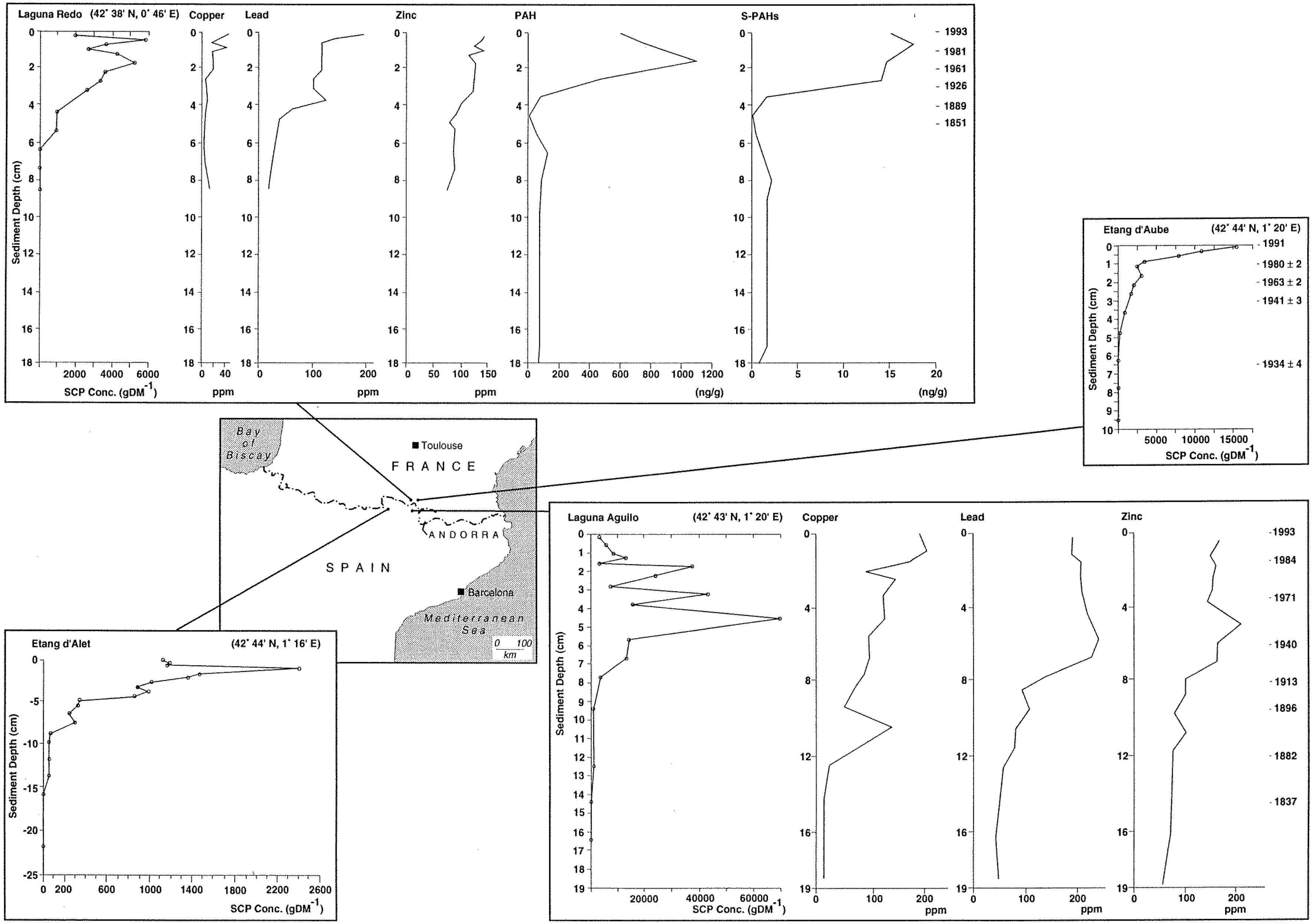


Figure 6 Pyrenees, summary of atmospheric contamination

5-15b

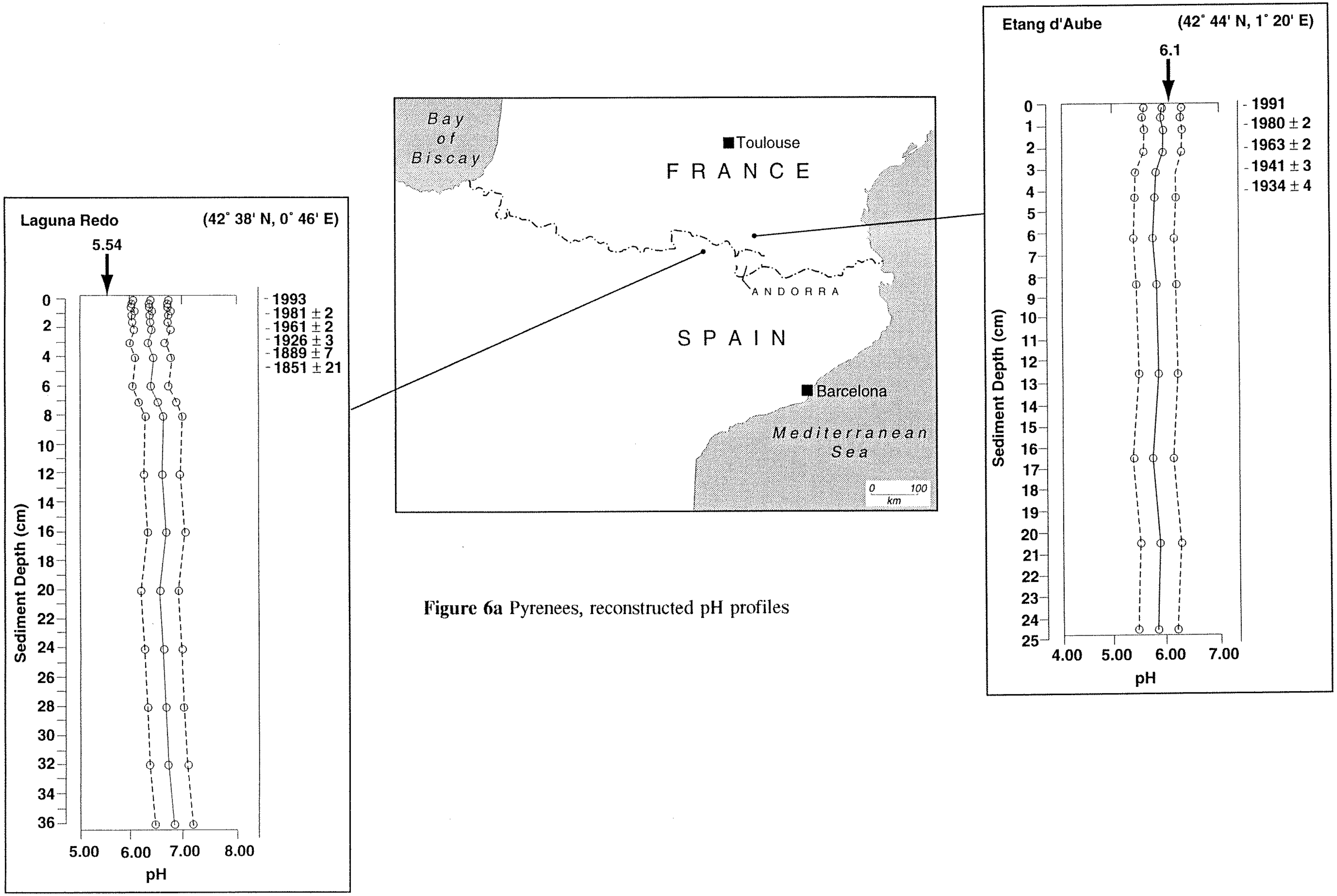


Figure 6a Pyrenees, reconstructed pH profiles

Five samples from the sediment core were analysed for chironomids. A total of 9 taxa were found. Annex B Figure 30 illustrates the number of taxa and specimens found in each sample. *Micropsectra radialis* was the most important taxon, and constituted about 50 % or more in the samples. *Heterotrissocladius marcidus* was also important.

Laguna Aguilo

Laguna Aguilo has a different SCP profile and shows fluctuations of up to 40,000 gDM^{-1} between consecutively analysed levels. The concentration peak of over 70,000 gDM^{-1} is the highest of all the Pyrenean cores and dates to the early 1960's which does not match with either Spanish combustion statistics or SO_2 emissions. The accumulation rate varies however, with a period of slow accumulation between 4.5-6.5cm and a period of high accumulation between 9.0 - 13.0cm. This has the effect of reversing the peak heights such that the maximum flux (670 cm^{-2} yr^{-1}) is found in 1984/5 which agrees well with combustion and SO_2 emission statistics. There is a decrease above this point and the surface flux is only 50 cm^{-2} yr^{-1}.

The core shows two periods of increased sedimentation rate, peaking around 1880 and again in 1980. This has surprisingly little affect on the major elements, although a small decrease in both the Al and LOI coincide with the more recent event. This suggests that enhanced erosion has not exploited any radically different sediment sources. However, the sedimentation rate peaks do have a profound effect on the trace elements. This is most strongly seen in Pb, Cd and Zn, where the peak in concentration corresponding to a date of approximately 1960, is entirely an artifact of reduced sedimentation rate. This is illustrated in the accumulation rate plot (Annex Figure 11b), where the true peak in the metals is seen to occur around 1980 (slightly earlier than the SCP flux peak). However, such interpretations of the data should be treated with caution. Major changes in accumulation rate strongly affect the dynamics of trace element cycling and preliminary experiments with mass balance models suggest that both the shape of the curve and the timing of the peak are not accurately reconstructed using accumulation rates.

Regional Discussion

Both French and Spanish combustion statistics show recent decreases from the mid-1970's and mid-1980's respectively. Similarly, SO_2 emissions from Spanish solid and liquid fuels and French liquid fuels decrease from 1980 and the mid-1970s respectively (Mylona, 1993). Both Laguna Redo and Laguna Aguilo show decreases from maxima (SCP, Pb, Zn, Cu and Cd in Aguilo; SCP, PCB, ΣPAH and HCB in Redo) in the mid-1980's and Etang d'Alet shows only a very recent decrease (in SCP) suggesting a similar date. This would suggest that Spanish emissions influence these lakes more than the French. The EMEP model supports this predicting 43% of the SO_x received by the EMEP square originates in Spain (probably from Barcelona and Bilbao) and 26% in France. This latter figure may be influenced by a sulphurous gas field in Lacq in the French Pyrenees. Germany contributes 17% to this EMEP square and UK 7%.

The Pyrenees and Alps region appear to receive moderate pollution deposition. Maximum PAH concentrations may reach up to 1200 ng/g. However, when these concentrations are transformed into fluxes they appear to be lower than those in Iberia (6.5 - 9 $ng/cm^2/yr$). The organochlorinated compounds are also moderately low. However, in the Pyrenees there is more pp'-DDE than PCB whereas in the Alps the opposite is observed. Laguna Redo shows some evidence of acidification whilst Etang d'Aube shows little evidence of pH change despite the higher SCP flux recorded in the surface sediments of this lake.

g) Alps

Western Alps

Five cores have been analysed for SCP in the western Alps. Two in the Italian Alps, Paione Superiore (46°11N', 8°11'E) and Paione Inferiore (46°10N', 8°11'E) and three in the French Alps, Lac Noir (45°25N', 7°07'E), Lac Long (45°08N', 6°36'E) and Lac du Serpent (45°03N', 6°34'E) (Figure 7). Both Paione Superiore and Lac Noir have been ^{210}Pb dated. Only Lac Noir has been analysed for major and trace element chemistry and POC (n-alkanes, PAH). A summary diagram is shown in Figure 7, Lac Noir metals are shown in Annex Figures 11a & b and POC results are given in Tables 21-24 (Annex) and Annex Figures 2-6. Diatom analysis has been carried out on mastercores from Paione Superiore and Lac Long.

Paione Superiore and Paione Inferiore

The Paione Superiore SCP profile is short (less than 3.5cm) starting in the 1930's and increasing continually and rapidly from this time to the surface. This is probably due to the slow sediment accumulation rate and so few features are seen on the profile. There is a 'shoulder' in the late 1970's and this is very similar to the Italian combustion statistics (Cameron *et al.*, 1993). However, given the accumulation rate this may also be due to a temporary decrease in SCP deposition at this time. Paione Superiore has the highest surface SCP concentration and surface SCP flux (146,000 gDM^{-1} and 4,090 cm^{-2} yr^{-1} respectively) by far of any AL:PE site. The SCP profile for Paione Inferiore is longer than that of P. Superiore and the concentrations are lower and show more features. This may therefore represent a better resolution picture of the temporal SCP deposition in the area. The profile starts at about 20cm and there is a long period of slow increase until 7-8cm when the concentration increase becomes more rapid. There is a peak at 4cm and a maximum of over 65,000 gDM^{-1} at 0.75-1cm, separated by a trough. This trough could correspond to the 'shoulder' feature in the P. Superiore profile. Above the maximum there is a decrease to the surface.

Details of core lithostratigraphy, radiometric, diatom and chironomid analyses for Paione Superiore are presented in Cameron *et.al.* 1993. The reconstructed pH for Paione Superiore, based on the SWAP diatom training set, shows negligible variation throughout the core and is in the range 5.1 to 5.2 throughout. The measured lakewater pH for Paione Superiore is 5.65, therefore the reconstructed surface sediment pH underestimates the mean present day pH significantly. Despite changes in the floristic composition of the diatom assemblages the SWAP reconstructed pH reflects little of their variability. Possible reasons for this are discussed in Cameron *et.al.* (1993). These include factors such as the absence of taxa common in Paione Superiore from the SWAP training set and the over-representation of epepelic and aerophilous taxa in the core. Using the AL:PE training set to reconstruct pH a slight pH decline is apparent and the estimate of present lakewater pH (5.62) is very close to the measured value (5.65) (Figure 7a). The reconstructed pH declines from approximately 5.8/5.9 to 5.6 at the surface. This acidification, beginning in the 1940s, follows the SCP profile beginning in the 1930s and increasing to the present day. Chironomid analysis shows the development of the chironomids *Micropsectra radialis* and *Tanytarsus lugens*. This indicates that Lago Paione Superiore is slightly eutrophicated and has changed to a more moderately oligotrophic lake during the last few decades. In contrast to the evidence from the diatom based pH reconstruction, it appears unlikely that acidification is the reason for the observed changes in chironomids, since both species are regarded as acid sensitive, *Tanytarsus lugens* even more so than *Micropsectra radialis*.

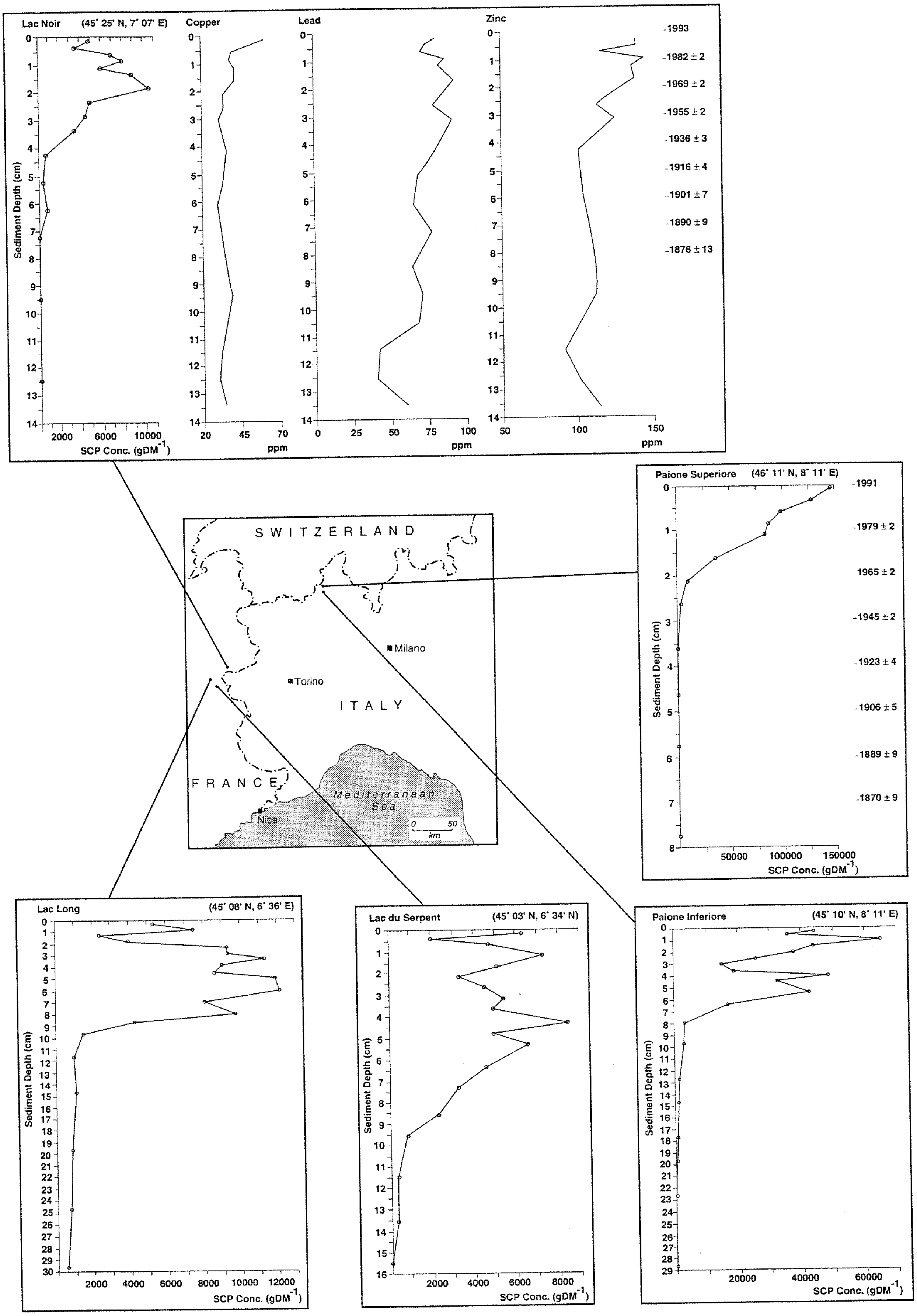


Figure 7 Western Alps, summary of atmospheric contamination

5-17b

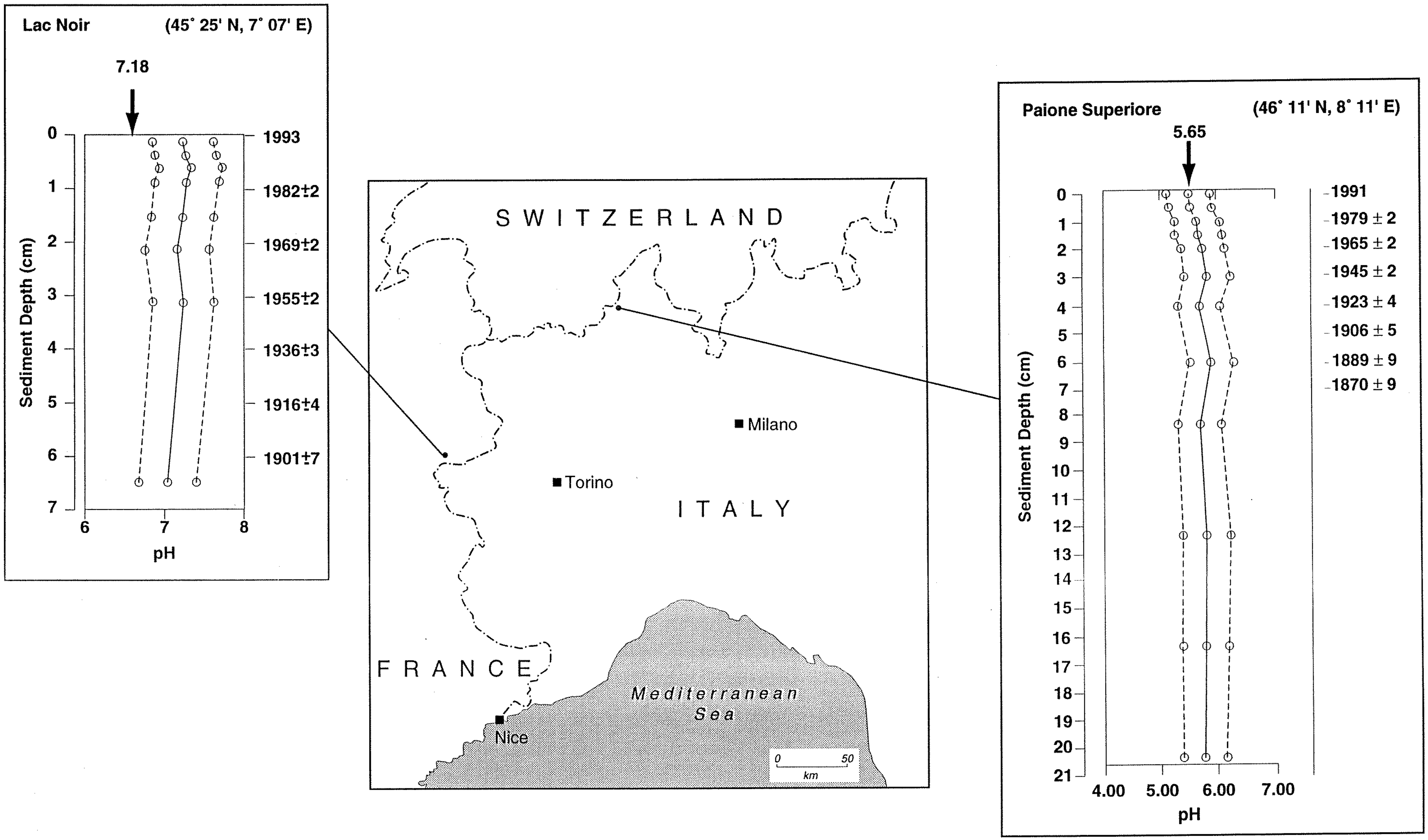


Figure 7a Western Alps, reconstructed pH profiles

Lac Noir

Three cores were retrieved from Lac Noir on 25/9/93 at the deepest point of the lake in 12 m of water. NOIR 93/1 was selected as the mastercore and NOIR 93/3 was extruded at coarse intervals. All three cores show similar lithostratigraphic profiles (Annex B Figures 31-33) with low % LOI values, of about 5% in the basal part of the core (except in the 2 basal samples of NOIR 93/3) and corresponding high %DW values of 40-60%. At approximately 19-17 cm depth in all three cores %DW declines to less than 20% and there are corresponding increases in %LOI to around 10%. In the upper part of each of the cores there are fluctuating %DW and %LOI values. In particular, in the mastercore, NOIR 93/1, there is a steep increase in %LOI values to over 30% in the surface sample.

The French Alp sites show more variability. Lac Noir, the dated site, shows the start of the SCP record to be at the turn of the century with a slow increase in concentration from this time until a more rapid increase in the 1940's to a peak of over 10,000 gDM^{-1} in the early-1970's. This is followed by a decline to the surface.

There are two sharp peaks in sedimentation rate (ca.1900 and ca.1960). The earlier peak occurs at a time likely to correspond with an increase in atmospheric pollutants above pre-industrial levels. This change in concentrations may therefore be obscured by the increase in sedimentation rate. The variable dry weight curve suggests other deposition events may have occurred for which there is no reliable information. The Zn, Pb and Cd fluxes initially started to rise ca.1920 and increase sharply after 1930-1940.

The TOC for Lac Noir is 3.5-5.5%. Higher plant n-alkanes are low (40-80 ng/g) and show a fairly constant concentration between 1876 - 1993. PAH concentrations start to increase at the turn of the century, reaching a peak of 1200 ng/g in the late-1950's. This is followed by a general decrease to the surface. This peak is significantly earlier than the SCP (early-1970's) and metal fluxes (Cd - early 1980's; Pb, Cu - surface maxima).

The state of diatom preservation in the sediments of Lac Noir is very poor. In many samples diatoms are absent and in levels where diatoms are present many valves are severely dissolved. It was, however, possible to produce a skeleton diagram for the uppermost 6 cm of the mastercore Noir 93/1 (Annex B Figure 34). The assemblages are stable and dominated by circumneutral or alkalophilous taxa such as *Achnanthes minutissima, Amphora ovalis* var. *libyca, Fragilaria* spp. and *Navicula wittrockii.* The uppermost 6 cm represents the period since 1900. Maximum levels of atmospheric deposition (SCP) were reached in the early 1970s (about 2 cm depth in the core), declining in recent times. Given the highly buffered nature of Lac Noir, there is no evidence for any diatom response to atmospheric deposition. The reconstructed pH varies from 7.2 to 7.3 with a minimum value of 7.0 at the base of the core (6 cm), which gives the impression of a gradual pH increase (Figure 7a). However, based on only a single sample, with diatoms almost absent from the intervening and deeper levels, it is not possible to verify this gradual change.

Lac Long and Lac du Serpent

Both Lac Long and Lac du Serpent show long, irregular SCP profiles. The start of the Lac Long profile is below the base of the core (30cm) and shows a period of low, almost constant concentration until a massive increase at 9-10cm. This is followed by a period of high, variable concentration and above 2cm a decline to the surface. The peak concentration at Lac Long (over 12,000 gDM^{-1}) is higher than at Lac Noir and coupled with the much longer profile suggests higher depositions at this site. If, however, the peak in Lac Long (5.5-6cm) corresponds to the 1970 peak in Lac Noir then the start of the profile (1900) should be above 30cm in Lac Long and therefore present in the profile. It would therefore appear that a degree of sediment accumulation variability has occurred at Lac Long.

The same may well be true of Lac du Serpent which also shows a highly variable SCP profile. Here there is a start to the record, at 14-16cm, but due to the 'noisy' profile between 0 and 5.5cm it is difficult to allocate any features or interpret the trends. The peak of over 8,000 gDM^{-1} occurs at 4-4.5cm and is the lowest peak concentration of the three French Alp cores. The peak and start depths cannot be consistent with the Lac Noir features and retain constant sediment accumulation rate and dating is needed to interpret the Lac Long and Serpent profiles further.

Regional discussion

The Paione lakes are only about 70km north of the major Italian industrial area around Milan and it is probable that this is the major source of pollutants at these sites. Prevailing wind directions are also from the south (A.Lami, pers. comm.). The EMEP model confirms this suggesting that 75% of the SO_x received by this EMEP square is of Italian origin. Smaller contributions are modelled to have come from Germany (7%), France (6%) and Switzerland (3%). Many other European countries contribute minor quantities.

As the industrialised area of north-western Italy is only a few hundred kilometres to the east and the French industrial area of Lyon and Grenoble is 100km to the west it would seem probable that these are the main sources for the Western Alp sites. The impact of atmospheric deposition on the Paione Superiore lake ecosystem is apparent from the diatom-based pH reconstruction, but cannot be assessed for Lac Noir. The EMEP model supports this predicting 32% and 22% of the depositions received by this EMEP square are from France and Italy respectively. Other contributions are received from Germany (15%), Switzerland (11%), Spain (7%) and UK (4%).

Eastern Alps

Five cores were analysed within this region. Milchsee (46°43'N, 11°04'E) and Lago Lungo (46°44'N, 11°05'E) in the Italian Tyrol, Scharzsee ob Solden in southern Austria and further east Zgornje Krisko Jezero (46°25'N, 13°48'E) and Jezero Ledvici in north-west Slovenia (Figure 8).All the cores were analysed for SCP. Only Zgornje Krisko Jezero was analysed for major and trace element chemistry and only Schwarzsee ob Solden was analysed for POC. A summary diagram is shown in Figure 8, the chemistry data is given in Annex Figures 13a & b, POC data are given in Tables 25-29 (Annex) and Annex Figures 2-6.

Zgornje Krisko Jezero

Three cores were taken from Zgornje Krisko Jezero, all show similar %DW and %LOI profiles with %LOI values fluctuating around 25% (Annex B Figures 35-37). ZKJZ2/94 and ZKJZ3/94 were sliced at 0.25, 0.50 and 1 cm intervals, both have a %DW maximum of about 15% and a %LOI minimum of about 17% at the base of the core. %DW then declines and %LOI increases to a maximum of 25-30% at about 20 cm depth. %DW is stable at over 5% and %LOI at over 20% almost to the surface with maxima and minima of smaller magnitude visible. There is a %DW decline and a %LOI increase at the surface. ZKJZ2/94 was selected as the mastercore.

The Zgornje Krisko Jezero SCP profile has a maximum concentration of over 90,000 gDM^{-1}s in the surface sample, but between 1cm and 18cm (1992 - 1968) concentrations remain between 60,000 - 80,000 gDM^{-1}. At the base of this 23cm core (1955) the concentration finally decreases. It appears that

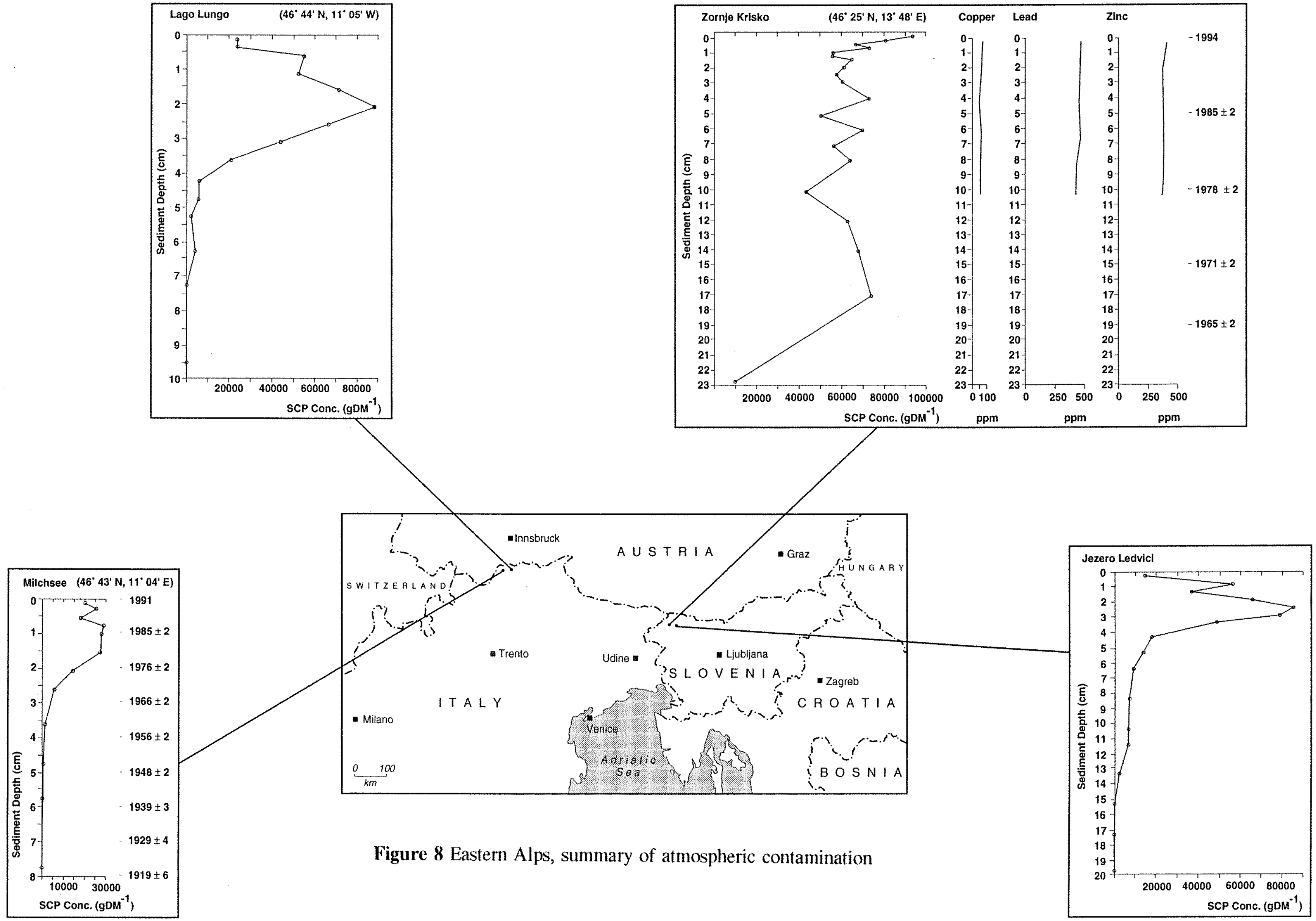
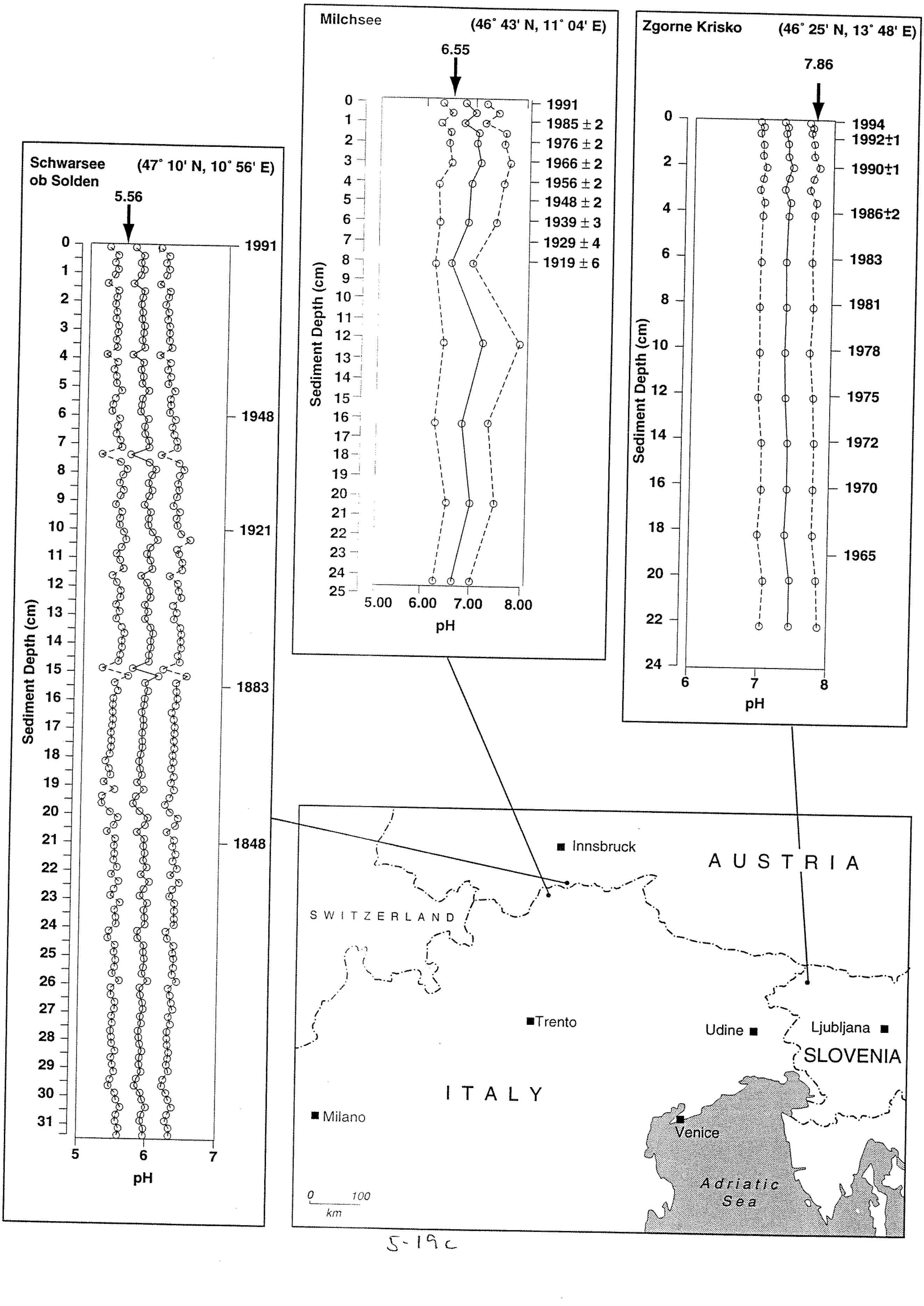


Figure 8 Eastern Alps, summary of atmospheric contamination

Figure 8a Eastern Alps, reconstructed pH profiles



5-19c

this is 18cm of recent material and any interpretation of the profile is almost impossible. An earthquake in the area in the 1970's may have influenced sediment distribution in this site (A. Brancelj, pers. comm.).

The lack of variability and high sediment accumulation rate in the major and trace element chemistry profiles from this site make it difficult to identify any trends in metal enrichment. The metal fluxes show a decrease in the mid-1980's but this appears to reflect changes in sedimentation rate (Annex Figure 13b). However, this decrease does not appear in the SCP profile.

With the exception of the species shifts at the base of the sequence the diatom assemblages in this core are relatively stable (Annex B Figure 38). The base of the core, below 20 cm is dominated by *Cymbella minuta* and *Fragilaria pinnata*, with 10% *Achnanthes conspicua* in the bottom sample. The maximum abundance of *Fragilaria pinnata* at 20 cm depth seems to be related to the maximum %LOI value at this depth. Above a depth of 20 cm *Achnanthes minutissima* becomes the dominant taxon increasing from less than 20% to almost 60%. *Navicula subminiscula* also increases slightly in abundance, reaching a maximum of over 10%. There is a slight decline in the abundance of *Achnanthes minutissima* between c. 4 cm to 1 cm, whilst there are slight increases in the percentages of *Cymbella minuta, Denticula tenuis* and *Fragilaria pinnata*. The percentage of *Achnanthes minutissima* recovers to almost 60% at the surface whilst the later species decline slightly in abundance.

The cladoceran remains in the Zgornje Krisko Jezero core belong to the taxa *Chydorus sphaericus* and *Daphnia pulicaria.* Head shields of both species were counted and the head shields of *Daphnia* are exceptionally well preserved in the sediment of this lake. There are no apparent changes in the proportions of the two species in the upper 5 cm of the sediment (Annex B Figure 39).
Counts of *Chydorus* are relatively stable in the whole core, while those of *Daphnia* decline in the intermediate layers. Both the species live in the lake at present.The uniform distribution of remains of the two species in the upper 5 cm sediment of Zgornje Krisko is in accordance with the assumption that the ecosystem has greater stability under alkaline conditions. The reasons for the changes in *Daphnia* head shields below 5 cm are not known.

The 22 cm core appears to cover the period since the early 1960s, however, the ^{210}Pb chronology at this site was not straightforward. Evidence for atmospheric contamination is difficult to interpret and metal fluxes show different patterns to the SCP profile. Overall there is a slight decline in reconstructed pH from about 7.5 at the base of the core to about 7.3 at the surface (Figure 8a). Given the evidence for disturbance from the above analyses, and the highly buffered nature of this lake, it is likely that changes in the diatom flora result from changes in source communities related to catchment and littoral zone erosion rather than changes in water quality related to atmospheric changes.

Jezero Ledvici

This site, adjacent to Zgornje Zrisko Jezero, shows the usual SCP profile and indicates that the problems with the profile obtained from Zgornje Zrisko Jezero are site specific. The peak of over 80,000 gDM^{-1} suggests that the area has been subjected to high deposition, in agreement with Zgornje Krisko Jezero, and also suggests that the Zgornje core is mostly recent sediment. Dating of this core is required to interpret the profiles from this region further.

Lago Lungo and Milchsee

The two Italian Tyrol sites are located very close together and although the profile shapes are similar they show significant differences in their concentrations. The Milchsee core has been ^{210}Pb dated and shows that the profile begins in the 1930's, increases rapidly in the 1950's and 1960's and reaches a peak of almost 30,000 gDM^{-1} in 1986. This is followed by a decrease to the surface. Lago Lungo, however, despite having a similar length of SCP profile has a much higher SCP peak concentration (almost 90,000 gDM^{-1}). Details of lithostratigraphic, radiometric, chironomid and diatom analyses of the Milchsee core are given in Cameron *et.al.* 1993. The results of pH reconstruction using both the AL:PE and SWAP diatom training sets is summarised below.
Using the SWAP training set to reconstruct pH: from the base of the core to 16.5 cm pH declines from 6.4 to a minimum of 5.7, increasing to a maximum of 6.8 at 12.5 cm. pH declines to 6.2 at 8.5 cm, increasing to 6.8 at 4.25 cm and then declines to 6.4 at the surface. The fluctuations in reconstructed pH follow the rise in *Synedra acus* and are driven to a large extent by this species, whose abundance appears to be related to events of accelerated catchment erosion (see %DW and %LOI profiles in Cameron *et.al.* 1993). The mean measured pH of Milchsee is in the range 6.55. The pH reconstruction based on the AL:PE training set follows similar trends to that based on the SWAP training set, but pH values are higher with a reconstructed pH of 6.6 at the sediment surface, which is slightly nearer to the measured value than the SWAP reconstruction. The pH increases from 6.6 at the base of the core to 7.0 at 12.5 cm, declining to 6.5 at 8 cm, increasing to 6.9 at 3.25 cm and declines to 6.6 at the sediment surface.

The underlying geology of Milchsee is of gneiss, lakewater has a high Ca concentration, the lake is therefore well buffered and would be unlikely to respond to acid deposition. The onset of atmospheric deposition at Milchsee occurs during the 1930s and there is a rapid increase in carbonaceous particle concentrations from the mid-1950s. There are however no perceptible changes in the diatom flora in response to acid deposition. The primary factor affecting diatom assemblages appear to be events of accelerated catchment inwash and of particular interest is the appearance in abundance of *Synedra acus* in the mid-19 th century.

Schwarzsee ob Sölden

Two sediment cores were taken from Schwarzee ob Solden in 16 m water depth during May 1993. The cores consisted of brown-grey mud with micaceous particles and irregular bands of darker and lighter coloured mud. The %DW profile for SOS2 shows a minimum of 9% at the top of the core and a maximum of 25% at 9.5 cm. Below 7 cm depth %DW fluctuates between 13-25%.

Schwarzsee ob Solden showed only very low concentrations of SCP in two sediment levels. At present it is unclear why this is so and interpretation is therefore impossible. It is hoped that the analysis of a further core from this site will enable a better interpretation.

The concentrations of the vascular wax n-alkanes are relatively high (100 ng/g). PAH concentrations increased sharply from 1960 to a peak concentration of 1300 ng/g in 1967 from which time they have slowly decreased to the present value of 800 ng/g. PCB are present in high concentrations in the sediments of this lake (maximum concentration 12 ng/g at the surface - 1991). The concentration profile shows a gradual increase above background from 1960 to 1978 and a sharper increase from this time to the surface. This pattern roughly parallels that of HCB and pp'-DDE.

The 32 cm sediment core SOS1 has been analysed for diatoms at intervals of 0.25 cm. The profile from Schwarzee shows significant variability and change within the diatom assemblages. A total of 51 diatom taxa were identified, the 33 taxa with abundances of more than 1% are shown in a summary diagram (Annex B Figure 40). In the lower part of the core, from the base to 27 cm, *Aulacosera lirata* var. *alpigena* is dominant. In the section 27 cm to 6 cm there are changing abundances of *Aulacoseira perglabra, A. alpigena* and *A. nygardii.* In the uppermost 6 cm *Pinnularia* cf. *microstauron* sp. 2 (Temporary sp. 3) and *Aulacoseira distans*, along with *Cymbella hebridica, Pinnularia subcapitata, Eunotia pectinalis, Eunotia exigua* and *Achnanthes* spp. all increase in abundance. Radiometric dating places the 21 cm level at 1848. During the period from the base of the core to the late 1940s, reconstructed pH remains relatively stable at around 6.0 - 5.8 (Figure 8a). In the uppermost 6 cm, a period representing approximately the last 50 years there is a slight decline in pH, to around 5.7, however the overall pattern is one of relative stability in reconstructed pH. The evidence for atmospheric contamination is unclear, with only very low concentrations of SCPs at two levels in the core. There are, however, increases in organic compounds since the 1960s.

Nine levels were analysed from the sediment core were analysed for chironomids. Annex B Figure 41 shows the number of specimens and the number of taxa found in the samples. Seven taxa were found. *Micropsectra radialis* and *Pseudodiamesa* cf. *branickii* were the dominant taxa, with other species present as single specimens only. Annex B Figure 42 shows the relative abundance of the two dominant taxa. *Pseudodiamesa* cf. *branickii* dominated in the bottom samples but decreased in relative abundance up-core, while *Micropsectra radialis* increases in relative abundance up-core.

Regional discussion

Although 31% of the SO_x received by the EMEP square in which the Slovenian sites lie is predicted to have been produced within Slovenia itself (Sandnes, 1993) there are significant inputs from other countries. 22% is calculated to have originated in (the industrial centre of Udine in north-eastern Italy is less than 100km away), 11% from Germany and 4-6% each from Austria (the industrial area at Kragenfurt is in the opposite direction to the prevailing wind), Poland, Czech Republic, Hungary and Croatia. A coal-fired power station downwind of the site, but 'close' (A. Brancelj, pers. comm.) could be a source of particles as many SCP are large indicating a probable local origin. The EMEP square in which the Tyrolean sites lie receives depositions originating from many countries. Germany (37%) and Italy (26%) are the main sources with smaller contributions (3-7%) from Austria, Belgium, France, Poland, Switzerland and the Czech Republic (Sandnes, 1993). Independent prevailing wind data from Brenner Pass and Mayrhofen are predominantly due north and due south and so support a German/Italian shared source.

h) Tatra Mountains

Five cores have been analysed from the Tatra Mountains, two in Slovakia, Starolesnianske Pleso (49°10'N, 20°10'E) and Nizne Terianske (49°10'N, 20°00'E), and three in Poland, Czarny Staw (49°15'N, 20°05'E), Zielowny Staw (49°13'N, 20°00'E) and Dlugi Staw (49°13'N, 20°05'E) (Figure 9). All the cores were analysed for SCP. Starolesnianske Pleso, Nizne Terianske, Zielowny Staw and Dlugi Staw were analysed for major and trace element chemistry (Annex Figures 14a-17b) and Starolesnianske Pleso and Dlugi Staw were analysed for POC (Tables 30-38 and Annex Figures 2-6). Starolesnianske Pleso, Nizne Terianske, Zielowny Staw and Dlugi Staw were analysed for diatoms.

Starolesnianske Pleso and Nizne Terianske

Three Glew cores (Glew 1989), STAR93/1-STAR93/3 were obtained from the deepest part of the Starolesnianske Pleso (3 - 3.5 m), and between 13.5 and 18.5 cm of sediment was recovered. STAR93/3 was extruded at a coarser interval and was used as a second back-up core. All three cores (Annex B

Figure 9 Tatra Mountains, summary of atmospheric contamination

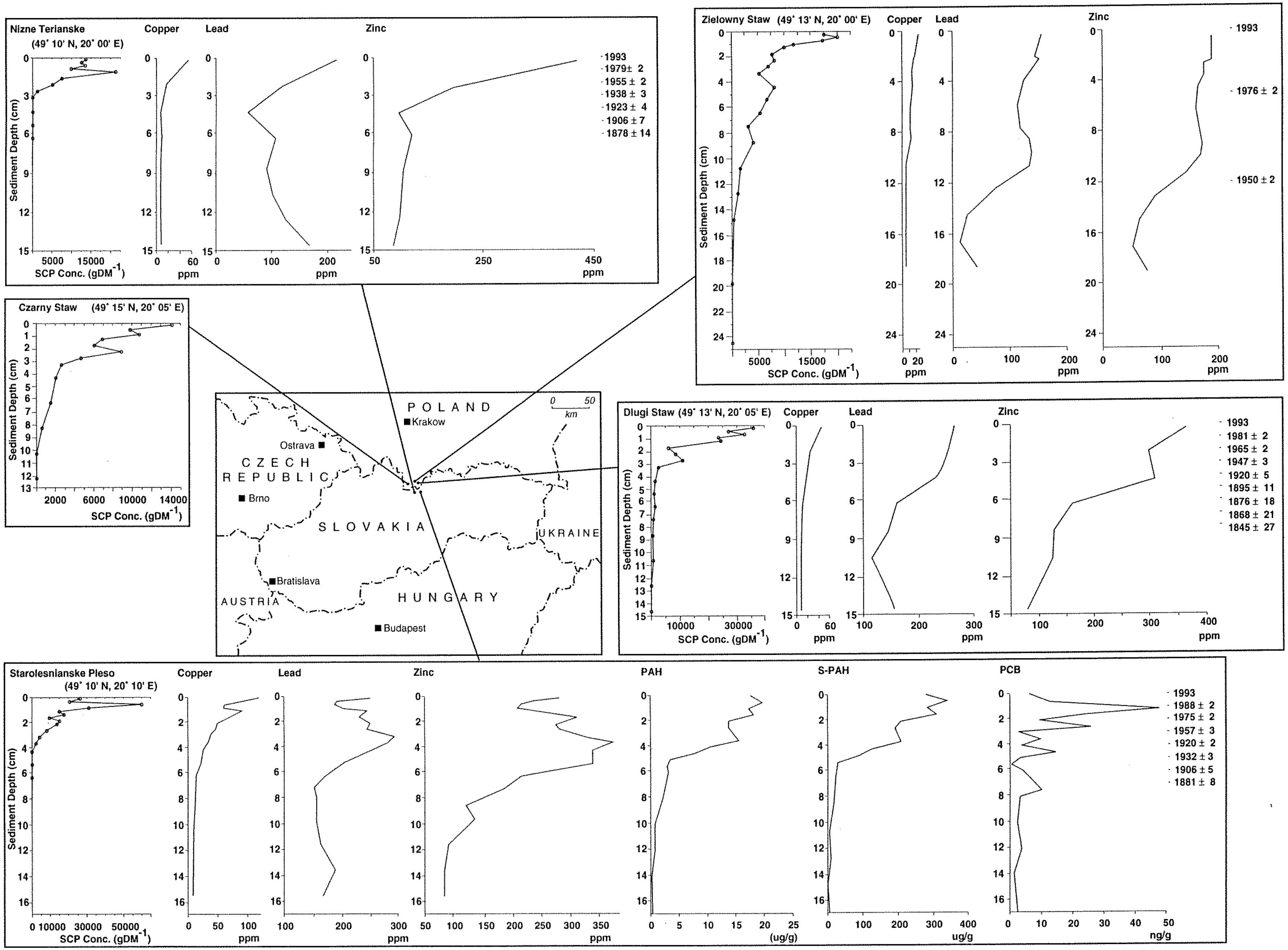
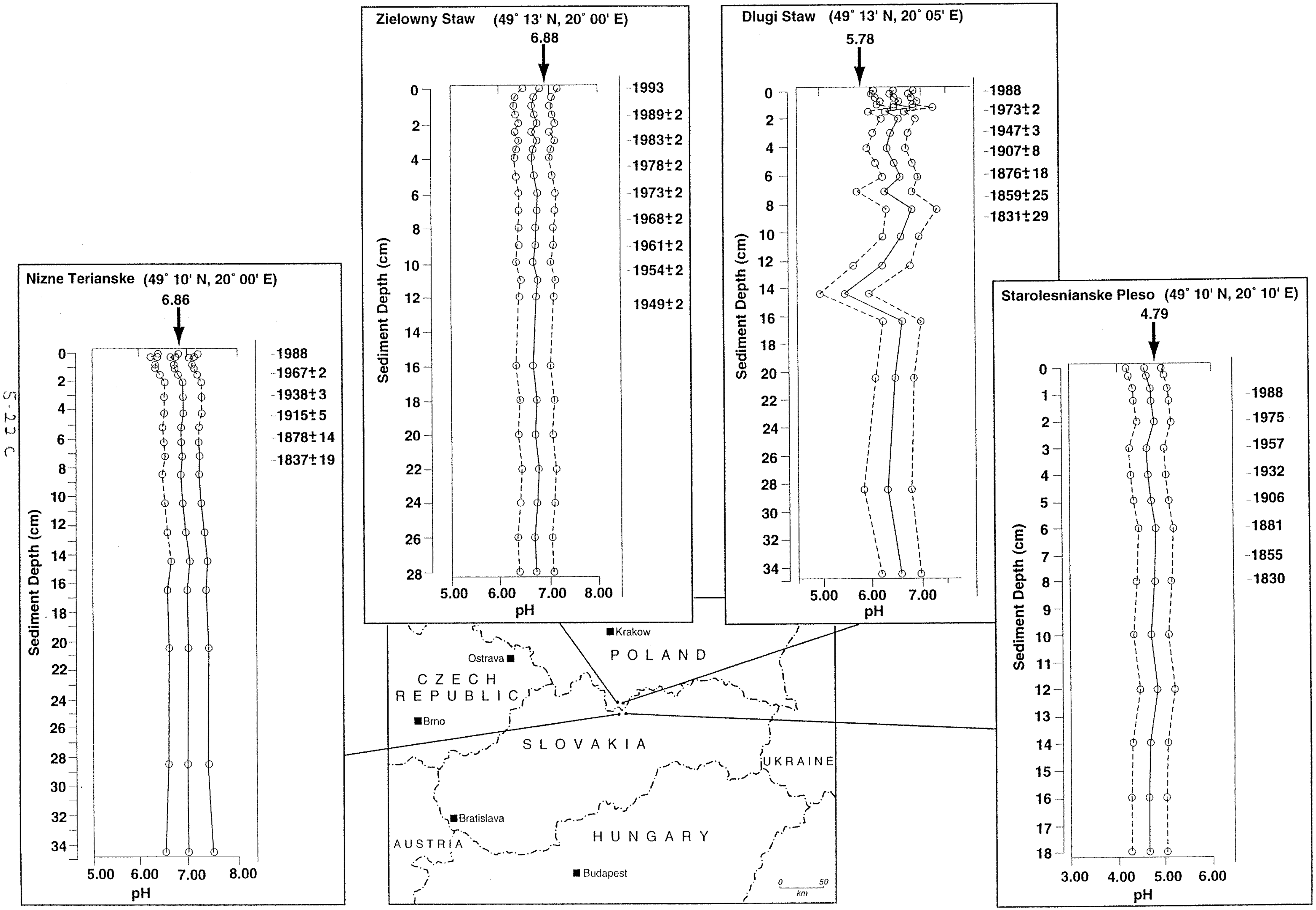


Figure 9a Tatra Mountains, reconstructed pH profiles



5-22 C

Figures 43-45) show a very stable %DW profile from their base to about 3 cm where %DW decreases to the surface and %LOI increases slightly, and all show a general trend of decreasing %LOI from the base of the core to about 3 cm. Both cores STAR93/1 and STAR93/2 show a small sub-surface peak in %LOI at 1.75 cm and 1.5 cm respectively with STAR93/2 showing another peak at 0.25 cm. In general the %LOI values are quite high compared to more unproductive systems eg. Arresjoen. STAR93/2 was chosen as the 'mastercore' for palaeolimnological analyses.

Nizne Terianske was cored on 6/10/93. The lake has a maximum depth of 46 m and 2 cores were taken from 44 m water depth. Core 1 was 31 cm long and Core 2 was 37 cm long. Both cores have similar lithostratigraphic profiles with %LOI values varying between approximately 10-30% (Annex B Figures 46 & 47). There are distinct peaks in %DW and matching troughs in %LOI at c. 24 cm, 17-18 cm, 4 cm and both cores have maximum %LOI values at the surface.

Although all the sites are situated close together the SCP profiles of the Slovakian sites show different trends to those of the sites just across the border in Poland. The Slovakian profiles are short (less than 4.5cm long) and increase rapidly to high concentrations with a peak of over 20,000 gDM^{-1} for Nizne Terianske (1978) and 60,000 gDM^{-1} in 1990 for Starolesnianske Pleso. This is followed in both cases by a sharp decrease to the surface. Neither of these SCP profiles correspond well with the metal profiles.

In Starolesnianske Pleso the sedimentation rate has risen steadily from 1950 to the present day and this has had the effect of flattening off some of the metal concentration profiles. Metal fluxes started to increase early in the nineteenth century and increased until 1930 (Cd), 1970's (Pb & Zn) and 1980 (Cu). Cu, Pb and Zn show deceases above these dates and followed by surface increases. Cd decreases after 1930 (25 ng/cm^2/yr) to the surface (12 ng/cm^2/yr). The very sharp peak in the sedimentation rate curve of the Nizne Terianske core has strongly affected the Cu, Pb, Cd and Zn flux profiles. The dry weight, LOI and sedimentation rate curves suggest that sedimentation rate change may be the most important controlling variable at this site. The accumulation rate curves all show a minimum at 4-5cm; however, this is an artifact of the approach. The real initial rise could be further down the core.

In the Starolesnianske Pleso core, TOC is 14%. The concentrations of higher plant n-alkanes are among the highest in the dataset (150-200 μg/g). This lake shows the highest concentrations of PAH in the dataset (maximum levels 20,000 ng/g in 1990) as well as all organochlorinated compounds (maximum concentrations of 80, 180 and 14 ng/g for the PCB, pp'-DDE and HCB, respectively). PCB, pp'-DDE and HCB all increase above 6cm (ca. 1900) and increase gradually to 3cm (1957) from which time they increase rapidly to a peak at 1cm (1988) followed by a marked decline to the surface. PAH increase sharply from the start of the century (1906) to ca. 1950 and then increase more slowly from this time to the present. S-PAH trends are very similar to those of ΣPAH suggesting that the profiles are a reflection of fossil-fuel combustion. Retene (from forest fires) does not show good agreement with ΣPAH. The n-alkanes exhibit a fairly uniform trend, representing the constancy of the contributions from higher plants.

The SCP maximum for Starolesnienske Pleso coincides with the peak in ΣPAH (0.5-1cm; 1990) but the other organics have peaks slightly earlier. The metal profiles do not appear to show any similarities with either the SCP or the organics.

Fifteen levels from the Starolesnianske Pleso core STAR93/2 have been analyzed for diatoms (500 valves per sample) and a total 44 taxa were found. A summary diagram illustrating the most important changes is shown in Annex B Figure 48. The diatom assemblage from this lake is not diverse with only 44 taxa being found (in comparison, three times as many taxa are found in the Arresjoen core) and only 14 taxa had an abundance greater than 1%. The entire core is dominated by one species, *Aulacoseira* *distans* var. *nivalis* which occurs at an abundance of 50-60% throughout the core. There are no major stratigraphic changes in the core with percentages of *A. distans* var. *nivalis* remaining quite constant throughout. However, slight changes do occur, above 1.5 cm *Tabellaria flocculosa*, *Neidium bisulcatum* and *Pinnularia caudata* are more abundant whilst *Achnanthes austriaca* var. *minor* declines in abundance. Above 8 cm there is a decline in the abundance of *Cymbella* species # 1 PIRLA and above 6 cm *Cymbella hedridica* declines. *Achnanthes austriaca* var. *minor* is more abundant between 2-6 cm than at levels either above or below. Species such as *Aulacoseira distans* var. *distans* and *Achnanthes marginulata* remain at fairly constant abundances throughout the core. Total diatom concentrations (Annex B Figure 49) are relatively constant from the base of the core to 6 cm, there is a slight increase to 4 cm and then a decline to the sediment surface, reflecting the higher amount of water in the top 4 cm. The reconstructed pH, using the AL:PE diatom training set (Figure 9a), is relatively stable, increasing from 5.1 at 18 cm to 5.3 at 12 cm. pH then declines to 5.1/5.2 between 10 cm and 0.25 cm and declines to 5.0 at the surface. This small pH decline at the surface may reflect the increased atmospheric deposition, although the maximum flux of SCP is recorded at 0.5 cm depth. The Starolesnianske Pleso core (Annex B Figure 50) contains remains of four cladoceran species: *Chydorus sphaericus, Alona quadrangularis, Alonella excisa* (counted as head shields) and *Ceriodaphnia quadrangula* (counted as ephippia). Concentrations of their remains in the sediment core are relatively stable up to the depth 3 cm, above which head shields of *Chydorus sphaericus* increase dramatically. Remains of *Alona quadrangularis* are the most abundant in the lower part of the core until the increase of *Chydorus* above 3 cm. The absolute counts are expressed as number per gram wet weight, so that the decrease of all remains at the top of the core is influenced by higher water content in the uppermost layer of the sediment. But when expressed as percentage values (Annex B Figure 51), the abundance of *Chydorus* in all Chydoridae remains increases from less than 20% below 3 cm to more than 90% above. The evidence for the recent decline of all cladocerans except *Chydorus sphaericus* is supported by the fact that no live cladocerans apart from *Chydorus* were found in littoral plankton samples taken in the autumn 1993 and 1994, with as many as 700 specimens of *Chydorus* counted in each sample. The only other crustacean found in the plankton and littoral samples from 1993 and 1994 is the copepod *Acanthocyclops vernalis*.

Minkiewicz (1917) found 4 cladoceran species in Starolesnianske Pleso, quoted by him as „Gr. Kolbach - See VI": *Ceriodaphnia quadrangula* (under the name *C. affinis*), *Alona quadrangularis, Alonella excisa* and *Chydorus sphaericus.* We have found all these species in the sediment core but *Chydorus* prevails greatly in the uppermost layers, being apparently the only cladoceran inhabiting the lake at present. From the three copepod species mentioned by Minkiewicz (*Mixodiaptomus tatricus, Eucyclops serrulatus, Acanthocyclops vernalis*) only *Acanthocyclops vernalis* lives in the lake now. The extinction of *Mixodiaptomus tatricus* from this lake and other shallow, recently acidified lakes in the High Tatra has already been reported by Stuchlik *et al.* (1985). The stable proportions of cladoceran remains throughout most of the core except the top contradict the changes interpreted from the diatom flora. The diatoms indicate a steady increase of pH from acid conditions in pre-industrial time, followed by a fast decrease during the past decades. The explanation may be that diatoms react primarily to pH, but cladocerans react to the toxic effects of labile aluminium. The lower pH limits of the cladocerans inhabiting the lake in the past are well below the recent pH of the lake (Chapter 3, Tab. A6.5). The hypothesis explaining different reaction of diatoms and cladocerans to historical changes of pH involves an assumption that the low pH in pre-industrial times was determined by organic anions (and Al was more bound to organic matter), while the recent low pH has resulted from the airborne strong acid which suppressed dissolved organic matter and liberated labile aluminium. The decline of *Ceriodaphnia quadrangula* with recent acidification was also noted by Uimonen-Simola & Tolonen (1987) and Nilssen & Sandoy (1990).

Three samples from the Starolesnianske Pleso sediment core were analysed for chironomids. The number of taxa and specimens are shown in Annex B Figure 52. The chironomid community is dominated by *Tanytarsus* cf. *gregarius* in all samples.

Diatom analysis of the Nizne Terianske core (Annex B Figure 53) shows that the assemblages in the bottom part of the core 35-17 cm have a diverse mixture of both planktonic and non-planktonic taxa, these include *Asterionella formosa, Synedra tenera, Fragilaria brevistriata, Fragilaria pinnata, Denticula tenuis, Navicula schassmanii, Achnanthes minutissima* and *Achnanthes curtissima.* Between 17 cm and 2 cm depth, the percentages of some of these taxa decline whilst the abundances of *Fragilaria construens, Navicula schassmanii, Achnanthes minutissima* and *Achnanthes curtissima* increase. At approximately 3 cm depth there is a small peak of an unknown *Navicula* sp. In the upper 2 cm of the core there are significant increases in many diatom taxa, previuously absent or rare in the core. These include *Achnanthes marginulata, Achnanthes subatomoides, Achnanthes austriaca* var. *helvetica, Achnanthes altaica* and *Synedra miniscula.* As with the other lakes in the Tatra Mountains Nizne Terianske is subject to a high level of deposition, the lakewater, however, has a high Ca concentration (159 $ueql^{-1}$). The reconstructed pH is stable at approximately 6.9 from the base of the core to about 2 cm depth (Figure 9a). The pH then declines to 6.6 at 0.4 cm depth, recovering to 6.8 at the surface. Despite the relatively low sensitivity of the site it appears that the high deposition levels in this region may have had a significant effect on the diatom assemblages in the lake. The surface reconstructed pH of 6.81 matches closely the mean measured lakewater pH of 6.86. The relative decrease in atmospheric deposition since the maximum (SCP) level in 1978 may be reflected in the slightly increased pH at the sediment surface.

The only cladoceran remains found in the Nizne Teriankske core are head shields and shells of *Chydorus sphaericus* and ephippia of *Daphnia pulicaria* (Annex B Figure 54). The ephippia are almost absent from the uppermost cm. Besides the remains of Cladocera, egg capsules of flatworms (Turbellaria Rhabdocoela) were found in large numbers (Annex B Figure 55). In Terianske, Minkiewicz (1917) found *Chydorus sphaericus* and *Daphnia pulicaria* (quoted as *D. wierzejskii*). Remains of both species are preserved in the sediment, but ephippia of *Daphnia* are missing in the upper 1 cm layer and live *Daphnia* have not been found since the team of Charles University started sampling in the Tatra in 1979; no data are available from the period in between. The reasons for the recent disappearance of *Daphnia* are not known, as discussed in Chapter 3.

Zielowny Staw, Dlugi Staw and Czarny Staw

Two cores were taken from Dlugi Staw on 8/10/93. The cores were taken from the deepest point of the lake in 9 m water depth. Core 1 is 34 cm long and Core 2 is 28 cm long. Both cores show similar %LOI & %DW profiles (Annex B Figures 56 & 57), % LOI varying from 20-35%. From these profiles Core 1 appeared to have a slightly faster accumulation rate, with %DW maxima occurring at about 11.5 cm and 27.5 cm, compared with 10.5 cm and 22.5 cm in Core 2. Broad maxima in %LOI occur at 29 cm & 16 cm in Core 1 and about 27 cm and 15 cm in Core 2. Maximum LOI values of approximately 30% occur at the surface in both cores. x was selected as the mastercore for dating, SCP and diatom analyses.

Two Glew cores (Glew 1989), ZIEL93/1 AND ZIEL93/2 were obtained from 13 m water depth and c 30 cm of sediment was recovered (Annex B Figures 58 & 59). Both cores have very strongly fluctuating, %LOI, %DW and WD profiles, and some features can be clearly seen in both cores. For example the large peak in %DW at 16 cm in ZIEL93/1 appears to correspond with a broad peak in %DW between 15-19 cm in ZIEL/2. These levels are associated with low %LOI and high WD measurements. However, other peaks in %DW can not be easily correlated between the cores. Such large fluctuations in %DW, %LOI and WD are indicative of a highly disturbed catchment with peaks in %DW being associated with discrete catchment erosion events, and there is visual evidence for former landslips and slides in the catchment. Core ZIEL93/1 was chosen as the 'mastercore' for palaeolimnological analyses at this site.

The SCP profiles for the Polish sediment cores are much longer (10 - 20cm) and show a period of slow increase before more rapidly increasing between 1-3cm. Zielowny Staw reaches a peak of 20,000 gDM^{-1} (1990) and then decreases slightly in the surface sample whilst Czarny Staw and Dlugi Staw show maximum concentrations of 14,000 gDM^{-1} and over 35,000 gDM^{-1} respectively at the surface.

Zielowny Staw has a hiatus below 10 cm and dating is only reliable after 1950. The metal profiles are simply products of the changing sedimentation and reliable correction would be as likely to eliminate any trend as to strengthen it. Dlugi Staw shows a single large peak in accumulation rate between 5 and 7 cm, but there is no evidence of an effect on the sediment parameters, dry weight and LOI. However, the event occurs at exactly the point at which the metals start to increase, thus any possible effect must be considered very carefully. The accumulation rate curves (Annex Figure 17b) are more spiky than the concentration curves, but at least in the case of Zn it is more monotonic. Deciding how to treat this event will alter both the start date, and the timing of any peaks. The large peak in Cd at 4 cm, possibly matched by a small peak in Zn, is discussed below.

TOC in Dlugi Staw is around 10%. The concentrations of vascular plant n-alkanes are among the highest in the AL:PE dataset (120-220 µg/g; Fig. 1). PAH are also very high with a maximum concentration of 14,000 ng/g showing a continuous increase from 1876 until the present. This pattern of continuous increase is also common to SCP and Zn, Pb and Cu fluxes showing the increasing deposition of atmospheric pollutants to the site. This pattern is repeated for SCP at Zielowny Staw and Czarny Staw but not for any other of the measured parameters.

The diatom assemblages from the Dlugi Staw core are composed entirely of non-planktonic species (Annex B Figure 60). At the base of the core *Aulacoseira lirata* var. *alpigena*, *Achnanthes subatomoides*, *Achnanthes curtissima*, *Cymbella perpusilla* and *Aulacoseira lirata* are the most common diatoms. The percentages of *Achnanthes scotica* and *Cymbella perpusilla* reach maxima at approximately 5 cm depth, but below this depth in the core the diatom assemblages were relatively stable. In the uppermost 2 cm of the core there are significant changes with maxima in *Achnanthes marginulata, Achnanthes austriaca* var. *minor* and *Achnanthes scotica*, whilst the percentages of *Achnanthes subatomoides, Achnanthes curtissima* and *Cymbella perpusilla* decline. A depth of approximately 4.3 cm in the core corresponds with the year 1910 according to preliminary 210-Pb measurements. Like the other lakes studied in the Tatra mountains Dlugi Staw is subject to a high level of sulphur deposition at the present time (2.6 $gm^{-2}a^{-1}$). This is supported by the SCP profile for this site which shows high, maximum concentrations at the surface (40000 gDM^{-1}). The SCP profile has a long 'tail', extending at low concentrations to below 10 cm. However, SCP concentrations increase sharply from a depth of about 3.5 cm. The reconstructed pH is for the Dlugi Staw core is highly variable throughout the sequence (Figure 9a), values ranging from 5.4 to 6.9. The surface sediment reconstructed pH of 6.5 is significantly different from the mean measured lakewater pH of 5.78. The site is of medium sensitivity, being partially buffered (Ca 109 $ueql^{-1}$), however, the fluctuating pH values do not follow the pattern of atmospheric deposition and must be ascribed to other causes.

In the Zielowny Staw core 24 levels have been analyzed for diatoms (500 valves per sample) and a total 124 taxa were found. A summary diagram illustrating the most important changes is shown in Annex B Figure 61. Zielowny Staw is dominated by benthic attached diatoms with only low abundances of centric species (eg. *Aulacoseira*) which are common at Starolesnianske Pleso, however it has a much more diverse assemblage than that found at Starolesnianske Pleso with 22 taxa with an abundance >3%. The total diatom concentration results (Annex B Figure 62) show that few diatoms are found between

12.5 and 17.5 cm in the core corresponding to the period of high %DW (Annex B Figure 58) which probably represents a period of inwash with very rapid sediment accumulation, which would dilute the diatoms. There are also floristic changes which appear to be associated with this event. Above 12.5 cm *Fragilaria* cf *tenera* is the most common taxa, however it is only present in extremely low abundances below 16 cm. Other species also demonstrate this pattern eg. *Achnanthes linearis*. By contrast species such as *Achnanthes suchlantii*, *Fragilaria pseudoconstruens*, *Navicula minima* and *Fragilaria* species 2 are more abundant below 16 cm than above 12.5 cm. Some species have fairly stable abundances throughout the core eg. *Achnanthes minutissima* and *Navicula seminulum*. Less significant floristic changes also occur throughout the core eg. the increase in *Fragilaria* cf *tenera* above 8 cm and the fluctuating abundance of *Navicula digitulus* at the base of the core. In general concentrations are lower at the base of the core than above 12 cm.

Zielowny Staw is a well buffered lake and the reconstructed pH is stable throughout the profile. Although sulphur deposition is very high and the lake may be close to exceedance of the critical load, pH varies between 6.7 and 6.8 and rises to 6.9 in the surface sample (Figure 9a). The reconstructed pH at the surface therefore matches the mean measured pH (6.88) closely.

Regional Discussion

The Tatras show the highest for the dataset in terms of PAH and organochlorinated compounds. The deposition fluxes of PAH in this area range between 90-190 ng/cm^2/yr. However, these two types of compound exhibit different temporal trends. Whereas PAH constantly increase until recent times, the organochlorinated compounds exhibit a period of highest concentration around 1988, followed by a decrease in recent times. This trend is not observed in the profiles of these compounds in the lakes from the Alps which exhibit a constant increase until present.

The EMEP SO_x budget model (Sandnes, 1993) suggests that 46% of the SO_x deposited in this EMEP square is from Poland with smaller contributions from Germany (17%), Czech Republic (12%), Slovakia (9%) and Hungary (7%). This data does not, however, explain the differences between the Polish and Slovakian sites. Historical SO_2 emission models (Mylona, 1993) also shed little light as both Polish and Czech & Slovakian profiles are very similar, both showing rapid increases in emissions during the 1950's and 1960's and peaks in the 1980's before a decline in recent years. UN combustion statistics (data up to 1990 available) similarly show little significant differences between the two countries except that Czech & Slovakia levels off in mid-1970's and then decreases after mid-1980's whereas Poland tends to increase up to 1990. It is difficult to explain why similarities should exist between sites within a country and yet be different to cores taken from lakes situated just across the border. ^{210}Pb dating is needed to try and explain these profiles further and it may be that this will show that SCP fluxes are similar and that any differences are due to sedimentary factors.

5.5 General Discussion

Temporal patterns

Considering the range of depositional regimes and meteorology experienced by the AL:PE sites, the temporal pattern of SCP distribution is remarkably consistent throughout the dataset. There are similarities in the profiles from Svalbard to the Sierra Nevada and from the Tatra Mountains to the west of Ireland. The exception is Zgornje Krisko Jezero. Both SCP and metals data show high concentrations for most of the length of the core. This is probably due to the high accumulation rate and in combination with very high concentrations, this suggests a massive pollutant flux at this site. It maybe that this is a site specific effect as the other Slovenian site, Jezero Ledvici, although showing similar concentrations over a short time period, shows the typical SCP profile exhibited throughout Europe. Unfortunately, this latter core was not dated.

The three main features of the SCP profile are the start of the record, the rapid increase in concentration and the near surface concentration maximum, and all three are present at nearly all the sites. The main exceptions, apart from Zgornje Krisko, are the Spanish Pyrenean sites Lagunas Aguilo and Redo. Aguilo shows an irregular profile due to differences in sedimentation rate and so peaks vary depending on whether concentration or flux is used. Redo shows a slow, steady increase rather than a rapid one.

The start of the SCP record is pre-1940 in all sites except those where concentrations are very low (Arresjøen, Laguna Caldera) suggesting that this is a detection limit problem rather than a depositional effect. Where the record starts early (mid-19th century) this appears to be in areas heavily impacted by deposition (Lochnagar, Dlugi Staw, Starolesnienske Pleso) although adjacent Tatra sites show later dates. The remainder of the sites show the start of the record to be 1900's - 1920's considerably later than the rise in the metal record (see below). This is consistent with other palaeolimnological studies (e.g. Battarbee *et al.*, 1988). Similarly consistent is the rapid increase in SCP concentration. In all cases this is post-Second World War but varies between the 1950's and 1980's.

The near surface SCP concentration peak is present in all but eight of the 31 sites. Five of these, Øvre Neådalsvatn, Paione Superiore, Birgervatnen, Scurvy Pond and Etang d'Aubé have very low accumulation rate and so there is insufficient sediment accumulation to resolve the surface decrease. Dlugi Staw and Czarny Staw have a surface maximum, although the profiles are spiky near the surface and it maybe that the peak at 0.5-1cm and 1-1.5cm respectively correspond to the peak and slight surface decrease in nearby Zielowny Staw. The other sites with surface maxima are the Portuguese sites discussed in more detail above. The reason for this is, at present, unclear but the profiles in all three lakes are similar and so there maybe a local depositional reason for this. Of the dated cores, the SCP peak falls between the 1970's to as late as 1990 at Zielowny Staw, Starolesnienske Pleso, Laguna Caldera and Laguna Redo.

All sites show at least some surface enrichment in trace metals. This is most marked for Pb, Cu and Cd, which show up-core increases at all sites. Zn usually behaves similarly, but at two sites (Arresjøen and Laguna Cimera) there is no clear increase. These are the sites which show least enrichment in Pb, Cu and Cd. In addition, Ni, V and Cr show up-core increases in at least some sites. Even where all the metals show enrichment, the pattern of behaviour is not the same. Excluding Arresjøen and Laguna Cimera, in which the patterns are indistinct, six of the sites show coincident subsurface peaks in the Cd, Pb and Zn profiles, while Cu continues to rise up to the surface. Furthermore, at eight of the sites Cu starts to increase up-core later than the other metals. The three reliable sites (Laguna Redo, Laguna Escura, Starolesnianske Pleso) show metals starting to increase significantly after 1810 to 1860.

In general, the organics from the AL:PE 2 sites also show consistent results throughout. The n-alkanes mostly show little temporal change suggesting that catchment vegetation has remained fairly constant throughout the periods covered by the cores. The exceptions are for Laguna Redo and Dlugi Staw where there are increases after 1970 and 1980 respectively. Schwarzsee ob Solden may also show an increase. ΣPAH shows increases at all sites except Lagoa Escura although individual PAH vary within this (see individual site discussion). This increase generally takes place between 1870 - 1900, slightly later than the metals, but a little earlier than the SCP. Schwarzsee ob Solden is the exception where the increase starts ca. 1960. There is no clear date for the maximum concentration of PAH. pp'DDE also shows an increase all sites starting ca. 1940's. The only exception to this is Arresjøen where there is an earlier secondary peak. This may be due to the very low levels at this site.

PCB and HCB both show increases at all sites starting at the end of the last century or the early years of this. The exception is again Schwarzsee ob Solden where the increase starts in the 1960's (becoming more rapid in the 1970's) and 1970's respectively. PCB were first synthesised industrially in the U.S.A. in 1929 and in 1954 in Europe and so these early increases may be due to contamination, sediment mixing or possibly as a by-product of industrial combustion processes. The latter may explain why there are some similarities between the PAH and PCB profiles.

Spatial patterns

SCP deposition

The groups of lakes in the AL:PE programme were selected so that they represented a broad range of depositional regimes. This is emphasised by looking at a map of Europe with the SCP surface concentrations shown as proportional circles (Annex Figure 18). There are some immediate points of interest:

- The area of highest SCP deposition is central Europe.
- Other high SCP deposition areas exist where these are directly influenced by 'regional' pollution e.g. Cairngorms from U.K. emissions, southern Norway from central Europe and U.K.
- SCP depositions decrease from high deposition areas to the west (i.e. central Europe to Spain and Portugal; UK to Ireland) and to the north.
- Especially noticeable is the gradient in Norway. The lowest concentrations are in Arresjøen but these are not too dissimilar to the AL:PE 1 reference site - Øvre Neådalsvatn.
- It maybe that there is a 'hemispherical background' of SCP deposition shown by the Svalbard sites and Øvre Neådalsvatn.

One of the main differences between the sites which raises inconsistencies when trying to compare concentrations is sediment accumulation rate. ^{210}Pb dating has shown that there are quite considerable differences between AL:PE sites, from Arresjøen where 1900 is at 2cm to Lough Maam and Laguna Aguilo where 1900 is at 12cm. It is possible to go some way to taking this into account by using the dated core data and looking at SCP fluxes. However, these seem to emphasise the patterns seen previously and exaggerate differences (Annex Figure 19):

- Paione Superiore is exceptionally high.
- French and Spanish values are now approximately equal.
- Lochnagar shows a high flux. Decreases to the west (Lough Maam) and to the north (through Norway to Svalbard) are still observed.
- Arresjøen shows by far the smallest flux, and whereas surface concentrations were similar to other low impacted sites (e.g. Øvre Neådalsvatn) surface fluxes are an order of magnitude lower. PAH results behave in an identical way.

Pollutant inventories allow even better inter-site comparisons.

Anthropogenic Pollutant Inventories

Many of the cores show elevated pollutant concentrations in the more recent part of the record, presumably due to increased anthropogenic inputs. Where there is a well defined natural background concentration (Cbg), the anthropogenic component can be determined by the subtraction:

$$C = Ctot - Cbg,$$

where Ctot is the total concentration. Such a differentiation is well illustrated by the stable Pb and Cd results from Aguilo (Annex Figures 20 & 21). Where the record has been perturbed by sedimentological events it may however be more difficult to identify the background level (see individual site discussions).

Although the timing of the anthropogenic increase and variations in flux are important to a description of the pollution history, a fairly simple measure of the general level of contamination is given by the inventory of the anthropogenic component, calculated by integrating the concentration with regard to the cumulative dry mass. Table 39 (Annex) shows the results of these calculations for stable Pb and Cd at each of the AL:PE sites, excluding Zgornje Krisko Jezero where there was a highly abbreviated record. Since sediment inventories may be significantly influenced by effects such as sediment focusing or indirect inputs via the catchment, a better comparison between sites is provided by normalising the inventories with respect to unsupported ^{210}Pb which, on a regional basis, can be regarded as deriving from a relatively uniform atmospheric flux. Table 39 also shows the unsupported ^{210}Pb inventories of each core, and the stable Pb/^{210}Pb and Cd/^{210}Pb inventory ratios. The normalised inventories are also plotted in Annex Figure 22.

In spite of uncertainties in the determining the anthropogenic component at some sites, a number of clear results do emerge. Stable Pb contamination levels are highest in the East-European sites, notably at Dlugi Staw. The lower value for Zielowny Staw almost certainly underestimates the true contamination levels due to the hiatus in the sediment record prior to ca.1945. Pb contamination levels at the Slovakian sites are however only slightly higher than at the two sites in the Pyrenees. At all East European sites, Cd contamination levels are an order of magnitude higher than at West European sites.

Of the West European sites, Lac Noir is singular in its low contamination levels for both Pb and Cd. Since the Pb inventory at Lac Noir is within normal margins, the low trace metal values cannot be attributed to problems with the core. The relatively high Cd inventory at Arresjøen arises from a concentration peak at a depth on 2.5-2.75 cm. This level is dated to the middle of the 19th century and may well be of natural rather than anthropogenic origin.

The same approach can be taken with the SCP and POC data. For SCP this shows two things (Annex Figure 23). Firstly, it emphasises the north/south pattern through Europe discussed above. The lowest values are at the extreme northern and southern latitudes (Arresjøen, Øvre Neådalsvatn and Laguna Caldera) with the highest concentrations at mid-latitudes. The possible exception to this is Lochnagar which appears to have a higher ratio than it should. The second point is that sites which showed different SCP profiles although geographically close, now plot close together. For example, the Tatra sites with the exception of Dlugi Staw plot almost as a single point and whereas it had been difficult to reconcile the differences between the SCP records of Aubé and Redo on either side of the French/Spanish border, these too now plot close together suggesting a similar SCP deposition through time.

The POC/^{210}Pb inventory ratios show similar patterns to the SCP (Annex Figure 24). The highest ratios (most polluted) are the mid-latitude Tatra sites with lower values to the south and especially the north. The only compound not fitting this pattern is retene which reflects forest-fires /wood combustion rather than pollutant deposition. PAH and S-PAH have the greatest inventory ratios of all pollutants suggesting that fossil-fuel combustion is a significant pollutant source for all sites.

Sedimentation rate

Considering their remoteness, it is surprising how variable the sedimentation rate is within the sites. Current sedimentation rates show some patterns; three of the four Tatras sites show current sedimentation rates below the mean, while all the Iberian sites are at or above the mean. However, this situation is recent as three of the four Tatras sites show very strong perturbation of sedimentation rates within the last century. Of all the sites, only Arresjøen lacks evidence of variation, while two others (Lake Redo and Starolesnianske Pleso) show a monotonic post-war sedimentation rate acceleration. The variable sedimentation rate hinders interpretation of trace metal abundances. While sedimentation rates can be used to estimate the impact on metal concentrations, there is no established theoretical basis for correcting the metal profiles for these effects.

Geology and baseline metals

The bedrock underlying the lakes varies considerably although little is known in detail and so the chemistry of the sediments provides a means of evaluating the composition of the bedrock, in a way which is particularly useful. Geological maps at the scale which exist in remote areas generally provide an oversimplified picture at best, and at worst are not based on composition but structure or age. Mg/K ratios will tend to separate acidic (low Mg, high K) from basic (high Mg, low K) rocks. Mg/K ratios are shown in Table 40 (Annex), together with a number of other elements which are dominantly controlled by the bedrock.

The most basic site is Zgornje Krisko Jezero which reflects the limestone present in its catchment. In this respect the site is exceptional; it has two orders of magnitude more Ca than the average AL:PE 2 site. The other more basic sites are Laguna Caldera, Laguna Aguilo and Arresjøen. Caldera is known to be situated on metamorphosed basic rocks. The composition of Laguna Aguilo sediments suggests that the granodiorite there must be particularly basic. The migmatite at Arresjøen, must contain significant amounts of amphibolite, as would be typical of the Scandinavian Caledonides, to account for the Mg content. At the other extreme, Laguna Escura, Nizne Terianske and Zielowny Staw, have particularly low Mg. These sites are interesting because, while Nizne Terianske is known to be situated on granite, the geology at Lagoa Escura is not known (but is likely to be granitic based on these results) and Zielowny Staw is described as having limestone in its catchment which clearly has little affect on the lake.

The spatial variation in bedrock geology is very important for a number a trace elements. Annex Figure 25 shows scatter plots of the minimum trace (plus Fe and Mn) metal contents of the lakes (excluding Zielowny Staw and Zgornje Krisko Jezero, as these cores do not extend down into unpolluted sediment) against Mg/K. Some trace elements are unaffected as expected; notably Cd and Pb. However, Cu, Ni, Cr and V show a strong, if rather erratic, relationship with bedrock basicity. This leads to widely varying pre-industrial baseline metal concentrations, and consequently variable sensitivity to trace pollution, i.e. it is much more difficult to detect a small Cu contamination in a lake on basalt than in one on granite.

Spatial patterns of metal enrichment

The enrichment in metals is very varied, it differs between metals, and between regions both in abundance and stratigraphy. The two most striking features are the particularly high enrichment in the Tatra Mountains, and the relatively low abundances to the west. The Tatra sites are particularly enriched in Cd, but they also have the highest Pb and Zn concentrations. In contrast, Cu is relatively low. The link with Cd goes strongly into the past; at Dlugi Staw and Starolesnianske Pleso there are exceptionally strong peaks in Cd which date to early this century. This may also be true of Nizne Terianske, but the sedimentation rate changes make interpretation unreliable.

The sites as yet provide no unequivocal evidence of spatial variation in the timing of metal increases, with the exception of the high early Cd in the Tatra Mountains. However, only three of the sites (Redo, Escura and Starolesnienske Pleso) provide reliable evidence about timing, mainly because of interference from sedimentation rate changes. It is hoped that a mass balance approach may provide a means of correcting for some of the interference.

Response of fossil diatom, chironomid and cladoceran assemblages

The variability and common features of diatom assemblages in remote lakes is discussed in Cameron *et.al.* 1993. The patterns observed in the group of AL:PE 1 lakes are reinforced by those seen in the AL:PE 2 sites. For example in the dominance of non-planktonic diatom species at the high altitude lakes and cosmopolitan nature of some alpine species such as the *Achnanthes* taxa discussed from the AL:PE 1 lakes. A plot of lakewater calcium concentrations against sulphur deposition for 13 AL:PE 1 and AL:PE 2 coring sites for which both these data are available (Annex B Figure 64) is used to assist in the interpretation of the diatom profiles in terms of the diatom critical load model (Battarbee 1989, 1992, 1994). Acidified sites will have relatively low water calcium in relation to sulphur loading. However, the Ca:S ratio of 94:1, separating acidified from non-acidified sites in the UK diatom model for predicting sites which had exceeded their critical loads (Battarbee 1994), may not necessarily be appropriate for the AL:PE 2 lakes. This ratio has not therefore been plotted. As an outlier in the dataset, Zgorne Krisko Jezero has been omitted from the plot. Calcium concentrations at this site are exceptionally high and sulphur deposition low, the diatom assemblages are not therefore influenced by atmospheric deposition.

Sites which have not acidified according to their diatom histories are Arresjoen, Chuna, Ovre Neadalsvatn and Milchsee. The latter is in an area of high deposition but also has a relatively high calcium concentration. In contrast Arresjoen, Chuna and Ovre Neadalsvatn are sensitive lakes but lie in northern areas of low deposition which are considered above in the discussion of spatial variation of atmospheric pollutants.

Clearly acidified sites (and the date for the onset of acidification) are: Stavsvatn (mid-19th Century), Lochnagar (mid-19th Century), Lough Maam (c.1900), Paione Superiore (1940s), Starolesnianske Pleso (1970s). These lakes all lie in areas of high sulphur deposition (either in regions of high sulphur deposition or in proximity to 'local' sulphur sources (again this is considered in the discussion of the spatial variation of atmospheric pollutants)and on sensitive geologies. Therefore a clear diatom response can be seen although the magnitude of pH change does not always appear to match the relative levels of atmospheric deposition and site sensitivity. For example at Starolesnianske Pleso the pH change is small whilst both sensitivity to acidification and the level of sulphur deposition are very high. Lake Redo shows some degree of acidification and this is reflected by its position between the non-acidified sites to the top left of the plot and those sites which have acidified on the bottom right (Annex B Figure 64). The remaining Tatra Mountain lakes Terianske Pleso, Zielowny Staw and Dlugi Staw are problematic in terms of predicted response for example according to a diatom critical loads model and actual response of the sediment diatom assemblages. The Tatra Mountains have the highest level of sulphur deposition and Dlugi Staw appears to be a site which would be predicted to have acidified. However, the diatom based pH reconstruction is highly erratic and shows no acidification trend. This probably reflects the disturbed nature of the sediments at this site, at which a suitable coring area was difficult to find and where there was evidence of significant lake level changes at the time of coring. Terianske Pleso and Zielowny Staw, although having high calcium concentrations have very high sulphur deposition levels. There is some evidence of acidification of Terianske Pleso, but Zielowny Staw does not show any response. These lakes lie on the boundary of acidified and non-acidified sites.

Of the lakes for which we have no sulphur deposition data at present, La Caldera and Lac Noir are well buffered and both have low levels of deposition according to the SCP data. The diatom-based pH profiles confirm that there is no acidification. From their water chemistries, Laguna Cimera in the Gredos Mountains of Central Spain and Lagoa Escura in the Serra d'Estrella of Portugal are both predicted to be lakes highly susceptible to acidification, however, as the analyses of SCP show, deposition levels are relatively low and neither shows signs of acidification. (The pH decline in the Lagoa Escura core is driven by the composition of a single sample and is discussed earlier).

Etang d'Aube does not show any indication of acidification, but lies on the boundary of acidified and non-acidified lakes with both high levels of deposition and sensitive water chemistry. Schwarzee ob Solden has relatively high sulphur deposition levels, although the SCP evidence for historical trends of atmospheric deposition is uncertain, and seems to show a slight pH decline since the 1920s. The evidence from chironomid assemblages (see below) does not indicate that this lake has acidified.

Despite the problems of time resolution in these slowly accumulating sediments, temporal patterns discussed for the atmospheric pollutants also seem to be borne out by the acidification histories. Sites with the earliest onset of acidification are generally found nearest to the regions of earliest industrial expansion and pH profiles are related to the magnitude of deposition. For example, comparing the significantly impacted pH profiles of Lochnagar and Stavsvatn with regions more peripheral to the earliest industrialisation in the mid-19th century or with later dates of intense industrialisation eg. (Schwarzsee ob Solden, Lough Maam and Paione Superiore).

The sediment records of cladoceran remains in the lakes Starolesnianske and Terianske in the Tatra are in accordance with both the early investigations of the fauna of these lakes and the recent zooplankton studies (unpublished data of Fott *et.al.*). The reduced diversity of the zooplankton fauna of the lake Starolesnianske pleso corresponds to the recent acidification of the lake. There is no explanation, however, for the retreat of *Daphnia pulicaria* in Terianske pleso, as the lake has not been acidified. The two cladoceran species of the alkaline Zgornje Krisko Jezero did not change in numbers during the recent history of the lake, as it is reflected in the upper 5 cm of the sediment. The response of Cladocera to long-term (pre-industrial) and the recent short-term (air-born acid) changes in lakewater pH may be different from the responses of other indicators, for example cladocerans may respond to the toxic effects of aluminium.

Sediment profiles were characterised by few chironomid species. In three of the five cores analysed for chironomids there was a clear change in the relationship between the dominant taxa. In the sediment samples from Schwarzsee ob Sölden *Micropsectra radialis* replaced *Pseudodiamesa branickii* up-core, while *Pseudodiamesa branickii* was not found at all in the recent bottom samples. However, one pupal exuvia was found in a surface sample, showing that the species is still present in the lake. This trend is not likely to be the result of acidification, as *Micropsectra radialis* is considered acid sensitive. It shows that Schwarzsee ob Sölden has changed from an ultra- to a medium oligotrophic stage during recent decades. This is similar to the situation found in Paione Superiore in Italy, where *Micropsectra radialis* was gradually replaced by *Tanytarsus* sp. B (Wathne *et. al.* 1995). Schwarzsee ob Sölden is now at the same trophic level as Paione Superiore was 300 years ago. These observations indicate an increase of nutrients in both regions.

In Escura one or more unidentified species of *Tanytarsus* replaced *Micropsectra* cf. *insignilobus* up-core. None of these taxa were found in the recent samples. As a result of the absence of a modern analogue the interpretation of this is not possible, either with respect to changes in the nutrition level or acidification. No species trends were detected in Lake Redó and Starolesnianske Pleso. In both lakes the number of chironomid head capsules decreased strongly up-core.

5.6 Conclusions

Mountain ranges have been used historically to delineate territory and consequently many mountain lakes are found close to national borders. In trying to explain pollutant patterns in these lakes it has therefore been necessary to look at combustion statistics and emission patterns not only from the host country but increasingly from neighbouring countries and even further afield. This work has served to emphasise the transboundary nature of the pollutants and the 'pan-European' nature of the AL:PE programme. i.e. it has not been possible to consider and interpret the depositional impact at these sites without using a larger than national scale. It is likely that there are no lakes in this dataset impacted by depositions of a single nation.

Long-range transport of pollutants (e.g. >500km) can be seen at remote sites e.g. Arresjøen, but it is also important for the Norwegian sites (from U.K.) and possibly Italian sites (e.g. from Germany). Long distance sources of pollutants almost certainly exist for all sites (e.g. the 'blame' matrices of Sandnes, 1993) but the impacts from these are probably small enough in most cases to be masked by local and regional effects. The results obtained here show that a range of depositional regimes exist for the AL:PE dataset, from 'local' (Paione Superiore) to `background' (Arresjøen, Øvre Neådalsvatn). Most sites show intermediate `regional' depositions reflecting patterns of a large, usually 'multi-national', scale.

The primary aim of the AL:PE 2 sediment diatom programme, the construction of a diatom/lakewater chemistry calibration set for remote lakes, has been fulfilled. Most diatom species found in the assemblages are cosmopolitan in remote lakes and species composition appears to be driven primarily by environmental factors rather than by biogeographic determinants. A few diatom taxa seem to be restricted to high altitude and/or high latitude sites. The diatom training set has been applied to AL:PE 1 lakes as well as to the AL:PE 2 lakes. For the AL:PE 1 sites, in most cases reconstructed pH values have been improved, with the exception of sites having diatom assemblages dominated by species poorly represented or absent from the calibration set. For studies involving diatom-based pH reconstruction, the importance of selecting sites with low alkalinity was reinforced. This does not preclude the use of lakes with slightly higher buffering capacity for studies of climate change. However, lakes lying in very highly buffered catchments are not generally suitable for such studies, partly because of diatom silica dissolution down-core resulting in poor diatom preservation. At lakes with catchments sensitive to acidification, the response of diatom, chironomid and cladoceran assemblages in sediment cores is largely in accordance with the magnitude and trends recorded by atmospheric pollutants in the cores. All areas show at least some degree of 'background' deposition, however, sites in central Norway and Svalbard, for example, do not show any related biological changes and can therefore be considered relatively clean.

5.7 References

Battarbee, R.W. 1989. The acidification of Scottish lochs and the derivation of critical sulphur loads from palaeolimnological data. Research Paper No. 36. Palaeoecology Research Unit, Department of Geography, University College London.

Battarbee, R.W. 1992. Critical loads and acid deposition for UK freshwaters. An interim report to the Department of the Environment (UK) from the Critical Loads Advisory Group (Freshwaters sub-group). ECRC Research Paper No. 5. Environmental Change Research Centre, University College London.

Battarbee, R.W. 1994. Critical loads of acid deposition for UK freshwaters. ECRC Research Paper No. 11. Environmental Change Research Centre, University College London.

Battarbee, R.W., Anderson, N.J., Appleby, P.G., Flower, R.J., Fritz, S.C., Haworth, E.Y., Higgitt, S., Jones, V.J., Kreiser, A., Munro, M.A.R., Natkanski, J. Oldfield, F., Patrick, S.T., Richardson, N.G., Rippey, B., Stevenson, A.C. 1988. Lake Acidification in the United Kingdom 1800-1986. Ensis Publishing. London, 68pp.

Cameron, N.G., Rose, N.L., Appleby, P.G., Schnell, O.A., Battarbee, R.W., Patrick, S.T. & Flower, R.J. (1993). ALPE 1: Palaeolimnology. ECRC Research Report No. 4. Environmental Change Research Centre, University College London.

Frey, D.G. 1976. Interpretation of quaternary paleoecology from Cladocera and midges, and prognosis regarding usability of other organisms. Can. J. Zool. 54, 2208-2226.

Frey, D.G. 1980. On the plurality of *Chydorus sphaericus* (O.F. Muller) (Cladocera, Chydoridae), and the designation of a neotype from Sjaelso, Denmark. Hydrobiologia 69, 83-123.

Frey, D.G. 1988. Littoral and offshore communities of diatoms, cladocerans and dipterous larvae, and their interpretation in paleolimnology. Journal of Paleolimnology 1, 179-191.

Glew, J.R. 1989. A new trigger mechanism for sediment samplers. Journal of Paleolimnology 2: 241-243.

Minkiewicz, S. 1917. Die Crustaceen der Tatraseen. Eine physiographisch-faunistische skizze. Bull. Acad. Sci. Cracov., Cl. Sci. Math. et Natur., Ser.B: Sci. Natur. Nov.-Dec. 1916, 262-278.

Mylona, S. (1993). Trends of sulphur dioxide emissions, air concentrations and depositions of sulphur in Europe since 1880. EMEP/MSC-W Report 2/93.

Nilssen, J.P and Sandoy, S. 1990. Recent lake acidification and cladoceran dynamics: surface sediment and core analyses from lakes in Norway, Scotland and Sweden. Phil. Trans. R. Soc. Lond. 299-309.

Parkin, D.W., Phillips, D.R., Sullivan, R.A.L. & Johnson, L. (1970). Airborne dust collections over the North Atlantic. J. Geophys. Res. 75: 1782-1793.

Prazakova, M. and Fott, J. 1994. Zooplankton decline in the Cerne Lake (Sumava Mountains, Bohemia) as reflected in the stratification of cladoceran remains in the sediment. Hydrobiologia 274, 121-126.

Rose, N.L. (1991). Fly-ash particles in lake sediments: Extraction, characterisation and distribution. Unpublished PhD thesis. University of London.

Rose, N.L. (1995). The carbonaceous particle record in lake sediments from the Arctic and other remote areas of the northern hemisphere. Sci. Tot. Env. 160/161: 487-496.

Rose, N.L. & Juggins, S. (1994). A spatial relationship between carbonaceous particles in lake sediments and sulphur deposition. Atmos. Env. 28: 177-183.

Rose, N.L., Harlock, S., Appleby, P.G. and Battarbee, R.W. (in press). The dating of recent lake sediments in the United Kingdom and Ireland using spheroidal carbonaceous particle profiles. Holocene.

Sandnes, H. (1993). Calculated budgets for airborne acidifying components in Europe, 1985, 1987, 1988, 1989, 1990, 1991 and 1992. EMEP / MSC-W Report 1/93.

Sarvala, J. and Halsinaho, S. 1990. Crustacean zooplankton of Finnish forest lakes in relation to acidity and other environmental factors. p. 1009-1027 in: Kauppi et al. (eds.), Acidification in Finland. Springer Verlag, Berlin.

Stuchlik,E., Stuchlikova, Z., Fott, J., Ruzicka, Z. and Vrba, J. 1985. Effects of acid precipitation on waters of the TANAP territory. (In Czech, with English summary). Treatises concerning the Tatra National Park 26, 173-211.

Toro, M., Flower, R.J., Rose, N. & Stevenson, A.C. (1993). The sedimentary record of the recent history in a high mountain lake in central Spain. Verh. Internat. Verein. Limnol. 25: 1108-1112.

Uimonen-Simola, P. and Tolonen, K. 1987. Effects of recent acidification on Cladocera in small clear-water lakes studied by means of sedimentary remains. Hydrobiologia 145, 343-351.

Wathne, B. M., Patrick, S. T., Monteith, D. & Barth, H. 1995. AL:PE 2 - Acidification of Mountain lakes, Remote mountain lakes as indicators of air pollution and climate change. AL:PE Report 1/1994. CEC-Environment, Bruxelles.

Whiteside, M. and Swindoll, M.R, 1988. Guidelines and limitations to cladoceran paleoecological interpretations. Palaeography, Palaeoclimatology, Palaeoecology 62, 405-412.

Wik, M. & Natkanski, J. (1990). British and Scandinavian lake sediment records of carbonaceous particles from fossil-fuel combustion. Phil. Trans. Roy. Soc. Lond. B327: 319-323.

Wik, M. & Renberg, I. (1991).Recent atmospheric deposition in Sweden of carbonaceous particles from fossil-fuel combustion surveyed using lake sediments. Ambio. 20: 289-292.

Table 39 Anthropogenic Trace Metal Inventories

Location	Inventories Pb mg/m^2	 Cd mg/m^2	 ^{210}Pb Bq/m^2	Inventory Ratios Pb/^{210}Pb g/Bq	 Cd/^{210}Pb g/Bq
Arresjoen	19	1.0	1560	12	0.6
Dlugi Staw	665	12.8	2185	305	5.9
Zielowny Staw *	1921	46.7	9659	199	4.8
Starolesnianske Pleso	540	23.6	4148	130	5.7
Nizne Terianske	297	16.1	3132	95	5.1
Noir	72	1.1	9707	7	0.1
Aguilo	1424	6.7	12823	111	0.5
Redo	665	2.2	5497	121	0.4
Cimera	494	1.4	10537	47	0.1
Caldera	1139	3.4	12325	92	0.3
Escura	699	1.9	9066	77	0.2

* Post-1945 inventories only

5.8 Chironomids

5.8.1 Introduction

The Chironomidae are an important group in high-altitude ecosystems partly due to their species richness and ecological diversity. Many of the chironomid head capsules in found in the sediments can be identified to species or genus, making this group valuable in detecting changes in the nutrient levels of lakes. Such changes in the fauna of remote areas can possibly be connected to acidification.

Based on field and literature studies, Wathne et al. (1995) published a list of acid-sensitive and acidophilous species of chironomids. By comparing the historical development of sensitive and acidophilous species in the AL:PE 1 dataset, significant trends towards increased acidity could be detected in some of the lakes (Schnell & Raddum 1993, Wathne et al. 1995). The main goal of this study was to increase the knowledge of the historical development of chironomid communities in alpine lakes, and to link these data to environmental changes and to the present ecological status of the lakes.

5.8.2 Methods

The core sampling was carried out with the same equipment as the diatom palaeolimnological samples. The core was sectioned into slices of 5 mm and stored fresh in plastic bags at at 4 ^{O}C.

After sieving the slices in a 100 : m sieve, the head capsules was picked directly out of the sediments without further treatment. This procedure ensures that taxonomically important structures of the head capsule, such as mandibles, labrum with premandibles, and maxillae, are often retained. These structures are of great value in species determination. All head capsules were mounted in Hoyer's solution on microscope slides and identified as far as possible.

5.8.3 Results

Svalbard

Arresjøen (9)

Figure 5.2.1 shows the number of chironomid head capsules and taxa found in the core from Arresjøen. A total of 6 taxa were found (Table 5.2.1). Most taxa were present at all levels in the core. There is a clear trend up-core where the relative abundance of *Micropsectra insignilobus* decrease, while *Micropsectra radialis* increase (Figure 5.2.2). However, in the samples of the contemporary fauna, *M. insignilobus* dominated at all depths. *Oliveridia tricornis* was not found in the deepest sediment core sample analysed, while *Orthocladius* (*Pogonocladius*) *consobrinus* was found only in this sample. The taxon called *Micropsectra* spp. are 2. and 3. instar larvae, most likely belonging to the two *Micropsectra* species identified from 4. instar larvae (i.e. *insignilobus* and *radialis*). The core was taken at the deepest point of the lake, where no chironomid larvae was found in the samples of the contemporary fauna.

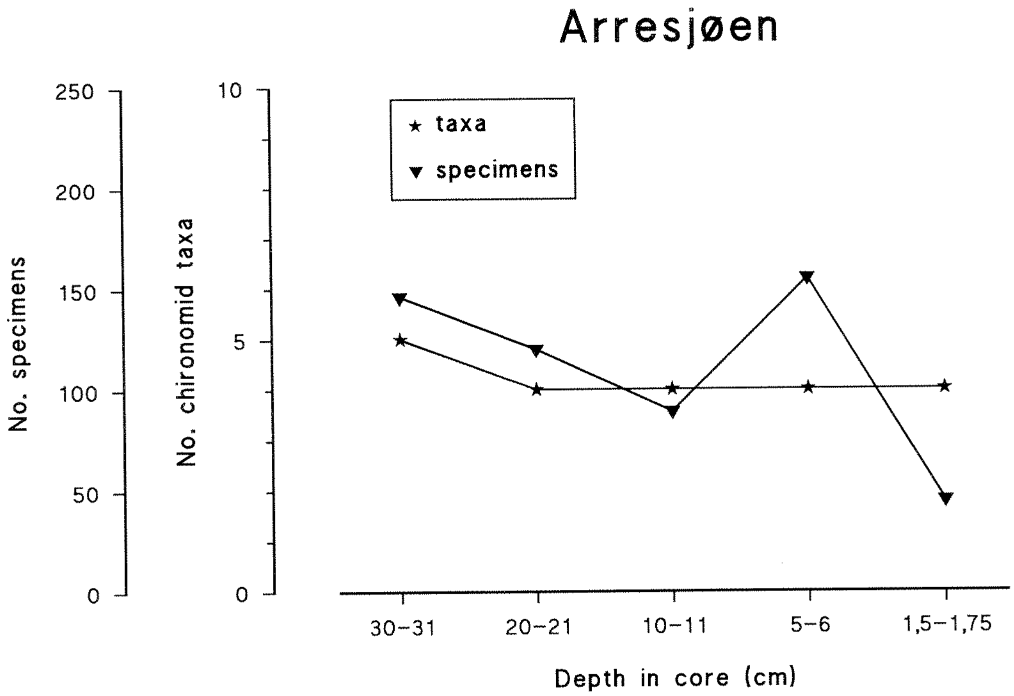


Figure 5.2.1 Arresjren: number of specimens and chironomidae taxa vs. depth in core.

Table 5.2.1 Subfossil records (relative abundance) of invertebrate taxa in core samples from Lake Arresjøen (9).

Depth in core (cm)	30-31	20-21	10-11	5-6	1.5-1.75
No. head capsules	146	120	89	155	45
No. taxa	5	4	4	4	4
Diamesa sp.	0,7	0,0	0,0	0,0	0,0
Micropsectra insignilobus	53,4	40,8	42,9	24,5	4,5
Micropsectra radialis	13,7	31,7	42,9	30,3	60,7
Micropsectra spp.	22,6	20,0	9,0	36,8	31,5
Oliveridia tricornis	0,0	5,0	4,0	6,5	3,4
Orthocladius (P.) *consobrinus*	7,5	0,0	0,0	0,0	0,0
Orthocladiinae indet.	2,1	2,5	1,1	1,9	0,0

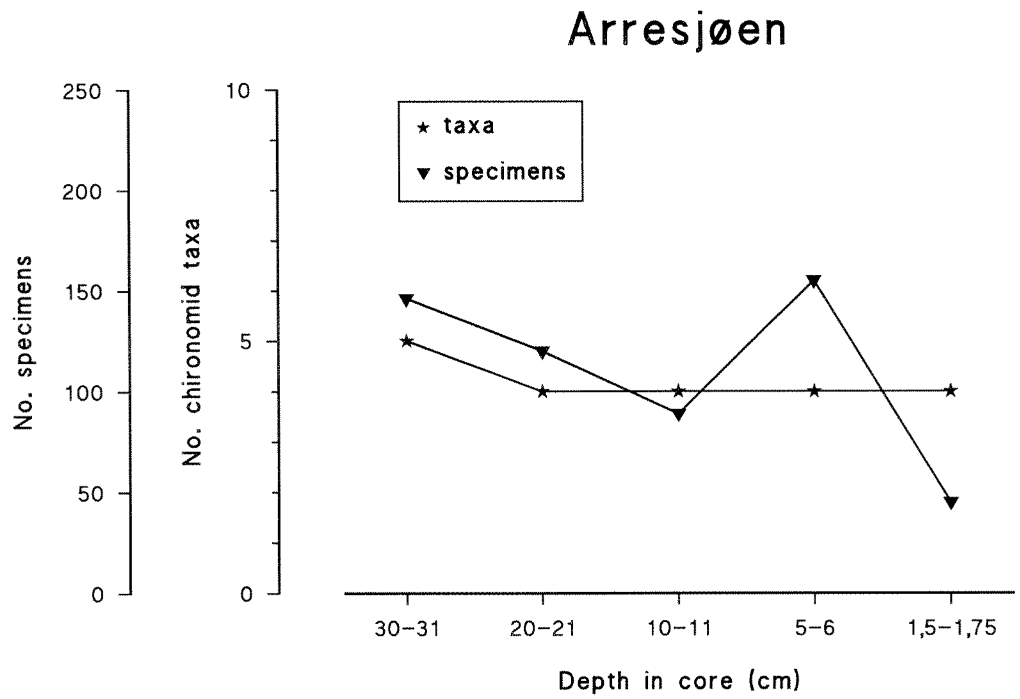


Figure 5.2.1 Arresjren: number of specimens and chironomidae taxa vs. depth in core.

Table 5.2.1 Subfossil records (relative abundance) of invertebrate taxa in core samples from Lake Arresjøen (9).

Depth in core (cm)	30-31	20-21	10-11	5-6	1.5-1.75
No. head capsules	146	120	89	155	45
No. taxa	5	4	4	4	4
Diamesa sp.	0,7	0,0	0,0	0,0	0,0
Micropsectra insignilobus	53,4	40,8	42,9	24,5	4,5
Micropsectra radialis	13,7	31,7	42,9	30,3	60,7
Micropsectra spp.	22,6	20,0	9,0	36,8	31,5
Oliveridia tricornis	0,0	5,0	4,0	6,5	3,4
Orthocladius (P.) *consobrinus*	7,5	0,0	0,0	0,0	0,0
Orthocladiinae indet.	2,1	2,5	1,1	1,9	0,0

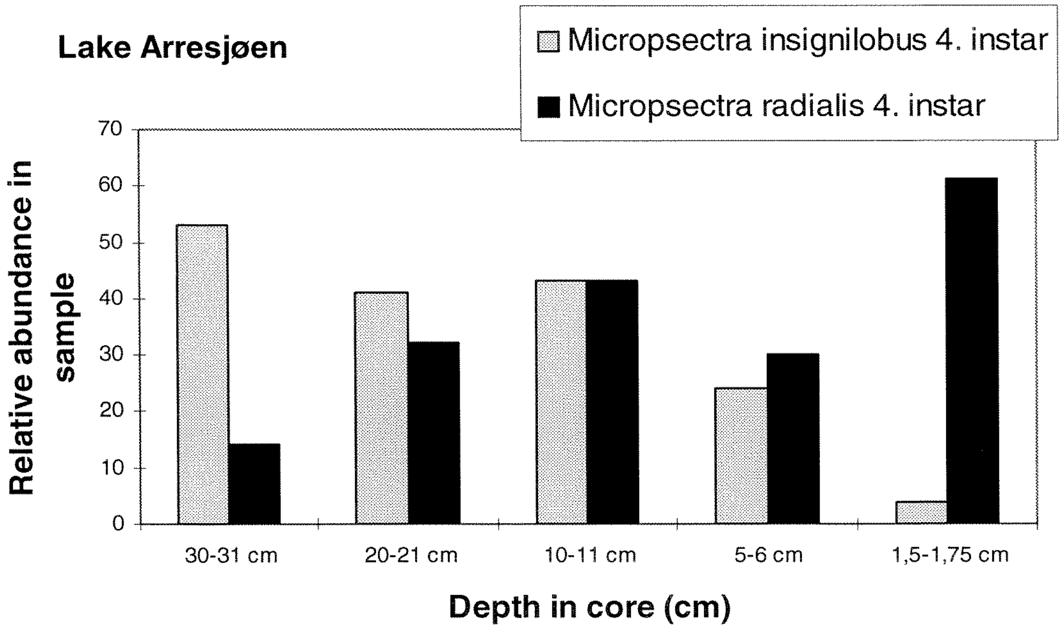


Figure 5.2.2 Arresjren: Relative abundance of *Micropsectra insignilobus* and *M. radialis* vs. core depth.

Iberia

Lagoa Escura (14)

Figure 5.2.3 shows the number of taxa and specimens found in the four samples analysed from the sediment core.

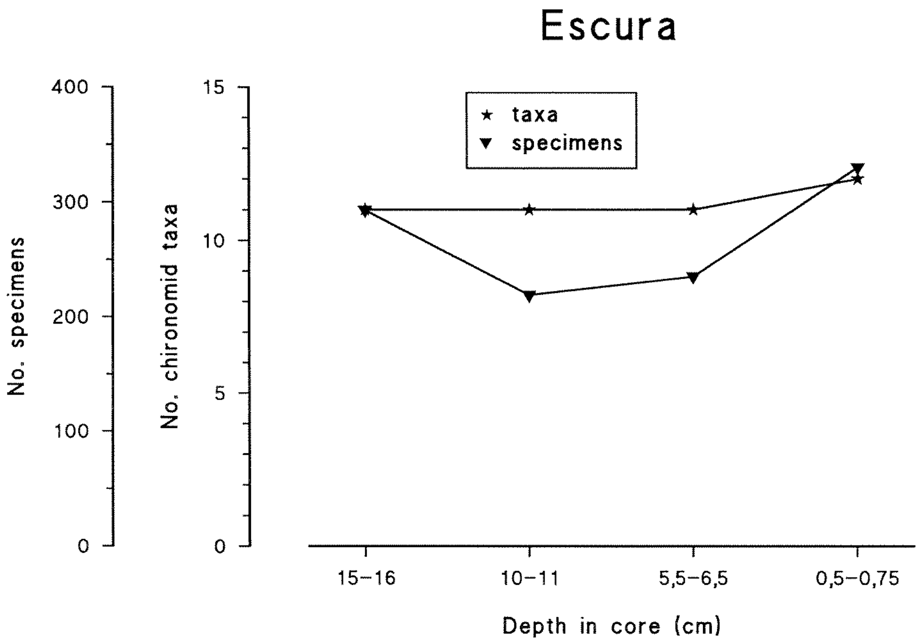


Figure 5.2.3 Lago Escura: number of specimens and chironomidae taxa vs. depth in core.

A total of 18 chironomid taxa were recorded (Table 5.2.2), more than in any of the other lakes studied. In addition remains of the phantom midge *Chaoborus flavicans* were found. Both number of head capsules and number of taxa were similar in the analysed samples. In the deepest sample *Micropsectra* cf. *insignilobus* dominated together with *Procladius* spp. No specimens of *Tanytarsus* were found in this sample. Up-core *Micropsectra* cf. *insignilobus* decreased in relative abundance at the same time as the taxon called *Tanytarsus* spp. increased (Figure 5.2.4). Also the relative abundance of *Procladius* spp. decreased up-core. For the other chironomid taxa there were no significant changes.

Table 5.2.2 Subfossil records (relative abundance) of invertebrate taxa in core samples from Lago Escura (14).

Depth in core (cm)	15-16	10-11	5.5-6.5	0.5-0.75
No. head capsules	293	219	235	330
No. taxa	11	11	11	12
Ablabesmyia cf. *longistyla*	0,0	0,5	0,0	1,2
Ablabesmyia sp.	0,0	0,0	0,4	6,1
Brillia modesta	0,7	0,0	0,0	0,0
Chaetocladius sp.	0,7	0,5	0,4	0,0
Chironomus sp.	0,7	1,0	0,9	5,8
Cladopelma cf. *viridula*	0,7	0,5	2,2	3,6
Glyptotendipes sp.	1,4	0,0	0,0	0,0
Heterotrissocladius marcidus	4,1	6,2	5,7	3,9
Micropsectra cf. *contracta*	0,0	1,0	0,0	0,0
Micropsectra cf. *insignilobus*	54,8	65,2	25,7	4,2
Microtendipes cf. *pedellus*	5,5	2,4	2,6	1,8
Nilothauma cf. *brayi*	0,0	0,0	0,4	1,8
Paracladopelma cf. *laminata*	1,4	0,0	1,7	1,5
Paratrichocladius sp.	0,0	0,5	0,0	0,0
Polypedilum sp.	0,0	0,0	0,0	0,3
Procladius spp.	28,1	12,4	16,5	5,5
Stictochironomus sp.	0,7	0,0	0,0	0,0
Tanytarsus spp.	0,0	10,0	41,7	63,6
Chironomini indet.	0,0	0,0	0,0	0,3
Orthocladiinae indet.	0,7	0,0	1,3	0,3
Tanypodinae indet.	0,7	0,0	0,4	0,0
Chaoborus cf. *flavicans*	X	X	X	0

There was a strong decline in concentration of head capsules up-core. *Micropsectra radialis* was the most important taxon, and constituted about 50 % or more in the samples, but showed a clear decrease up-core. Also *Heterotrissocladius marcidus* was important. Specimens identified as *Procladius* spp. decreased up-core and was not found in the top sample. The abundance of *Pseudodiamesa* sp. was low in the deeper samples, but the taxon was important in the top sample.

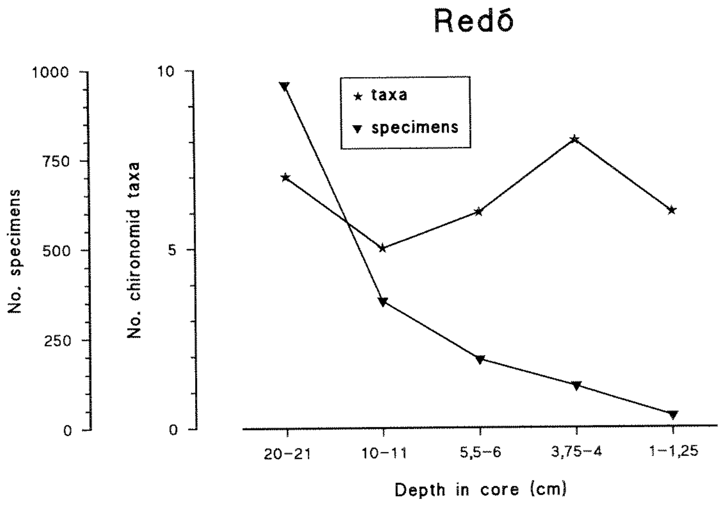


Figure 5.2.5 Lago Redo: number of specimens and chironomidae taxa vs. depth in core.

Alps

Schwarzsee ob Sölden (11)

Nine levels were analysed from the sediment core. Figure 5.2.6 shows the number of specimens and taxa found in the samples.

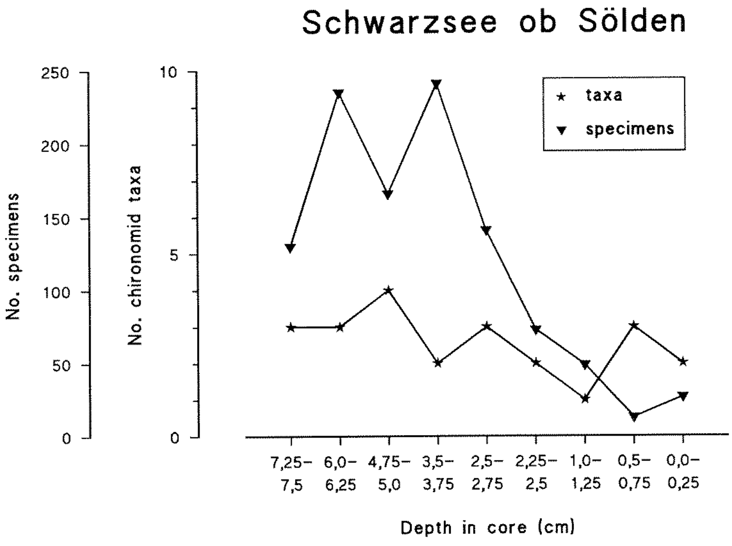


Figure 5.2.6 Schwarzsee ob S`lden: number of specimens and chironomidae taxa vs. depth in core.

Seven taxa were found (Table 5.2.4). *Micropsectra radialis* and *Pseudodiamesa* cf. *branickii* were the dominant taxa, with the other present as single specimens only. Figure 5.2.7 shows the relative abundance of the dominant taxa. *Pseudodiamesa* cf. *branickii* dominated in the deepest samples but decrease in relative abundance up-core, while *Micropsectra radialis* shows the opposite trend.

Table 5.2.4 Subfossil records (relative abundance) of invertebrate taxa in core samples from Schwarzsee ob Sölden (11).

Depth in core (cm)	7.25-7.5	6.0-6.25	4.75-5.0	3.5-3.75	2.5-2.75	2.25-2.5	1.0-1.25	0.5-0.75	0-0.25
No. head capsules	130	235	166	241	141	73	49	13	27
No. taxa	3	3	4	2	3	2	1	3	2
Diamesa sp.	0,0	0,4	0,6	0,0	0,0	0,0	0,0	0,0	0,0
Heterotrissocladius marcidus	0,0	0,0	0,0	0,0	0,0	0,0	0,0	7,7	0,0
Micropsectra radialis	5,4	45,1	29,5	17,0	35,5	47,9	100,0	76,9	92,6
cf. *Paracladius* sp.	0,0	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0
Procladius sp.	0,0	0,0	0,0	0,0	0,7	0,0	0,0	0,0	0,0
Protanypus sp.	3,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Pseudodiamesa cf. *branickii*	91,5	54,5	69,3	83,0	63,8	52,1	0,0	15,4	7,4

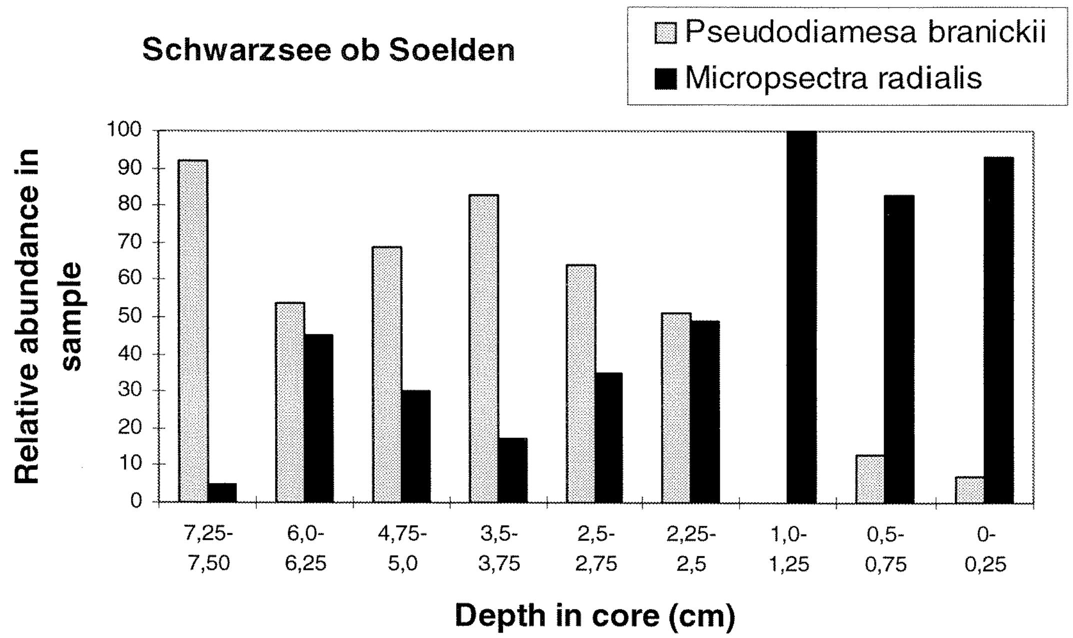


Figure 5.2.7 Schwarzsee ob Sölden: Relative abundance of *Pseudodiamesa branickii* and *Micropsectra radialis* vs. core depth.

Tatra

Starolesnianske Pleso (15.1)

Three samples were analysed from the sediment core. Number of taxa and specimens are shown in Figure 5.2.8 and Table 5.2.5. There was a strong decrease in number of head capsules found up-core. Based on the relative abundances, the chironomid community in the lake have changed little. *Tanytarsus* cf. *gregarius* dominated in the samples.

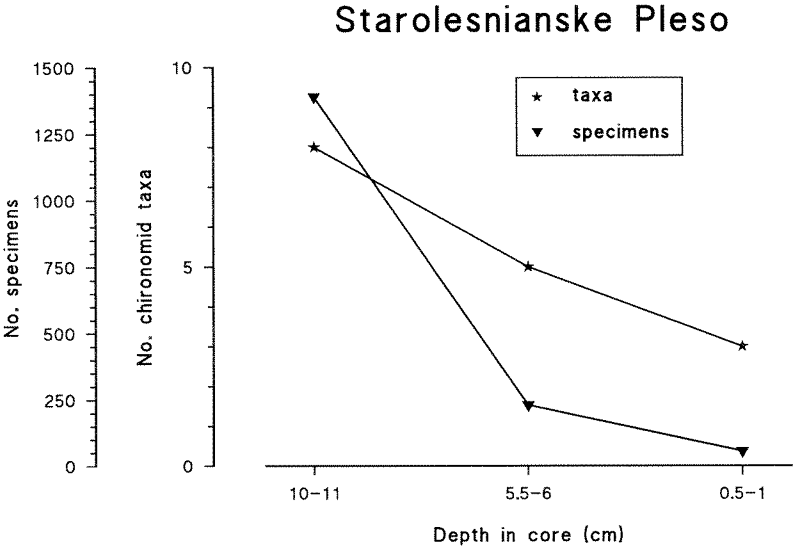


Figure 5.2.8 Starolesnianske Pleso: number of specimens and chironomidae taxa vs. depth in core.

Table 5.2.5 Subfossil records (relative abundance) of invertebrate taxa in core samples from Starolesnianske Pleso.

Depth in core (cm)	10-11	5.5-6.0	0.5-1.0
No. head capsules	1389	230	55
No. taxa	6	5	3
Corynoneura cf. *arctica*	1,9	0,0	0,0
Cricotopus sp.	0,0	1,8	0,0
Heterotrissocladius marcidus	6,1	2,7	9,1
Micropsectra cf. *insignilobus*	1,1	0,0	0,0
Micropsectra sp.	0,0	2,7	0,0
Procladius spp.	4,2	7,3	3,6
Psectrocladius (P.) limbatellus group	0,4	0,0	0,0
Tanytarsus cf. *gregarius*	85,2	85,5	87,3
Orthocladiinae indet.	0,4	0,0	0,0
Tanypodinae indet.	0,8	0,0	0,0

5.8.4 Discussion

The sediment samples from the investigated lakes were characterised by few species. With the exception of *Nilothauma* cf. *brayi* from Lagoa Escura, all identified species are typical for oligotrophic or even ultraoligotrophic conditions all over Europe. In four of the five analysed cores there were clear changes in the relationships between the dominant taxa. In Arresjren, the replacement of *Micropsectra insignilobus* by *Micropsectra radialis* up-core indicates that the lake has become more oligotrophic during the investigated time period. In the samples of the recent fauna, however, *Micropsectra insignilobus* was much more numerous than *Micropsectra radialis*. This may have to do with the phenology of *Micropsectra radialis*, i.e. that this species was hatching at the time of sampling. In Lagoa Escura one or more unidentified species of *Tanytarsus* replaced *Micropsectra* cf. *insignilobus* up-core. None of these taxa were found in the recent samples. As long as *Tanytarsus* spp. remains unidentified it is difficult to speculate about the reason behind these changes. However, with the exception of the *Tanytarsus lugens* group, most members of the genus *Tanytarsus* that inhabit the profundal zone indicates less oligotrophic conditions. The trend found in Lagoa Escura may therefore be a result of an increased nutrient load to the lake. The samples from Llac Red\ showed an increase in the relative abundance of a species belonging to the genus *Pseudodiamesa*. The members of this genus are all strong indicators of ultraoligotrophic conditions. Combined with the decrease in *M. radialis*, the development of the *Pseudodiamesa* population indicates more oligotrophic conditions in the lake recently. In the sediment samples from Schwarzsee ob S`lden *Micropsectra radialis* replaced *Pseudodiamesa* cf. *branickii* up-core, while *Pseudodiamesa* cf. *branickii* was not found at all in the recent bottom samples. However, one pupal exuvia was found in a surface sample, showing that the species is still present in the lake. This trend is not likely to be the result of acidification, as *Micropsectra radialis* is considered acid sensitive. The pattern strongly suggests that Schwarzsee ob S`lden has changed from an ultraoligotrophic to a less oligotrophic lake during the last decades. It is interesting to compare Schwarzsee ob S`lden with the results of the analyses of the sediments in Lago Paione Superiore in Italy (Figure 5.2.9), where *Micropsectra radialis* was gradually replaced by *Tanytarsus* sp. B (probably *T. niger*) (Wathne et al. 1995). Schwarzsee ob S`lden is now at the same trophic level as Lago Paione Superiore was about 300 years ago. Both observations indicate an increased nutrient input to the areas of the lakes.

No trend at the species level could be detected Starolesnianske Pleso.

Based on the chironomid communities found in the sediment cores, Arresjren and Llac Red\ shows signs of increased oligotrophy, while Schwarzsee ob S`lden and possibly Lagoa Escura shows the opposite.

The changes observed, at least in Arresjren and Schwarzsee ob S`lden, are not thought to be the result of acidification. The taxa involved in these changes are *Micropsectra insignilobus* and *Micropsectra radialis* in Arresjren, and *M. radialis* and *Pseudodiamesa* cf. *branickii* in Schwarzsee ob S`lden. *M. insignilobus* and *M. radialis* are listed as acid sensitive by to Wathne et al. (1995), while nothing is known about the reaction of *P.* cf. *branickii* towards acidification. However, since *M. radialis* increased in Schwarzsee ob S`lden during the last decades, it is unlikely that the lake is exposed to acid rain. Both for Arresjren and Schwarzsee ob S`lden climatic factors may be invoked to explain the changes in the chironomid fauna. In the case of Arresjren the replacement of *M. insignilobus* by *M. radialis* indicates lowered productivity in the lake, while the replacement of *P.* cf. *branickii* by *M. radialis* in Schwarzsee ob S`lden indicates increased productivity. Changes in lake productivity is probably caused by changes in lake temperature.

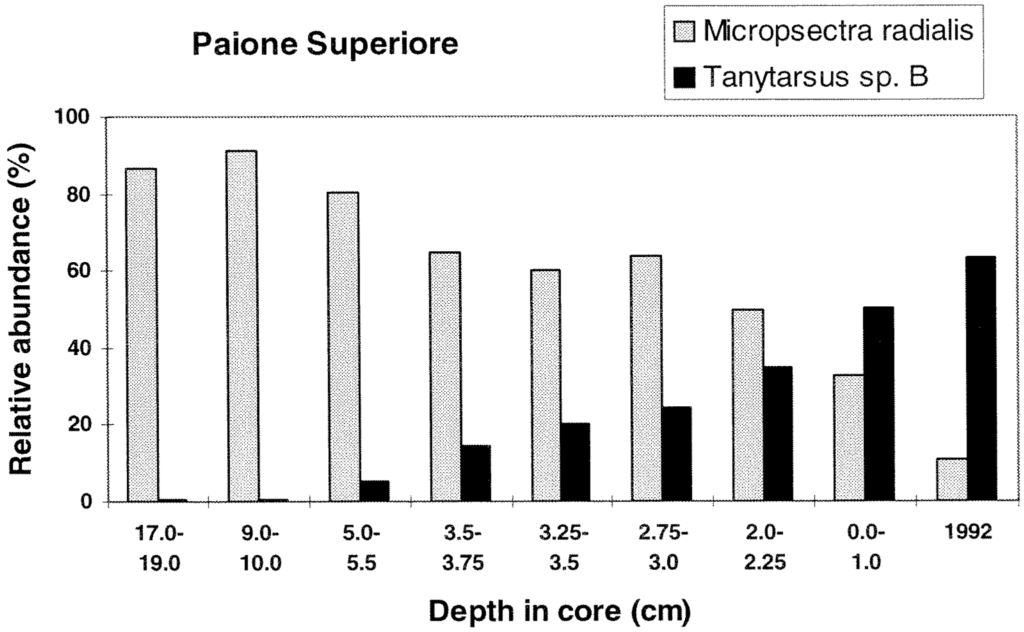


Figure 5.2.9 Lago Paione Superiore: Relative abundance of *Micropsectra radialis* and *Tanytarsus* sp. B vs. core depth (after Wathne et al. 1995).

In Llac Red\ *M. radialis* was replaced by an unidentified species of *Pseudodiamesa*. Since we do not know anything about the reactions of any *Pseudodiamesa* species towards acidification, it is difficult to interpret the changes that have taken place in the lake. However, if the *Pseudodiamesa* species in question is sensitive towards acidification the process that has taken place in Llac Red\ is similar to the one in Arresjren, i.e. a decrease in lake productivity. The replacement in Lagoa Escura of *M.* cf. *insignilobus* by *Tanytarsus* spp. is even more difficult to interpret. In the species-rich genus *Tanytarsus* there are both sensitive and tolerant species, and the one(s) found in Lagoa Escura can be any of a large number of *Tanytarsus* species.

5.8.5 Summary and conclusions

Fossil chironomid assemblages were characterised by the presence of few species and temporal changes in the relationship between important taxa occurred at all sites except for Starolesnianske Pleso.

In Arresjren *Micropsectra insignilobus* decreased in relative abundance up-core while *Micropsectra radialis* increased. This probably indicates that the lake has become more oligotrophic during this period. In Lagoa Escura the strong drop in relative abundance of *M. insignilobus* and an increase in unidentified *Tanytarsus* specimens may indicate less oligotrophic conditions in the lake recently. The increase in the relative abundance of an unidentified species belonging to the ultraoligotrophic genus *Pseudodiamesa* indicates that Llac Redo is in the process of becoming a more oligotrophic lake. In the core from Schwarzsee ob S`lden *Micropsectra radialis* replaced *Pseudodiamesa* cf. *branickii* up-core, and *P.* cf. *branickii* was not found in the samples of the contemporary fauna. It indicates that Schwarzsee ob S`lden has become less oligotrophic during recent decades, and is the opposite of what is seen in the core from Llac Redo. Schwarzsee ob S`lden can be compared to Lago Paione

Superiore in Italy, where *Micropsectra radialis* was gradually replaced by a species of *Tanytarsus*, also indicating that the lake has become less oligotrophic recently. Typologically Schwarzsee ob S`lden is now similar to what Lago Paione Superiore was about 300 years ago. The samples analysed from Starolesnianske Pleso showed no trends in the chironomid community.

5.8.6 References

Schnell, q. A. & Raddum G. G. 1993. Past and present fauna of chironomids in remote mountain lakes. Preliminary results from the AL:PE 1 Project. - In: G.Giussani and C. Callieri (eds), Strategies for Lake Ecosystems Beyond 2000, Proceedings, Stresa, pp. 444-447.

Wathne, B. M., Patrick, S. T., Monteith, D. & Barth, H. 1995. AL:PE Project part 1. European commission, Ecosystem research report 9, 292pp. CEC-Environment, Bruxelles.

5.9 The AL:PE Modern Diatom - pH Training-Set and its application to the AL:PE Palaeolimnological Studies

5.9.1 Introduction

Diatoms are widely recognised to be sensitive ecological indicators of lake-water pH. In recent years this sensitivity has been exploited to reconstruct quantitatively pH from diatom assemblages preserved in lake sediments. Such quantitative reconstructions require not only fossil diatom assemblages but also modern diatom assemblages and associated pH determinations, a so-called modern "training-set" (Birks *et al.*, 1990). A training-set is needed because, in practice, quantitative pH reconstructions are a two-stage process. First, the responses of modern diatoms to contemporary pH are modelled. This is a regression problem (ter Braak and Prentice, 1988) and involves a modern training-set of diatom assemblages ("response" variables) from surface lake-sediment samples with associated pH data ("predictor" or "explanatory" variable). In this regression step, the aim is to estimate modern regression coefficients or "optima" for the different taxa in the training-set. Second, the modelled responses are used to infer pH from the composition of fossil diatom assemblages. This is a calibration problem (ter Braak and Prentice, 1988).

This chapter describes the development of a modern diatom-pH training-set for high alpine lakes, summarises the statistical properties of the training-set, and discusses its application in AL:PE palaeolimnological studies.

5.9.2 Requirements

Birks (1994, 1995) present several basic requirements in quantitative palaeoenvironmental reconstructions. In terms of the AL:PE project, the most critical are: (1) the need for a large high-quality training set that is representative of the likely range of environmental variables, is of consistent taxonomy and nomenclature, is of comparable quality (count size, methodology, etc.), and has all samples from the same sedimentary environment (in the case of AL:PE from lakes above the (potential) altitudinal tree-line or beyond the arctic tree-line); (2) the fossil data-sets used for reconstruction purposes should be of comparable taxonomy, nomenclature, and quality, and from the same sedimentary environment as the modern training set; (3) statistical methods for regression and calibration that can adequately model the non-linear, often unimodal, relationships between modern taxa and their environment and (4) statistically reliable standard errors of prediction are required for each reconstructed environmental value. As the reliability of the reconstructed pH values may vary from one fossil sample to another depending on, for example, taxonomic composition, sample-specific standard errors of prediction are needed.

5.9.3 The Training Set

The AL:PE diatom-pH training-set consists of 118 surface samples from lakes in the Italian and Austrian Alps (31 samples), Spanish Pyrenees (28 samples), and Norway and UK (29 samples), as well as the 30 lakes studied within the AL:PE-1 and AL:PE-2 projects. It includes all diatom taxa (550). Abundances are expressed as percentages of the total diatom count (*ca.* 500 valves). The pH data for each lake are based on the arithmetic mean of $[H^+]$. The pH range is 4.48-8.04 (mean = 6.15, median = 6.10, standard deviation = 0.76).

As a result of an AL:PE diatom taxonomy workshop held in 1994, N.G. Cameron and V.J. Jones harmonised, as far as possible, the diatom taxonomy and nomenclature within both the modern training-set and the fossil core-data.

Because these AL:PE diatom data commonly show a considerable range in values for individual taxa, all values were transformed to their square-roots in an attempt to stabilise the variances.

5.9.4 Statistical Analyses

Weighted-averaging partial least squares (WA-PLS) regression (ter Braak and Juggins, 1993) was used for the modelling of modern diatom taxa in relation to pH. The idea behind simple weighted averaging (WA) is that at a lake with a certain pH value today, taxa with their pH optima close to that lake's pH will tend, under a simple Gaussian unimodal response model, to be the most abundant taxa present. A simple and ecologically realistic estimate of a taxon's pH optimum is thus the average of all the pH values for the lakes in which the taxon occurs, weighted by the taxon's relative abundances (WA regression). Conversely a simple estimate of a lake's pH is the WA of the pH optima of all the taxa present (WA calibration). ter Braak and van Dam (1989) and Birks *et al.* (1990) have shown the superiority of simple WA over statistically more complex techniques (e.g. maximum likelihood regression and calibration) or ecologically less realistic procedures (e.g. inverse linear regression). Despite the superiority of WA, it has some weaknesses (ter Braak and Juggins, 1993). It is sensitive to the distribution of the environmental variable in the training set, and it disregards residual correlations between taxa, namely correlations that remain after fitting the environmental variable of interest and that often result from other environmental variables that are not considered in WA (ter Braak and Juggins, 1993).

In WA-PLS successive components are extracted from the training set so as to improve, in a statistical sense, the predictive power of the regression model. These components use the residual structure in the biological data to improve the taxon parameters ("optima") in the final calibration function. The appropriate number of WA-PLS components to include is selected on the basis of the root mean square of the error (RMSE), the mean bias along the environmental gradient, and the maximum bias along parts of the environmental gradient (ter Braak and Juggins, 1993). Estimating these statistics on the basis of the training-set alone gives so-called "apparent statistics". Since the same data are being used to generate **and** to evaluate the model, these statistics will always be over-optimistic. A more realistic and reliable estimate of the "prediction statistics", or the likely prediction error when the training-set is applied to new, independent data (e.g. fossil assemblages) is obtained by "leave-one-out" jack-knifing, a form of computer intensive statistical cross-validation (ter Braak and Juggins, 1993).

The "apparent" and "prediction" errors for the AL:PE training set are summarised in Table 1 for 1-6 WA-PLS components. These results show the importance of using statistical cross-validation to identify the appropriate number of WA-PLS components to include in the transfer function. As more and more WA-PLS components are added, the model fits the pH variable better and better, as measured by the "apparent" RMSE and R^2. But these are not adjusted for the degrees of freedom and eventually the fit can be perfect ($R^2=1$, RMSE = 0) with n samples and n-1 components, even if there is no relation at all between the taxa and the environmental variable (ter Braak and Juggins, 1993). Thus "apparent" RMSE decreases and R^2 increases as additional WA-PLS components are included. However, in terms of "prediction" errors, the lowest RMSEP and mean and maximum bias, and the highest R^2 occur with three WA-PLS components in the model. The improvement in RMSEP by including 3 WA-PLS components here is relatively modest (7.4%), but there is a considerable reduction in maximum bias (35.3%) and mean bias (52.6%).

Plots of estimated or "apparent" pH against observed pH (Figure 1), of "predicted" pH against observed pH (Figure 2), of the differences (residuals) between "predicted" pH and observed pH and observed pH (Figure 3), and of the differences (residuals) between "predicted" pH and observed pH and "predicted" pH (Figure 4) show that there is little or no systematic bias in the predictive model, except for a slight tendency (Figure 3) for predictions to be slightly over-predicted at low observed pH and slightly under-predicted at high observed pH values.

5.9.5 Palaeolimnological Applications

This 3-component WA-PLS model has been applied to reconstruct pH from fossil diatom assemblages in sediment cores from 15 AL:PE lakes. Sample-specific prediction errors have been estimated by Monte Carlo simulation for each reconstructed value by means of the program WA-PLS (S. Juggins, unpublished program).

As a comparison of the predictive abilities of the AL:PE diatom-pH training set, the diatom-inferred pH for the uppermost sediment sample is listed along with the RMSEP, in Table 2, with the measured annual mean pH. In addition the magnitude of pH change since 1900 AD (_ pH), the diatom-inferred pH for that time, and its RMSEP are also listed.

For the eleven lakes for which Pb^{210} chronologies are available, two show no changes in diatom-inferred pH between 1900 and 1990 (Laguna Cimera, Étang d'Aube), one shows a pH increase of nearly half a pH unit (Le Caldera), and eight show a pH decrease between 0.03 to 0.62 pH units from 1900 to 1990. The largest pH decreases are at Lough Maam (0.62 pH units), Milchsee (0.42), and Paione Superiore (0.35).

5.9.6. Conclusions

A diatom-pH training-set consisting of surface diatom assemblages and associated pH data from 118 high-alpine and high-arctic lakes has been assembled by the various diatomists within the AL:PE project and co-ordinated by N.G. Cameron and V.J. Jones. The training-set closely predicts the modern pH from the 15 AL:PE lakes (Table 2), even if the lake whose pH is being inferred is not included in the training set, indicating the reliability of the training-set. The sample-specific errors of prediction are usually about 0.34 - 0.38 pH units. The training-set has been used for pH reconstructions for all the AL:PE sediment cores, as discussed in the palaeolimnology chapter by N.G. Cameron.

5.9.7 References

Birks, H.J.B. 1994. The importance of pollen and diatom taxonomic precision in quantitative palaeoenvironmental reconstructions. *Review of Palaeobotany and Palynology* **83**, 107-117.

Birks, H.J.B. 1995. Quantitative palaeoenvironmental reconstructions. In *Handbook of Quantitative Techniques in Quaternary Research* (ed. D. Maddy & J.S. Brew), Quaternary Research Association (in press).

Birks, H.J.B., Line, J.M., Juggins, S., Stevenson, A.C. & ter Braak, C.J.F. 1990. Diatoms and pH reconstruction. *Philosophical Transactions of the Royal Society of London B*, **327**, 263-278.

ter Braak, C.J.F. & Juggins, S. 1993. Weighted averaging partial least squares regression (WA-PLS): an improved method for reconstructing environmental variables from species assemblages. *Hydrobiologia* **269/270**, 485-502.

ter Braak, C.J.F. & Prentice, I.C. 1988. A theory of gradient analysis. *Advances in Ecological Research* **18**, 271-317.

ter Braak, C.J.F. & van Dam, H. 1989. Inferring pH from diatoms: a comparison of old and new calibration methods. *Hydrobiologia* **178**, 209-223.

FIGURE CAPTIONS

Figure 1. Plot of estimated pH values for the 118 lakes within the AL:PE training set against observed pH values. The estimated values are based on a three-component weighted averaging partial least squares (WA-PLS) regression.

Figure 2. Plot of predicted pH values for the 118 lakes within the AL:PE training set against observed pH values. The predicted values are based on a leave-one-out jack-knifing where the lake whose pH value is being predicted is left out from the training-set and treated as an independent test-sample. The model is based on a 3-component WA-PLS regression.

Figure 3. Plot of (predicted pH-observed pH) against observed pH for the AL:PE 118 lake training-set based on a 3-component WA-PLS model. The solid line is a loess scatterplot smoother fitted to detect any trends within the plot.

Figure 4. Plot of (predicted pH-observed pH) against observed pH for the AL:PE 118 lake training-set based on a 3-component WA-PLS model. The solid line is a loess scatterplot smoother fitted to detect any trends within the plot.

Table 1

"Apparent" and "prediction" errors for the AL:PE diatom-pH training-set for a WA-PLS regression. RMSE = root mean square of the error; RMSEP = root mean square error of prediction, R^2 = coefficient of determination

(a) "Apparent" or "estimation" errors

Component	RMSE	R^2	Mean-bias	Maximum-bias
1	0.294	0.850	0.018	0.453
2	0.182	0.943	0.000	0.207
3	0.133	0.969	0.003	0.086
4	0.101	0.982	0.001	0.117
5	0.075	0.990	0.000	0.074
6	0.060	0.004	0.000	0.044

(b) "Prediction" errors based on leave-one-out jack-knifing

Component	RMSEP	R^2	Mean-bias	Maximum-bias
1	0.352	0.786	0.019	0.560
2	0.331	0.811	-0.022	0.428
3	0.326	0.816	-0.009	0.362
4	0.329	0.813	-0.008	0.407
5	0.337	0.803	-0.011	0.391
6	0.342	0.798	-0.017	0.393

Table 2

Comparison of measured annual mean pH and diatom-inferred pH for the uppermost surface sediment at 15 AL:PE lakes. The diatom-inferred pH estimates for 1900 AD are also given, along with their ±RMSEP. The magnitude of pH change since 1900 (ΔpH) is listed. The percentage of taxa in each sediment core that are in the modern training-set is given as an index (% Taxa) of how representative the modern training-set is of the fossil diatom assemblages. (nk = not known, ^{210}Pb datings awaited).

	Measured annual mean pH	Diatom-inferred pH		ΔpH	%Taxa
		1990	1900		
Arresjøen, Svalbard	5.81	5.85 ±0.37	5.96 ±0.39	-0.11	84.1
Øvre Neådalsvatn, Norway	6.20	6.03 ±0.35	5.94 ±0.36	-0.09	97.6
Stavsvatn, Norway	5.94	5.63 ±0.35	5.73 ±0.35	-0.10	97.6
Lochnagar, Scotland	5.40	5.35 ±0.36	5.38 ±0.36	-0.03	96.9
Lough Maam, Ireland	5.04	5.21 ±0.37	5.83 ±0.37	-0.62	88.6
Laguna Cimera, Spain	6.18	6.16 ±0.34	6.16 ±0.34	0.00	92.2
Le Caldera, Spain	8.04	7.97 ±0.63	7.49 ±0.47	+0.48	86.5
Laguna Redo, Spain	6.32	6.35 ±0.34	6.41 ±0.35	-0.06	95.0
Étang d'Aub, France	6.10	5.91 ±0.36	5.91 ±0.37	0.00	96.9
Paione Superiore, Italy	5.65	5.62 ±0.37	5.97 ±0.38	-0.35	96.4
Milchsee, Italy (Lago di Latte)	6.55	6.62 ±0.43	7.04 ±0.76	-0.42	97.3
Zielowny Staw, Poland	6.88	6.86 ±0.37	nk	nk	93.4
Dlugi Staw, Poland	5.78	6.48 ±0.42	nk	nk	89.6
Nizne Terianske, Slovakia	6.86	6.81 ±0.39	nk	nk	88.2
Starolesnianske Pleso, Slovakia	4.79	5.02 ±0.36	5.15 ±0.35	-0.13	97.7

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

AL:PE 2 report for the period January 1993-June 1995.

Appendix 8A

Evidence for Atmospheric Contamination from Lake Sediment Analyses

Annex Tables & Figures

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Table 1 . **Arresjoen lake. TOC (mg/g dry sediment) and alkanes (µg/g dry sediment).**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	5-5.5
C14-alkane	n.d.	0.016	0.018	n.d.	n.d.	n.d.	n.d.
C15-alkane	n.d.	0.018	0.013	n.d.	n.d.	n.d.	n.d.
C16-alkane	n.d.	0.023	0.022	0.026	0.013	0.020	0.073
C17-alkane	0.279	0.111	0.069	0.090	0.027	0.024	0.010
C18-alkane	0.117	0.061	0.050	0.074	0.032	0.022	0.090
C19-alkane	0.660	0.505	0.413	0.707	0.129	0.072	0.024
C20-alkane	0.874	0.882	0.810	1.492	0.270	0.147	0.038
C21-alkane	4.923	5.830	5.738	11.628	2.519	1.377	0.317
C22-alkane	1.618	1.677	1.626	3.175	0.873	0.641	0.265
C23-alkane	5.745	6.001	5.713	11.168	3.240	2.639	1.310
C24-alkane	2.824	2.895	2.831	5.656	1.464	1.083	0.626
C25-alkane	7.716	8.205	8.057	17.188	4.379	3.764	2.268
C26-alkane	2.311	2.374	2.346	4.586	1.320	1.060	0.720
C27-alkane	7.273	8.091	7.686	16.613	5.284	4.662	2.703
C28-alkane	0.906	1.239	1.285	2.463	0.945	0.778	0.464
C29-alkane	2.100	2.751	3.029	6.166	2.284	1.949	1.138
C30-alkane	0.242	0.359	0.573	1.099	0.458	0.348	0.235
C31-alkane	1.286	1.487	1.864	3.398	1.411	1.154	0.841
C32-alkane	0.227	0.335	0.328	0.267	0.107	0.161	0.081
C33-alkane	0.288	0.358	0.357	0.789	0.380	0.280	0.192
Pristane	0.036	0.019	0.014	0.020	0.005	0.004	0.003
Phytane	0.025	0.010	0.010	0.013	0.004	0.002	0.002
Total resolved alkanes	39.451	43.248	42.852	86.619	25.145	20.185	11.254
TOC	60.279	62.954	64.695	66.173	48.078	37.284	33.039

n.d., below quantification limit

Table 2 . Arresjoen lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment)

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	5-5.5
Fluorene	5.99	1.56	1.74	1.58	0.94	0.62	0.49
Phenanthrene	47.00	9.49	9.13	10.63	5.43	3.22	2.64
Anthracene	2.70	0.73	0.87	0.91	0.26	0.19	0.09
Fluoranthene	19.82	11.13	12.08	13.35	4.22	1.83	0.97
Acephenanthrilene	1.33	1.24	1.45	1.57	0.35	0.07	0.05
Pyrene	17.43	6.89	10.68	7.42	2.79	1.21	0.78
Benzo[a]fluorene	0.41	0.34	0.40	0.19	0.10	0.05	0.05
Retene	<0.1	0.58	0.47	0.41	0.08	0.02	0.02
Benzo[ghi]fluoranthene	2.47	2.61	3.24	3.52	0.75	0.17	0.04
Ciclopenta[cd]pyrene	1.48	1.50	1.60	1.55	0.15	0.02	0.01
Benz[a]anthracene	3.63	3.28	3.55	4.04	0.59	0.25	0.25
Chrysene+Triphenylene	17.19	16.82	19.33	18.91	4.35	1.80	0.64
Benzo[b+j]fluoranthene*	31.00	30.81	49.31	31.10	4.31	1.40	0.48
Benzo[k]fluoranthene	13.09	13.86	1.60	12.07	1.85	0.51	0.19
Benzo[a]fluoranthene	1.28	1.53	n.d.	1.40	0.19	n.d.	n.d.
Benzo[e]pyrene	22.46	21.01	22.05	19.08	3.03	0.99	0.39
Benzo[a]pyrene	5.31	4.65	5.03	4.50	0.63	0.25	0.13
Perylene	1.30	0.94	1.28	0.90	0.25	0.14	0.15
Indene[7,1,2,3-cdef]chrysene	10.35	10.34	11.07	9.18	1.25	0.36	0.12
Indene[1,2,3-cd]pyrene	34.47	32.47	35.80	31.28	3.98	1.58	0.40
Benzo[ghi]perylene	33.05	30.78	35.11	27.42	4.29	1.76	0.51
Dibenz[aj]anthracene	2.69	3.04	3.21	2.73	0.31	n.d.	0.25
Dibenz[ah]anthracene	4.66	4.79	5.26	4.23	0.78	0.67	0.24
Dibenz[ac]anthracene	0.48	n.d.	n.d.	0.73	n.d.	n.d.	n.d.
Benzo[b]chrysene	1.04	1.51	1.36	1.49	0.12	0.12	n.d.
Coronene	31.50	28.07	30.87	23.51	2.93	0.97	0.31
SUM PAH	312.13	240.00	266.50	233.70	43.94	18.21	9.20
SUM PAH (-Perylene)	310.83	239.06	265.22	232.80	43.69	18.07	9.06

*Mixture of b and j isomers. n.d., below quantification limit

Table 3 . **Arresjoen lake. Polycyclic Aromatic Hydrocarbons. Metilderivatives (ng/g dry sediment)**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	5-5.5
3-Metilphenanthrene	0.85	0.77	0.53	1.16	0.62	0.14	0.31
2-Metilphenanthrene	1.17	1.04	0.80	1.64	0.81	0.19	0.44
4H-Ciclopenta[def]phenan	0.80	coel.	0.62	coel.	0.18	0.14	0.60
4-Metilphenanthrene	1.07	0.91	0.59	1.34	0.62	0.21	0.34
1-Metilphenanthrene	0.73	0.76	0.72	0.89	0.51	0.14	0.18
Dimetilphenanthrene	0.24	0.23	0.10	0.18	0.08	0.03	0.04
Dimetilphenanthrene	0.29	0.31	0.32	0.39	0.16	0.07	0.11
Dimetilphenanthrene	0.15	0.10	n.d.	0.10	0.08	0.03	0.03
Dimetilphenanthrene	0.81	0.64	0.59	0.87	0.59	0.19	0.25
Dimetilphenanthrene	0.68	0.45	0.43	0.55	0.34	0.11	0.14
Dimetilphenanthrene	0.64	0.59	0.48	0.50	0.31	0.11	0.13
Dimetilphenanthrene	0.23	0.15	0.14	0.19	0.12	0.05	0.06
Dimetilphenanthrene	0.13	0.15	0.16	0.15	0.11	0.04	0.03
Dimetilphenanthrene	0.05	0.06	0.06	n.d.	0.05	0.01	0.02
Dimetilphenanthrene	0.04	0.04	0.06	0.08	0.05	<0.005	<0.005
Metilfluoranthene/pyrene	0.19	0.16	0.18	0.31	0.09	0.03	0.01
Metilfluoranthene/pyrene	0.14	0.18	0.19	0.23	0.06	0.03	0.01
Metilfluoranthene/pyrene	0.31	0.23	0.27	0.26	0.10	0.05	0.03
1-Metilpyrene	0.29	0.21	0.23	0.28	0.10	0.05	0.03
Metilfluoranthene/pyrene	0.15	0.13	0.13	0.15	0.05	0.02	0.01

n.d., below quantification limit. coel., chromatographic coelution.

Table 4 . **Arresjoen lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	5-5.5
Naphto[1,2-b]tiophene	n.d.	0.14	0.02	0.08	0.02	n.d.	n.d.
Dibenzotiophene	0.04	0.55	0.63	0.93	0.31	0.14	0.11
Naphto[2,1-b]tiophene	n.d.	0.09	0.08	0.11	0.02	n.d.	0.02
4-Metildibenzotiophene	<0.01	0.20	0.06	0.48	0.26	0.03	0.09
3+2-Metildibenzotiophene	n.d.	0.12	coel.	0.20	0.11	0.03	0.04
1-Metildibenzotiophene	n.d.	0.06	0.04	0.14	0.08	n.d.	n.d.
Benzo(b)naphto[2,1-d]tiophene	1.35	1.45	1.70	1.74	0.34	0.16	0.08
Benzo(b)naphto[1,2-d]tiophene	0.30	0.32	0.39	0.42	0.09	0.04	0.01
Benzo(b)naphto[2,3-d]tiophene	0.28	0.29	0.34	0.14	0.05	0.01	<0.01
SUM S-PAH	1.97	2.84	3.17	3.43	0.82	0.34	0.22

n.d., below quantification limit. coel., chromatographic coelution

Table 5 . **Arresjoen lake. Organochlorined compounds ng/g (dry sediment).**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	5-5.5
HCB	1.02	1.03	1.46	1.66	n.d.	n.d.	n.d.
pp'-DDE	0.38	0.73	0.18	0.47	0.02	n.d.	n.d.
PCB N° 28	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
52	n.d.	0.23	n.d.	n.d.	n.d.	n.d.	n.d.
101	n.d.	0.18	0.08	n.d.	0.15	n.d.	n.d.
118	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	n.d.
153	0.03	0.25	0.02	0.14	n.d.	n.d.	n.d.
138	0.47	0.40	n.d.	0.29	n.d.	n.d.	n.d.
180	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
SUM PCBs	0.50	1.18	0.09	0.43	0.15	----	----

n.d., below quantification limit

Table 6 **Cimera lake. TOC* (mg/g dry sediment) and alkanes (µg/g dry sediment).**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	8-9	9-10	16-17	17-18	18-19
C14-alkane	0.11	0.14	0.32	0.23	0.13	0.20	0.15	0.07	0.18	0.13	0.16	0.07	0.05	0.05	0.04	0.02	0.02	0.04	0.03	0.04
C15-alkane	0.20	0.18	0.18	0.12	0.07	0.11	0.09	0.06	0.09	0.07	0.09	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.05
C16-alkane	0.28	0.30	0.32	0.21	0.12	0.21	0.15	0.51	0.15	0.11	0.14	0.08	0.06	0.06	0.06	0.03	0.05	0.04	0.03	0.05
C17-alkane	1.01	1.57	1.10	0.72	0.44	0.66	0.61	0.26	0.45	0.36	0.42	0.26	0.18	0.19	0.16	0.15	0.20	0.15	0.12	0.21
C18-alkane	0.75	0.59	0.66	0.40	0.24	0.47	0.30	0.21	0.25	0.19	0.23	0.17	0.12	0.12	0.12	0.10	0.14	0.09	0.07	0.14
C19-alkane	1.03	0.81	0.66	0.42	0.32	0.56	0.36	0.35	0.30	0.25	0.29	0.23	0.17	0.19	0.19	0.24	0.24	0.17	0.19	0.28
C20-alkane	1.11	0.83	0.70	0.46	0.38	0.68	0.43	0.44	0.32	0.26	0.31	0.24	0.20	0.20	0.22	0.28	0.24	0.21	0.24	0.31
C21-alkane	1.65	1.40	1.39	0.85	0.95	1.36	1.02	1.01	0.76	0.70	0.87	0.60	0.51	0.54	0.62	0.87	0.72	0.65	0.81	0.99
C22-alkane	1.14	0.86	1.07	0.70	0.69	1.02	0.75	0.75	0.64	0.54	0.67	0.49	0.46	0.42	0.51	0.67	0.56	0.54	0.61	0.76
C23-alkane	1.82	1.67	1.65	1.38	1.52	1.94	1.61	1.56	1.47	1.25	1.57	1.12	1.10	1.00	1.20	1.66	1.35	1.34	1.60	1.89
C24-alkane	0.99	0.85	0.97	0.76	0.81	1.04	0.82	0.81	0.73	0.63	0.79	0.60	0.58	0.54	0.64	0.87	0.69	0.71	0.80	0.95
C25-alkane	2.24	2.17	2.12	1.93	2.22	2.57	2.32	2.21	2.07	1.78	2.28	1.59	1.64	1.49	1.75	2.53	2.03	1.97	2.45	2.82
C26-alkane	1.07	1.03	1.02	0.92	1.07	1.24	1.11	1.03	0.98	0.84	1.05	0.08	0.77	0.69	0.82	1.17	0.94	0.86	1.07	1.27
C27-alkane	3.14	3.20	2.90	2.85	3.39	3.56	3.47	3.26	3.11	2.60	3.33	2.33	2.41	2.14	2.51	3.73	3.03	2.71	3.51	4.12
C28-alkane	1.77	1.77	1.73	1.62	1.98	2.12	2.02	1.86	1.88	1.50	1.97	1.34	1.37	1.22	1.44	2.31	1.68	1.56	1.75	2.05
C29-alkane	8.58	8.65	7.76	7.38	8.96	9.52	8.96	8.44	8.64	6.82	9.07	6.21	6.36	5.64	6.70	10.89	8.70	6.76	8.79	10.15
C30-alkane	1.45	1.45	1.47	1.38	1.67	1.76	1.69	1.58	1.66	1.27	1.69	1.17	1.21	1.06	1.28	1.88	1.49	1.25	1.66	1.93
C31-alkane	10.23	10.31	8.99	8.70	10.35	11.10	10.36	9.93	10.44	8.15	10.91	7.66	7.67	6.98	8.18	13.64	10.72	8.31	11.21	12.95
C32-alkane	0.98	1.05	0.98	0.99	1.16	1.42	1.17	1.13	1.14	0.96	1.17	0.81	0.87	0.76	0.89	1.35	1.07	0.92	1.14	0.17
C33-alkane	4.44	4.36	3.97	3.96	4.55	4.96	4.55	4.49	4.77	3.69	4.93	3.52	3.52	3.19	3.71	5.85	4.64	3.87	4.95	5.69
C34-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.35	0.27	n.d.	0.27	0.30
Pristane	0.27	0.23	0.21	0.14	0.08	0.14	0.09	0.08	0.09	0.07	0.08	0.06	0.04	0.04	0.03	0.03	0.04	0.03	0.02	0.04
Phytane	0.32	0.25	0.28	0.25	0.14	0.25	0.15	0.17	0.14	0.12	0.14	0.12	0.09	0.12	0.09	0.12	0.09	0.09	0.11	0.13
Total resolved alkanes	44.58	43.68	40.47	36.38	41.22	46.91	42.17	40.21	40.26	32.29	42.16	28.76	29.40	26.66	31.20	48.79	38.93	32.29	41.49	47.27
UCM**	112.60	102.82	56.18	35.11	23.12	52.13	24.84	27.70	13.15	6.80	9.11	8.35	6.75	9.96	8.43	n.d.	n.d.	n.d.	n.d.	n.d.
TOC	33.07	24.31	34	36	41	52	39	23	20	34	33	19.90	32	29	22	21.65	17.42	24.27	22.52	24.50

*Total organic carbon; ** Unresolved complex mixture n.d., below quantification limit

Table 7 Cimera lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	8-9	9-10	16-17	17-18	18-19
Fluorene	1.08	1.09	4.50	3.13	2.45	1.79	2.27	1.75	2.39	1.47	2.77	1.56	1.03	0.70	1.29	0.58	0.86	1.14	1.34	1.53
Phenanthrene	10.48	9.99	35.76	22.80	21.27	15.17	19.45	17.67	16.68	14.38	1.92	11.43	9.29	5.06	9.30	5.26	5.22	4.74	7.21	5.69
Anthracene	0.53	0.66	1.30	0.93	0.99	0.64	1.24	0.98	1.06	0.85	1.28	0.75	0.46	0.27	0.56	0.22	0.21	0.19	0.29	0.24
Fluoranthene	21.86	21.18	35.31	22.89	28.30	20.61	27.00	27.30	23.81	21.52	27.49	14.77	15.82	8.41	14.55	6.87	7.26	3.99	6.65	5.41
Acephenanthrilene	0.77	0.78	1.12	0.80	1.00	0.73	1.05	0.84	0.80	0.62	1.30	0.59	0.69	0.39	0.68	0.27	0.34	0.20	0.26	0.25
Pyrene	16.92	13.05	31.38	17.29	20.45	15.13	21.28	19.40	17.66	15.35	20.65	10.49	11.21	5.77	10.42	5.02	5.46	2.75	4.05	4.23
Benzo[a]fluorene	n.d.	n.d.	0.78	0.60	0.49	0.44	0.54	0.58	0.50	0.45	0.26	0.26	0.38	0.19	0.35	0.05	0.01	0.11	0.01	n.d.
Retene	0.17	0.14	11.66	5.38	7.46	6.18	7.04	6.43	3.99	2.53	4.20	2.63	2.19	1.44	2.54	1.70	1.29	1.19	0.98	0.83
Benzo[ghi]fluoranthene	4.02	3.98	10.33	6.60	9.52	7.12	9.28	9.28	8.41	7.66	5.45	5.93	6.55	3.88	6.85	1.48	1.46	2.01	1.15	0.92
Ciclopenta[cd]pyrene	0.67	0.91	1.53	1.11	1.52	1.14	1.37	1.70	1.48	1.41	1.19	0.98	1.16	0.64	1.20	0.25	0.17	0.14	0.06	0.06
Benz[a]anthracene	4.64	4.86	6.08	4.21	6.21	4.34	5.64	6.06	5.33	5.67	6.20	3.47	4.12	2.34	4.13	1.34	1.67	0.67	0.89	0.74
Chrysene+Triphenylene	24.55	24.50	28.00	20.56	29.32	19.35	28.30	28.00	24.50	23.41	26.65	14.75	18.33	10.16	18.04	7.68	7.39	5.76	5.79	4.54
Benzo[b+j]fluoranthene*	29.69	28.35	30.77	22.90	34.94	22.00	30.28	30.98	29.86	30.23	32.69	16.91	22.47	12.31	21.17	8.34	10.84	5.29	6.41	5.59
Benzo[k]fluoranthene	16.45	17.08	21.23	14.68	21.20	14.12	20.50	20.69	21.08	17.60	21.52	11.09	18.24	9.17	14.79	5.59	2.82	4.13	1.37	1.08
Benzo[a]fluoranthene	0.66	0.93	1.56	1.31	1.80	0.43	1.62	1.31	1.88	1.60	1.47	1.27	1.72	0.65	1.22	0.29	0.22	0.15	0.01	n.d.
Benzo[e]pyrene	16.13	16.43	20.88	15.70	21.98	14.03	20.37	21.73	20.65	20.05	20.45	12.34	16.76	8.64	14.79	5.07	4.92	4.11	3.66	3.37
Benzo[a]pyrene	4.88	5.38	7.84	6.10	8.52	5.51	7.96	7.76	7.98	8.51	8.36	5.18	6.62	3.38	5.32	1.60	1.98	0.78	0.88	0.81
Perylene	32.13	40.86	42.06	36.96	96.31	78.78	54.87	76.16	138.02	105.86	144.88	109.50	150.84	84.27	172.59	105.58	200.47	150.01	132.75	148.56
Indene[7,1,2,3-cdef]chrysene	7.86	7.45	8.53	7.01	8.68	7.06	8.48	8.90	8.50	8.49	9.71	5.23	8.66	5.25	7.02	2.79	3.82	1.99	3.04	2.77
Indene[1,2,3-cd]pyrene	23.00	23.32	26.66	22.41	30.39	22.65	27.27	30.99	29.22	28.70	31.47	17.17	29.79	13.76	23.50	7.63	6.64	4.38	3.04	2.62
Benzo[ghi]perylene	20.52	20.81	22.67	19.79	26.04	19.96	25.12	26.96	26.44	26.37	30.72	17.26	27.42	12.79	20.92	7.39	6.36	3.81	2.99	2.47
Dibenz[aj]anthracene	2.13	2.14	2.19	2.06	2.53	2.08	2.25	2.72	2.25	2.60	2.80	1.45	2.78	1.18	1.94	0.56	0.50	0.27	n.d.	0.58
Dibenz[ah]anthracene	2.87	2.99	3.17	2.80	3.63	28.16	3.13	3.88	3.56	3.63	4.38	2.00	3.87	1.61	2.64	0.98	1.73	0.48	0.03	0.25
Dibenz[ac]anthracene	0.41	0.45	0.54	0.52	0.64	0.46	0.65	0.70	0.73	0.79	0.59	0.44	0.88	0.34	0.54	0.14	n.d.	0.06	n.d.	n.d.
Benzo[b]chrysene	0.64	0.72	0.84	0.79	1.05	0.75	0.84	0.99	0.97	0.99	1.08	0.52	1.03	0.43	0.72	0.20	0.19	0.09	0.56	0.05
Coronene	15.12	17.72	30.89	27.40	35.20	26.15	30.63	36.80	33.86	33.13	24.10	20.96	35.20	15.91	24.83	5.83	2.46	5.01	1.50	1.27
SUM PAH	258.20	265.76	387.59	286.73	421.86	334.77	358	390.57	431.61	383.87	433.58	288.93	397.50	208.95	381.86	182.73	274.28	203.42	184.92	193.86
SUM PAH (-Perylene)	225.90	224.75	333.87	244.38	318.09	249.81	296.49	307.98	289.60	275.48	284.50	176.80	244.46	123.24	206.74	75.45	72.51	52.23	51.18	44.47

*Mixture of b and j isomers. n.d., below quantification limit

Table 8 Cimera lake. Polycyclic Aromatic Hydrocarbons. Metilderivatives (ng/g dry sediment)

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	8-9	9-10	16-17	17-18	18-19
3-Metilphenanthrene	0.76	0.73	5.32	2.98	2.44	1.83	1.21	2.17	1.89	1.45	2.64	1.18	0.86	0.48	0.76	0.46	1.45	0.37	1.47	1.40
2-Metilphenanthrene	1.15	1.14	6.49	3.80	3.10	2.32	1.52	2.85	2.47	1.88	3.35	1.58	1.17	0.66	1.04	0.62	1.59	0.48	1.79	1.67
4H-Ciclopenta[def]phenan.	0.14	0.10	0.13	0.14	0.11	0.11	0.04	0.12	0.08	0.13	0.12	0.06	0.06	0.03	0.06	0.01	0.08	0.02	0.13	0.09
4-Metilphenanthrene	0.56	0.55	4.46	2.43	1.94	1.70	1.04	1.92	1.63	1.21	2.22	0.92	0.71	0.41	0.68	0.38	1.26	0.34	1.35	1.29
1-Metilphenanthrene	0.69	0.70	4.42	2.58	2.33	1.91	1.17	2.16	1.84	1.34	2.33	1.10	0.87	0.51	0.86	0.58	1.07	0.44	1.33	1.18
Dimetilphenanthrene	0.09	0.08	1.27	0.70	0.56	0.45	0.28	0.53	0.40	0.28	0.46	0.25	0.20	0.10	0.18	0.09	0.12	0.08	0.09	0.10
Dimetilphenanthrene	0.15	0.14	1.68	0.87	0.69	0.58	0.65	0.64	0.55	0.39	0.58	0.34	0.28	0.13	0.22	0.10	0.24	0.11	0.19	0.24
Dimetilphenanthrene	0.09	0.10	1.04	0.55	0.42	0.37	0.24	0.44	0.40	0.24	0.39	0.22	0.18	0.09	0.16	0.07	0.15	0.07	0.10	0.13
Dimetilphenanthrene	0.38	0.40	4.03	1.93	1.54	1.44	0.92	1.56	1.33	0.94	2.69	0.77	0.57	0.32	0.53	0.42	0.60	0.29	0.42	0.63
Dimetilphenanthrene	0.33	0.31	2.13	1.08	0.88	0.80	0.51	0.89	0.75	0.51	1.53	0.44	0.34	0.18	0.33	0.28	0.33	0.17	0.29	0.34
Dimetilphenanthrene	0.42	0.41	2.11	1.04	0.96	0.81	0.52	0.92	0.76	0.57	1.62	0.70	0.46	0.22	0.39	0.40	0.33	0.22	0.20	0.22
Dimetilphenanthrene	0.29	0.12	1.14	0.57	0.46	0.40	0.26	0.46	0.31	0.25	0.60	0.21	0.21	0.08	0.16	0.11	0.44	0.06	0.05	0.07
Dimetilphenanthrene	n.d.	0.07	1.57	0.74	0.71	0.70	0.43	0.73	0.53	0.40	0.72	0.35	0.33	0.16	0.35	0.16	0.05	0.16	0.05	0.06
Dimetilphenanthrene	0.04	0.05	0.69	0.35	0.26	0.26	0.17	0.27	0.30	0.15	0.29	0.14	0.16	0.06	0.13	0.06	0.05	0.06	n.d.	n.d.
Dimetilphenanthrene	0.08	0.07	0.62	0.32	0.33	0.24	0.14	0.26	0.25	0.16	0.34	0.14	0.14	0.06	0.15	0.07	n.d.	0.07	n.d.	n.d.
Metilfluoranthene/pyrene	0.27	0.31	1.53	0.90	1.13	0.87	0.56	1.09	0.90	0.78	0.21	0.58	0.61	0.32	0.55	0.18	0.35	0.15	0.24	0.21
Metilfluoranthene/pyrene	0.42	0.56	0.92	0.45	0.66	0.45	0.30	0.61	0.52	0.47	0.93	0.31	0.31	0.19	0.28	0.16	0.26	0.09	0.14	0.12
Metilfluoranthene/pyrene	0.40	0.39	1.05	0.54	1.19	0.99	0.75	1.13	1.41	0.63	0.58	0.75	0.61	0.45	0.66	0.12	0.46	0.14	0.34	0.33
Metilfluoranthene/pyrene	n.d.	n.d.	0.75	0.59	1.04	0.79	0.48	0.94	1.16	0.79	n.d.	0.59	0.74	0.45	0.71	n.d.	0.17	0.18	0.10	0.09
1-Metilpyrene	0.32	0.33	1.40	0.73	0.91	0.78	0.48	0.98	0.74	0.65	0.56	0.42	0.45	0.26	0.40	0.12	0.40	0.10	0.13	0.15
Metilfluoranthene/pyrene	0.17	0.16	1.39	0.75	0.87	0.73	0.47	0.89	0.73	0.62	0.31	0.41	0.44	0.25	0.42	0.07	0.12	0.15	0.32	0.08

n.d., below quantification limit

Table 9 Cimera lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	8-9	9-10	16-17	17-18	18-19
Naphto[1,2-b]tiophene	0.07	0.06	0.57	0.19	0.14	0.13	0.07	0.11	0.08	0.07	0.14	n.d.	0.04	n.d.	n.d.	0.04	1.13	0.03	1.01	n.d.
Dibenzotiophene	0.80	0.70	2.83	1.39	1.21	1.00	0.66	1.12	0.91	0.80	1.03	0.58	0.45	0.24	0.47	0.24	0.35	0.22	0.41	0.41
Naphto[2,1-b]tiophene	0.09	0.09	0.28	0.17	0.19	0.16	0.09	0.15	0.18	0.13	0.18	0.11	0.09	0.05	0.08	0.04	0.15	0.05	0.04	n.d.
4-Metildibenzotiophene	0.56	0.43	3.09	1.40	0.96	0.94	0.57	1.02	0.78	0.58	1.01	0.46	0.32	0.16	0.27	0.25	0.94	0.20	0.83	0.51
3+2-Metildibenzotiophene	0.39	0.30	1.47	0.62	0.46	0.44	0.28	0.46	0.36	0.27	0.52	0.20	0.15	0.08	0.14	0.12	0.28	0.09	0.42	0.51
1-Metildibenzotiophene	0.17	0.12	0.91	0.35	0.23	0.26	0.18	0.25	0.23	0.14	0.25	0.11	0.08	0.04	0.06	0.06	0.44	0.06	0.20	n.d.
Benzo(b)naphto[2,1-d]tiophen	2.31	2.31	4.25	2.96	3.97	2.55	2.02	3.89	2.91	2.92	2.28	1.68	1.93	1.04	1.79	0.33	0.72	0.36	0.13	0.08
Benzo(b)naphto[1,2-d]tiophen	0.46	0.46	0.86	0.60	0.80	0.50	0.42	0.86	0.58	0.58	0.44	0.33	0.36	0.22	0.39	0.08	0.08	0.10	0.05	0.05
Benzo(b)naphto[2,3-d]tiophen	0.18	0.16	0.22	0.19	0.30	0.17	0.14	0.25	0.24	0.20	0.19	0.16	0.17	0.10	0.20	0.04	0.08	0.04	0.19	0.01
SUM S-PAH	3.89	3.77	9.01	5.51	6.60	4.51	3.40	6.38	4.89	4.69	4.25	2.86	3.04	1.65	2.93	0.77	2.52	0.80	1.84	0.54

n.d., below quantification limit

Table 10 Cimera lake. Organochlorinated compounds ng/g (dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	8-9	16-17	17-18	18-19
HCB	0.44	0.32	4.10	2.36	1.71	1.71	1.78	1.26	1.52	1.13	1.27	0.98	0.46	0.31	0.39	n.d.	0.47	0.08	0.10
pp'-DDE	4.89	4.72	6.94	4.52	3.81	9.33	7.10	3.81	1.72	1.69	2.27	0.87	0.64	0.72	0.87	0.31	0.32	0.35	0.33
PCB Nº 28	n.d.	n.d.	1.04	0.22	0.46	0.42	0.62	0.24	0.34	0.17	0.41	0.39	0.16	0.30	0.03	n.d.	n.q.	n.d.	0.09
52	n.d.	0.46	0.64	0.45	0.37	0.70	0.69	0.13	0.20	0.17	0.17	0.19	n.d.	0.22	n.d.	0.15	n.q.	0.16	0.18
101	0.08	0.16	1.82	1.06	0.82	1.46	1.48	0.59	0.57	0.42	0.19	0.70	0.27	0.40	0.23	0.21	n.q.	0.47	0.31
118	n.d.	0.28	0.70	0.87	0.67	1.44	1.07	0.34	0.41	0.33	0.19	0.50	0.16	0.41	0.18	0.27	n.q.	0.32	0.22
153	n.d.	n.d.	0.65	0.39	0.41	0.65	0.70	0.32	0.13	0.15	0.25	0.21	0.21	0.23	0.41	n.d.	n.q.	0.16	0.21
138	n.d.	n.d.	0.70	0.52	0.63	0.82	0.09	0.38	0.13	0.14	0.18	0.18	0.15	0.23	0.38	n.d.	n.q.	0.21	0.12
180	n.d.	0.30	0.05	0.18	n.d.	0.15	n.d.	0.23	n.d.	0.03	n.d.	0.08	n.d.	0.14	n.d.	n.d.	n.q.	0.15	n.d.
SUM PCBs	0.08	1.20	5.61	3.67	3.35	5.64	4.65	2.24	1.78	1.40	1.39	2.26	0.96	1.92	1.24	0.63	n.q.	1.47	1.13

n.d., below quantification limit. n.q., not quantified

Table 11 Escura lake. TOC* (mg/g dry sediment) and alkanes (µg/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9	9-10
C14-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C15-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C16-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C17-alkane	0.49	0.48	0.45	0.47	0.45	0.48	0.64	0.35	0.49	0.57	0.68	0.44	0.36	0.43	0.34	0.27	0.28	0.25
C18-alkane	0.17	0.18	0.19	0.18	0.16	0.14	0.18	0.13	0.17	0.19	0.20	0.17	0.18	0.17	0.16	0.14	0.14	0.12
C19-alkane	0.81	0.87	0.91	0.91	0.91	0.83	1.01	0.81	0.94	0.95	1.01	0.99	1.05	1.06	1.10	1.07	1.08	1.05
C20-alkane	0.43	0.45	0.47	0.48	0.48	0.43	0.53	0.47	0.53	0.50	0.53	0.53	0.55	0.55	0.57	0.57	0.57	0.55
C21-alkane	2.05	2.17	2.25	2.22	2.18	1.95	2.26	2.02	2.23	2.17	2.26	2.29	2.37	2.42	2.53	2.53	2.53	2.42
C22-alkane	0.91	1.00	1.05	1.11	1.13	1.08	1.23	1.11	1.21	1.11	1.18	1.20	1.27	1.20	1.30	1.28	1.26	1.25
C23-alkane	3.08	3.41	3.56	3.66	3.58	3.41	3.80	3.46	3.59	3.48	3.61	3.67	3.82	3.78	4.38	3.90	3.93	3.83
C24-alkane	1.37	1.53	1.61	1.70	1.70	1.64	1.85	1.72	2.39	1.65	1.76	1.75	1.87	1.85	1.99	1.92	2.39	2.36
C25-alkane	5.79	6.47	6.94	6.83	6.48	6.07	7.06	6.29	6.25	6.08	6.45	6.92	6.73	6.64	7.12	6.25	6.63	6.27
C26-alkane	2.47	2.77	3.00	3.03	2.78	2.70	3.08	2.77	2.84	2.66	2.90	3.39	3.20	3.07	3.29	3.08	3.11	3.07
C27-alkane	11.33	12.36	13.66	13.39	12.30	11.90	13.04	11.55	11.90	11.62	12.76	13.10	13.05	12.84	12.97	11.88	12.03	12.12
C28-alkane	4.84	5.12	5.66	5.68	5.17	4.96	5.49	4.89	4.93	4.63	5.12	5.42	5.61	5.50	5.61	5.17	5.17	5.09
C29-alkane	31.88	33.56	25.93	37.15	33.97	33.03	36.26	32.24	33.14	30.59	34.01	35.80	35.83	36.00	35.64	32.22	33.02	36.60
C30-alkane	5.21	6.01	5.95	6.03	5.53	5.44	6.08	5.38	5.49	5.15	5.60	6.06	6.82	6.37	6.48	5.79	5.87	6.47
C31-alkane	65.12	68.30	72.15	75.92	68.69	67.82	75.43	67.63	70.79	63.01	70.65	75.94	76.48	76.81	75.05	67.68	61.68	78.27
C32-alkane	5.04	5.29	5.53	5.70	5.12	4.98	5.51	4.98	5.14	4.70	5.23	5.67	5.88	5.83	5.75	5.21	4.93	5.68
C33-alkane	32.17	33.82	36.25	38.53	35.04	34.59	38.97	35.41	36.94	32.50	37.07	40.32	41.72	41.35	40.55	36.08	34.63	40.73
C34-alkane	1.02	1.12	1.19	1.28	1.14	1.11	1.21	1.11	1.10	1.03	1.17	1.32	1.36	1.31	1.31	1.17	1.09	1.24
C35-alkane	2.53	2.67	2.95	3.12	2.84	2.78	3.15	2.80	2.93	2.61	3.06	3.30	3.42	3.43	3.40	3.04	2.74	3.25
Pristane	0.02	0.01	0.01	0.05	0.06	0.06	0.09	0.06	0.09	0.06	0.09	0.06	0.07	0.07	0.05	0.05	0.05	0.03
Phytane	0.04	0.05	0.07	0.12	0.17	0.19	0.27	0.21	0.32	0.21	0.27	0.28	0.28	0.28	0.28	0.25	0.24	0.20
Total resolved alkanes	176.71	187.55	189.68	207.41	189.67	185.33	206.79	185.12	192.99	175.18	195.26	208.28	211.58	210.64	209.54	189.23	183.08	210.61
TOC	108.79	107.77	108.55	107.20	102.94	111.53	n.q.	103.05	107.06	105.73	111.35	116.82	109.64	n.q.	100.76	102.24	104.00	104.71

*Total organic carbon; n.d., below quantification limit n.q., not determined.

Table 12 Escura lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9	9-10
Fluorene	9.01	8.41	11.77	10.93	15.67	12.64	18.21	16.63	19.89	15.99	13.02	19.34	12.04	15.11	13.35	9.44	6.66	8.63
Phenanthrene	52.10	47.25	53.32	46.29	53.41	48.65	50.45	41.00	43.31	50.92	45.33	53.48	65.32	48.74	36.52	31.19	26.39	30.16
Anthracene	2.22	1.85	3.11	2.57	3.83	3.35	4.32	3.61	4.67	3.17	3.26	4.67	8.94	4.26	3.18	2.75	2.29	2.90
Fluoranthene	78.14	76.56	71.65	79.71	84.65	86.33	77.17	58.37	58.05	69.11	78.94	73.80	134.52	69.79	63.10	47.81	36.56	39.26
Acephenanthrilene	3.23	2.73	2.36	2.83	2.04	3.06	2.60	2.27	1.96	2.45	3.36	2.67	2.10	2.60	2.96	2.00	1.54	1.44
Pyrene	50.29	48.14	49.10	48.04	51.76	53.35	48.15	38.05	36.75	45.37	52.47	47.11	96.02	41.60	36.85	35.21	28.14	27.49
Benzo[a]fluorene	7.68	7.10	4.14	9.97	10.98	12.81	11.53	9.03	8.00	9.25	10.99	11.08	20.05	8.86	9.67	2.93	5.02	5.73
Retene	1.02	0.86	0.92	0.87	1.14	1.36	1.43	1.08	0.92	1.20	1.27	1.68	2.20	1.45	1.03	0.73	0.58	0.69
Benzo[ghi]fluoranthene	22.77	26.42	20.60	24.64	26.09	27.56	23.05	20.06	20.40	20.19	25.82	21.64	25.98	20.29	23.25	15.37	12.13	12.23
Ciclopenta[cd]pyrene	3.18	3.37	3.00	3.61	4.16	4.20	3.38	2.64	2.56	2.79	4.02	2.98	2.75	2.61	3.13	2.17	1.63	1.50
Benz[a]anthracene	12.82	14.72	15.13	15.19	19.76	18.42	16.68	12.92	14.10	13.04	14.44	13.35	47.81	12.32	14.04	9.72	6.71	7.59
Chrysene+Triphenylene	53.65	63.69	52.14	60.33	64.92	67.87	54.88	43.03	43.03	46.58	56.30	46.74	79.71	44.33	45.60	29.95	22.79	25.03
Benzo[b+j]fluoranthene*	91.25	93.68	80.91	119.67	102.36	98.97	86.58	69.54	58.66	80.75	89.93	88.86	103.82	75.50	86.03	66.79	55.36	53.07
Benzo[k]fluoranthene	64.14	63.61	57.67	76.40	76.36	62.07	62.50	44.63	49.39	59.61	55.31	55.80	73.90	50.69	57.07	45.86	37.26	33.08
Benzo[a]fluoranthene	4.97	3.99	3.44	5.70	4.06	5.91	4.51	3.61	4.41	4.14	4.35	4.48	9.16	4.17	4.57	3.85	2.48	1.93
Benzo[e]pyrene	55.76	60.96	50.29	71.16	64.99	58.39	52.70	39.55	39.97	51.18	50.36	51.88	64.67	45.19	52.49	42.87	35.51	32.99
Benzo[a]pyrene	21.13	23.89	19.49	28.37	26.94	26.37	23.99	17.66	19.03	22.07	23.15	23.52	45.62	19.57	23.49	17.52	13.81	13.05
Perylene	15.05	17.80	15.81	25.81	26.92	31.42	32.28	30.57	37.23	35.86	47.72	67.09	77.20	68.50	108.75	131.44	195.97	263.25
Indene[7,1,2,3-cdef]chrysene	25.81	29.06	24.21	29.29	26.17	24.84	23.08	22.36	18.52	24.41	22.11	24.17	23.31	19.27	25.73	25.26	20.36	18.28
Indene[1,2,3-cd]pyrene	82.12	95.33	68.52	95.93	90.77	88.61	77.97	57.71	56.02	72.19	78.42	76.50	86.58	68.05	83.70	70.71	54.62	48.23
Benzo[ghi]perylene	70.90	73.89	58.71	79.50	74.69	74.51	66.71	49.72	49.20	64.14	71.44	66.76	76.14	58.29	69.55	60.56	45.20	41.78
Dibenz[aj]anthracene	7.93	9.24	6.90	9.04	8.81	8.18	6.84	5.52	4.90	7.96	7.39	6.95	9.05	5.97	7.62	7.51	6.02	5.82
Dibenz[ah]anthracene	10.62	17.04	9.71	12.85	11.51	11.59	11.30	7.32	7.06	9.75	9.98	9.83	13.75	9.02	10.86	8.63	6.94	6.79
Dibenz[ac]anthracene	1.72	2.04	1.33	2.19	1.97	2.07	1.75	1.34	1.26	1.49	1.68	1.52	3.01	1.39	1.93	1.61	1.17	0.88
Benzo[b]chrysene	3.03	3.91	2.81	3.96	3.67	3.59	2.98	2.25	2.40	2.80	3.29	3.13	5.98	2.54	3.69	2.85	2.13	1.87
Coronene	39.12	38.35	32.35	42.49	40.73	40.32	33.92	27.51	29.92	33.07	37.30	34.85	37.07	29.54	37.42	36.29	28.82	23.37
SUM PAH	789.66	833.87	719.39	907.33	898.34	876.43	798.96	627.98	631.61	749.49	811.66	813.87	1126.69	729.64	825.56	711.01	656.06	707.05
PAH (-Perylene)	774.61	816.06	703.58	881.52	871.42	845.01	766.69	597.41	594.38	713.64	763.93	746.79	1049.50	661.15	716.82	579.57	460.10	443.80

*Mixture of b and j isomers. n. d. below quantification limit

Table 13 Escura lake. Polycyclic Aromatic Hydrocarbons. Methylderivatives (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9	9-10
3-Methylphenanthrene	1.27	1.12	1.17	1.06	1.13	1.15	1.10	1.04	0.95	1.13	1.14	1.19	2.07	1.02	0.87	0.72	0.62	0.60
2-Methylphenanthrene	2.58	1.85	2.10	1.82	1.98	1.98	1.91	1.58	1.63	1.91	1.92	1.97	3.28	1.76	1.51	1.32	1.16	1.33
4H-Ciclopenta[def]phenan.	coel.	coel.	coel.	coel.	coel.	0.23	0.27	coel.	0.25	coel.	0.27	coel.	0.98	0.26	0.24	coel.	coel.	coel.
4-Methylphenanthrene	1.99	1.41	coel.	1.24	1.32	1.49	1.52	1.35	1.29	coel.	1.58	1.98	2.36	1.48	1.32	1.43	coel.	coel.
1-Methylphenanthrene	1.79	1.50	2.72	1.42	1.57	1.68	1.65	1.56	1.50	2.34	1.74	2.08	2.66	1.78	1.56	1.25	1.69	1.68
Dimethylphenanthrene	0.30	0.24	0.46	0.22	0.22	0.29	0.34	0.22	0.25	0.45	0.20	0.30	0.45	0.19	0.19	0.31	0.32	0.39
Dimethylphenanthrene	0.99	0.14	1.17	0.11	0.08	n.d.	n.d.	0.29	n.d.	0.54	0.13	0.20	0.60	0.08	0.07	0.35	0.41	0.51
Dimethylphenanthrene	0.67	0.32	0.92	0.31	0.28	0.31	0.30	0.35	0.22	0.50	0.32	0.44	0.32	0.26	0.25	0.42	0.39	0.46
Dimethylphenanthrene	0.60	0.29	0.53	0.21	0.20	0.17	0.20	0.23	0.14	0.40	0.22	0.22	0.28	0.17	0.16	0.23	0.19	0.24
Dimethylphenanthrene	0.58	0.55	0.58	0.58	0.61	0.63	0.60	0.46	0.47	0.58	0.74	0.63	1.26	0.61	0.53	0.37	0.30	0.43
Dimethylphenanthrene	0.47	0.45	0.50	0.48	0.50	0.51	0.51	0.41	0.41	0.48	0.62	0.55	1.02	0.52	0.46	0.34	0.23	0.34
Dimethylphenanthrene	1.05	1.02	0.97	1.09	1.14	1.29	1.35	1.05	1.21	1.14	1.48	1.38	1.90	1.28	1.25	0.93	0.66	0.72
Dimethylphenanthrene	0.13	0.12	0.11	0.12	0.13	0.15	0.12	0.08	0.10	0.11	0.16	0.15	0.36	0.14	0.11	0.08	0.06	0.08
Dimethylphenanthrene	0.17	0.23	0.15	0.17	0.18	0.18	0.15	0.12	0.08	0.16	0.20	0.18	0.33	0.16	0.14	0.10	0.07	0.10
Dimethylphenanthrene	0.08	0.19	n.d.	0.11	0.09	0.14	0.09	0.10	0.08	0.09	0.13	0.12	0.12	0.09	0.08	0.06	0.07	0.06
Dimethylphenanthrene	0.19	0.12	0.16	0.22	0.25	0.29	0.30	0.24	0.29	0.26	0.33	0.29	0.42	0.25	0.24	0.18	0.15	0.18
Dimethylphenanthrene	0.23	0.20	0.20	0.19	0.21	0.27	0.23	0.21	0.23	0.25	0.27	0.27	0.38	0.24	0.24	0.20	0.15	0.16
Methylfluoranthene/pyrene	2.94	2.74	2.49	3.09	3.32	3.57	3.31	2.61	2.51	2.58	3.16	2.83	5.76	2.56	2.57	2.04	1.41	1.70
Methylfluoranthene/pyrene	1.22	1.71	1.58	1.73	2.53	1.92	1.63	1.81	1.18	1.23	1.68	1.46	2.88	1.77	1.42	1.28	1.08	1.07
Methylfluoranthene/pyrene	3.35	3.50	1.59	5.91	7.28	8.93	8.64	9.47	7.14	6.76	7.72	7.77	14.82	6.27	7.71	6.29	4.87	5.14
Methylfluoranthene/pyrene	1.79	1.58	1.70	2.04	1.99	2.00	1.67	1.95	1.72	1.64	1.70	1.61	4.44	1.32	0.99	0.94	0.57	0.79
1-Methylpyrene	1.88	1.90	1.18	2.33	2.34	2.59	2.68	1.26	1.98	1.74	2.44	2.18	4.52	1.98	2.10	1.49	1.00	1.14
Methylfluoranthene/pyrene	1.23	1.05	0.75	1.30	1.29	1.47	1.46	0.27	1.14	1.10	1.36	1.44	3.19	1.13	1.21	1.06	0.78	0.80

n.d., below quantification limit   coel., chromatographic coelution.

Table 14 Escura lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9	9-10
Naphto[1,2-b]tiophene	0.32	0.33	0.30	0.28	0.38	0.38	0.55	0.49	0.69	0.41	0.46	0.72	0.62	0.54	0.55	0.43	0.35	0.37
Dibenzotiophene	2.73	2.55	2.94	2.66	3.03	2.55	2.57	2.06	2.03	2.70	2.40	2.62	2.92	2.29	1.69	1.38	1.18	1.30
Naphto[2,1-b]tiophene	0.38	0.34	0.39	0.32	0.43	0.37	0.39	0.38	0.40	0.42	0.39	0.50	0.67	0.42	0.32	0.35	0.32	0.34
4-Methyldibenzotiophene	0.48	0.51	0.49	0.46	0.46	0.38	0.34	0.26	0.25	0.36	0.45	0.34	0.40	0.30	0.24	0.17	0.15	0.15
3+2-Methyldibenzotiophene	0.34	0.32	0.31	0.32	0.31	0.30	0.26	0.18	0.17	0.25	0.33	0.25	0.32	0.22	0.16	0.11	0.10	0.12
1-Methyldibenzotiophene	0.15	0.14	0.14	0.13	0.11	0.11	0.11	0.09	0.06	0.12	0.16	0.09	0.14	0.10	0.08	0.05	0.04	0.05
Benzo(b)naphto[2,1-d]tiophene	7.80	8.57	7.22	8.59	8.65	9.28	7.23	5.70	5.43	6.47	7.79	6.43	13.83	5.75	5.75	3.69	2.69	3.09
Benzo(b)naphto[1,2-d]tiophene	1.80	2.06	1.92	2.03	2.15	2.24	1.82	1.51	1.44	1.65	1.90	1.68	3.35	1.53	1.65	1.05	0.77	0.82
Benzo(b)naphto[2,3-d]tiophene	1.74	2.02	1.73	2.23	2.28	2.43	2.09	1.58	1.55	1.68	2.19	1.83	4.84	1.71	1.91	1.21	0.81	0.90
SUM PAH-S	14.76	15.87	14.51	16.11	16.93	17.25	14.64	11.72	11.55	13.33	15.12	13.79	26.23	12.25	11.88	8.10	6.11	6.81

Table 15 Escura lake. Organochlorinated compounds ng/g (dry sediment).

COMPOUND	cm	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	7.5-8	8-9	9-10
HCB		0.95	0.83	0.90	0.82	0.67	0.46	0.38	0.19	0.25	0.51	0.64	0.53	0.41	0.25	0.22	0.30
pp'-DDE		2.33	2.31	2.40	2.98	3.25	2.57	2.55	1.53	0.92	1.30	1.44	1.26	1.39	0.56	0.55	0.78
PCB N°	28+31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.20	n.d.	0.17	0.17	0.04	0.07	0.07	n.d.
	52	0.05	0.11	0.08	0.06	n.d.	0.00	0.06	0.03	n.q.	0.03	n.q.	n.q.	n.q.	n.q.	n.q.	0.02
	101	0.12	0.18	0.14	0.13	0.12	0.10	0.23	0.10	0.14	0.21	0.07	0.07	0.21	0.06	0.06	0.04
	118	n.d.	0.17	0.18	0.18	0.13	0.09	0.13	0.08	0.08	0.15	0.19	n.d.	0.11	0.05	0.04	n.d.
	153	0.11	0.20	0.12	0.12	0.13	0.15	0.15	0.09	0.04	0.14	0.08	0.09	0.10	0.04	0.03	n.d.
	138+163	0.15	0.16	0.16	0.16	0.15	0.13	0.13	0.08	0.06	0.15	0.10	0.06	0.09	0.05	0.04	n.d.
	180	0.12	0.13	0.13	0.13	0.13	0.12	0.14	0.08	n.q.	0.13	n.q.	n.q.	n.q.	n.q.	n.q.	n.d.
SUM PCBs		0.55	0.96	0.81	0.78	0.67	0.59	0.83	0.45	0.52	0.80	0.61	0.39	0.55	0.27	0.23	0.07

n.d. below quantification limit n.q., not determined.

Table 16 Redó lake. TOC (mg/g dry sediment) and alkanes (µg/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6.5-7	8-9	9-10	17-18	18-19
C14-alkane	0.14	0.14	0.76	0.23	0.28	0.04	0.22	0.07	0.49	0.03	0.18	0.09	0.09	n.d.	n.d.	0.05	0.02
C15-alkane	0.14	0.13	0.33	0.19	0.13	0.08	0.13	0.06	0.21	0.03	0.10	0.07	0.12	n.d.	n.d.	0.04	0.02
C16-alkane	0.43	0.37	0.52	0.48	0.23	0.14	0.22	0.14	0.33	0.10	0.17	0.19	0.27	0.07	0.06	0.09	0.06
C17-alkane	1.50	1.35	1.64	1.35	0.85	0.39	0.93	0.45	1.28	0.64	0.84	0.76	0.71	0.57	0.71	0.59	0.33
C18-alkane	0.82	0.57	0.64	0.87	0.23	0.29	0.30	0.28	0.47	0.42	0.24	0.48	0.49	0.14	0.11	0.16	0.10
C19-alkane	0.65	0.59	0.60	0.72	0.36	0.42	0.36	0.34	0.61	0.42	0.42	0.39	0.46	0.22	0.19	0.27	0.25
C20-alkane	1.62	1.75	0.54	0.60	0.45	0.44	0.41	0.39	0.57	0.44	0.48	0.40	0.46	1.13	1.13	0.39	0.38
C21-alkane	1.49	1.54	1.70	1.72	1.55	1.47	1.51	1.33	1.87	1.40	1.72	1.20	1.34	0.99	1.00	1.47	1.53
C22-alkane	3.64	3.80	1.31	1.44	1.14	1.27	1.23	1.23	1.58	1.29	1.43	1.10	1.50	3.17	3.37	1.48	1.60
C23-alkane	1.75	1.83	3.16	3.38	2.83	3.27	3.30	3.29	3.86	3.45	3.78	2.99	4.01	1.08	1.10	5.40	6.13
C24-alkane	5.12	5.32	1.39	1.54	1.24	1.45	1.32	1.35	1.56	1.42	1.46	1.17	1.45	4.29	4.68	1.49	1.55
C25-alkane	2.33	2.44	3.91	4.51	3.53	4.27	3.78	3.85	4.34	4.25	4.40	3.77	4.24	1.26	1.25	7.29	8.43
C26-alkane	8.85	9.20	1.75	1.97	1.56	1.82	1.52	1.53	1.73	1.67	1.61	1.35	1.31	5.08	5.19	1.41	1.41
C27-alkane	10.48	10.90	6.41	9.16	5.80	8.26	5.14	6.14	5.74	7.12	5.60	6.05	6.36	6.02	6.15	6.79	7.13
C28-alkane	4.34	4.59	3.89	4.32	3.16	3.85	2.88	2.74	2.74	3.18	2.64	2.57	2.51	2.25	2.23	2.15	1.99
C29-alkane	25.68	26.44	19.58	21.50	17.47	18.70	13.09	11.58	12.97	14.10	13.59	12.59	13.57	11.69	11.83	12.04	11.94
C30-alkane	3.17	3.27	2.60	2.78	2.35	2.47	1.86	1.68	1.95	1.98	1.93	1.63	1.65	1.51	1.51	1.54	1.39
C31-alkane	29.36	30.01	21.85	23.20	19.16	20.11	13.77	11.67	13.34	14.38	14.15	12.92	14.42	11.77	12.20	12.84	11.44
C32-alkane	1.49	1.72	1.10	1.15	0.99	1.05	0.76	0.80	0.76	0.83	0.81	0.68	0.72	0.96	0.86	0.63	0.57
C33-alkane	7.62	7.49	5.58	5.98	4.88	5.36	3.93	3.56	4.12	4.49	4.35	3.86	4.19	3.95	4.15	4.08	3.91
Pristane	0.34	0.28	0.30	0.61	0.08	0.12	0.13	0.12	0.20	coel	0.12	0.39	0.20	0.03	0.02	0.05	0.03
Phytane	0.21	0.15	0.18	0.32	0.06	0.11	0.09	0.14	0.19	0.23	0.14	0.27	0.26	0.05	0.03	0.07	0.04
Total resolved alkane	111.16	113.89	79.73	88.00	68.33	75.36	56.88	52.72	60.90	61.87	60.17	54.91	60.33	56.25	57.79	60.31	60.24
TOC	41.00	40.00	49.50	45.80	52.15	40.29	35.61	40.71	n.q.	n.q.	47.74	n.q.	47.66	55.60	61.30	n.q.	n.q.

n.d., below quantification limit. coel. chromatographic coelution. n.q., not determined

Table 17 Redó lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6.5-7	8-9	9-10	17-18	18-19
Fluorene	2.35	3.66	3.09	1.72	4.54	0.56	3.03	0.02	2.61	0.03	1.74	0.12	1.79	0.81	0.71	1.06	0.73
Phenanthrene	41.11	49.50	29.45	48.43	4.29	17.07	38.32	0.97	19.85	0.78	10.14	3.20	31.08	10.42	9.31	10.98	6.69
Anthracene	1.90	5.28	1.86	1.11	0.27	1.23	2.72	0.03	0.81	0.29	0.34	0.61	1.34	0.18	0.18	0.25	0.18
Fluoranthene	75.86	96.40	54.80	102.72	81.47	54.50	72.99	7.44	24.44	1.23	9.19	9.26	15.31	10.13	7.77	7.97	6.06
Acephenanthrilene	2.55	2.71	1.93	2.16	1.77	2.21	2.85	0.32	1.46	n.d.	0.46	0.42	0.30	0.38	0.20	0.25	0.12
Pyrene	38.24	61.91	28.01	51.08	36.50	28.03	34.98	3.22	15.56	0.84	6.22	8.52	11.37	4.36	4.42	7.85	2.83
Benzo[a]fluorene	2.82	1.22	0.25	5.92	3.55	4.76	1.67	0.42	0.22	0.08	0.15	0.97	1.38	0.13	0.15	0.34	0.30
Retene	1.82	1.15	1.95	2.40	2.46	1.14	2.31	0.43	1.81	0.22	1.21	2.40	1.18	0.39	0.46	0.68	0.51
Benzo[ghi]fluoranthene	8.98	10.89	12.95	30.22	20.16	17.63	20.86	3.10	7.91	0.41	2.99	3.32	4.04	1.72	1.53	1.62	1.45
Ciclopenta[cd]pyrene	2.55	2.48	2.11	1.13	4.24	0.94	3.59	0.22	1.17	0.04	0.30	0.14	0.21	0.15	0.15	0.46	0.09
Benz[a]anthracene	14.02	26.79	11.18	14.55	17.31	9.34	16.06	1.20	4.44	0.10	1.22	0.51	0.66	1.52	1.56	1.27	1.43
Chrysene+Triphenylene	77.69	85.32	66.71	121.96	103.16	72.26	82.02	10.51	26.36	1.23	10.40	9.09	11.97	11.39	11.30	12.24	12.22
Benzo[b+j]fluoranthene*	123.85	137.52	90.19	168.60	117.09	81.76	104.44	13.87	24.12	1.28	9.59	7.65	13.08	16.99	14.92	14.14	13.70
Benzo[k]fluoranthene	21.08	25.56	47.18	81.90	60.57	38.52	60.86	5.45	16.71	0.93	6.62	3.79	6.69	3.44	3.52	2.25	3.35
Benzo[a]fluoranthene	3.17	3.36	2.16	3.42	3.82	2.32	3.70	0.40	0.88	0.18	0.22	0.48	0.53	n.d.	n.d.	n.d.	n.d.
Benzo[e]pyrene	49.02	50.18	42.98	86.09	57.94	39.80	54.37	6.81	12.89	0.76	4.55	2.76	5.05	4.32	2.67	3.25	4.79
Benzo[a]pyrene	14.83	15.63	14.59	7.87	19.94	5.46	19.82	1.27	4.03	0.07	1.19	n.d.	n.d.	0.73	0.32	0.75	0.48
Perylene	4.29	3.93	3.82	1.21	6.16	0.41	14.11	1.47	30.56	1.26	71.36	0.64	34.43	87.68	105.60	204.04	154.70
Indene[7,1,2,3-cdef]chrysene	26.24	30.50	19.40	84.70	22.85	13.79	24.67	3.80	7.33	0.43	3.39	3.17	8.84	7.76	5.15	5.45	4.28
Indene[1,2,3-cd]pyrene	50.09	62.63	68.12	147.41	94.06	48.54	99.55	11.79	27.38	1.21	10.18	3.70	8.94	8.67	7.80	5.63	4.40
Benzo[ghi]perylene	34.81	45.21	43.04	68.91	60.71	28.11	67.41	6.79	16.90	0.57	5.65	1.02	2.50	3.97	3.50	2.54	1.69
Dibenz[aj]anthracene	6.05	7.72	5.96	31.04	8.00	9.14	7.60	2.00	1.76	0.21	0.56	0.55	1.52	1.13	0.38	1.96	0.31
Dibenz[ah]anthracene	8.26	6.98	8.54	21.60	11.65	5.63	11.63	1.25	2.76	0.13	1.09	0.32	0.83	0.76	1.41	0.67	1.38
Dibenz[ac]anthracene	1.07	n.d.	1.26	3.30	1.65	0.64	1.83	0.18	0.44	n.d.	0.13	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
Benzo[b]chrysene	1.92	2.71	2.10	3.30	2.85	1.29	2.79	0.25	0.75	n.d.	0.20	0.11	1.54	0.21	0.09	0.10	0.07
Coronene	15.90	24.79	33.27	69.33	48.66	17.01	53.96	3.66	14.44	0.46	5.28	1.36	2.65	2.89	1.91	2.01	1.68
SUM PAH	613.78	751.24	596.89	1101.58	795.67	475.78	808.17	82.38	267.58	12.49	164.38	60.06	160.95	178.27	183.93	284.68	222.25
PAH (-Perylene)	609.49	747.31	593.07	1100.37	789.51	475.37	794.06	80.91	237.02	11.23	93.02	59.42	126.52	90.59	78.33	80.63	67.83

*Mixture of b and j isomers. n. d. below quantification limit

Table 18 Redó lake. Polycyclic Aromatic Hydrocarbons. Methylderivatives (ng/g dry sediment)

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6.5-7	8-9	9-10	17-18	18-19
3-Methylphenanthrene	9.96	10.85	1.63	7.30	1.76	2.14	1.39	0.55	1.16	0.42	0.52	2.50	5.71	1.58	1.37	2.03	1.35
2-Methylphenanthrene	9.83	10.74	2.10	8.03	2.47	2.69	2.01	0.62	1.49	0.30	0.70	1.63	4.81	1.70	1.50	2.04	1.52
4H-Ciclopenta[def]phenan.	1.09	1.79	0.13	n.d.	0.19	n.d.	0.18	n.d.	0.06	n.d.	0.02	n.d.	n.d.	0.17	0.12	0.18	0.10
4-Methylphenanthrene	5.76	6.94	1.31	5.49	1.44	1.49	1.09	0.19	0.92	0.11	0.44	0.95	3.34	0.97	1.01	1.32	0.94
1-Methylphenanthrene	5.44	5.95	1.22	3.40	1.42	1.49	1.17	0.20	1.03	0.13	0.55	0.80	2.12	1.07	1.23	1.78	1.38
Dimethylphenanthrene	0.66	0.58	0.52	1.47	0.40	0.26	0.33	0.07	0.39	0.02	0.17	0.45	0.90	0.09	0.07	0.11	0.08
Dimethylphenanthrene	1.13	1.04	0.62	1.48	0.55	0.50	0.42	0.09	0.47	0.04	0.21	0.56	1.13	0.15	0.16	0.20	0.19
Dimethylphenanthrene	0.68	0.64	0.43	0.86	0.39	0.34	0.31	0.06	0.31	0.03	0.12	0.40	0.62	0.08	0.09	0.13	0.13
Dimethylphenanthrene	2.47	2.49	1.50	4.14	1.24	1.20	1.03	0.23	1.14	0.12	0.50	1.46	2.61	0.35	0.35	0.53	0.43
Dimethylphenanthrene	1.38	1.62	0.85	2.10	0.74	0.65	0.64	0.14	0.64	0.07	0.29	0.81	1.36	0.22	0.20	0.34	0.26
Dimethylphenanthrene	1.24	1.24	0.82	1.75	0.78	0.73	0.76	0.16	0.77	0.08	0.39	0.80	1.02	0.28	0.30	0.51	0.44
Dimethylphenanthrene	n.d.	n.d.	0.29	0.63	0.29	0.19	0.22	0.04	0.23	0.02	0.09	0.23	0.39	n.d.	n.d.	n.d.	n.d.
Dimethylphenanthrene	0.79	0.92	0.37	0.56	0.29	0.22	0.27	0.04	0.27	0.02	0.12	0.31	0.41	0.13	0.13	0.20	0.19
Dimethylphenanthrene	0.25	0.22	0.15	0.45	0.13	0.11	0.12	0.02	0.13	0.01	0.07	0.10	0.18	0.03	0.04	0.06	0.08
Dimethylphenanthrene	0.15	0.16	0.15	0.41	0.11	0.11	0.14	0.02	0.11	0.03	0.06	0.11	0.18	0.04	0.04	0.06	0.06
Methylfluoranthene/pyrene	1.97	3.39	2.21	5.38	3.41	3.14	3.20	0.50	1.19	0.10	0.45	0.65	0.64	0.21	0.18	0.25	0.18
Methylfluoranthene/pyrene	7.89	2.38	2.13	9.26	1.86	1.77	1.67	0.36	1.39	0.32	0.33	0.48	0.46	0.14	0.24	0.14	0.23
Methylfluoranthene/pyrene	0.64	1.54	0.82	1.67	1.55	1.26	1.50	0.13	0.70	0.03	0.34	0.71	0.43	0.10	0.06	0.16	n.d.
Methylfluoranthene/pyrene	1.63	1.44	1.57	3.51	2.31	1.36	1.95	0.08	0.77	0.03	0.28	0.21	0.14	0.08	0.08	n.d.	0.04
1-Methylpyrene	0.94	1.45	1.45	2.33	2.07	1.07	1.84	0.14	0.88	0.06	0.34	0.39	0.33	0.11	0.07	0.12	0.09
Methylfluoranthene/pyrene	0.60	0.87	0.79	n.d.	1.17	n.d.	0.94	n.d.	0.44	n.d.	0.17	n.d.	n.d.	0.07	0.06	0.08	0.05

n.d., below quantification limit

Table 20 Redo lake. Organochlorinated compounds ng/g (dry sediment).

COMPOUND cm	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6.5-7	8-9	9-10	17-18	18-19
HCB	1.04	1.00	2.72	1.45	1.54	0.62	0.62	0.19	1.45	0.48	0.98	0.94	0.59	0.08	n.q.	0.07	0.03
pp'-DDE	9.95	9.70	8.40	7.27	4.92	3.67	1.56	0.66	1.19	1.30	0.41	0.90	0.87	0.32	n.d.	0.27	0.17
PCB N° 28	0.06	0.29	0.56	0.75	0.25	0.12	0.20	n.d.	0.37	0.36	0.16	0.27	0.79	n.d.	n.d.	n.d.	n.d.
52	0.13	0.57	1.23	1.11	0.49	0.53	0.29	n.d.	1.64	0.91	0.26	0.31	1.08	0.17	n.d.	n.d.	n.d.
101	0.22	0.80	1.41	1.54	0.34	0.63	0.37	0.17	0.72	1.38	0.28	0.58	0.97	0.33	n.d.	n.d.	n.d.
118	0.46	0.63	0.85	1.35	0.33	0.89	0.34	0.30	0.43	0.96	0.18	0.50	0.84	n.d.	n.d.	n.d.	n.d.
153	0.49	0.32	0.50	0.51	0.23	0.15	0.17	0.10	0.20	0.27	0.09	0.18	0.24	n.d.	n.d.	n.d.	n.d.
138+163	0.31	0.39	0.48	0.59	0.27	0.29	0.21	0.14	0.19	0.27	0.06	0.23	0.22	n.d.	n.d.	n.d.	n.d.
180	0.38	0.36	0.34	0.45	0.33	0.23	0.13	0.07	0.10	0.08	0.03	0.06	n.d.	n.d.	n.d.	n.d.	n.d.
SUM PCBs	2.05	3.35	5.37	6.28	2.23	2.85	1.70	0.77	3.65	4.22	1.06	2.14	4.15	0.50	----	----	---

n.d. below quantification limit n.q., not determined.

Table 19 Redó lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

COMPOUND CM	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6.5-7	8-9	9-10	17-18	18-19
Naphto[1,2-b]tiophene	0.15	0.22	0.65	0.73	0.55	0.20	0.43	n.d.	0.24	n.d.	0.11	0.04	0.30	0.14	0.10	0.22	0.12
Dibenzotiophene	1.63	2.39	2.51	1.04	3.60	0.80	2.54	0.04	1.29	0.02	0.58	0.08	0.30	1.06	1.12	1.10	0.42
Naphto[2,1-b]tiophene	0.23	0.34	0.26	0.56	0.40	0.20	0.33	n.d.	0.12	n.d.	0.05	0.05	0.29	0.72	0.32	0.37	0.14
4-Methyldibenzotiophene	0.33	0.34	1.04	0.79	1.16	0.40	0.57	0.04	0.61	0.01	0.27	0.05	0.23	1.01	0.91	1.18	0.78
3+2-Methyldibenzotiophene	0.23	0.25	0.59	0.31	0.53	0.22	0.31	0.02	0.30	n.d.	0.11	0.07	0.11	1.31	1.25	1.67	1.08
1-Methyldibenzotiophene	0.10	0.09	0.35	coel.	0.30	coel.	0.14	coel.	0.18	n.d.	0.06	coel.	coel.	n.d.	n.d.	n.d.	n.d.
Benzo(b)naphto[2,1-d]tiophene	9.26	10.12	11.27	9.44	14.86	10.01	11.19	1.16	2.06	0.05	0.42	0.11	coel.	0.14	0.09	0.08	0.06
Benzo(b)naphto[1,2-d]tiophene	1.59	1.73	1.96	1.71	2.56	2.13	2.02	0.21	0.44	n.d.	0.11	0.09	coel	0.07	0.03	0.03	0.02
Benzo(b)naphto[2,3-d]tiophene	0.64	0.63	2.06	1.07	2.69	0.61	2.15	0.12	0.50	n.d.	0.08	n.d.	coel.	0.04	0.01	0.01	0.01
SUM PAH-S	13.50	15.43	18.72	14.55	24.66	13.94	18.67	1.53	4.65	0.07	1.33	0.37	0.89	2.17	1.68	1.80	0.78

n.d., below quantification limit. coel., chromatographic coelution

Table 21 Noir lake. TOC* (mg/g dry sediment) and Alkanes (µg/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
C14-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.
C15-alkane	n.d.	0.08	0.05	n.d.	0.10	0.04	n.d.	n.d.	n.d.	0.04	0.04	0.01	0.05	0.04	0.03	0.03	0.02
C16-alkane	n.d.	0.06	0.04	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.03	n.d.	n.d.	0.01	0.02	0.03	0.01
C17-alkane	1.66	3.13	3.42	4.08	1.99	0.30	0.31	0.69	0.25	0.36	0.49	0.13	0.07	0.18	0.18	0.17	0.10
C18-alkane	n.d.	0.02	0.07	0.09	0.08	0.06	0.09	0.07	0.05	0.08	0.12	0.04	0.03	0.05	0.07	0.08	0.07
C19-alkane	0.79	1.26	0.50	0.42	0.39	0.36	0.48	0.66	0.48	0.48	0.51	0.24	0.16	0.48	0.59	0.51	0.54
C20-alkane	0.26	0.34	0.45	0.50	0.48	0.44	0.62	0.67	0.56	0.56	0.64	0.32	0.32	0.52	0.71	0.70	0.73
C21-alkane	0.88	1.14	1.59	1.82	1.78	1.79	2.44	2.49	2.36	2.11	2.26	1.22	1.25	1.99	2.52	2.74	2.69
C22-alkane	0.85	1.01	1.34	1.50	1.49	1.58	2.33	2.43	2.15	1.94	2.18	1.28	1.28	1.99	2.55	2.40	2.55
C23-alkane	2.36	2.70	3.83	4.33	4.21	4.50	7.70	8.37	7.08	5.69	6.70	3.58	3.42	5.78	7.68	6.96	7.05
C24-alkane	1.11	1.16	1.62	1.79	1.75	2.00	2.45	2.46	2.10	2.05	2.16	1.56	1.72	2.27	2.61	2.49	2.74
C25-alkane	2.79	3.18	4.43	4.91	4.72	5.20	6.78	6.99	5.81	5.34	5.66	3.75	4.09	5.59	6.71	6.31	6.66
C26-alkane	1.29	1.41	1.96	2.15	2.10	2.45	2.75	2.70	2.19	2.24	2.30	1.77	2.03	2.55	2.87	2.76	3.01
C27-alkane	4.54	5.34	6.92	7.67	7.48	7.58	9.39	9.52	7.78	8.14	7.91	5.24	5.74	7.71	9.64	9.31	9.76
C28-alkane	1.25	1.39	1.83	2.59	1.94	2.61	2.37	3.12	2.45	2.45	2.47	1.74	1.96	2.51	2.90	2.97	3.16
C29-alkane	6.37	7.07	9.44	10.51	9.61	9.16	12.32	12.60	9.71	10.73	10.52	6.16	6.56	9.25	12.75	11.88	12.59
C30-alkane	1.12	1.36	1.53	1.67	1.57	1.67	2.34	2.01	1.59	1.66	1.75	1.36	1.47	1.85	2.06	2.34	2.42
C31-alkane	8.19	9.21	10.69	11.98	10.74	10.02	14.57	14.72	11.36	12.45	12.42	7.14	7.40	9.75	14.66	13.91	14.28
C32-alkane	0.46	0.75	0.79	0.90	9.06	0.74	1.07	1.06	0.94	0.82	0.85	0.52	0.57	0.70	1.14	1.01	1.07
C33-alkane	5.60	6.35	7.60	8.58	7.70	6.91	10.13	10.78	8.47	8.61	8.79	4.70	4.66	6.13	10.40	9.76	10.32
C34-alkane	0.63	0.00	0.17	0.18	0.16	0.07	0.82	0.14	0.18	0.14	0.17	0.06	0.08	0.18	0.34	0.32	0.34
C35-alkane	0.44	0.18	0.52	0.64	0.50	0.56	0.73	0.82	0.56	0.57	0.74	0.36	0.41	0.48	0.95	0.82	0.95
Pristane	n.d.	0.05	0.14	0.22	0.13	0.07	0.06	0.09	0.05	0.06	0.10	0.05	0.03	0.04	0.03	0.04	0.01
Phytane	n.d.	0.06	0.18	0.28	0.30	0.17	0.23	0.31	0.20	0.22	0.25	0.11	0.07	0.12	0.14	0.15	0.12
Total resolved alkanes	40.57	47.27	59.10	66.87	68.25	58.28	79.98	82.71	66.30	66.76	69.06	41.36	43.37	60.19	81.58	77.68	81.21
TOC	33.50	37.10	56.00	45.50	45.10	28.90	n.q.	n.q.	43.60	n.q.	43.80	n.q.	20.40	n.q.	33.10	36.90	28.97

*Total Organic Carbon

n.d. below quantification limit. n.q., not determined.

Table 22 Noir lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
Fluorene	3.09	1.04	2.50	2.99	4.57	4.06	2.91	5.02	1.94	3.94	4.60	2.06	1.96	2.44	1.71	3.82	2.59
Phenanthrene	32.76	12.29	43.55	42.56	57.06	50.69	48.77	61.72	41.77	32.61	32.20	11.33	9.19	11.68	7.14	17.48	9.01
Anthracene	1.62	0.59	1.37	1.16	3.34	2.56	3.24	3.26	2.04	2.32	1.66	0.80	0.54	0.76	0.49	0.95	0.40
Fluoranthene	71.21	32.89	94.04	92.23	124.85	99.48	136.02	123.72	102.00	69.37	59.31	21.43	14.58	19.04	9.42	26.62	11.98
Acephenanthrilene	1.15	0.71	1.10	1.28	1.33	2.03	4.13	2.13	2.48	2.52	2.07	0.77	0.51	0.91	0.55	1.35	0.29
Pyrene	45.77	22.86	57.05	57.42	78.41	60.09	93.01	79.86	66.89	42.40	53.30	12.83	8.82	11.42	7.92	17.40	14.51
Benzo[a]fluorene	1.85	0.91	2.97	1.99	3.34	2.37	3.39	3.18	2.53	1.44	1.30	0.63	0.25	0.45	0.16	0.86	0.19
Retene	0.06	0.06	0.06	0.05	0.05	0.11	0.03	0.04	0.02	0.05	0.05	0.03	0.04	0.06	0.05	0.11	0.08
Benzo[ghi]fluoranthene	9.66	5.89	10.34	10.90	15.72	12.68	24.71	18.70	16.25	14.09	14.62	4.86	3.36	4.21	2.40	6.60	2.68
Ciclopenta[cd]pyrene	1.32	0.59	1.32	1.34	2.28	1.91	3.93	3.01	2.62	3.55	2.46	0.93	0.51	0.93	0.38	1.14	0.26
Benz[a]anthracene	19.52	9.02	23.84	24.25	38.72	24.44	42.88	30.79	28.21	20.28	15.74	5.88	3.19	4.85	2.17	6.16	1.90
Chrysene+Triphenylene	86.32	47.07	94.60	97.18	136.92	99.74	146.15	106.65	101.95	73.16	58.66	23.77	15.21	21.01	8.93	26.39	9.66
Benzo[b+j]fluoranthene*	96.06	48.11	117.90	117.17	145.93	114.38	151.62	147.33	118.27	81.97	72.40	26.13	17.82	23.95	8.78	27.44	11.23
Benzo[k]fluoranthene	48.48	19.67	52.44	51.15	75.06	55.77	73.19	83.36	70.51	47.53	41.89	16.52	10.81	14.21	6.17	18.75	7.59
Benzo[a]fluoranthene	1.63	0.54	1.29	1.39	3.88	2.52	4.03	3.02	2.70	2.86	2.39	1.09	0.47	0.93	0.35	0.89	0.28
Benzo[e]pyrene	51.68	22.21	62.57	60.12	77.84	57.06	80.22	80.70	68.53	46.37	38.95	13.57	8.49	13.14	5.90	17.27	5.16
Benzo[a]pyrene	23.39	9.31	21.96	22.86	39.66	25.31	38.40	37.60	31.09	25.07	18.46	4.14	2.35	4.25	2.04	3.81	coel.
Perylene	685.15	279.40	656.35	764.92	1102.55	1027.16	912.69	970.18	1202.11	1419.88	1655.03	1748.05	1905.94	2186.54	2010.85	4859.35	3497.94
Indene[7,1,2,3-cdef]chrysene	12.79	5.42	13.50	13.92	19.38	15.47	23.17	22.93	20.14	15.29	13.61	5.03	3.62	4.91	2.28	7.17	2.80
Indene[1,2,3-cd]pyrene	58.78	26.07	72.79	76.89	104.39	74.68	127.79	122.16	110.16	78.65	65.73	22.48	14.80	23.85	10.47	33.02	10.82
Benzo[ghi]perylene	48.92	21.90	58.41	60.44	76.97	53.96	98.87	95.28	90.31	63.95	50.92	17.19	11.06	18.56	8.21	23.95	7.63
Dibenz[aj]anthracene	5.57	2.41	7.19	7.64	9.98	7.59	12.00	10.85	9.71	7.10	5.73	2.00	1.30	1.98	0.82	2.36	0.76
Dibenz[ah]anthracene	8.98	4.16	11.91	12.10	15.89	11.36	17.83	16.46	14.72	10.10	8.55	3.18	2.17	3.59	1.42	4.36	1.78
Dibenz[ac]anthracene	1.35	0.71	1.84	1.65	2.82	1.50	3.02	3.18	2.30	1.67	1.46	0.49	0.27	0.50	0.20	0.64	0.16
Benzo[b]chrysene	2.49	0.97	2.65	3.21	4.93	3.05	5.58	4.65	4.03	3.12	2.56	1.07	0.57	0.99	0.41	1.15	0.27
Coronene	25.59	10.75	28.59	28.43	33.53	24.66	48.11	41.93	45.86	37.65	27.34	10.09	7.49	12.02	4.58	13.97	3.57
SUM PAH	1345.22	585.54	1442.13	1555.25	2179.43	1834.62	2105.69	2077.72	2159.13	2106.95	2251.00	1956.36	2045.32	2387.19	2103.81	5123.01	3603.53
PAH (-Perylene)	660.07	306.14	785.78	790.32	1076.88	807.46	1193.00	1107.54	957.02	687.07	595.97	208.31	139.38	200.64	92.96	263.67	105.59

*Mixture of b and j isomers.

Table 23 **Noir lake. Polycyclic Aromatic Hydrocarbons. Methylderivatives (ng/g dry sediment)**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
3-Methylphenanthrene	1.09	0.59	1.32	1.26	1.69	1.49	1.54	1.63	1.22	0.92	0.99	0.34	0.27	0.36	0.22	0.51	0.21
2-Methylphenanthrene	1.65	0.82	1.85	2.00	2.62	2.31	2.43	2.35	1.88	1.35	1.47	0.50	0.41	0.52	0.31	0.75	0.31
4H-Ciclopenta[def]phenan.	0.09	0.08	0.06	0.09	0.17	0.17	0.17	0.14	0.09	0.11	0.10	0.06	0.03	0.04	0.03	0.05	0.03
4-Methylphenanthrene	0.86	0.53	0.98	0.98	1.18	1.11	1.15	1.11	0.89	0.73	0.90	0.27	0.21	0.30	0.21	0.40	0.23
1-Methylphenanthrene	0.92	0.53	0.92	0.91	1.22	1.02	1.20	1.27	1.11	0.71	0.87	0.30	0.26	0.35	0.23	0.51	0.25
Dimethylphenanthrene	0.06	0.04	0.05	0.06	0.10	0.03	0.07	0.06	0.06	0.04	0.05	0.01	0.01	0.02	0.02	0.04	0.02
Dimethylphenanthrene	0.09	0.07	0.21	0.10	0.30	0.02	0.21	0.08	0.05	0.04	0.08	0.02	0.02	0.03	0.02	0.04	0.02
Dimethylphenanthrene	0.13	0.11	0.27	0.13	0.38	0.06	0.32	0.12	0.11	0.08	0.09	0.03	0.02	0.03	0.04	0.05	0.01
Dimethylphenanthrene	0.28	0.22	0.19	0.30	0.24	0.08	0.22	0.30	0.22	0.18	0.21	0.07	0.05	0.08	0.06	0.11	0.04
Dimethylphenanthrene	0.20	0.15	0.01	0.21	0.06	0.16	0.04	0.23	0.20	0.14	0.14	0.05	0.04	0.05	0.04	0.08	0.03
Dimethylphenanthrene	0.03	0.01	0.57	0.02	0.71	0.35	0.62	0.06	0.02	0.03	0.03	0.01	0.01	0.02	0.01	0.02	0.01
Dimethylphenanthrene	0.63	0.63	0.36	0.56	0.45	0.24	0.42	0.57	0.50	0.36	0.48	0.13	0.11	0.15	0.12	0.24	0.10
Dimethylphenanthrene	0.41	0.35	0.35	0.36	0.46	0.07	0.40	0.36	0.31	0.26	0.31	0.10	0.08	0.11	0.08	0.15	0.07
Dimethylphenanthrene	0.39	0.34	0.16	0.36	0.20	0.65	0.17	0.35	0.33	0.26	0.30	0.11	0.10	0.14	0.11	0.25	0.14
Dimethylphenanthrene	0.18	0.13	0.13	0.16	0.18	0.43	0.16	0.17	0.15	0.12	0.12	0.04	0.03	0.04	0.02	0.07	0.03
Dimethylphenanthrene	0.14	0.14	0.07	0.13	0.09	0.42	0.07	0.14	0.14	0.10	0.13	0.03	0.03	0.03	0.03	0.07	0.04
Dimethylphenanthrene	0.09	0.07	0.05	0.07	0.08	0.20	0.07	0.08	0.04	0.05	0.04	0.02	0.02	0.01	0.01	0.02	0.03
Dimethylphenanthrene	0.07	0.06	0.05	0.06	0.07	0.15	0.08	0.06	0.05	0.05	0.06	0.02	0.00	0.02	0.02	0.03	0.02
Dimethylphenanthrene	0.03	n.d.	n.d.	0.05	n.d.	0.08	n.d.	0.07	0.06	0.05	0.08	0.00	0.01	0.01	0.01	0.01	0.01
Dimethylphenanthrene	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	0.02	0.01	0.02	coel.	0.04	0.03
Dimethylphenanthrene	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	coel.	0.01	0.01	0.01	coel.	0.02	0.01
Methylfluoranthene/pyrene	3.02	1.49	3.70	3.88	5.51	4.25	6.07	5.09	4.15	2.82	2.54	0.89	0.63	0.84	0.41	1.23	0.57
Methylfluoranthene/pyrene	1.23	0.74	1.55	2.10	2.16	1.74	2.63	1.84	1.61	1.05	0.92	0.36	0.27	0.37	0.17	0.48	0.21
Methylfluoranthene/pyrene	6.01	2.21	5.74	8.00	13.45	10.71	12.79	10.51	4.06	7.84	6.66	2.63	1.70	2.27	1.08	2.83	1.38
Methylfluoranthene/pyrene + + 1-Methylpyrene	6.22	2.53	6.32	8.24	14.55	10.89	14.38	12.18	7.05	8.55	7.55	3.26	1.95	2.66	1.30	3.52	1.54
Methylfluoranthene/pyrene	2.36	1.12	2.67	2.93	3.90	2.91	4.04	3.03	2.68	1.91	1.82	0.57	0.37	0.55	0.29	0.79	0.32
Methylfluoranthene/pyrene	1.62	0.72	1.92	2.05	2.58	1.94	2.67	2.00	1.73	1.27	1.15	0.41	0.26	0.38	0.24	0.59	0.25

n.d., below quantification limit. coel., chromatographic coelution

Table 24 Noir lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
Naphto[1,2-b]tiophene	0.14	0.05	0.06	0.08	0.10	0.09	n.d.	0.10	0.14	0.09	0.18	0.05	0.04	0.07	0.08	0.13	0.08
Dibenzotiophene	2.45	0.93	3.19	2.99	3.70	3.68	3.48	4.71	2.93	2.55	3.29	1.07	0.87	1.06	0.69	1.58	0.79
Naphto[2,1-b]tiophene	0.27	0.10	0.43	0.41	0.53	0.50	0.49	0.73	0.46	0.33	0.40	0.11	0.09	0.13	0.07	0.18	0.09
4-Methyldibenzotiophene	0.44	0.22	0.45	0.44	0.52	0.46	0.48	0.40	0.34	0.30	0.86	0.10	0.10	0.15	0.15	0.18	0.09
3+2-Methyldibenzotiophene	0.30	0.14	0.31	0.32	0.39	0.32	0.37	0.38	0.24	0.21	0.54	0.08	0.06	0.09	0.10	0.11	0.06
1-Methyldibenzotiophene	0.14	0.08	0.13	0.14	0.15	0.10	0.13	0.10	0.08	0.08	0.30	0.03	0.03	0.03	0.06	0.05	0.03
Benzo(b)naphto[2,1-d]tiophene	12.94	6.08	16.40	17.61	25.63	18.27	29.08	20.79	18.68	13.55	10.86	3.50	2.13	2.95	1.14	3.67	1.00
Benzo(b)naphto[1,2-d]tiophene	2.14	1.14	2.92	2.97	4.30	3.22	5.09	3.73	3.25	2.15	1.82	0.60	0.38	0.49	0.20	0.65	0.19
Benzo(b)naphto[2,3-d]tiophene	2.63	1.30	3.78	3.52	5.08	4.13	6.42	4.83	4.35	3.20	2.55	0.80	0.48	0.70	0.29	0.86	0.23
SUM PAH-S *	20.57	9.59	26.79	27.59	39.35	29.89	44.56	34.89	29.81	21.88	19.10	6.13	3.98	5.40	2.47	7.08	2.37

n.d., below quantification limit.
* Parent compounds

Table 25 Schwarzsee ob Sölden. Alkanes (μg/g dry sediment).

CM COMPOUND	0-0.25	0.25-0.5	0.5-0.75	1.25-1.5	1.75-2.0	3.0-3.25	4.0-4.25	4.5-4.75	5.25-5.5
C14-alkane	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	n.d.	n.d.
C15-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C16-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C17-alkane	0.60	0.66	0.49	0.32	0.27	0.26	0.05	0.04	0.06
C18-alkane	0.28	0.31	0.24	0.26	0.26	0.33	0.09	0.07	0.10
C19-alkane	0.27	1.27	0.44	0.39	1.07	1.36	0.36	0.31	0.60
C20-alkane	1.29	1.36	1.09	1.33	1.44	1.61	0.56	0.50	1.05
C21-alkane	4.55	4.65	3.46	4.28	4.65	4.61	1.75	1.73	3.99
C22-alkane	3.54	3.62	2.92	3.60	3.85	3.69	1.43	1.42	3.21
C23-alkane	7.74	7.82	6.19	7.46	8.08	7.16	2.85	3.04	7.25
C24-alkane	6.02	5.99	4.48	4.58	5.02	4.35	1.86	1.72	3.85
C25-alkane	12.84	12.89	9.55	9.90	10.77	9.08	3.85	3.68	8.56
C26-alkane	5.77	5.86	4.76	4.89	5.19	4.54	1.81	1.75	4.25
C27-alkane	14.54	14.87	12.06	12.34	12.55	12.19	4.59	4.17	10.29
C28-alkane	4.35	4.56	3.77	3.84	3.93	3.60	1.33	1.28	3.20
C29-alkane	14.99	15.89	13.25	13.10	13.82	13.24	4.52	4.36	10.84
C30-alkane	4.02	3.77	3.48	2.96	3.04	2.81	1.05	0.99	2.35
C31-alkane	16.07	16.38	14.03	13.69	14.45	14.15	4.67	4.89	12.04
C32-alkane	1.96	1.75	1.48	1.50	0.96	0.94	0.28	0.38	0.58
C33-alkane	4.39	4.45	3.70	3.47	3.50	3.67	0.99	0.97	2.34
C34-alkane	0.64	0.65	0.54	0.32	0.33	0.40	0.09	0.09	0.17
C35-alkane	0.72	0.67	0.59	0.36	0.38	0.42	0.03	0.10	n.d.
C36-alkane	0.50	0.51	0.38	0.58	0.09	0.66	0.06	0.16	0.21
Pristane	0.03	0.04	0.06	0.05	0.05	0.07	0.01	0.01	0.04
Phytane	0.06	0.11	0.23	0.36	0.35	0.83	0.11	0.12	0.19
Total resolved alkanes	105.17	108.07	87.17	89.58	94.08	89.98	32.34	31.78	75.19

n.d., below quantification limit

Table 26 **Schwarzsee ob Sölden. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).**

CM COMPOUND	0-0.25	0.25-0.5	0.5-0.75	1.25-1.5	1.75-2.0	3.0-3.25	4.0-4.25	4.5-4.75	5.25-5.5
Fluorene	6.22	6.16	6.15	6.38	6.64	10.03	1.71	1.89	3.42
Phenanthrene	47.25	50.60	47.19	45.18	51.98	60.07	7.42	6.58	7.91
Anthracene	2.96	4.41	3.26	4.23	3.99	5.03	0.45	0.43	0.43
Fluoranthene	77.18	96.18	80.01	94.76	108.74	111.17	12.78	8.52	7.72
Acephenanthrilene	2.56	2.58	1.90	3.29	3.23	4.53	0.32	0.25	0.24
Pyrene	38.28	66.40	51.85	65.90	75.24	72.44	8.59	6.15	5.06
Benzo[a]fluorene	1.32	2.13	1.95	2.52	2.70	3.93	0.27	0.17	0.16
Retene	0.15	0.18	0.12	0.27	0.25	0.23	0.08	0.08	0.14
Benzo[ghi]fluoranthene	11.26	12.59	9.09	15.43	17.62	19.32	1.81	1.25	1.05
Ciclopenta[cd]pyrene	2.07	5.26	4.46	6.39	7.04	8.53	0.47	0.21	0.23
Benz[a]anthracene	17.86	22.61	15.31	24.13	28.79	26.33	1.92	1.53	1.15
Chrysene+Triphenylene	68.67	89.70	64.68	82.90	87.52	73.62	8.18	6.12	5.66
Benzo[b+j]fluoranthene*	111.79	116.85	105.71	123.34	124.05	184.24	9.16	6.67	6.67
Benzo[k]fluoranthene	62.51	71.36	70.61	77.84	82.07	126.59	6.93	6.20	5.98
Benzo[a]fluoranthene	4.81	6.08	4.66	6.58	6.87	13.68	0.48	0.27	0.34
Benzo[e]pyrene	64.07	69.75	61.06	68.31	70.94	104.06	5.60	4.10	3.82
Benzo[a]pyrene	36.56	41.30	34.84	45.53	45.91	72.12	3.51	2.83	2.32
Perylene	25.56	30.51	35.30	19.91	15.14	14.75	3.51	5.02	10.08
Indene[7,1,2,3-cdef]chrysene	19.27	21.37	19.20	28.47	25.08	41.59	2.36	1.72	1.46
Indene[1,2,3-cd]pyrene	93.43	102.22	87.03	134.56	131.11	192.89	9.90	8.49	7.57
Benzo[ghi]perylene	77.24	86.68	68.62	107.21	104.10	129.34	7.72	6.47	6.37
Dibenz[aj]anthracene	10.29	10.93	8.73	11.04	11.03	15.26	0.77	0.76	0.31
Dibenz[ah]anthracene	15.81	14.19	11.43	16.65	15.57	20.26	1.42	1.40	0.89
Dibenz[ac]anthracene	2.11	1.85	1.40	2.89	2.76	3.67	0.23	0.19	1.61
Benzo[b]chrysene	5.62	3.28	11.31	5.09	4.13	7.76	0.34	0.28	0.53
Coronene	40.38	45.69	35.80	68.66	66.17	70.08	4.27	3.84	2.94
SUM PAH	845.22	980.88	841.68	1067.45	1098.68	1391.52	100.21	81.42	84.06
PAH (-Perylene)	819.67	950.37	806.38	1047.54	1083.54	1376.76	96.70	76.40	73.99

*Mixture of b and j isomers.

Table 27 Schwarzsee ob Sölden. Polycyclic Aromatic Hydrocarbons. Methylderivatives (ng/g dry sediment)

CM COMPOUND	0-0.25	0.25-0.5	0.5-0.75	1.25-1.5	1.75-2.0	3.0-3.25	4.0-4.25	4.5-4.75	5.25-5.5
3-Methylphenanthrene	1.40	1.48	1.27	1.46	1.69	1.80	0.25	0.23	0.35
2-Methylphenanthrene	2.14	2.32	1.87	3.65	2.52	2.41	0.27	0.24	0.29
4H-Ciclopenta[def]phenan.	0.25	0.21	0.42	0.22	0.23	0.28	0.04	0.02	0.03
4-Methylphenanthrene	1.11	1.12	1.67	1.08	1.25	1.47	0.25	0.14	0.20
1-Methylphenanthrene	1.90	1.37	8.38	1.39	1.54	1.75	0.84	0.29	0.79
Dimethylphenanthrene	0.22	0.21	0.17	0.21	0.27	0.23	0.03	0.03	0.04
Dimethylphenanthrene	0.33	0.34	0.25	0.35	0.34	0.32	0.03	0.03	0.03
Dimethylphenanthrene	0.20	0.24	0.23	0.22	0.27	0.24	0.07	0.02	0.04
Dimethylphenanthrene	0.70	0.76	0.68	0.66	0.69	0.61	0.11	0.05	0.09
Dimethylphenanthrene	0.43	0.44	0.35	0.46	0.47	0.52	0.05	0.05	0.06
Dimethylphenanthrene	0.49	0.51	0.39	0.58	0.65	0.64	0.11	0.11	0.19
Dimethylphenanthrene	0.17	0.19	0.14	0.18	0.19	0.21	0.01	0.01	0.02
Dimethylphenanthrene	0.14	0.17	0.13	0.15	0.15	0.20	0.02	0.01	0.02
Dimethylphenanthrene	0.29	0.20	0.12	0.12	0.14	0.14	0.03	0.03	0.04
Dimethylphenanthrene	0.06	0.08	0.08	0.11	0.11	0.10	0.02	0.02	0.02
Methylfluoranthene/pyrene	3.38	3.90	2.95	4.63	5.34	5.04	0.46	0.30	0.30
Methylfluoranthene/pyrene	1.63	1.89	1.51	2.32	2.27	3.19	0.23	0.14	0.13
Methylfluoranthene/pyrene	8.10	8.54	6.84	10.07	11.94	10.41	1.30	0.96	0.97
Methylfluoranthene/pyrene	4.32	5.23	4.91	6.57	7.76	8.30	0.90	0.81	0.54
1-Methylpyrene	3.52	3.86	2.99	5.40	5.55	5.71	0.55	0.21	0.44
Methylfluoranthene/pyrene	2.44	2.58	2.03	5.07	3.54	3.14	0.31	0.21	0.25
Methylfluoranthene/pyrene	1.45	1.73	1.25	1.94	2.10	1.99	0.19	0.16	0.22

Table 28 Schwarzsee ob Sölden. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

CM COMPOUND	0-0.25	0.25-0.5	0.5-0.75	1.25-1.5	1.75-2.0	3.0-3.25	4.0-4.25	4.5-4.75	5.25-5.5
Naphto[1,2-b]tiophene	0.15	0.10	0.12	0.11	0.13	0.18	0.01	0.02	0.02
Dibenzotiophene	3.54	3.73	3.60	2.75	2.89	3.43	0.29	0.23	0.23
Naphto[2,1-b]tiophene	0.44	0.44	0.46	0.45	0.50	0.61	0.05	0.03	0.04
4-Methyldibenzotiophene	1.67	1.78	1.40	1.12	1.03	0.95	0.12	0.14	0.14
3+2-Methyldibenzotiophene	0.55	0.63	0.48	0.40	0.46	0.32	0.03	0.02	0.04
1-Methyldibenzotiophene	0.17	0.17	0.15	0.09	0.10	0.09	0.01	0.01	0.01
Benzo(b)naphto[2,1-d]tiophene	8.35	10.44	7.93	9.05	9.32	8.05	0.50	0.31	0.23
Benzo(b)naphto[1,2-d]tiophene	1.24	1.72	1.14	1.47	1.40	1.24	0.12	0.07	0.06
Benzo(b)naphto[2,3-d]tiophene	2.63	3.50	2.63	3.35	3.40	3.17	0.23	0.13	0.10
SUM PAH-S	16.35	19.94	15.88	17.18	17.64	16.68	1.19	0.79	0.69

Table 29 Schwarzsee ob Sölden. Organochlorinated compounds ng/g (dry sediment).

cm COMPOUND		0-0.25	0.25-0.5	0.5-0.75	1.25-1.5	1.5-2	3-3.25	4-4.25	4.25-4.75	5.25-5.5
HCB		0.57	0.51	0.37	0.07	0.10	0.04	0.01	0.01	0.11
pp'-DDE		7.72	7.05	5.33	1.63	1.03	0.33	0.08	0.06	0.09
PCB N°	28+31	0.26	0.22	0.20	0.15	0.12	0.19	0.03	0.03	0.11
	52	0.85	0.89	0.58	0.37	0.30	0.41	0.09	0.14	0.08
	101	1.87	2.57	1.28	0.39	0.40	0.32	0.13	0.13	0.14
	118	1.06	0.97	0.67	0.18	0.19	0.13	0.05	0.04	0.05
	153	2.61	2.24	1.86	0.48	0.34	0.15	0.05	0.04	0.06
	138+163	3.04	2.58	2.22	0.66	0.47	0.16	0.05	0.05	0.08
	180	2.08	1.70	1.50	0.35	0.25	0.05	0.02	0.01	0.03
SUM PCBs		11.78	11.17	8.32	2.58	2.06	1.42	0.42	0.44	0.55

Table 30 Starolesnianske pleso lake. TOC*(mg/g dry sediment) and alkanes (µg/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	7.5-8	8-9	10-11	12-13	14-15	17-18
C14-alkane	n.d.	n.d.	0.80	0.50	0.48	n.d.	0.31	0.57	0.08	0.49	0.32	0.24	n.d.	n.d.	n.d.	0.16	n.d.	n.d.	n.d.
C15-alkane	10.68	5.22	17.68	9.12	9.64	3.33	4.77	9.23	2.13	11.25	5.31	4.79	n.d.	n.d.	2.29	3.08	3.80	1.09	2.71
C16-alkane	1.67	0.52	1.66	1.09	0.92	0.43	0.43	1.03	0.26	1.31	0.45	0.42	0.04	n.d.	0.30	0.33	0.43	0.15	0.30
C17-alkane	10.72	3.12	7.55	5.47	3.70	1.78	1.67	4.23	1.32	6.17	1.61	1.83	0.39	0.30	1.58	1.67	2.29	0.87	1.91
C18-alkane	1.35	0.40	0.94	1.19	0.53	0.47	0.28	1.02	0.25	1.44	0.31	0.31	0.24	0.16	0.64	0.57	0.83	0.23	0.42
C19-alkane	2.67	1.10	1.36	1.71	0.69	0.64	0.46	1.16	0.61	1.77	0.48	0.52	0.56	0.53	0.64	0.54	0.70	0.28	0.47
C20-alkane	1.27	0.94	1.06	1.51	0.62	0.67	0.52	1.03	0.62	1.43	0.66	0.64	0.76	0.66	0.69	0.67	0.87	0.43	0.72
C21-alkane	4.70	3.94	4.11	4.58	2.69	2.25	2.27	2.95	2.42	3.60	3.05	3.14	3.71	3.34	2.50	2.93	3.39	2.43	3.14
C22-alkane	3.37	2.82	2.96	3.25	1.78	1.63	1.52	2.17	1.67	2.54	1.76	1.72	2.24	1.97	1.72	1.77	2.03	1.39	1.81
C23-alkane	12.69	11.46	11.31	10.97	6.67	5.74	5.87	6.68	6.69	7.04	6.76	6.90	8.61	8.01	6.24	7.20	8.56	6.77	9.29
C24-alkane	6.50	5.99	5.71	6.05	3.70	3.43	3.33	4.09	3.90	4.23	3.46	3.67	4.77	4.41	3.38	3.79	4.48	3.12	4.09
C25-alkane	27.26	26.07	23.70	24.60	15.95	15.31	15.03	17.58	17.51	17.57	15.77	16.45	21.11	19.73	15.04	17.80	20.66	15.62	19.89
C26-alkane	11.74	11.60	10.04	11.08	8.10	8.40	7.96	9.35	9.64	9.27	8.33	8.81	11.68	11.00	8.04	9.44	10.85	7.91	11.00
C27-alkane	39.83	40.30	34.36	37.95	24.25	25.41	23.79	28.36	28.52	28.61	25.63	27.95	34.32	33.28	25.05	29.38	33.35	25.36	33.80
C28-alkane	8.02	8.05	6.93	7.01	4.79	5.07	4.54	5.46	5.44	5.61	4.99	5.15	6.81	6.23	4.43	5.05	6.17	4.69	6.54
C29-alkane	30.80	30.87	26.45	0.29	18.48	19.46	18.13	21.70	22.80	22.71	20.22	22.42	28.90	31.60	19.11	23.27	27.88	20.06	29.99
C30-alkane	6.21	5.92	5.41	5.74	3.77	3.67	3.47	3.94	3.26	4.03	3.69	3.91	4.10	4.78	3.16	3.90	3.51	3.22	3.65
C31-alkane	32.14	30.05	27.53	30.04	20.76	20.79	20.80	23.04	21.23	24.69	24.09	24.59	27.81	31.58	19.84	27.56	27.06	23.14	28.94
C32-alkane	2.30	3.44	2.00	2.31	1.19	1.51	1.18	2.26	1.22	1.40	1.19	1.44	1.62	2.81	1.18	1.36	1.36	1.01	1.43
C33-alkane	7.45	6.24	6.23	6.45	4.77	4.63	4.83	5.10	5.20	5.83	5.81	5.78	6.81	10.38	4.43	6.33	6.50	5.36	6.84
Pristane	0.45	0.13	0.35	0.48	0.28	0.19	0.09	0.44	0.10	0.55	0.07	0.09	0.02	0.12	0.09	0.07	0.13	0.04	0.09
Phytane	0.30	0.14	0.35	0.56	0.32	0.35	0.34	0.82	0.57	1.21	0.69	0.58	0.50	0.32	0.37	0.20	0.28	0.07	0.14
Total resolved alkanes	222.12	198.34	198.48	171.95	134.10	125.15	121.59	152.23	135.44	162.73	134.67	141.35	165.00	171.21	120.71	147.08	165.13	123.23	167.16
TOC	137.02	137.20	140.30	146.50	128.30	119.60	115.50	117.20	n.q.	121.30	113.50	97.20	104.60	99.50	132.50	122.00	142.00	137.30	140.30

* Total Organic Carbon. n.d., below quantification limit. n.q., not determined.

Table 31 Starolesniaske pleso lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	8-9	10-11	12-13	14-15	17-18
Fluorene	23.2	8.7	43.2	58.8	33.5	29.0	31.9	17.6	23.1	7.3	13.1	5.9	8.7	6.5	9.9	4.7	7.6
Phenanthrene	617.3	564.9	690.2	778.2	511.9	426.8	486.5	296.1	250.8	114.9	123.3	109.2	84.8	39.4	61.0	21.9	39.5
Anthracene	49.4	58.9	54.6	60.3	33.9	27.3	38.7	24.7	18.9	11.4	9.4	9.2	7.3	2.9	4.1	1.7	2.5
Fluoranthene	1757.3	2145.0	1751.5	1903.7	1366.0	1295.1	1331.6	870.1	647.0	293.1	253.3	278.0	179.5	73.7	68.7	32.4	42.4
Acephenanthrilene	40.8	49.5	31.6	33.9	23.5	30.2	45.2	27.6	20.8	8.6	7.6	9.3	7.0	2.8	2.4	1.3	1.0
Pyrene	1161.1	1446.9	1137.8	1264.1	720.5	667.0	672.4	410.9	341.9	144.0	124.9	130.7	93.0	37.6	35.8	13.0	19.8
Benzo[a]fluorene	35.1	68.3	34.2	54.9	12.3	39.9	33.1	15.7	12.4	5.9	5.2	4.1	3.2	1.6	1.4	0.6	1.6
Retene	3.5	2.7	3.4	4.8	3.4	4.4	6.6	3.5	5.3	3.4	3.8	3.1	2.9	1.6	2.7	1.6	2.1
Benzo[ghi]fluoranthene	425.1	537.6	443.2	513.0	416.6	436.5	487.9	325.2	242.0	108.5	94.1	98.5	64.1	27.2	31.2	12.6	18.3
Ciclopenta[cd]pyrene	75.6	101.3	79.1	88.1	63.8	70.3	87.5	66.1	43.6	19.2	13.9	14.7	10.2	4.1	3.5	1.1	1.2
Benz[a]anthracene	375.5	456.1	381.0	402.1	302.9	248.7	264.4	201.9	130.9	56.3	49.7	53.2	33.2	11.9	15.8	4.1	5.5
Chrysene+Triphenylene	1663.6	2019.8	1614.8	1719.8	1217.2	1182.2	1191.5	845.2	595.7	263.9	246.0	277.4	176.0	75.2	88.4	40.2	55.2
Benzo[b+j]fluoranthene*	2389.5	2824.8	2250.7	2547.5	1683.0	1875.1	2042.3	1356.0	878.6	424.4	377.2	413.4	314.0	110.0	121.4	47.2	61.9
Benzo[k]fluoranthene	1522.4	1624.5	1346.1	1247.4	1185.8	986.8	1274.7	831.0	702.7	298.8	240.0	295.9	170.1	55.8	58.0	21.5	28.5
Benzo[a]fluoranthene	92.3	113.8	101.8	100.0	89.5	77.7	95.6	64.5	43.5	19.6	15.8	18.6	12.1	3.5	3.8	1.4	1.7
Benzo[e]pyrene	1386.5	1440.2	1183.6	1232.1	994.8	986.6	1280.7	749.6	548.2	264.1	221.1	242.7	166.5	59.5	69.5	29.5	41.2
Benzo[a]pyrene	750.9	783.4	666.8	639.9	462.0	403.7	505.8	344.3	245.7	112.0	89.3	97.2	60.6	18.0	19.3	6.2	7.6
Perylene	102.5	111.0	97.6	85.7	68.0	63.0	86.9	51.5	18.6	20.5	25.3	24.9	31.1	35.5	88.4	83.3	138.6
Indene[7,1,2,3-cdef]chrysene	390.1	464.7	408.0	487.3	380.6	418.3	476.1	344.8	249.1	120.8	96.9	113.1	86.4	33.6	34.8	16.9	24.7
Indene[1,2,3-cd]pyrene	1809.6	1942.1	1768.1	2015.2	1652.9	1711.1	1915.3	1448.3	1090.2	482.3	405.6	436.0	307.7	107.9	110.2	48.5	62.6
Benzo[ghi]perylene	1379.8	1311.5	1465.6	1442.0	1238.8	1285.2	1315.1	1026.5	785.6	383.5	323.5	329.7	236.2	83.2	72.4	37.7	45.7
Dibenz[aj]anthracene	168.0	174.6	177.8	172.6	125.2	140.3	140.3	101.5	76.7	33.0	27.8	30.6	20.9	7.8	8.1	3.0	3.9
Dibenz[ah]anthracene	220.5	250.3	214.6	237.9	185.1	186.7	207.7	148.3	103.8	46.5	39.3	42.0	29.5	10.2	9.2	3.9	4.7
Dibenz[ac]anthracene	43.0	47.3	40.5	44.6	35.3	36.1	42.0	29.7	22.2	7.8	7.1	7.4	5.2	1.7	1.4	0.6	0.9
Benzo[b]chrysene	84.9	105.2	92.2	95.9	75.1	70.7	93.2	68.0	44.5	17.2	15.8	16.0	12.2	3.8	3.3	1.1	1.2
Coronene	1481.4	1546.8	1464.6	1438.4	1329.1	1569.1	1812.4	1244.2	849.5	419.7	333.4	302.2	270.2	97.1	93.6	46.7	53.4
SUM PAH	17714	19802	17194	18296	13140	13976	15651	10694	7830	3619	3103	3302	2348	896	1002	476	674
PAH (-Perylene)	17612	19691	17097	18210	13891	13913	15564	10643	7812	3599	3077	3277	2317	860	913	392	520

*Mixture of b and j isomers

Table 32 Starolesnianske pleso lake. Polycyclic Aromatic Hydrocarbons. Metilderivatives (ng/g dry sediment)

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	8-9	10-11	12-13	14-15	17-18
3-Metilphenanthrene	38.84	37.89	35.66	38.84	23.12	20.60	25.90	12.14	15.79	4.74	5.07	3.80	4.97	2.15	4.24	1.10	2.95
2-Metilphenanthrene	58.96	60.42	53.68	59.74	35.82	33.84	41.70	21.97	23.57	8.61	8.73	7.25	7.80	3.42	5.94	1.60	4.12
4H-Ciclopenta[def]phenan.	7.09	7.58	6.39	6.35	4.14	3.79	5.66	3.24	2.35	1.67	1.16	1.29	0.84	0.30	0.42	0.16	0.34
4-Metilphenanthrene	32.67	32.62	31.61	32.88	19.91	20.36	26.75	13.47	16.29	6.39	5.91	5.04	5.69	2.44	4.52	1.40	3.39
1-Metilphenanthrene	34.70	36.07	30.59	33.29	20.19	18.74	25.06	13.42	15.89	7.83	7.71	7.09	5.79	2.54	4.35	1.54	3.37
Dimetilphenanthrene	4.40	4.09	3.71	4.98	2.42	2.96	4.43	1.46	3.16	0.68	0.69	0.37	1.04	0.46	3.81	0.23	0.77
Dimetilphenanthrene	6.55	7.20	5.89	7.05	3.61	3.88	5.43	2.15	3.98	0.82	0.73	0.68	1.26	0.55	0.96	0.26	0.78
Dimetilphenanthrene	4.76	5.31	4.20	4.57	2.60	2.86	3.90	1.58	2.51	0.60	0.51	0.47	0.84	0.34	1.10	0.17	0.47
Dimetilphenanthrene	14.23	14.65	12.60	14.98	8.38	9.65	13.68	5.46	9.84	2.24	1.94	1.63	3.26	1.39	0.71	0.65	2.11
Dimetilphenanthrene	9.86	10.48	8.27	9.65	5.44	6.14	8.33	3.66	5.65	1.49	1.36	1.12	1.92	0.85	3.02	0.45	1.29
Dimetilphenanthrene	19.10	21.53	17.57	19.31	11.70	12.37	16.12	8.55	11.55	5.00	5.02	4.77	4.33	1.90	1.76	1.32	2.75
Dimetilphenanthrene	5.70	6.78	5.54	6.24	3.36	3.55	4.86	2.19	3.24	0.85	0.76	0.63	1.01	0.43	3.54	0.21	0.58
Dimetilphenanthrene	6.08	7.41	6.47	6.81	4.42	4.55	6.68	3.15	3.77	1.18	1.04	0.72	1.16	0.51	0.89	0.33	0.66
Dimetilphenanthrene	3.11	3.95	3.51	3.51	1.74	1.97	3.03	1.27	2.14	0.52	0.52	0.44	0.59	0.24	0.95	0.15	0.35
Dimetilphenanthrene	3.31	3.83	3.17	3.71	1.98	1.95	2.65	1.20	1.83	0.53	0.54	0.48	0.59	0.25	0.54	0.17	0.38
Metilfluoranthene/pyrene	51.58	68.46	54.20	61.02	41.36	42.86	42.95	25.56	20.61	9.07	7.88	7.77	5.76	2.46	0.52	1.05	1.38
Metilfluoranthene/pyrene	24.21	32.14	28.03	30.84	19.85	20.87	20.24	12.64	9.63	4.83	4.09	3.68	3.10	1.28	2.18	0.56	1.62
Metilfluoranthene/pyrene	35.07	68.33	34.24	54.92	12.28	39.89	33.08	17.05	16.31	5.28	9.70	10.97	5.33	2.03	1.14	0.90	0.68
Metilfluoranthene/pyrene	24.37	42.93	26.92	31.68	17.28	19.18	23.89	14.48	11.09	5.51	6.84	6.68	3.75	1.55	1.76	0.67	0.69
1-Metilpyrene	39.71	53.59	42.60	46.45	29.68	29.36	28.73	16.46	11.94	5.54	4.53	4.64	3.56	1.33	1.32	0.49	0.95
Metilfluoranthene/pyrene	33.10	42.87	34.92	39.77	26.78	26.80	28.32	17.42	14.02	6.49	5.93	5.22	4.16	1.66	1.38	0.75	n.d.
Metilfluoranthene/pyrene	20.15	25.56	20.91	22.67	14.29	13.10	14.84	9.26	7.30	3.44	3.25	2.76	2.30	0.88	1.71	0.42	0.47

n.d., below quantification limit

Table 33 **Starolesniaske pleso lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).**

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	8-9	10-11	12-13	14-15	17-18
Naphto[1,2-b]tiophene	0.83	0.09	1.49	5.23	3.05	3.00	1.47	1.72	2.78	0.93	1.05	0.19	0.74	0.41	0.66	0.28	0.57
Dibenzotiophene	10.77	3.13	17.44	40.89	25.34	21.23	15.15	12.19	13.81	4.98	5.33	1.49	4.29	1.95	3.08	0.63	1.97
Naphto[2,1-b]tiophene	5.23	5.00	6.43	7.17	5.53	4.70	4.40	3.05	2.53	0.98	1.00	0.71	0.71	0.29	0.44	0.12	0.24
4-Metildibenzotiophene	7.00	3.00	7.69	12.43	6.13	5.79	9.34	2.85	9.97	1.62	2.08	0.51	3.39	1.66	3.55	0.79	2.64
3+2-Metildibenzotiophene	3.55	1.83	4.60	7.60	3.86	3.94	5.33	1.88	5.57	0.99	0.97	0.34	1.84	0.85	1.94	0.32	1.30
1-Metildibenzotiophene	2.27	0.97	2.45	3.64	1.79	1.77	3.13	0.93	3.09	0.53	0.57	0.28	0.95	0.46	1.09	0.20	0.86
Benzo(b)naphto[2,1-d]tiophene	201.20	252.71	192.38	195.03	132.90	124.66	140.41	84.65	53.21	19.70	17.17	19.26	11.42	4.08	4.69	0.56	1.08
Benzo(b)naphto[1,2-d]tiophene	45.31	55.57	43.47	44.00	30.19	27.85	31.20	18.49	12.39	4.42	3.91	4.22	2.69	1.02	1.18	0.21	0.44
Benzo(b)naphto[2,3-d]tiophene	22.32	30.30	28.77	24.81	17.71	17.79	22.35	12.12	9.26	3.72	3.23	3.30	2.07	0.63	0.63	0.10	0.11
SUM PAH-S	285.66	346.79	289.97	317.13	214.72	199.24	214.99	132.22	93.98	34.73	31.67	29.18	21.92	8.39	10.66	1.90	4.41

CM COMPOUND		0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	7.5-8	8-9	10-11	12-13	14-15	17-18
HCB		10.92	9.67	13.68	8.81	5.77	4.16	2.75	4.03	4.04	4.38	2.23	2.35	0.80	1.40	0.83	0.74	1.09	0.51	0.81
pp`-DDE		54.10	55.63	188.74	74.51	41.09	59.78	11.39	14.64	4.49	14.00	2.26	1.73	2.40	5.94	3.10	1.25	2.83	0.09	1.31
PCB N°	28	2.96	0.68	4.19	1.95	0.93	2.22	0.32	2.39	0.40	2.76	0.45	0.01	0.49	0.18	0.51	0.23	0.51	0.15	0.26
	52	3.89	n.d.	6.78	0.96	0.83	1.29	2.37	1.76	0.72	2.23	1.74	n.d.	0.89	0.65	n.d.	0.78	0.84	0.43	0.63
	101	4.30	2.06	10.68	5.30	1.23	5.00	1.21	5.67	0.83	6.63	0.72	0.29	0.56	1.19	1.42	0.70	1.40	0.39	0.89
	118	5.97	3.54	15.61	6.45	1.83	5.65	1.13	4.40	0.63	5.56	0.69	0.14	0.57	0.77	1.14	0.59	1.13	0.27	0.58
	153	4.61	3.74	12.61	4.70	1.45	3.85	0.75	2.13	0.55	2.58	0.27	n.d.	0.01	3.09	0.61	0.29	0.62	0.26	0.35
	138	4.89	4.19	15.87	5.50	1.93	4.78	0.43	1.92	0.41	2.29	0.28	0.17	0.57	1.21	0.62	0.24	0.38	n.d.	0.31
	180	5.50	4.73	18.88	5.34	1.65	3.12	0.63	0.33	0.28	0.42	0.22	0.12	0.35	1.53	0.14	0.09	0.14	n.d.	0.13
SUM PCBs		32.12	18.94	84.62	30.19	9.87	25.91	6.85	18.60	3.82	22.48	4.38	0.72	3.44	8.62	4.44	2.91	5.02	1.51	3.15

n.d., below quantification limit

Table 29. Organochlorinated compounds in Starolesnianske Pleso Lake (ng/g sediment)

Table 35 Dlugi Staw lake. TOC* (mg/g dry sediment) and alkanes (µg/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
C14-alkane	0.10	0.04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C15-alkane	2.65	0.13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C16-alkane	0.26	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C17-alkane	5.16	0.58	0.27	0.02	0.04	0.08	0.21	0.42	0.25	0.23	0.23	0.16	0.09	0.11	0.08	0.12	0.09
C18-alkane	0.81	0.36	0.11	0.02	0.04	0.03	0.07	0.11	0.08	0.08	0.08	0.07	0.04	0.06	0.07	0.05	0.04
C19-alkane	1.45	0.93	0.49	0.25	0.26	0.28	0.34	0.46	0.46	0.49	0.46	0.30	0.21	0.36	0.29	0.35	0.30
C20-alkane	1.31	1.02	0.63	0.42	0.37	0.40	0.46	0.51	0.51	0.54	0.51	0.46	0.40	0.46	0.47	0.47	0.44
C21-alkane	5.42	3.89	2.50	1.65	1.43	1.56	1.68	1.84	1.85	2.01	1.88	1.71	1.44	1.73	1.72	1.73	1.60
C22-alkane	4.10	3.57	2.30	1.66	1.42	1.45	1.60	1.65	1.71	1.73	1.64	1.44	1.22	1.45	1.45	1.49	1.38
C23-alkane	12.41	9.93	7.31	5.16	4.59	4.53	5.01	5.19	5.66	5.59	5.19	4.70	3.97	4.74	4.73	4.84	4.61
C24-alkane	7.15	6.31	4.19	3.18	2.79	2.71	2.94	2.92	1.66	3.01	2.79	2.47	2.03	2.39	2.39	2.38	2.26
C25-alkane	20.80	17.19	11.83	9.35	8.44	8.22	9.19	9.37	2.55	9.90	9.27	8.34	6.93	8.23	8.21	8.28	8.00
C26-alkane	8.34	7.48	5.21	4.14	3.67	3.50	3.80	3.78	1.09	3.78	3.53	3.14	2.60	3.03	0.35	3.03	2.87
C27-alkane	29.95	24.98	18.40	15.28	14.07	13.56	15.35	15.81	5.69	16.27	16.02	14.70	12.06	14.39	14.58	14.89	11.33
C28-alkane	9.93	8.85	6.92	6.15	5.82	5.27	6.20	6.23	2.40	5.35	5.17	5.20	4.68	4.91	4.94	5.09	5.22
C29-alkane	42.02	36.94	30.68	27.09	26.62	26.46	29.18	30.69	13.66	30.22	29.73	30.32	25.30	29.85	30.57	31.83	29.62
C30-alkane	6.29	5.93	4.66	3.90	3.78	3.82	4.22	4.59	1.73	3.63	3.45	3.50	2.99	3.38	3.36	3.50	3.06
C31-alkane	35.17	34.65	30.40	28.20	28.39	28.46	31.33	32.51	15.69	32.78	32.40	33.10	27.95	32.51	33.70	35.57	31.48
C32-alkane	2.34	2.48	1.81	1.64	1.34	1.43	1.52	1.68	0.66	1.51	1.53	1.45	1.21	1.37	1.43	1.64	1.30
C33-alkane	16.37	17.82	15.45	15.09	14.96	14.91	16.54	16.74	8.63	17.33	17.14	17.88	15.36	17.87	18.61	20.05	17.90
C34-alkane	0.91	0.91	0.81	0.47	0.80	0.68	0.79	0.85	0.31	0.59	0.69	0.61	0.45	0.59	0.44	0.47	0.48
C35-alkane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pristane	0.83	0.52	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Phytane	0.33	0.21	n.d.	n.d.	n.d.	n.d.	0.02	0.10	0.08	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total resolved alkanes	214.10	184.76	143.96	123.66	118.82	117.35	130.45	135.46	64.67	135.11	131.73	129.55	108.92	127.42	127.41	135.80	121.98
TOC	105.40	102.10	91.70	91.80	93.50	91.10	94.00	101.70	89.70	89.60	91.00	89.10	84.20	84.10	84.90	83.30	88.90

*Total organic carbon; n.d., below quantification limit

Table 36 Dlugi Staw lake. Polycyclic Aromatic Hydrocarbons (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
Fluorene	25.49	32.66	17.52	12.76	8.61	7.08	9.91	8.34	7.84	8.58	9.54	7.24	5.08	5.58	4.30	3.99	4.34
Phenanthrene	442.88	499.50	369.67	244.69	183.18	173.54	167.98	134.09	104.97	93.60	88.60	54.79	35.91	37.42	29.57	20.27	27.49
Anthracene	32.26	33.27	28.00	19.88	16.19	14.93	15.03	13.10	10.98	8.10	8.76	3.61	2.42	2.37	2.61	1.57	1.80
Fluoranthene	1439.55	1369.49	1012.87	623.94	556.43	491.73	457.07	148.65	297.07	239.00	197.73	120.48	73.49	74.93	66.56	40.39	58.51
Acephenanthrilene	52.96	42.89	43.01	32.91	30.35	22.89	24.91	8.33	18.36	11.74	10.61	5.13	3.41	3.97	3.15	2.04	2.51
Pyrene	855.29	765.69	515.18	317.75	268.19	218.97	213.96	223.19	148.61	114.97	105.77	56.10	37.27	62.76	33.82	18.77	28.42
Benzo[a]fluorene	49.92	48.59	30.98	19.53	22.38	17.90	14.08	13.48	8.93	7.22	5.57	3.17	1.53	1.76	1.80	1.25	1.55
Retene	1.54	1.33	0.80	0.56	0.65	0.44	0.56	1.10	0.67	0.92	0.55	0.48	0.32	0.34	0.33	0.28	0.23
Benzo[ghi]fluoranthene	225.64	217.26	218.61	176.22	168.80	134.64	126.66	107.82	79.29	51.62	50.51	29.07	18.89	18.72	18.21	12.22	14.37
Ciclopenta[cd]pyrene	80.98	70.42	60.01	48.73	48.62	35.01	36.98	34.00	22.06	13.12	11.44	4.13	3.03	2.82	3.25	1.74	2.39
Benz[a]anthracene	372.29	307.40	276.39	165.39	155.07	126.27	115.40	117.56	68.83	50.57	43.96	19.86	13.74	11.43	13.83	7.39	10.23
Chrysene+Triphenylene	1627.54	1389.34	1177.90	801.59	780.47	540.65	508.30	501.60	305.09	220.67	197.28	109.33	78.91	73.41	85.18	51.97	62.30
Benzo[b+j]fluoranthene*	1724.94	1872.37	2286.87	1699.01	1221.75	1473.53	820.18	680.25	455.15	384.25	360.30	217.64	114.27	110.18	95.96	62.03	122.28
Benzo[k]fluoranthene	1021.41	887.38	1100.70	833.32	692.97	375.36	497.90	418.97	298.20	211.49	202.70	120.89	67.76	69.06	56.77	41.69	66.08
Benzo[a]fluoranthene	75.13	77.97	77.58	66.33	50.11	52.58	44.84	35.24	25.57	17.12	17.28	5.58	3.49	3.60	2.90	2.18	4.12
Benzo[e]pyrene	1022.54	987.34	1184.20	976.47	700.81	690.08	496.44	405.11	271.59	219.79	198.57	120.45	65.70	64.94	53.55	38.28	67.42
Benzo[a]pyrene	502.92	438.82	428.66	297.47	207.22	235.40	198.11	177.55	117.77	88.98	80.39	36.87	19.20	18.48	16.64	11.06	21.26
Perylene	78.15	68.55	70.87	48.17	32.69	38.96	31.59	30.84	24.18	21.23	24.06	15.54	9.94	12.32	10.84	13.56	25.03
Indene[7,1,2,3-cdef]chrysene	346.33	369.45	377.12	334.53	270.72	278.94	204.24	184.55	122.86	106.59	46.48	53.14	30.96	30.46	28.47	23.46	30.05
Indene[1,2,3-cd]pyrene	1509.83	1379.78	1344.61	1090.36	991.20	893.09	716.65	695.15	462.69	349.08	160.68	166.51	91.61	89.15	84.28	59.35	91.56
Benzo[ghi]perylene	1190.13	1152.33	1110.87	885.33	854.24	723.67	609.50	580.78	383.35	289.68	135.52	133.74	70.23	68.31	65.48	45.02	69.43
Dibenz[aj]anthracene	137.39	121.48	142.68	108.37	81.71	77.97	61.98	54.36	21.05	25.79	15.01	12.76	7.32	7.18	6.58	4.65	8.91
Dibenz[ah]anthracene	194.45	185.69	199.26	150.89	89.95	123.26	90.44	84.39	35.94	41.89	21.43	18.50	10.74	10.85	9.41	6.64	11.94
Dibenz[ac]anthracene	37.66	35.29	36.53	30.05	130.42	20.50	17.75	18.85	66.11	9.19	3.80	3.13	1.86	1.83	1.85	1.02	2.18
Benzo[b]chrysene	61.58	59.44	63.26	45.16	25.39	29.57	31.02	28.96	19.21	12.64	6.78	5.32	3.06	2.66	2.70	1.93	3.07
Coronene	702.84	647.64	706.53	530.68	578.39	415.79	379.09	396.34	260.49	160.69	76.34	73.20	38.69	38.94	39.92	27.25	41.22
SUM PAH	13811.65	13061.37	12880.69	9560.11	8166.53	7212.73	5890.58	5102.58	3636.86	2758.55	2079.63	1396.64	808.84	823.45	737.96	500.01	778.69
PAH (-Perylene)	13733.50	12992.82	12809.83	9511.94	8133.84	7173.77	5858.99	5071.74	3612.67	2737.32	2055.58	1381.10	798.90	811.13	727.12	486.45	753.66

*Mixture of b and j isomers.

Table 37 Dlugi Staw lake. Polycyclic Aromatic Hydrocarbons. Methylderivatives (ng/g dry sediment)

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
3-Methylphenanthrene	15.96	16.10	12.55	7.02	5.91	5.28	4.75	1.05	2.91	2.46	1.68	1.00	0.91	0.86	0.82	0.53	0.78
2-Methylphenanthrene	24.54	24.17	19.30	11.29	10.26	8.20	7.68	1.58	4.71	3.90	2.62	1.56	1.37	1.43	1.24	0.84	1.11
4H-Ciclopenta[def]phenan.	2.67	3.46	2.35	1.49	1.28	1.11	1.00	0.25	0.70	0.56	0.37	0.13	0.13	0.10	0.11	0.09	0.11
4-Methylphenanthrene	14.73	12.52	10.89	6.33	5.39	4.87	4.39	0.93	2.84	2.50	1.65	0.97	0.92	0.94	0.86	0.62	0.77
1-Methylphenanthrene	16.94	16.13	10.97	6.87	5.72	6.82	4.93	1.10	3.48	3.46	2.02	1.46	1.32	1.44	1.27	1.45	1.98
Dimethylphenanthrene	1.39	1.27	0.78	0.18	0.16	0.14	0.28	0.94	0.19	0.20	0.09	0.06	0.08	0.05	0.06	0.05	0.06
Dimethylphenanthrene	1.84	1.42	0.81	0.22	0.18	0.13	0.41	1.13	0.27	0.25	0.11	0.07	0.10	0.07	0.09	0.05	0.07
Dimethylphenanthrene	4.29	3.79	2.21	0.48	0.30	0.36	0.93	0.95	0.54	0.51	0.25	0.12	0.17	0.14	0.14	0.09	0.15
Dimethylphenanthrene	3.30	2.60	1.76	0.52	0.54	0.42	0.64	0.67	0.36	0.39	0.15	0.08	0.12	0.08	0.08	0.08	0.11
Dimethylphenanthrene	1.08	1.02	0.70	1.41	1.26	1.14	0.30	0.34	0.19	0.19	0.09	0.31	0.02	0.33	0.29	0.02	0.03
Dimethylphenanthrene	9.88	7.64	4.60	1.13	1.02	0.81	2.11	2.23	1.33	1.29	0.59	0.21	0.03	0.23	0.21	0.29	0.02
Dimethylphenanthrene	6.92	5.28	3.55	0.51	0.43	0.41	1.50	1.57	0.93	0.88	0.41	0.56	0.40	0.57	0.53	0.19	0.39
Dimethylphenanthrene	8.00	6.63	3.97	2.81	2.53	2.40	1.89	2.21	1.35	1.60	0.79	0.09	0.28	0.08	0.08	0.45	0.25
Dimethylphenanthrene	2.86	2.35	1.47	2.34	2.04	1.84	0.59	0.69	0.39	0.37	0.18	0.12	0.61	0.11	0.11	0.06	0.49
Dimethylphenanthrene	2.58	2.11	1.28	2.49	2.24	2.06	0.63	0.61	0.36	0.37	0.19	0.07	0.11	0.07	0.08	0.09	0.09
Dimethylphenanthrene	1.85	1.49	0.84	0.96	0.87	0.75	0.32	0.50	0.28	0.28	0.11	0.07	0.13	0.06	0.06	0.06	0.11
Dimethylphenanthrene	0.19	0.15	0.06	0.82	0.69	0.66	0.36	0.06	0.20	0.03	0.10	0.04	0.08	0.08	0.02	0.05	0.07
Dimethylphenanthrene	1.51	1.31	0.69	0.59	0.53	0.45	0.19	0.35	0.13	0.21	0.05	n.d.	0.06	n.d.	n.d.	0.01	0.06
Dimethylphenanthrene	0.63	0.53	0.44	0.48	0.42	0.39	n.d.	0.16	n.d.	0.10	n.d.	n.d.	0.03	n.d.	n.d.	n.d.	0.02
Methylfluoranthene/pyrene	79.33	75.95	60.25	39.54	36.32	28.76	27.50	24.17	15.95	13.00	6.85	3.71	3.50	2.90	3.33	1.98	2.84
Methylfluoranthene/pyrene	39.36	43.36	33.91	22.35	18.89	17.15	14.55	13.81	7.89	7.63	3.65	2.08	2.17	1.84	1.76	1.25	1.37
Methylfluoranthene/pyrene	77.29	67.58	47.89	31.73	24.73	20.64	27.98	36.57	29.60	23.34	14.66	8.81	8.27	7.12	6.88	4.49	5.49
Methylfluoranthene/pyrene	32.86	31.98	22.81	12.31	11.00	9.03	11.31	16.54	15.40	14.30	8.88	9.85*	9.17*	9.00*	3.85	6.01*	6.52*
1-Methylpyrene	66.81	58.82	40.33	29.19	25.00	20.65	19.55	20.79	13.18	11.27	6.08	coel.	coel.	coel.	4.33	coel.	coel.
Methylfluoranthene/pyrene	47.99	44.51	31.79	20.25	19.20	15.51	15.63	16.24	10.02	7.93	4.19	2.06	1.92	1.81	1.69	1.09	1.57
Methylfluoranthene/pyrene	27.15	24.41	16.52	10.66	9.58	7.58	8.07	9.78	5.70	4.51	2.57	1.12	1.15	1.03	0.97	0.67	0.92

n.d., below quantification limit. coel., chromatographic coelution.
*Mixture of Methylfluoranthene and 1-Methylpyrene

Table 38 Dlugi Staw lake. Polycyclic Aromatic Hydrocarbons. S-Heterocycles (ng/g dry sediment).

CM COMPOUND	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-9
Naphto[1,2-b]tiophene	2.07	2.32	1.55	1.00	0.79	0.66	0.67	0.59	0.32	0.34	0.29	0.13	0.11	0.11	0.08	0.07	0.09
Dibenzotiophene	18.74	21.79	17.83	11.04	7.93	7.35	7.45	5.22	4.11	3.42	3.30	1.79	1.08	1.22	0.87	0.48	0.92
Naphto[2,1-b]tiophene	4.64	5.47	3.85	2.63	1.86	1.88	1.64	1.32	0.98	0.88	0.86	0.41	0.27	0.30	0.22	0.15	0.20
4-Methyldibenzotiophene	6.01	5.95	6.57	2.76	2.36	1.90	1.77	1.50	1.06	0.84	0.87	0.48	0.33	0.46	0.38	0.22	0.33
3+2-Methyldibenzotiophene	2.86	2.70	3.32	2.12	1.88	0.87	1.40	0.63	0.74	0.40	0.33	0.18	0.18	0.25	0.23	0.12	0.21
1-Methyldibenzotiophene	0.55	0.46	0.70	0.24	0.19	0.08	0.14	0.11	0.08	0.10	0.11	0.05	0.04	0.08	0.04	0.03	0.03
Benzo(b)naphto[2,1-d]tiophene	103.32	94.22	86.56	56.66	53.91	37.25	34.92	28.32	18.12	11.22	10.24	4.15	2.99	2.39	2.94	1.36	2.61
Benzo(b)naphto[1,2-d]tiophene	19.33	18.31	16.26	11.29	11.27	7.90	7.44	6.24	3.97	2.49	2.25	0.99	0.67	0.56	0.70	0.37	0.58
Benzo(b)naphto[2,3-d]tiophene	35.86	34.18	28.55	19.60	19.41	13.76	14.02	12.91	7.82	5.00	4.12	1.86	1.18	0.96	1.17	0.49	1.02
SUM PAH-S	183.97	176.29	154.59	102.21	95.15	68.79	66.15	54.60	35.33	23.35	21.05	9.33	6.31	5.54	5.99	2.92	5.42

Table 39 Anthropogenic Trace Metal Inventories

Location	Inventories Pb mg/m^2	 Cd mg/m^2	 ^{210}Pb Bq/m^2	Inventory Ratios Pb/^{210}Pb g/Bq	 Cd/^{210}Pb g/Bq
Arresjoen	19	1.0	1560	12	0.6
Dlugi Staw	665	12.8	2185	305	5.9
Zielowny Staw *	1921	46.7	9659	199	4.8
Starolesnianske Pleso	540	23.6	4148	130	5.7
Nizne Terianske	297	16.1	3132	95	5.1
Noir	72	1.1	9707	7	0.1
Aguilo	1424	6.7	12823	111	0.5
Redo	665	2.2	5497	121	0.4
Cimera	494	1.4	10537	47	0.1
Caldera	1139	3.4	12325	92	0.3
Escura	699	1.9	9066	77	0.2

* Post-1945 inventories only

Table 40

AL:PE II Sediment chemical composition
Mean and standard deviations for elements not usually associated with atmospheric pollution
All values as mg/g

	Ti	Al	Ca	Mg	Na	K	Mg/K
AGUI	3.15	81.24	3.16	7.88	3.63	11.53	0.68
	0.30	12.74	0.63	0.66	0.97	0.92	
ARSJ	3.10	73.28	6.35	8.26	10.74	14.88	0.55
	0.72	12.70	1.21	0.75	2.15	2.24	
CALD	4.86	118.66	12.76	13.97	17.43	19.69	0.71
	0.43	8.19	3.12	1.40	1.86	4.59	
CIME	4.17	93.33	7.92	9.76	11.13	23.58	0.41
	0.37	6.91	1.12	0.89	1.31	5.78	
DLUG	3.38	55.71	3.83	5.09	8.69	12.54	0.41
	0.43	16.21	1.31	0.87	2.02	2.50	
ESCU	2.64	73.80	2.08	4.00	11.83	13.60	0.29
	0.21	9.19	0.57	0.38	3.01	2.68	
NOIR	4.67	76.74	5.57	10.72	12.52	25.82	0.42
	0.46	5.23	1.50	1.85	1.27	1.32	
REDO	3.88	75.43	5.12	8.03	8.69	16.91	0.47
	0.36	6.68	1.23	1.75	1.40	1.85	
STAR	2.87	47.65	3.22	4.58	5.09	10.73	0.43
	0.39	2.94	0.73	0.37	0.53	1.34	
TERI	2.69	68.91	7.22	5.80	17.21	17.72	0.33
	0.37	13.51	1.41	0.84	4.67	3.81	
ZIEL	3.11	80.66	4.12	7.22	8.91	22.40	0.32
	0.46	17.82	0.32	0.66	6.37	5.55	
ZKJZ	3.32	48.19	223.71	12.23	3.16	7.94	1.54
	0.29	5.02	59.11	1.46	0.31	1.28	

Table 41

TOC* (mg/g dry sediment) and alkanes (µg/g dry sediment) in surficial sedime

COMPOUND	AGUILÓ	LA CALDERA
C14-alkane	n.d.	0.45
C15-alkane	n.d.	0.23
C16-alkane	n.d.	0.32
C17-alkane	1.37	1.86
C18-alkane	0.49	0.24
C19-alkane	2.20	0.19
C20-alkane	2.24	0.11
C21-alkane	6.32	0.30
C22-alkane	4.59	0.23
C23-alkane	11.73	0.74
C24-alkane	6.11	0.23
C25-alkane	19.06	0.90
C26-alkane	7.49	0.31
C27-alkane	31.39	1.27
C28-alkane	2.25	0.44
C29-alkane	89.47	3.05
C30-alkane	11.12	0.41
C31-alkane	108.42	3.16
C32-alkane	6.81	0.22
C33-alkane	41.69	1.16
C34-alkane	1.95	0.05
C35-alkane	4.31	0.14
Pristane	0.12	0.19
Phytane	0.43	0.10
Total resolved alkane	359.58	16.30
TOC	130.11	22.74

* Total organic carbon; n.d., below quantification limit.

Table 42

Polycyclic Aromatic Hydrocarbon in surficial sediment samples (0-0.5 cm). Values in ng/g dry sediment.

COMPOUND	AGUILO	LA CALDERA
Fluorene	23.83	4.29
Phenanthrene	179.39	41.85
Anthracene	16.45	0.82
Fluoranthene	468.74	18.44
Acephenanthrilene	32.61	0.81
Pyrene	326.47	13.33
Benzo[a]fluorene	64.54	0.38
Retene	1.74	0.86
Benzo[ghi]fluoranthene	170.20	3.93
Ciclopenta[cd]pyrene	55.36	0.80
Benz[a]anthracene	149.34	4.33
Chrysene+Triphenylene	702.93	15.49
Benzo[b+j]fluoranthene*	848.48	13.05
Benzo[k]fluoranthene	519.40	9.16
Benzo[a]fluoranthene	46.07	0.76
Benzo[e]pyrene	543.04	8.07
Benzo[a]pyrene	269.27	4.60
Perylene	207.79	2.42
Indene[7,1,2,3-cdef]chrysene	216.70	3.31
Indene[1,2,3-cd]pyrene	883.43	13.84
Benzo[ghi]perylene	731.71	10.91
Dibenz[aj]anthracene	90.84	1.32
Dibenz[ah]anthracene	144.16	2.70
Dibenz[ac]anthracene	22.40	0.36
Benzo[b]chrysene	37.72	0.68
Coronene	413.54	6.77
SUM PAH	7166.13	183.27
PAH (-Perylene)	6958.34	180.86

*Mixture of b and j isomers.

Table 43

Polycyclic Aromatic Hydrocarbons. Methylderivatives in surficial sediment samples (0-0.5 cm). Values in ng/g dry sediment.

COMPOUND	AGUILO	LA CALDERA
3-Methylphenanthrene	6.17	2.48
2-Methylphenanthrene	9.81	2.97
4H-Ciclopenta[def]phenan.	1.33	0.12
4-Methylphenanthrene	5.40	1.46
1-Methylphenanthrene	5.91	1.67
Dimethylphenanthrene	1.32	0.55
Dimethylphenanthrene	1.83	n.d.
Dimethylphenanthrene	1.51	0.68
Dimethylphenanthrene	4.46	0.42
Dimethylphenanthrene	2.85	1.22
Dimethylphenanthrene	2.93	0.71
Dimethylphenanthrene	1.36	0.71
Dimethylphenanthrene	1.13	0.31
Dimethylphenanthrene	0.17	0.28
Dimethylphenanthrene	0.94	n.d.
Dimethylphenanthrene	0.62	0.13
Dimethylphenanthrene	0.36	0.13
Methylfluoranthene/pyrene	24.30	0.75
Methylfluoranthene/pyrene	12.69	0.79
Methylfluoranthene/pyrene	38.32	0.58
Methylfluoranthene/pyrene	17.38	0.36
1-Methylpyrene	18.71	0.58
Methylfluoranthene/pyrene	10.95	0.34

n.d., below quantification limit

Table 44

Polycyclic Aromatic Hydrocarbons. S-Heterocycles in surficial sediment samples (0-0.5 cm). Values in ng/g dry sediment.

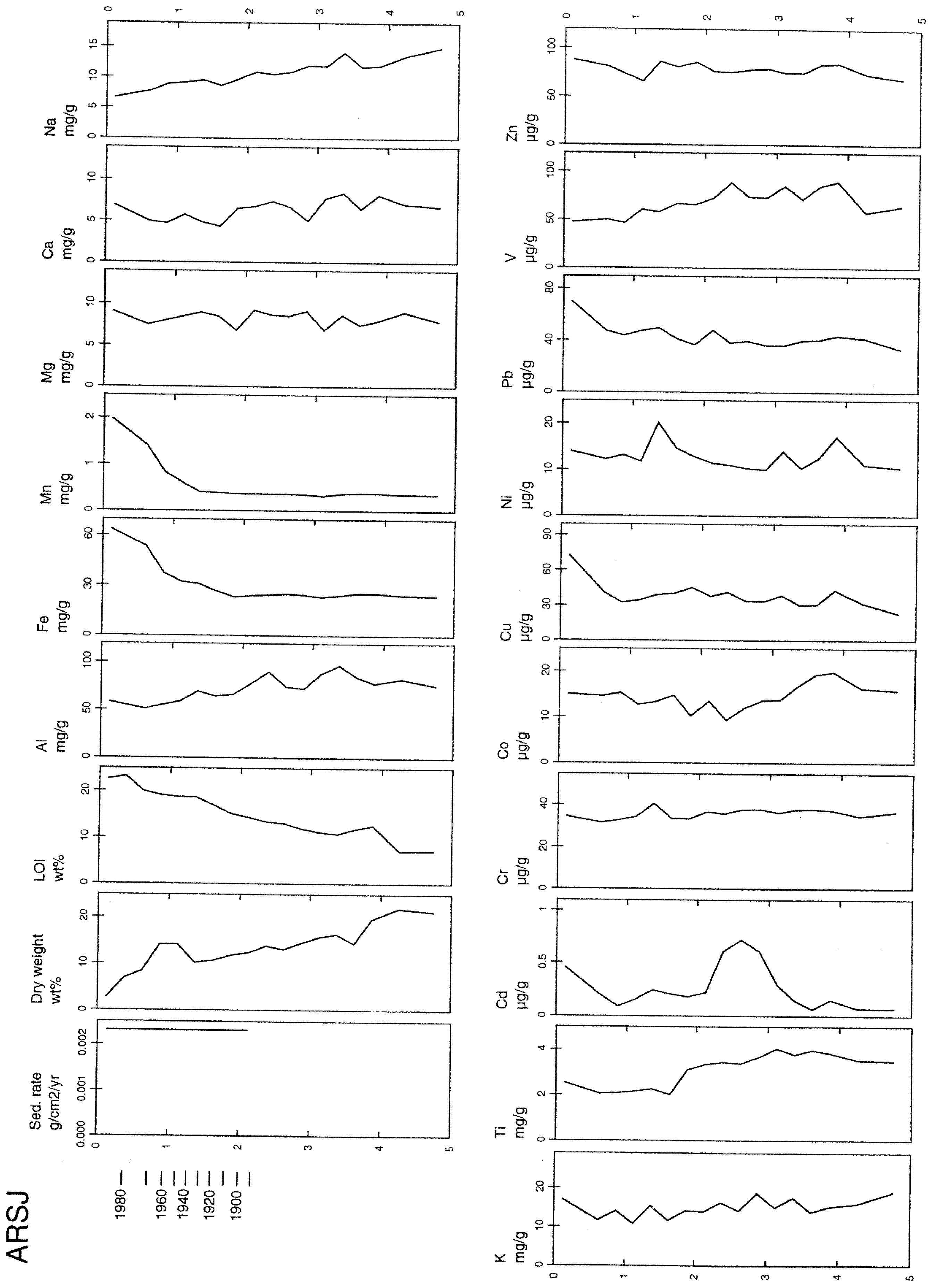
COMPOUND	AGUILÓ	LA CALDERA
Naphto[1,2-b]tiophene	0.40	0.17
Dibenzotiophene	13.02	1.46
Naphto[2,1-b]tiophene	2.14	0.26
4-Methyldibenzotiophene	2.15	0.63
3+2-Methyldibenzotiophene	1.61	0.24
1-Methyldibenzotiophene	0.53	0.14
Benzo(b)naphto[2,1-d]tiophene	136.00	2.81
Benzo(b)naphto[1,2-d]tiophene	23.57	0.53
Benzo(b)naphto[2,3-d]tiophene	26.25	0.61
SUM PAH-S	201.36	5.84

Table 45

Organochlorinated compounds in surficial sediment samples (0-0.5 cm). Values in ng/g dry sediment.

COMPOUND		AGUILÓ	LA CALDERA
HCB		1.09	6.30
pp'-DDE		5.23	5.30
PCB Nº	28+31	1.42	2.71
	52	0.40	0.52
	101	0.78	0.61
	118	1.26	0.17
	153	0.96	0.36
	138+163	1.06	0.24
	180	0.81	0.11
SUM PCBs		6.69	4.73

Figure 1a. Arresjoen (ARSJ) metal concentrations



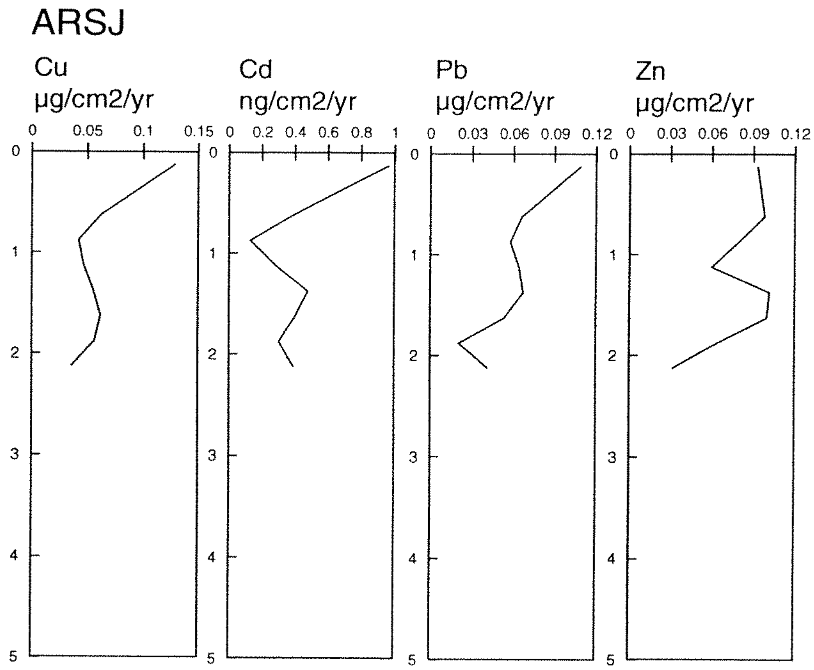
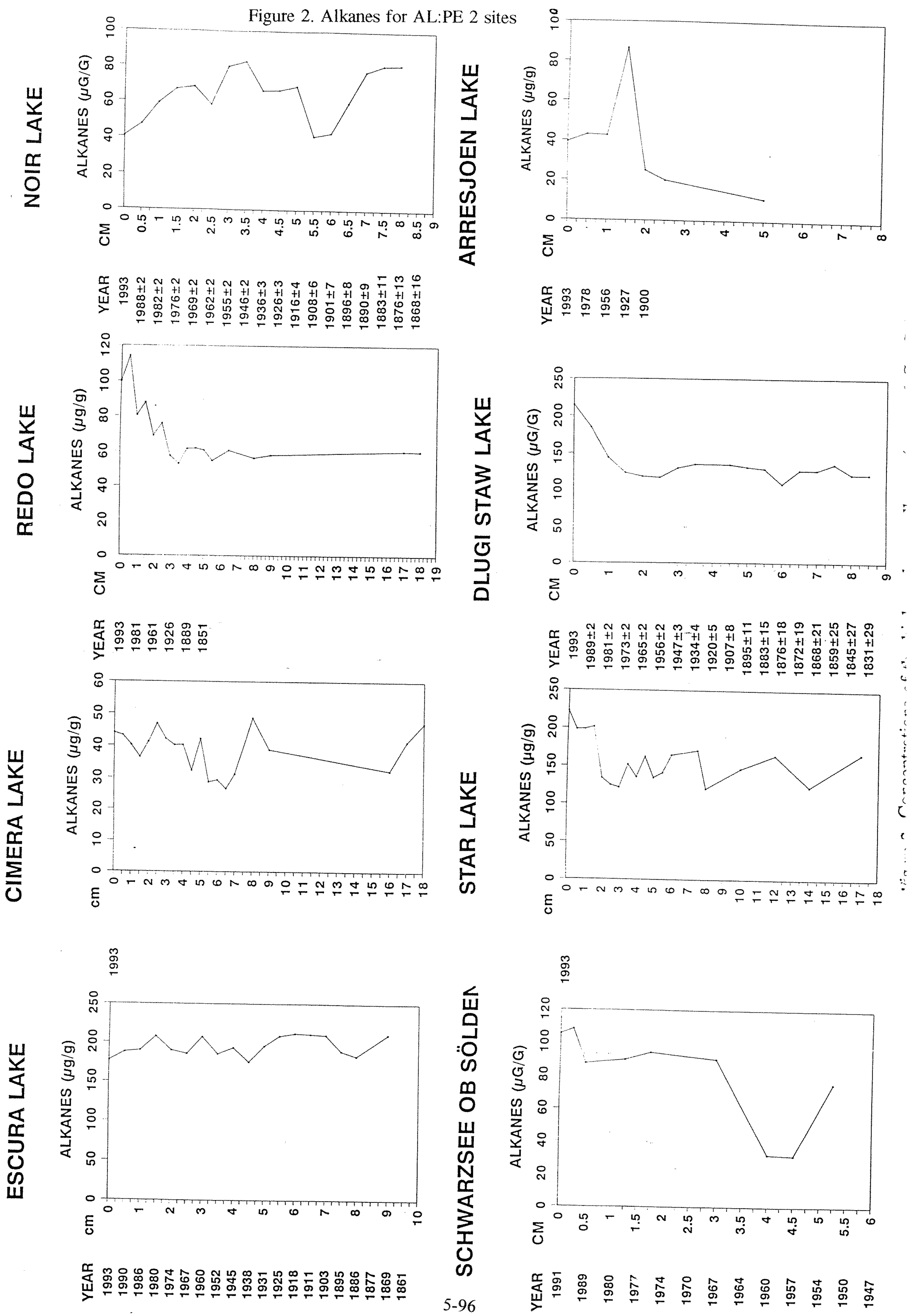


Figure 1b. Arresjoen (ARSJ) metal fluxes

Figure 2. Alkanes for AL:PE 2 sites



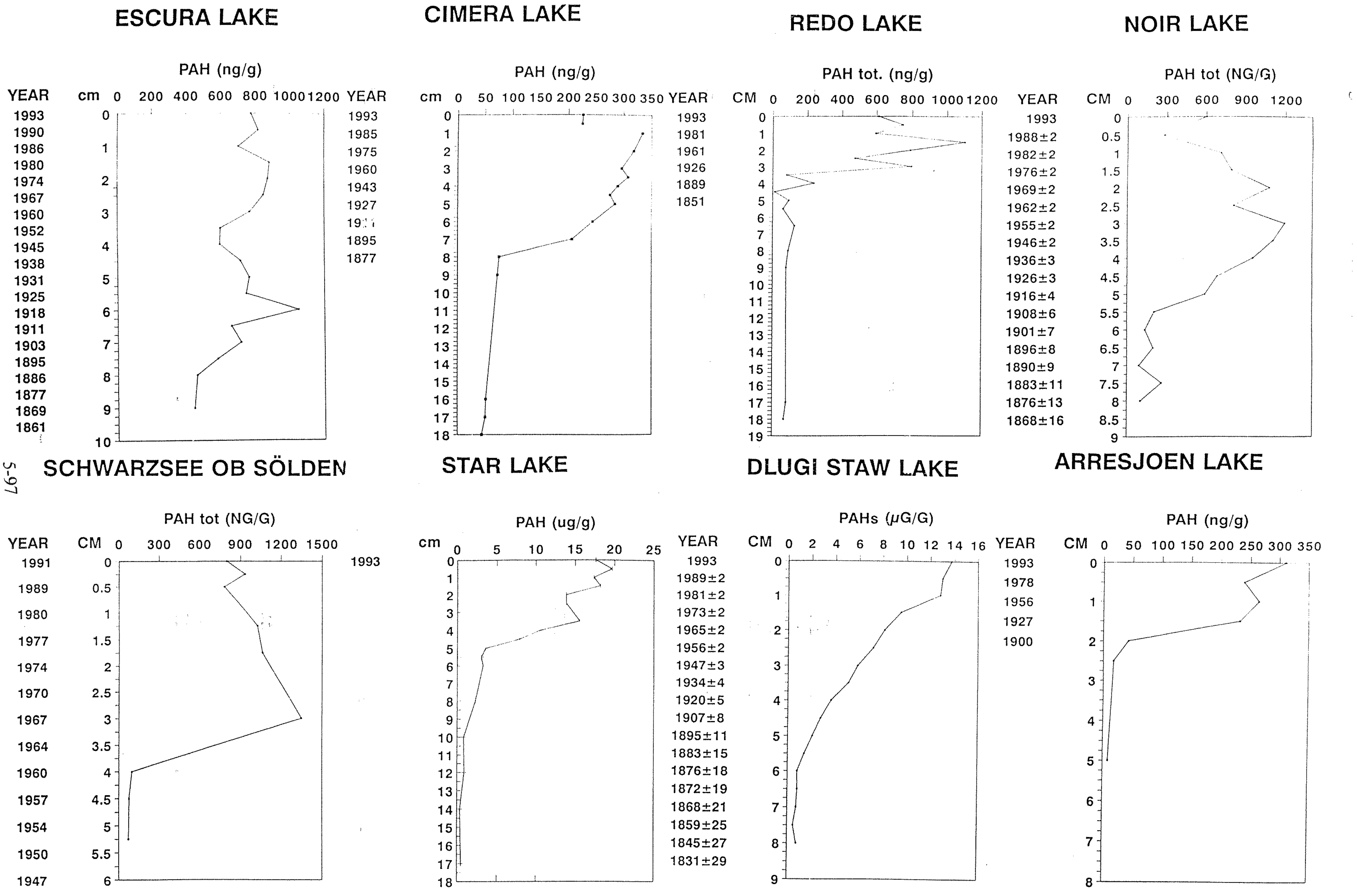


Figure 3. Concentrations of total polycyclic aromatic hydrocarbons (PAH) except perylene.

Figure 4. pp'-DDE for AL:PE 2 sites

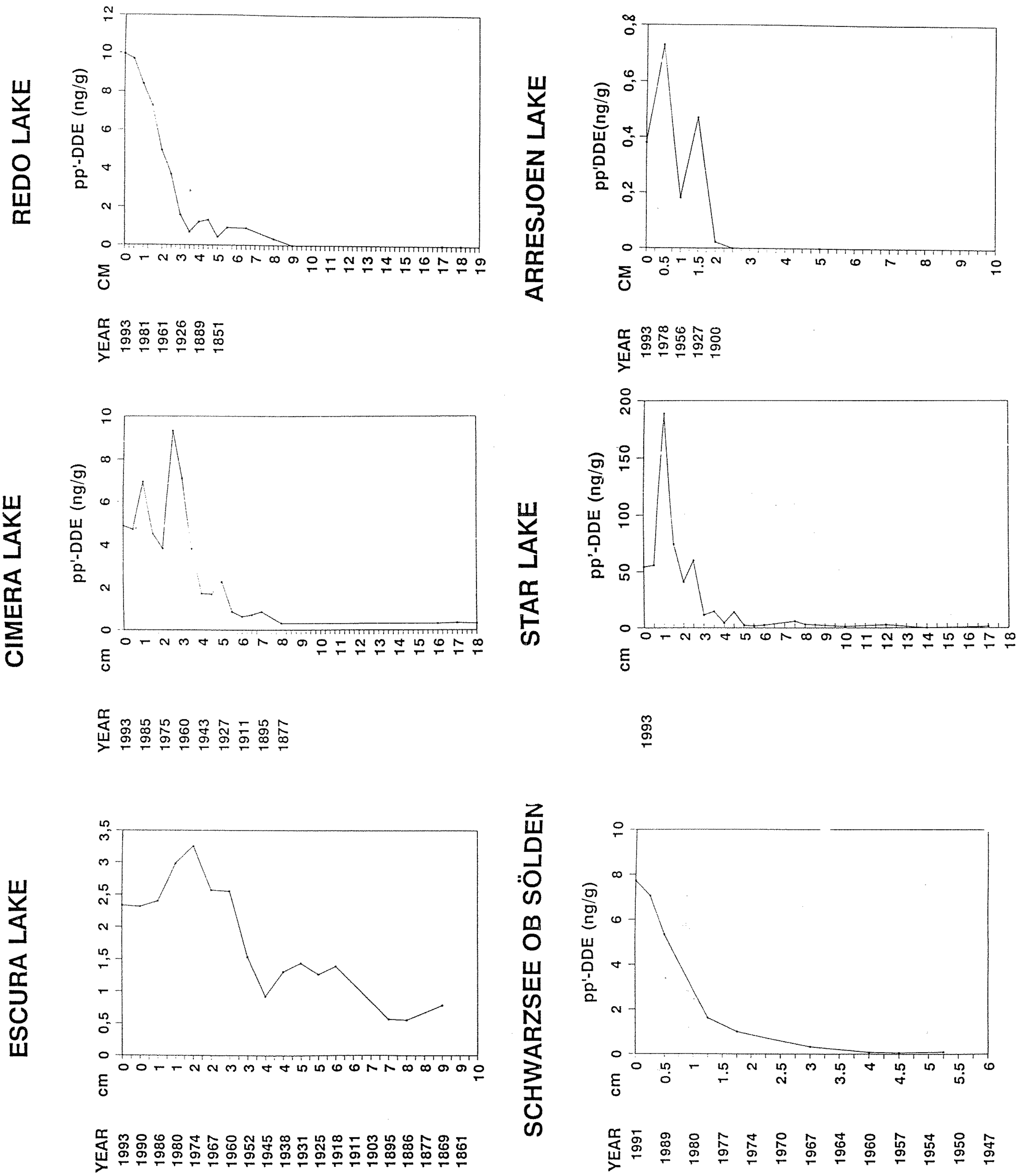


Figure 4. Concentrations of pp'-DDF

Figure 5. PCBs for AL:PE 2 sites

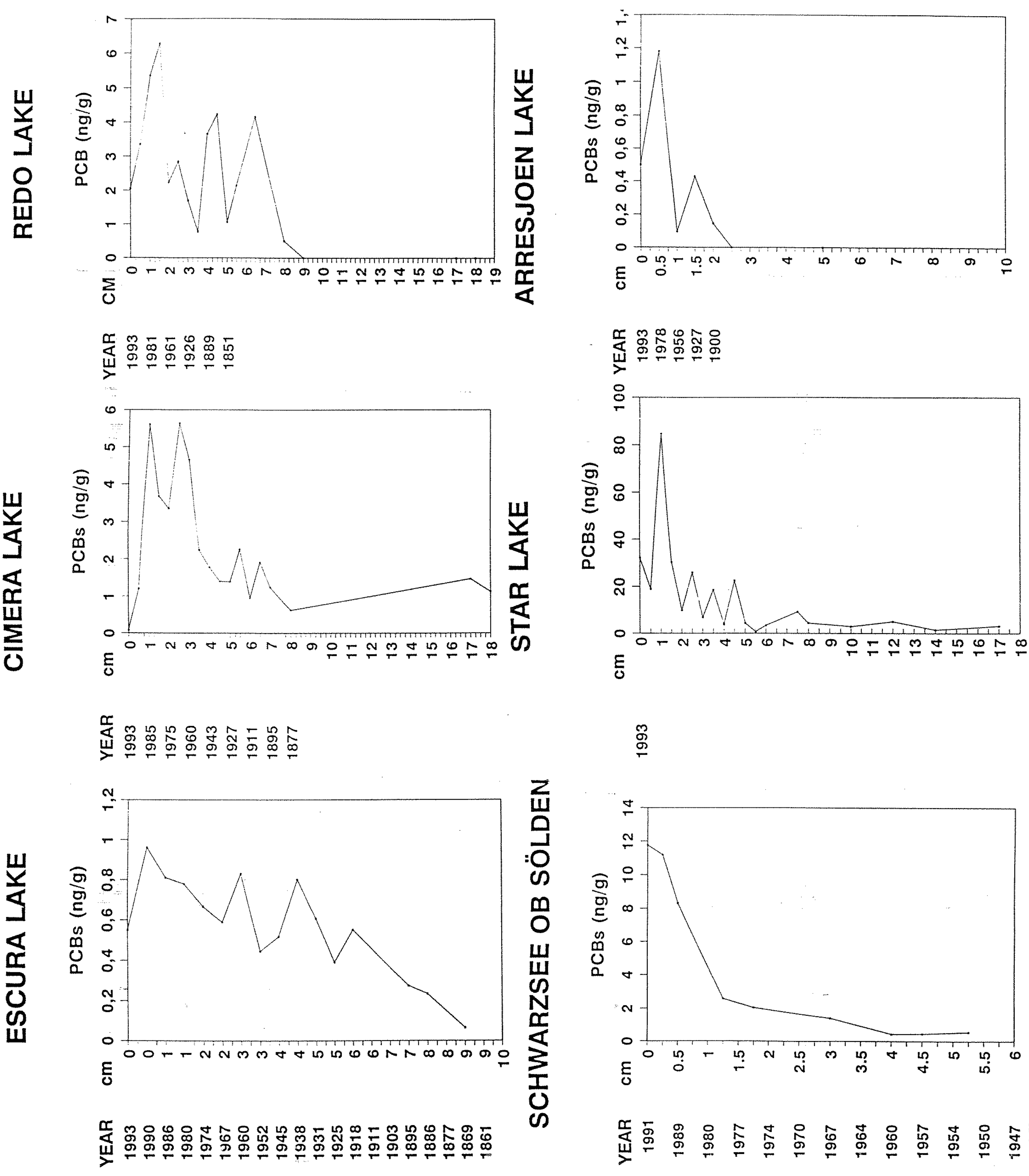


Figure 5. Concentrations of total polychlorobiphenyls (summed Congeners Nos. 28, 31, 52, 101, 118, 153, 138 and 180).

Figure 6. HCB for AL:PE 2 sites

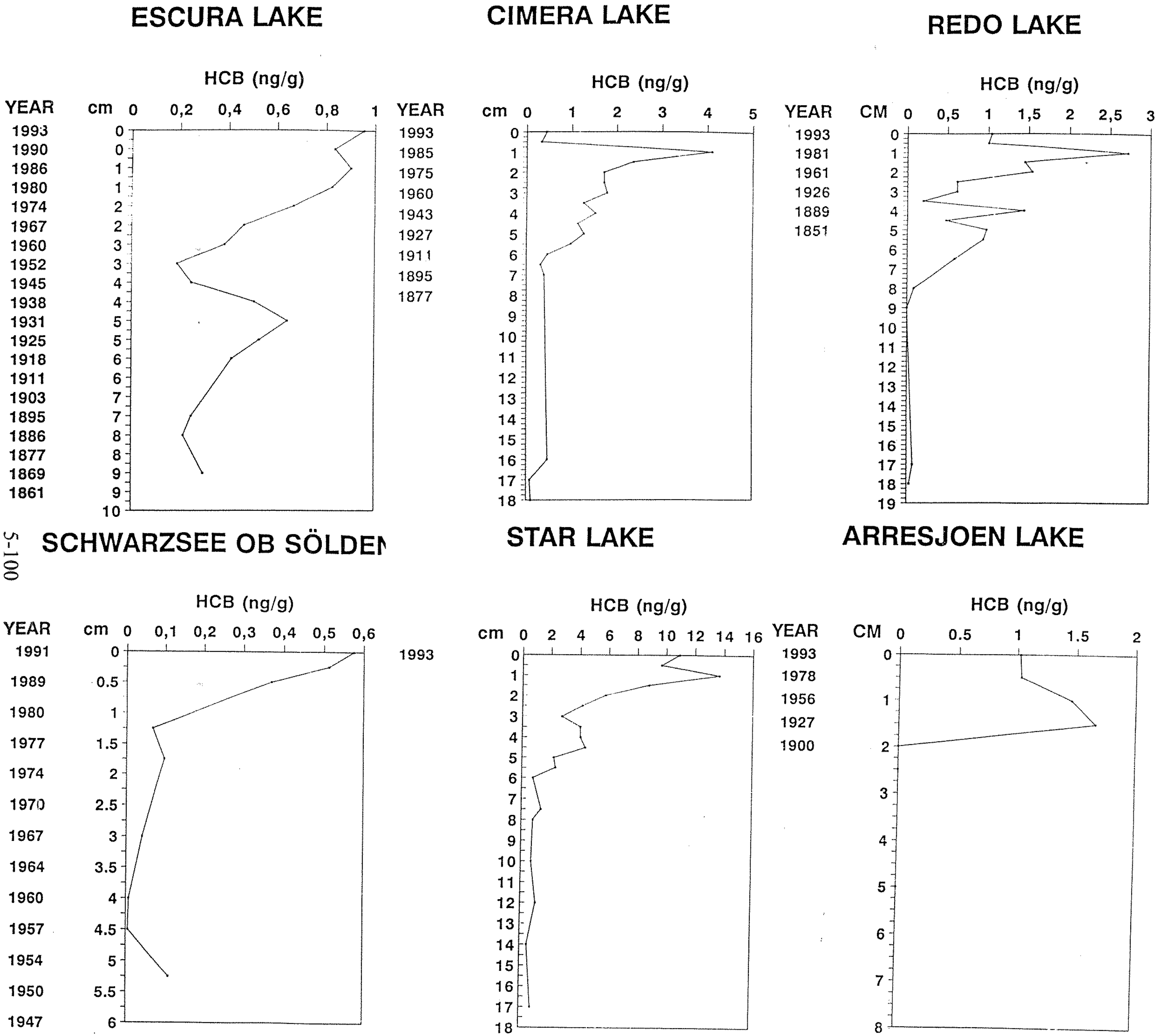
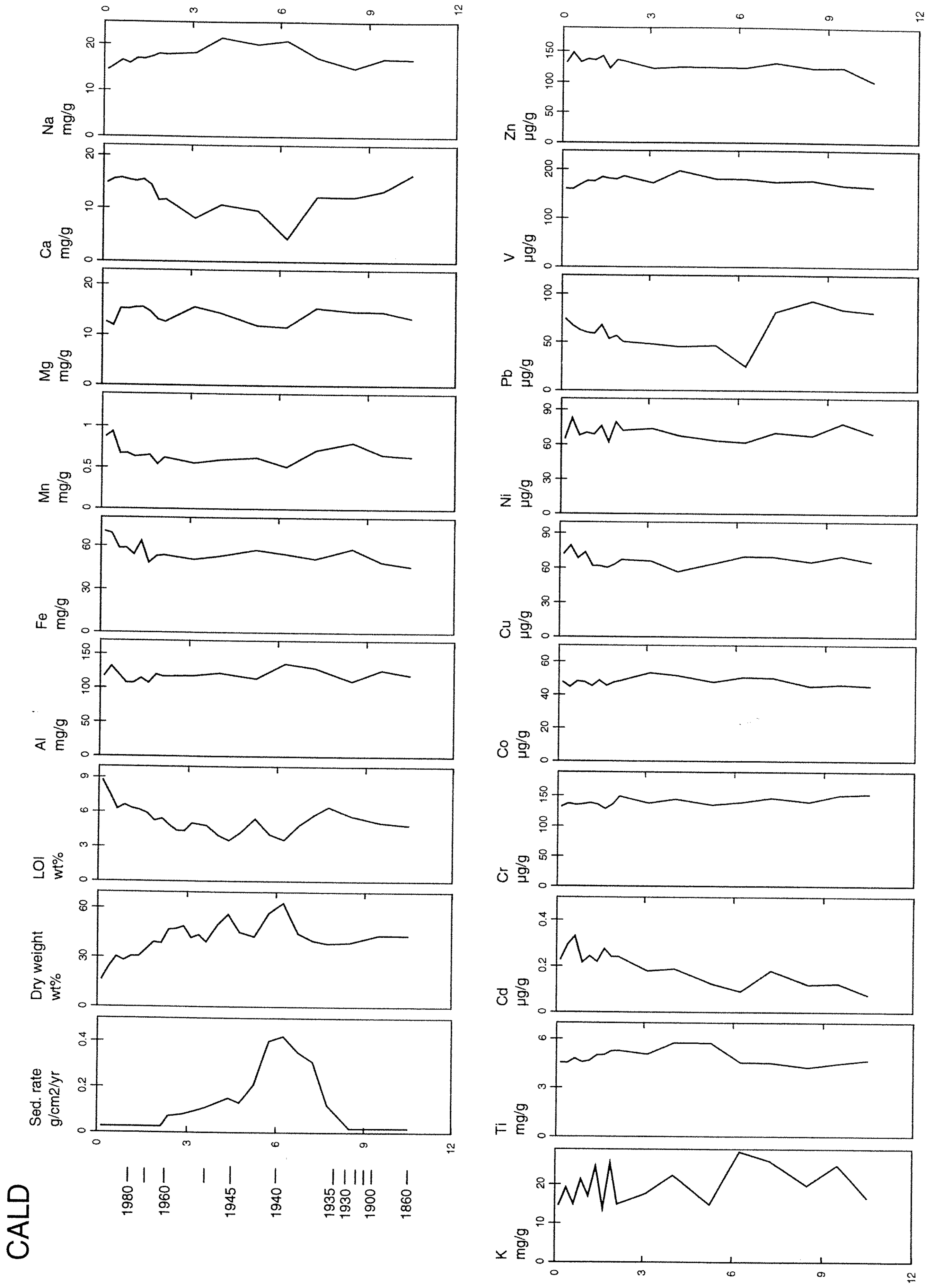


Figure 6. Concentrations of hexachlorobenzene (HCB)

Figure 7a. Caldera (CALD) metal concentrations



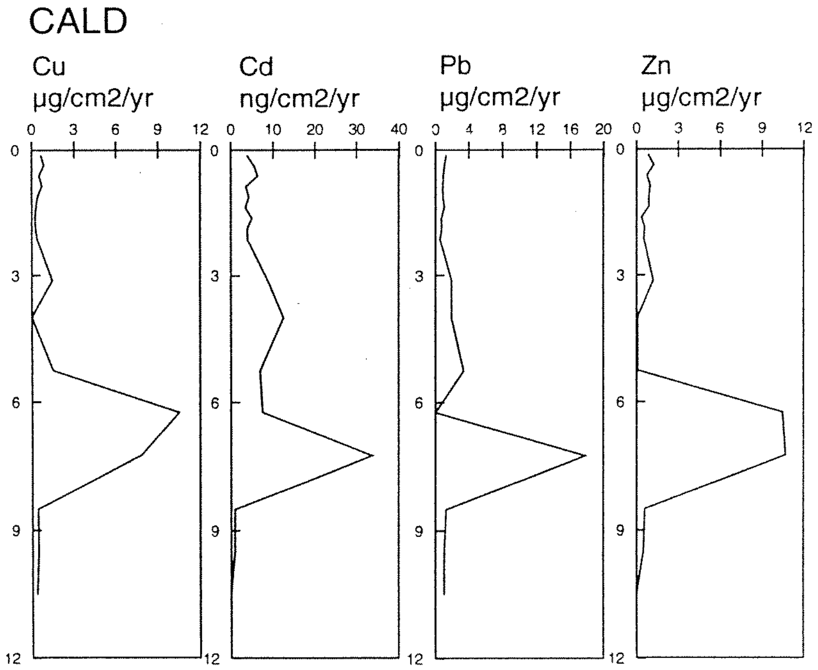
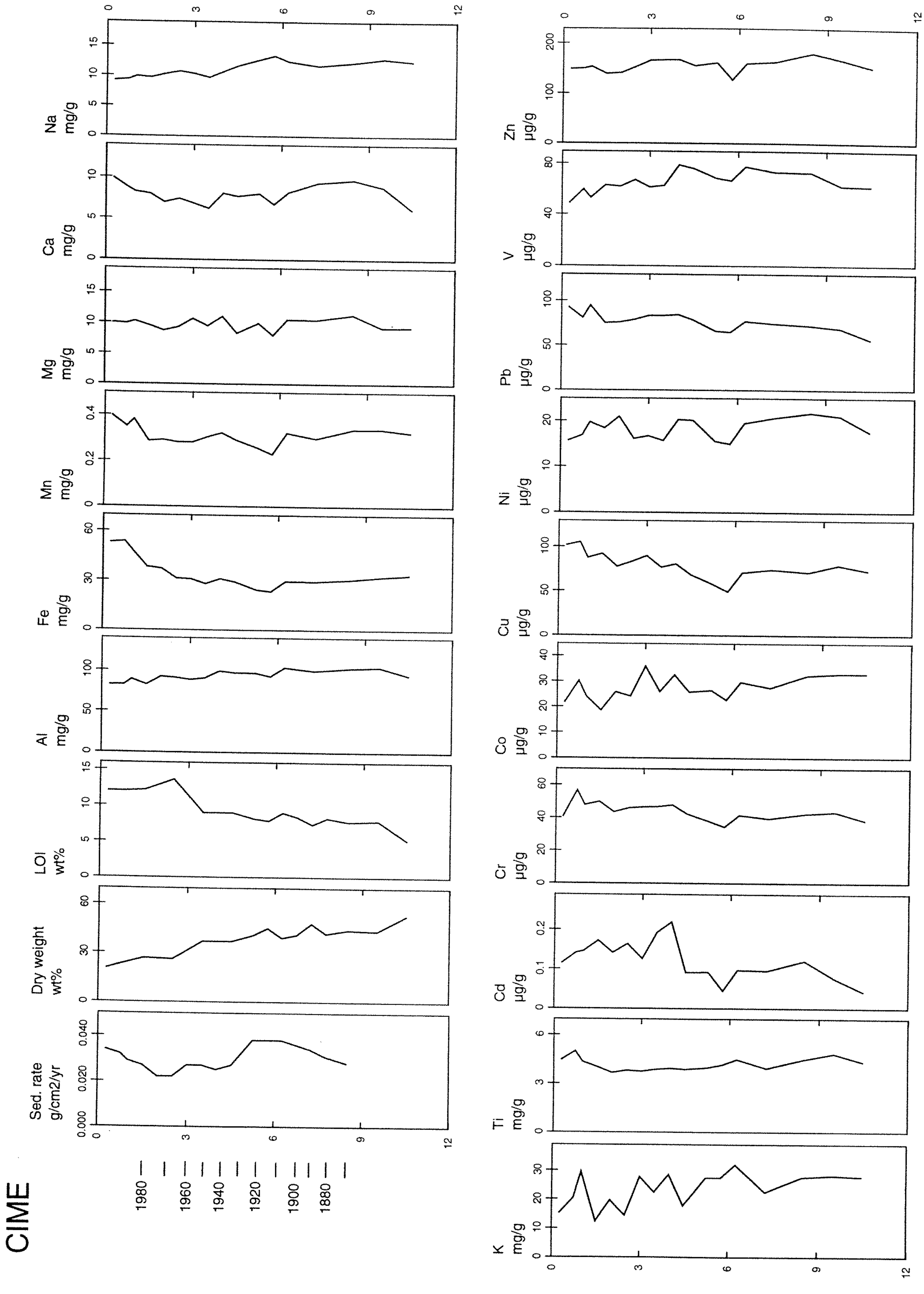


Figure 7b. Caldera (CALD) metal flux

Figure 8a. Cimera (CIME) metal concentrations



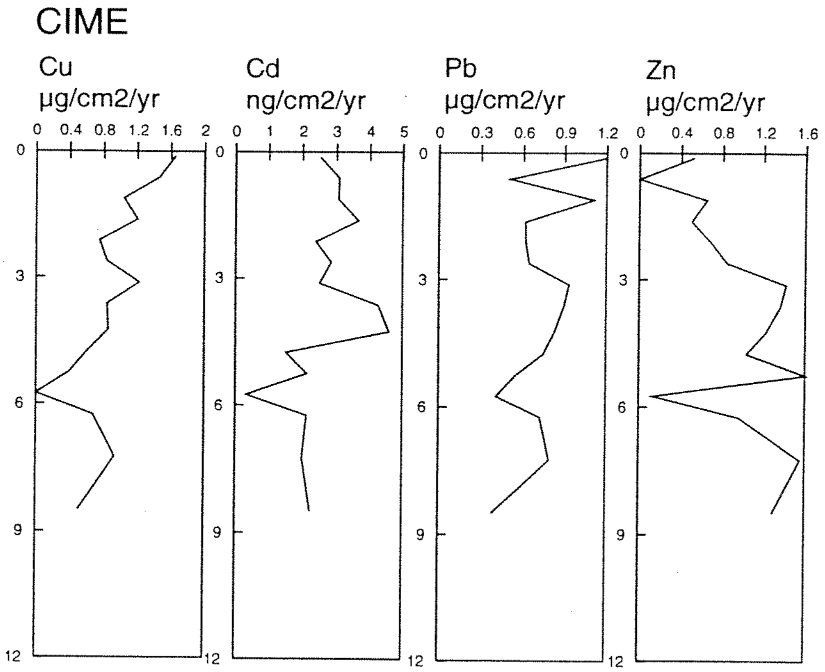
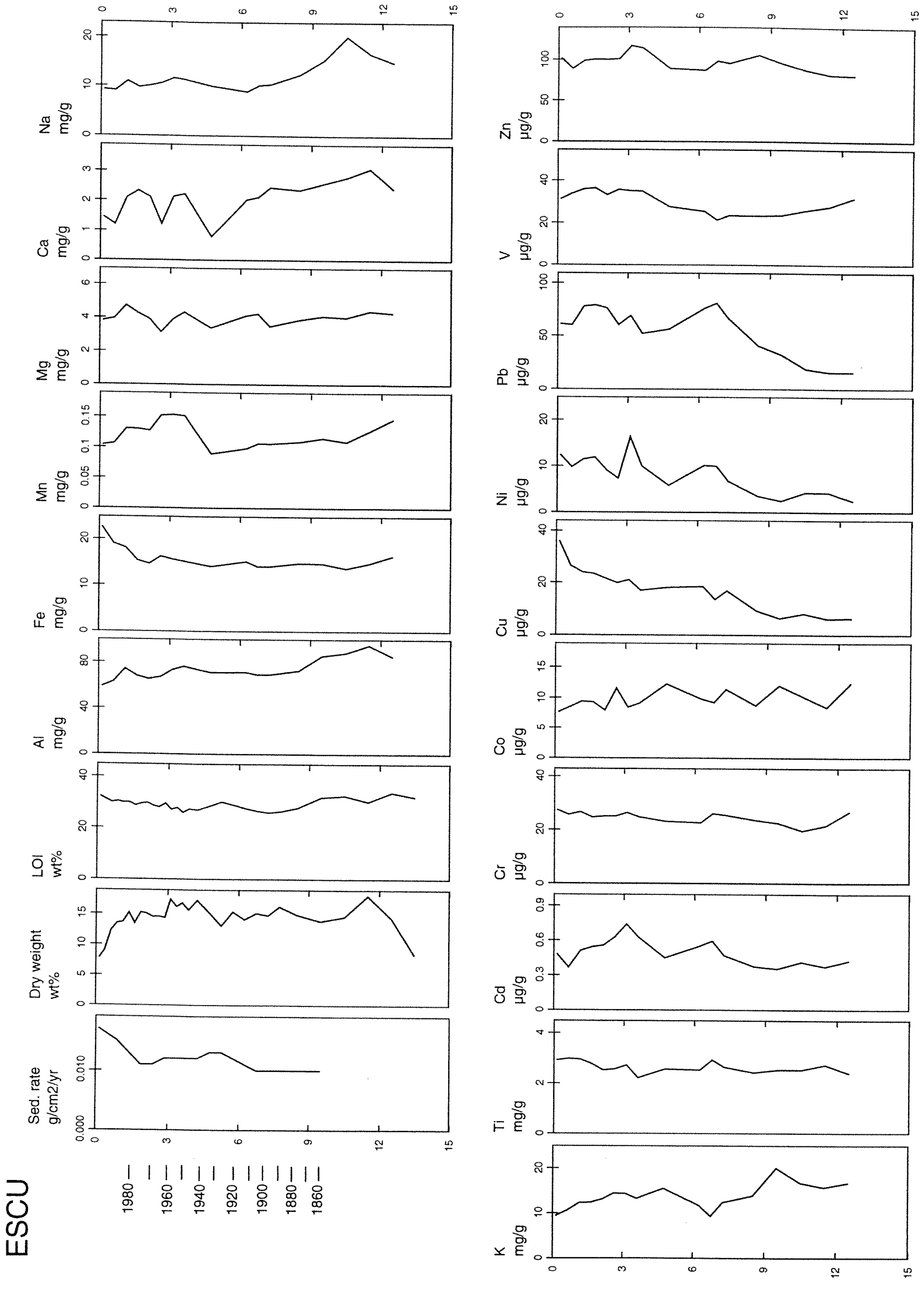


Figure 8b. Cimera (CIME) metal flux

Figure 9a. Escura (ESCU) metal concentrations



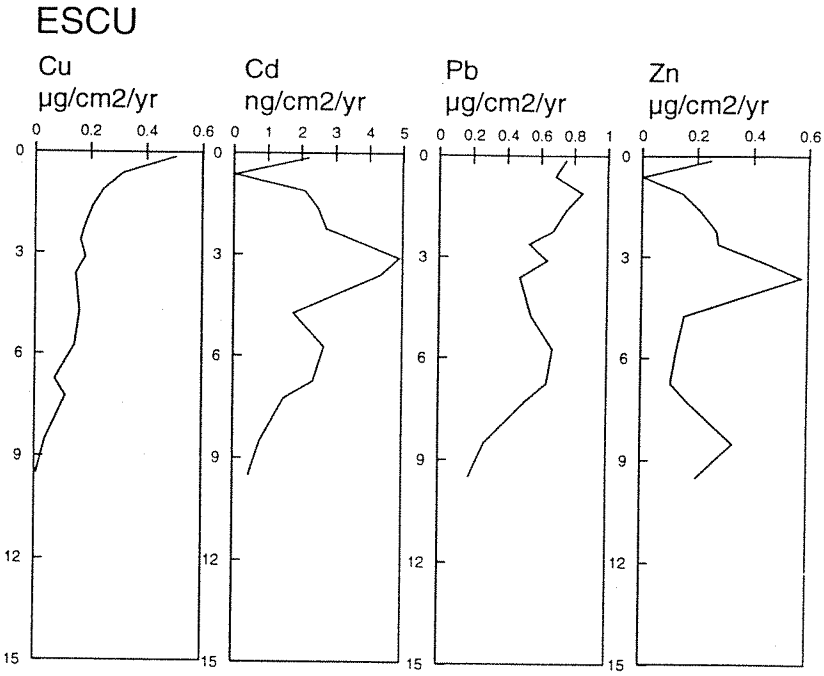
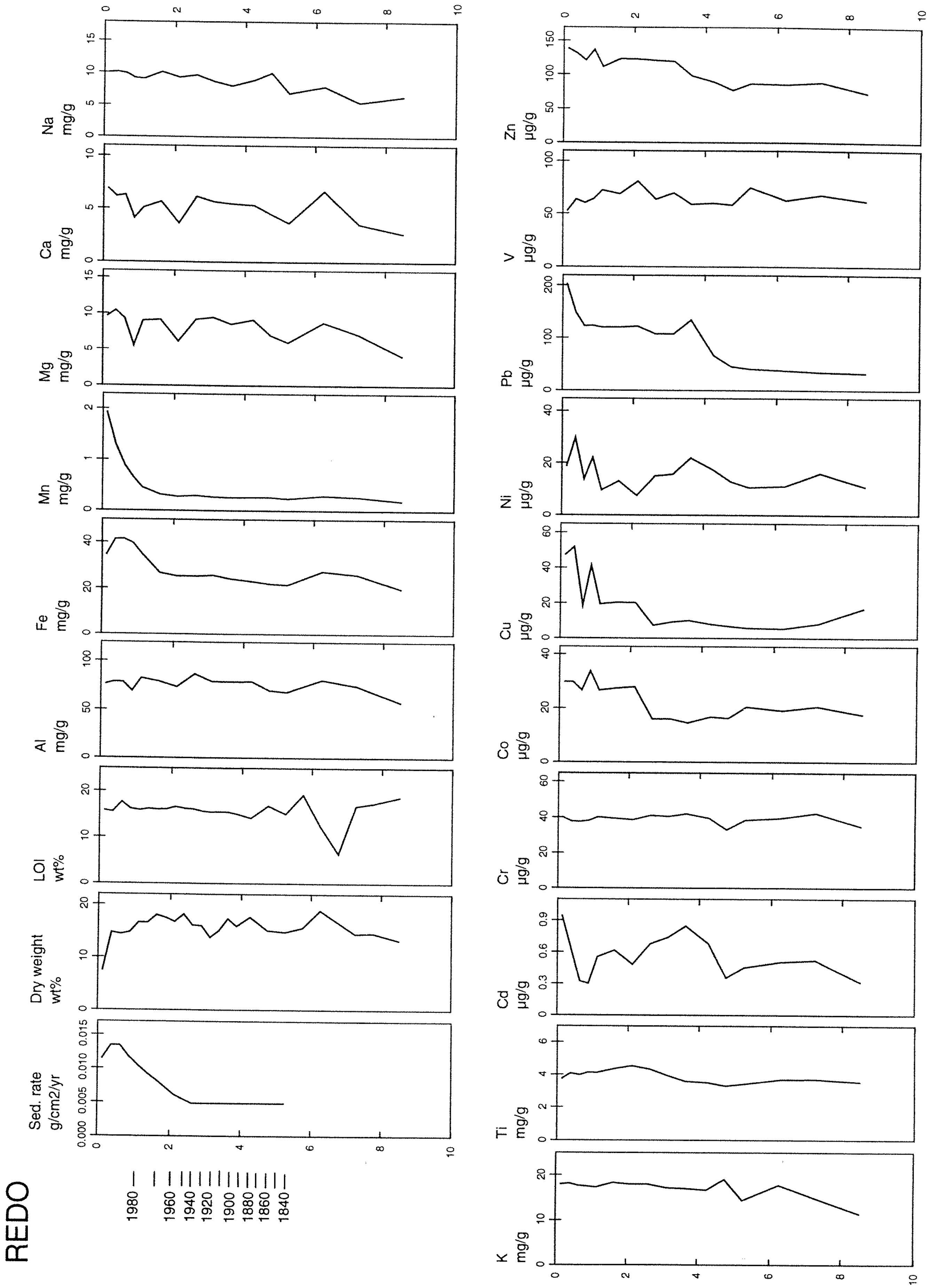


Figure 9b Escura (ESCU) metal flux

Figure 10a. Redo metal concentrations



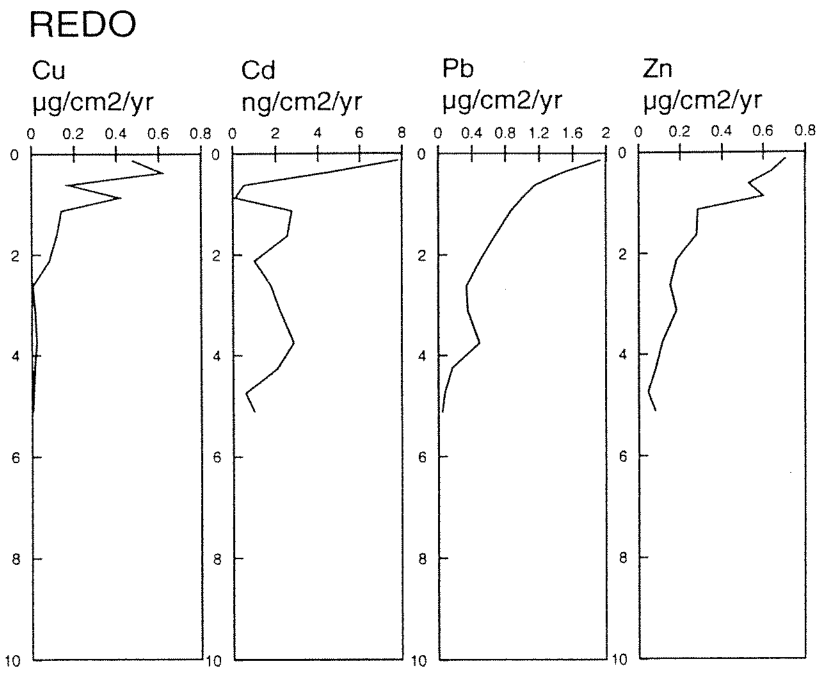
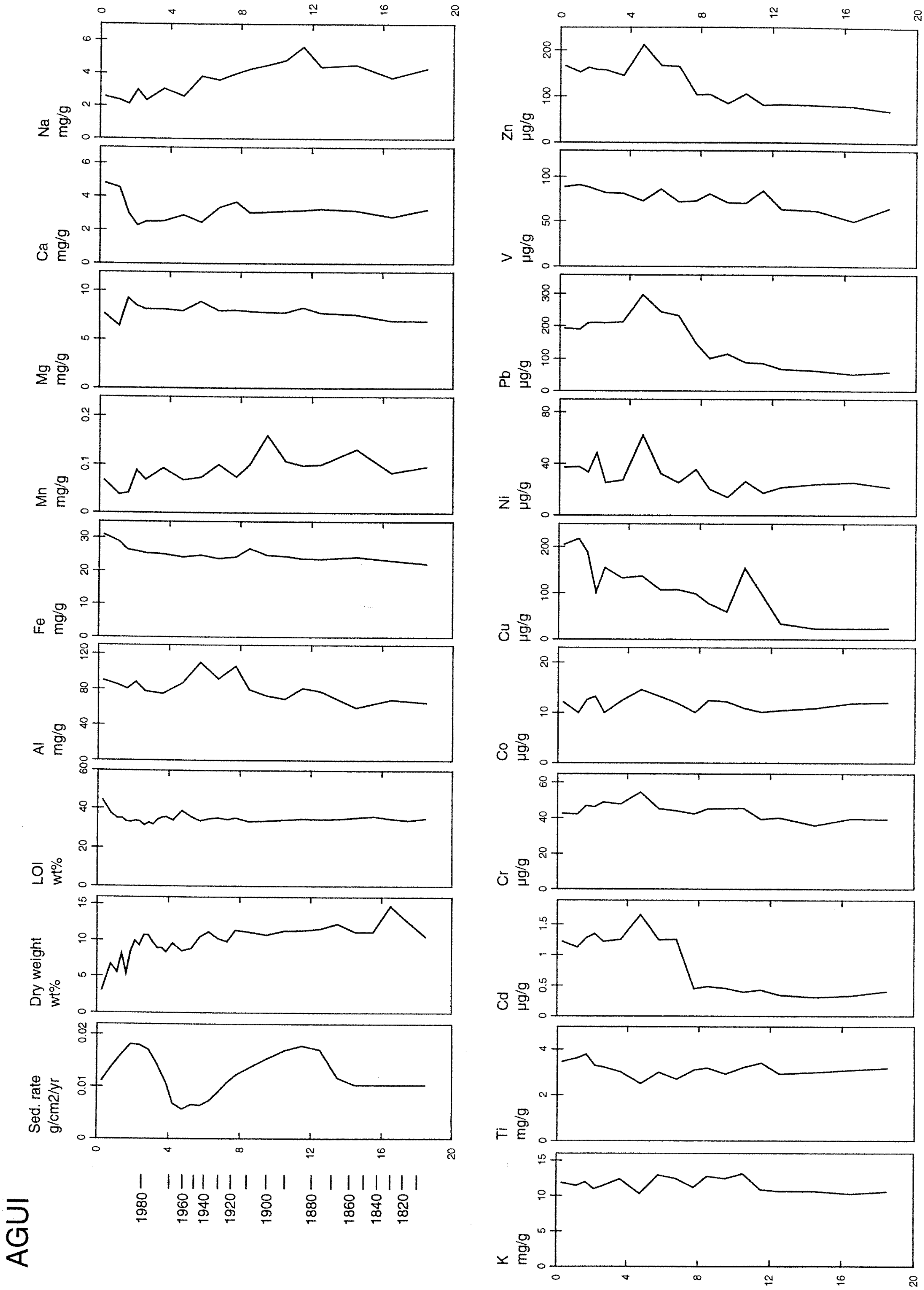


Figure 10b. Redo metal flux

Figure 11a. Aguilo (AGUI) metal concentrations



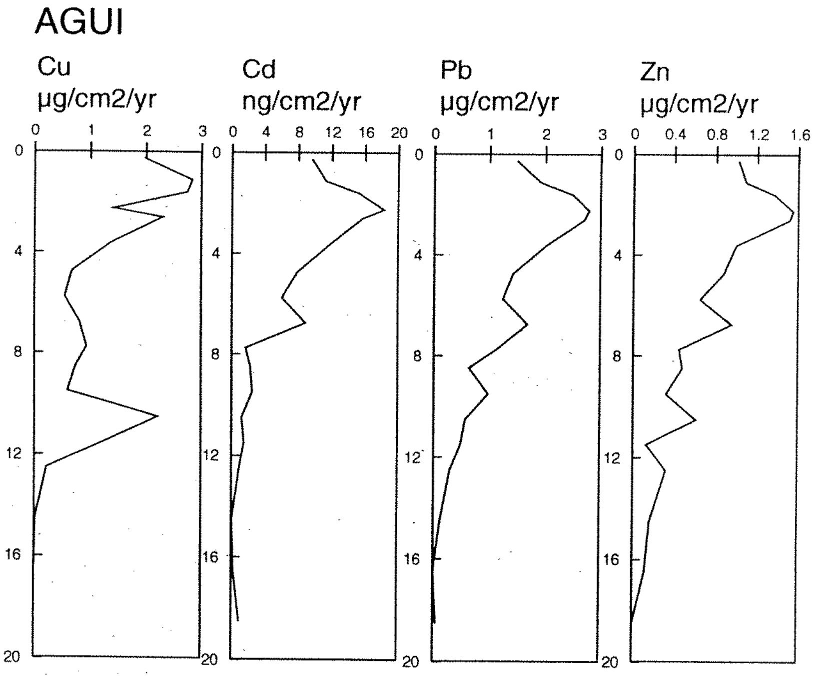
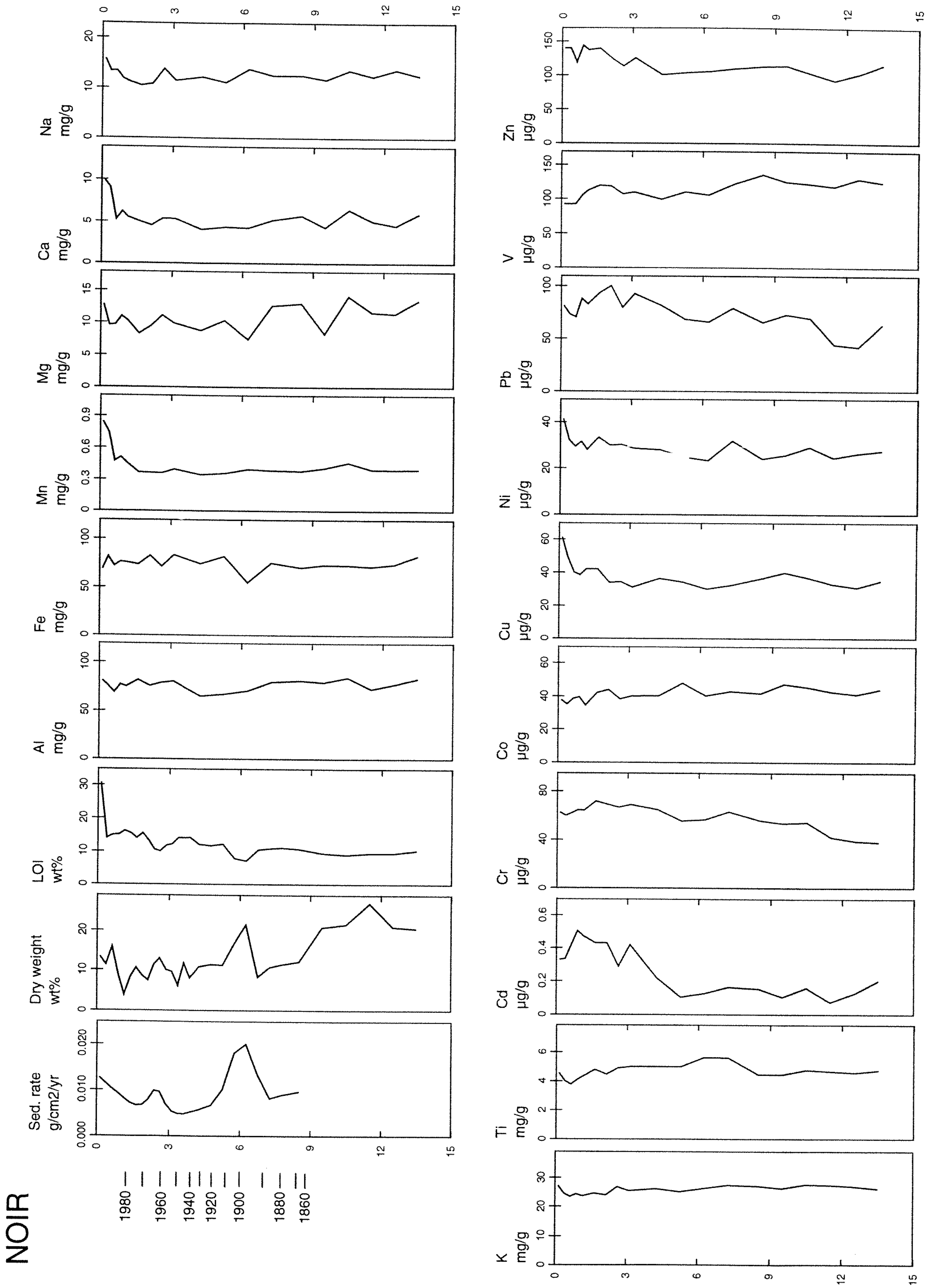


Figure 11b. Aguilo (AGUI) metal flux

Figure 12a. Noir metal concentrations



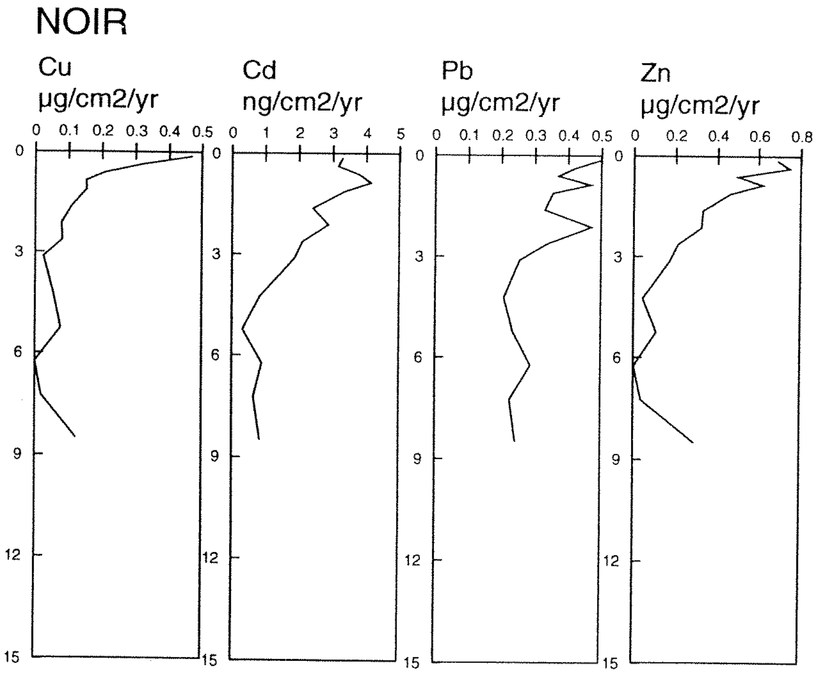
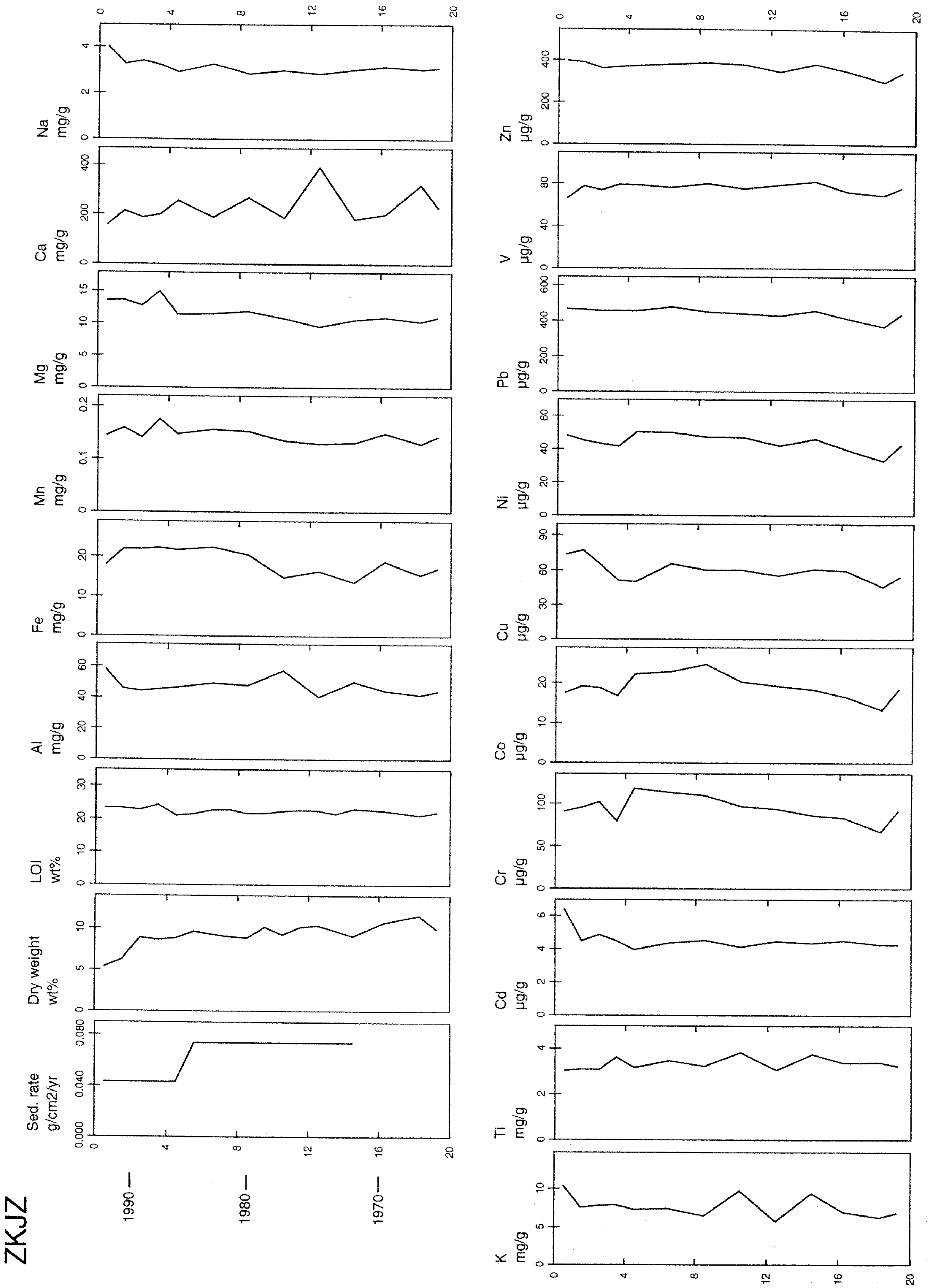


Figure 12b. Noir metal flux

Figure 13a. Zgornje Krisko Jezero (ZKJZ) metal concentrations



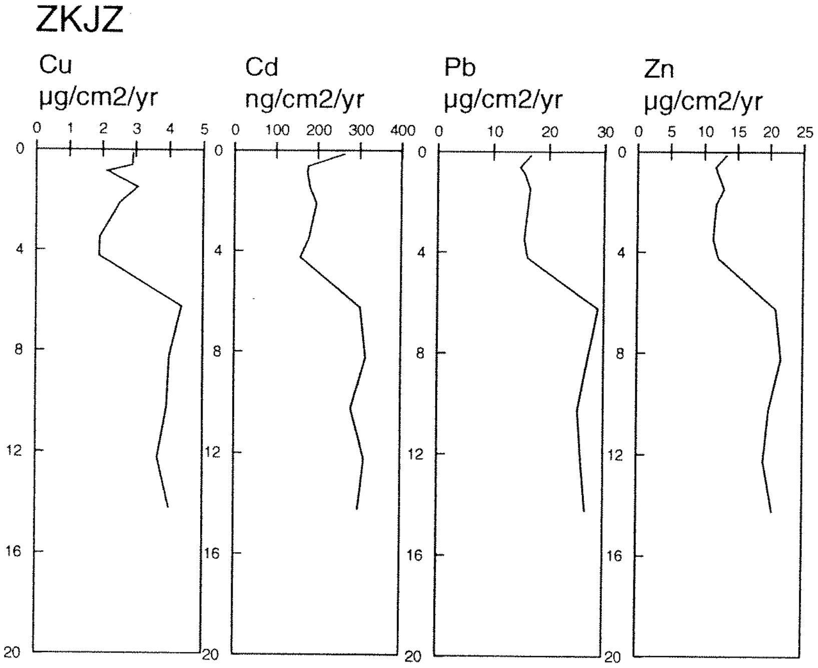
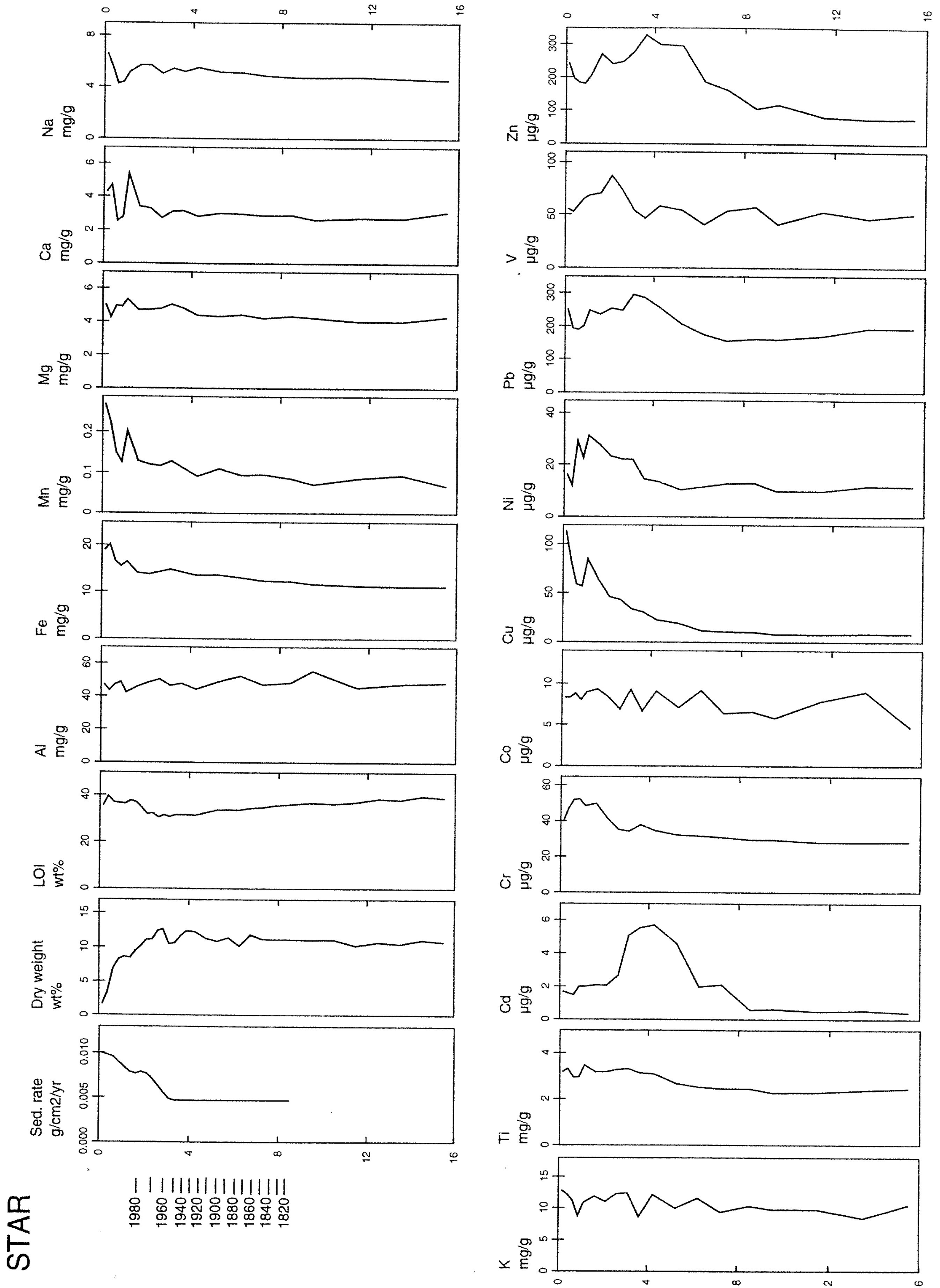


Figure 13b. Zgornje Krisko Jezero (ZKJZ) metal flux

Figure 14a. Starolesnianske Pleso (STAR) metal concentrations



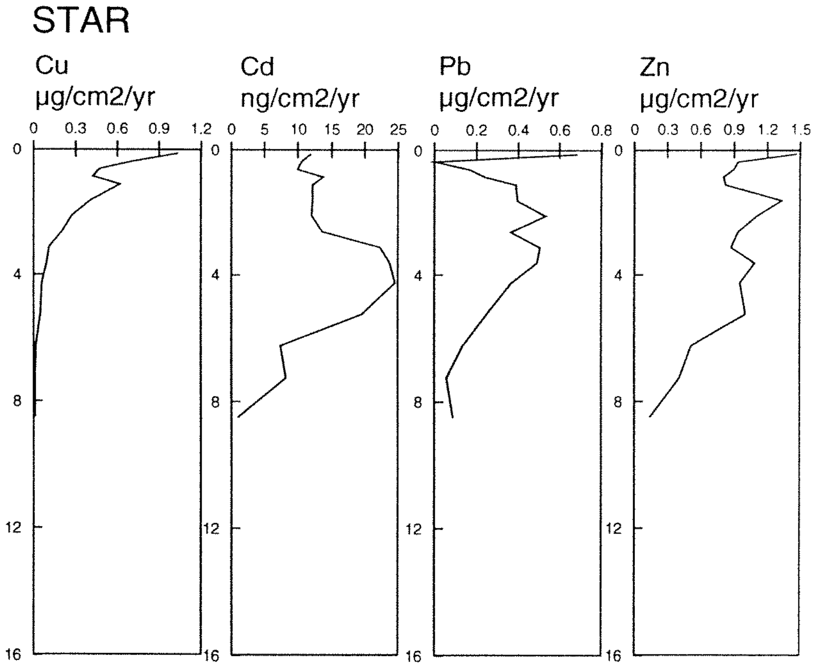
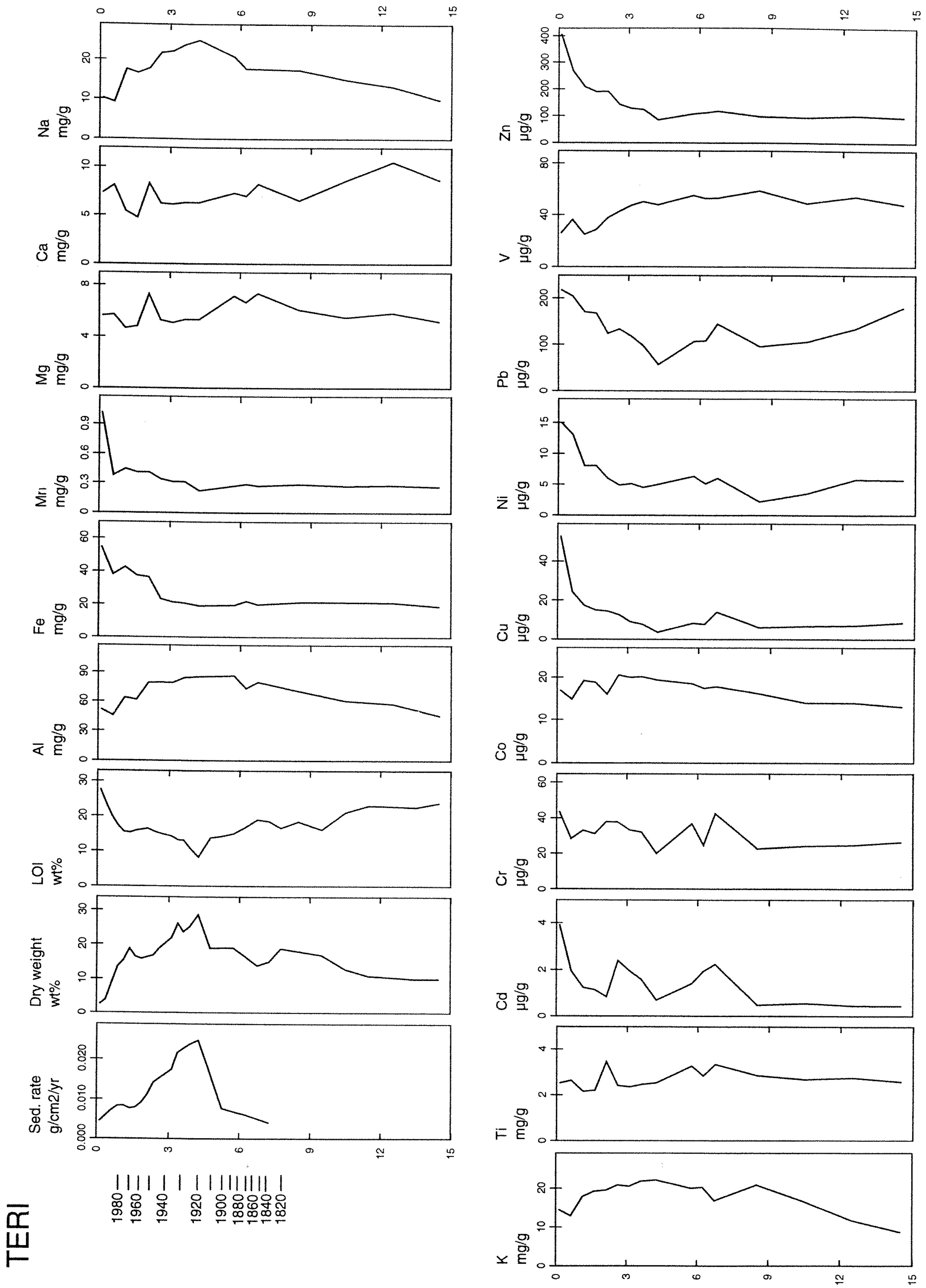


Figure 14b. Starolesnianske Pleso (STAR) metal flux

Figure 15a. Terianske Pleso (TERI) metal concentrations



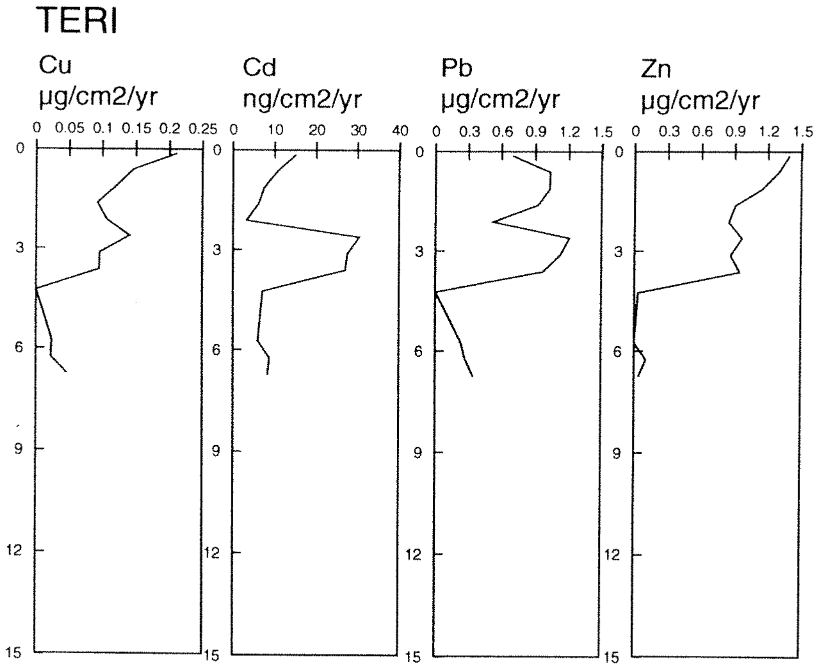
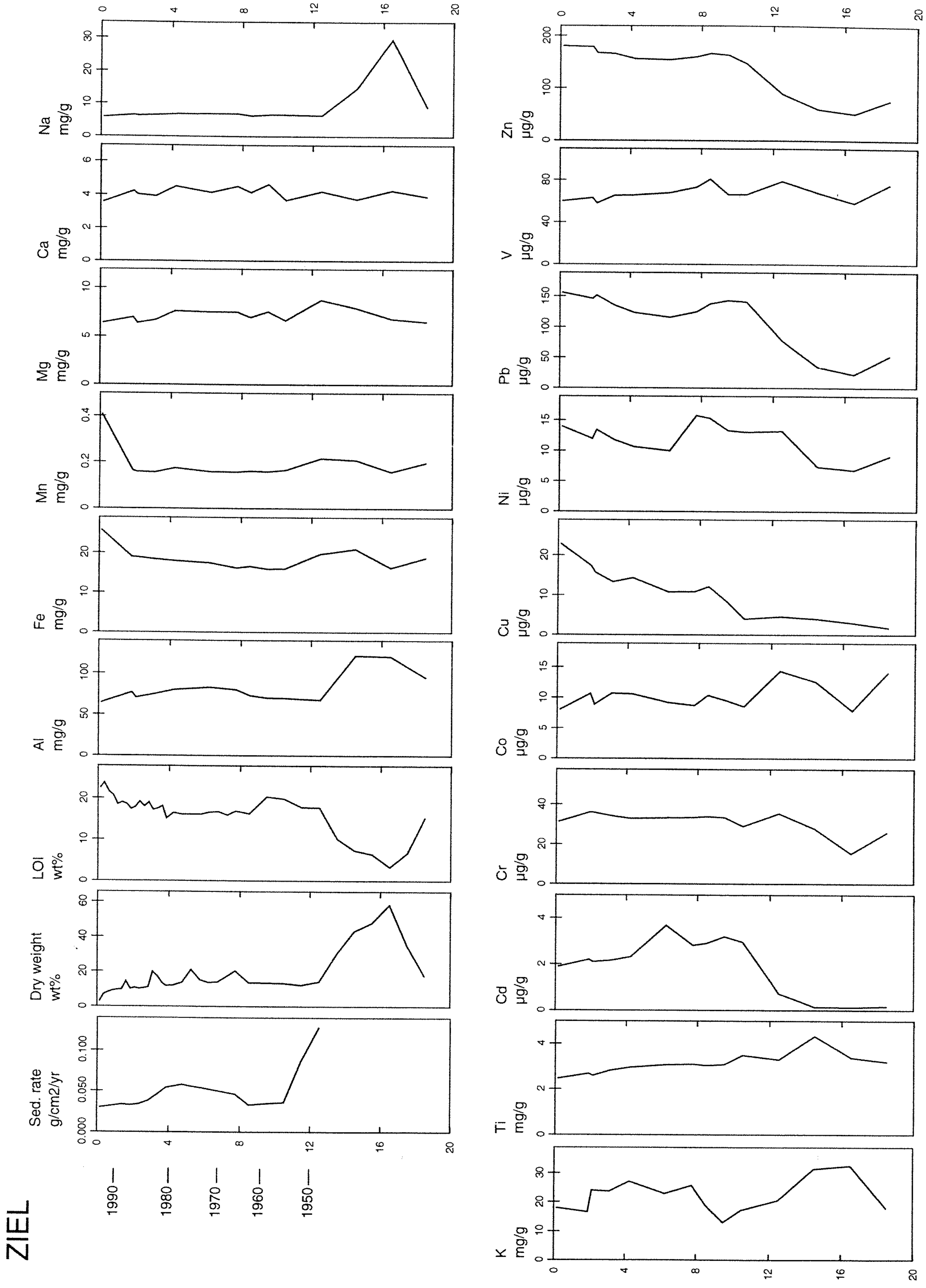


Figure 15b. Terianske Pleso (TERI) metal flux

Figure 16a. Zielowny Staw (ZIEL) metal concentrations



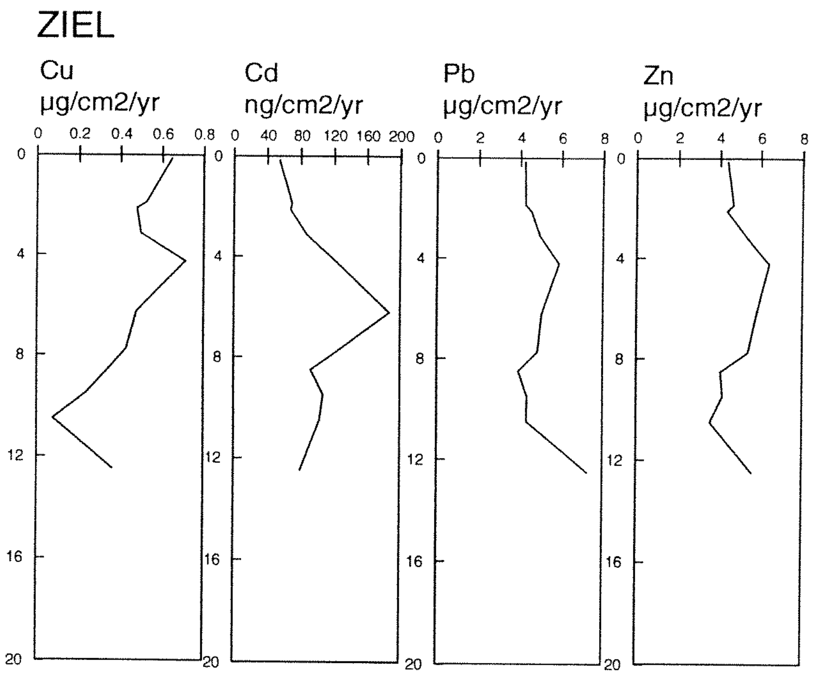
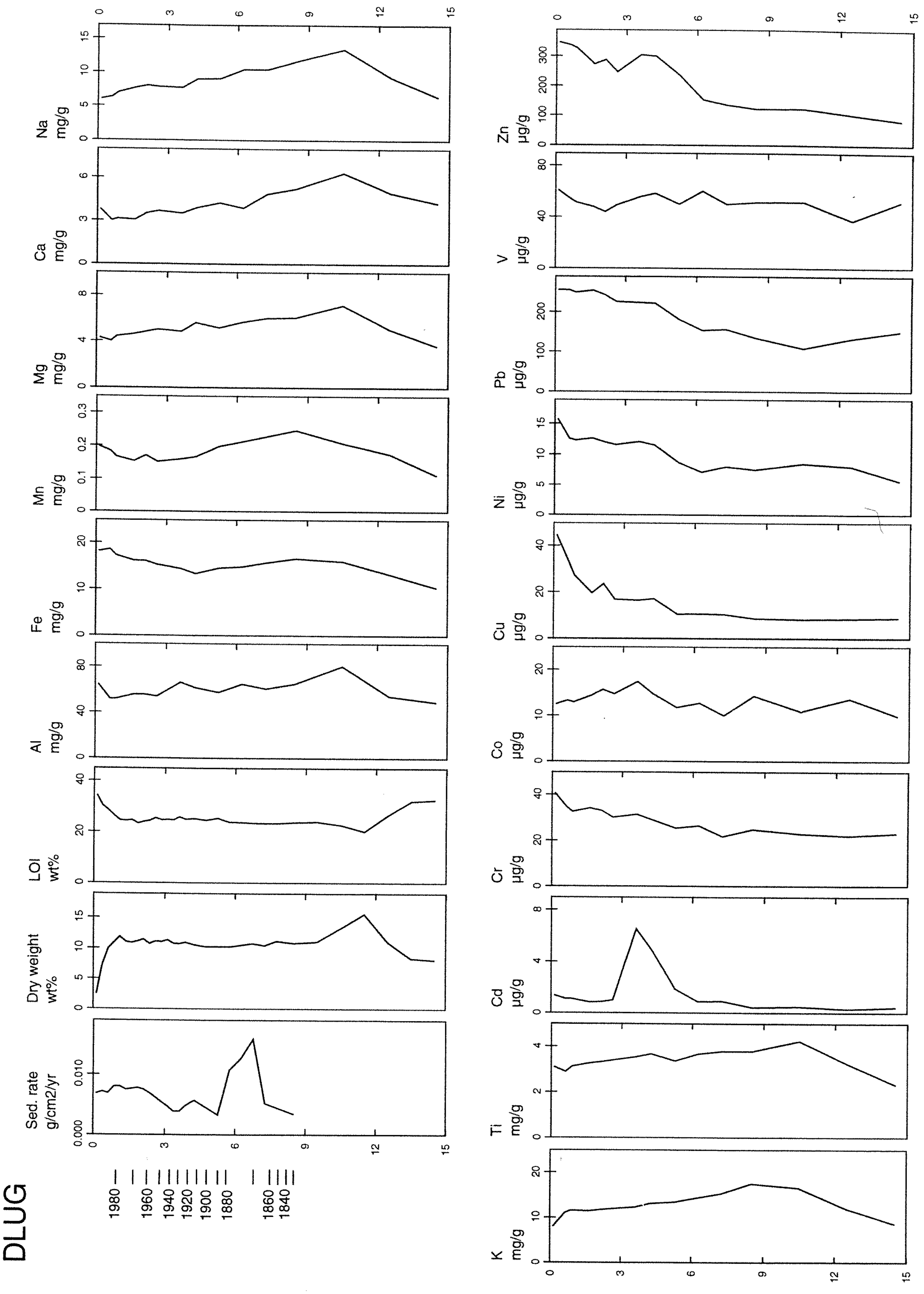


Figure 16b. Zielowny Staw (ZIEL) metal flux

Figure 17a. Dlugi Staw (DLUG) metal concentrations



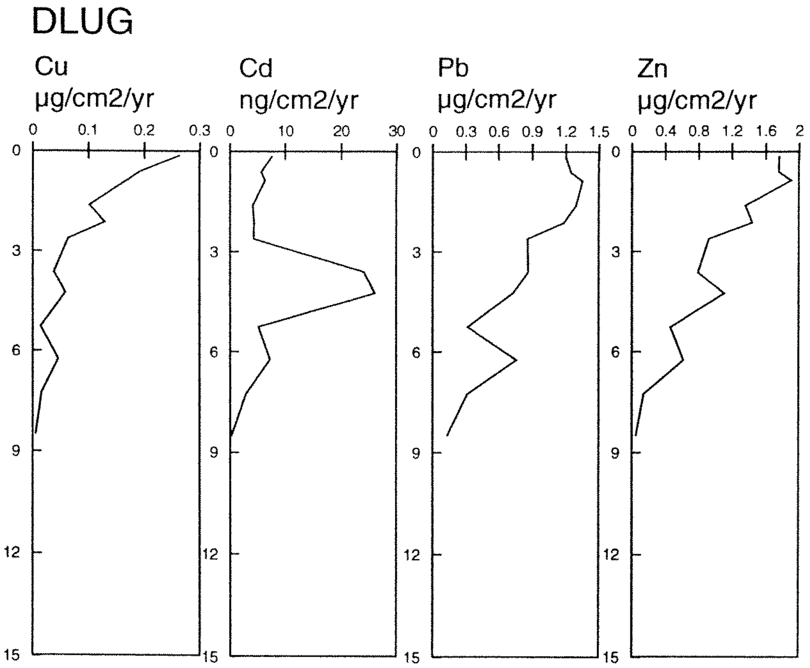


Figure 17b. Dlugi Staw (DLUG) metal flux

Figure 18. SCP concentration represented by proportional circles

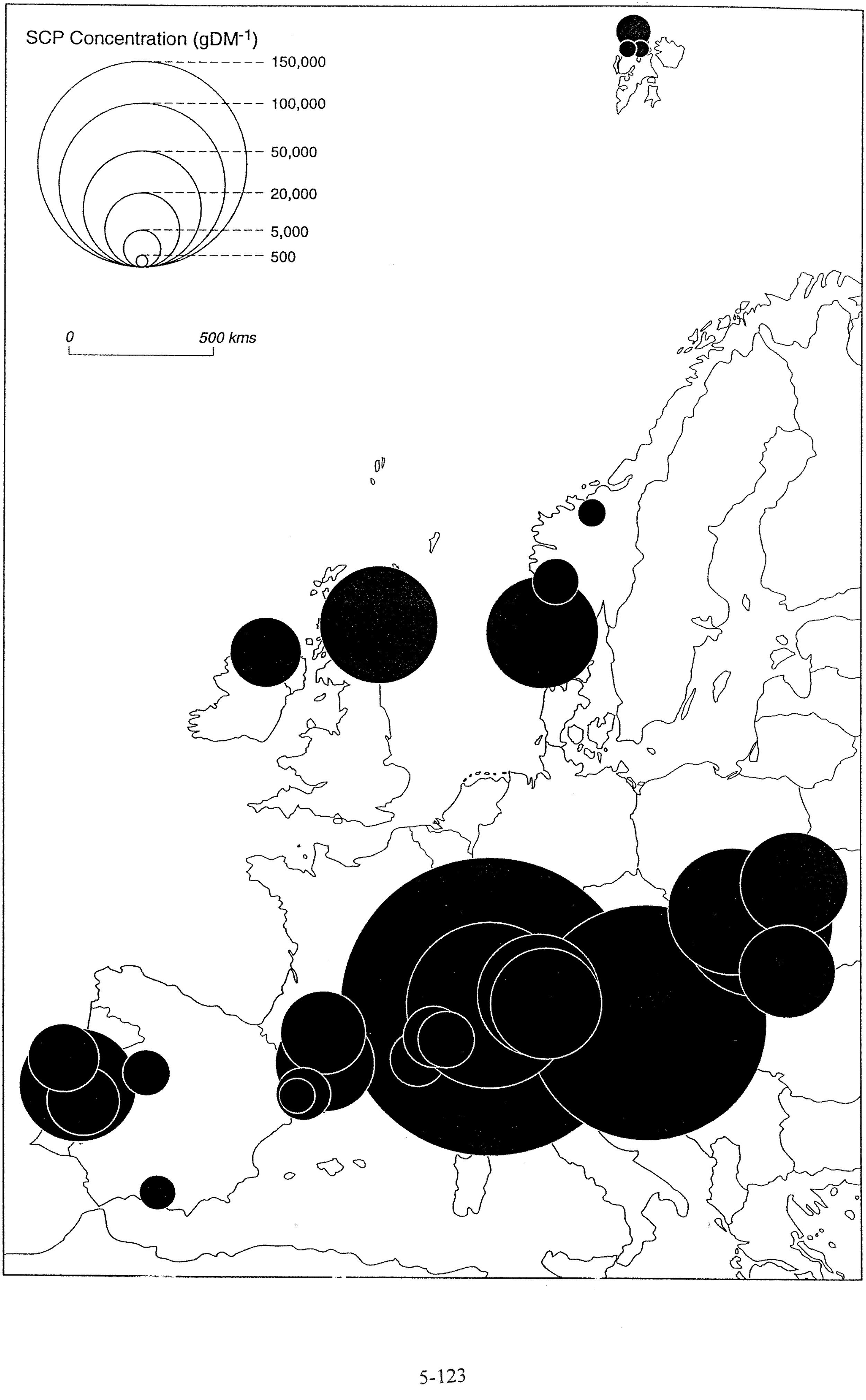


Figure 19. SCP flux represented by proportional circles

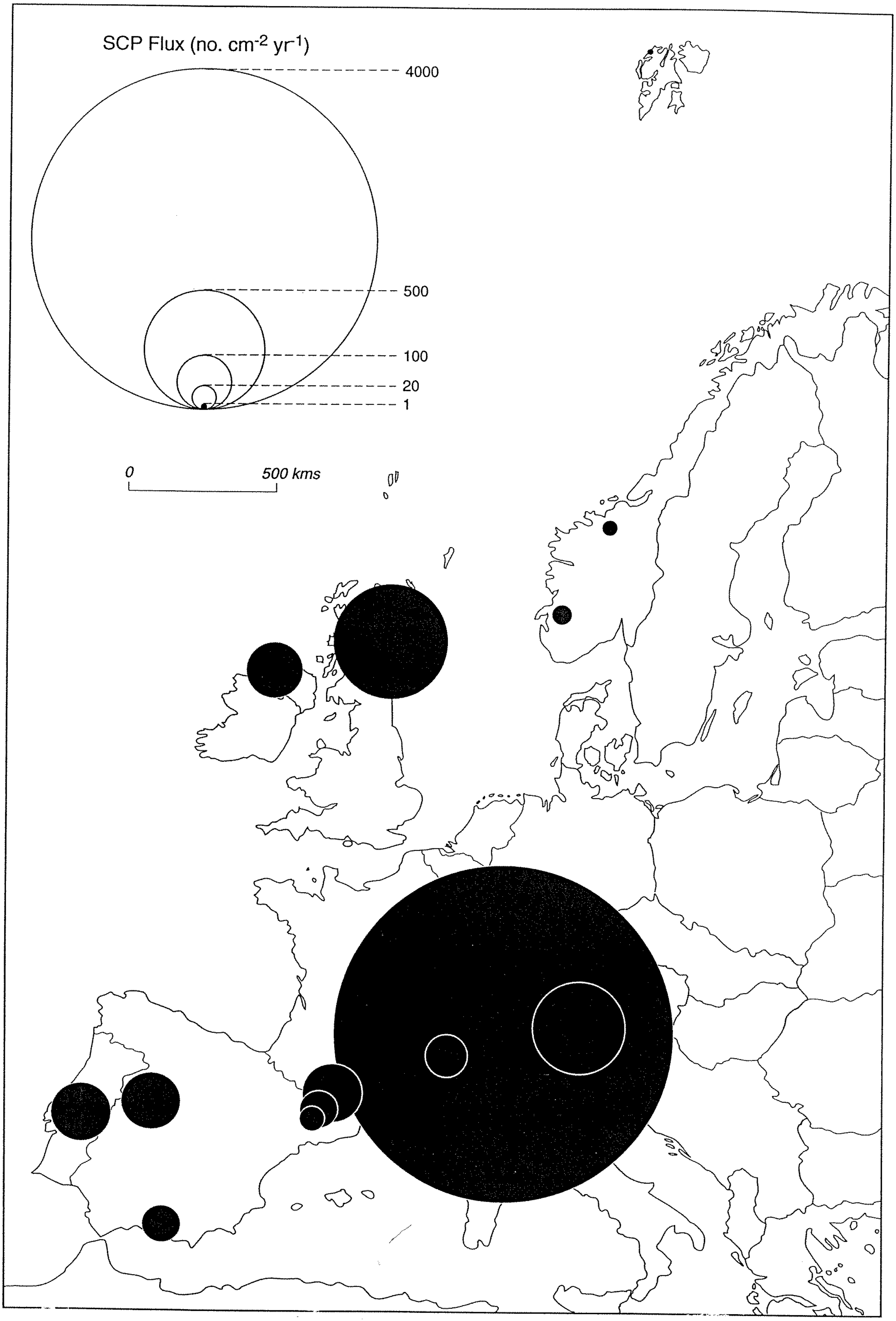


Figure 20. Aguilo, stable Pb concentration vs. depth

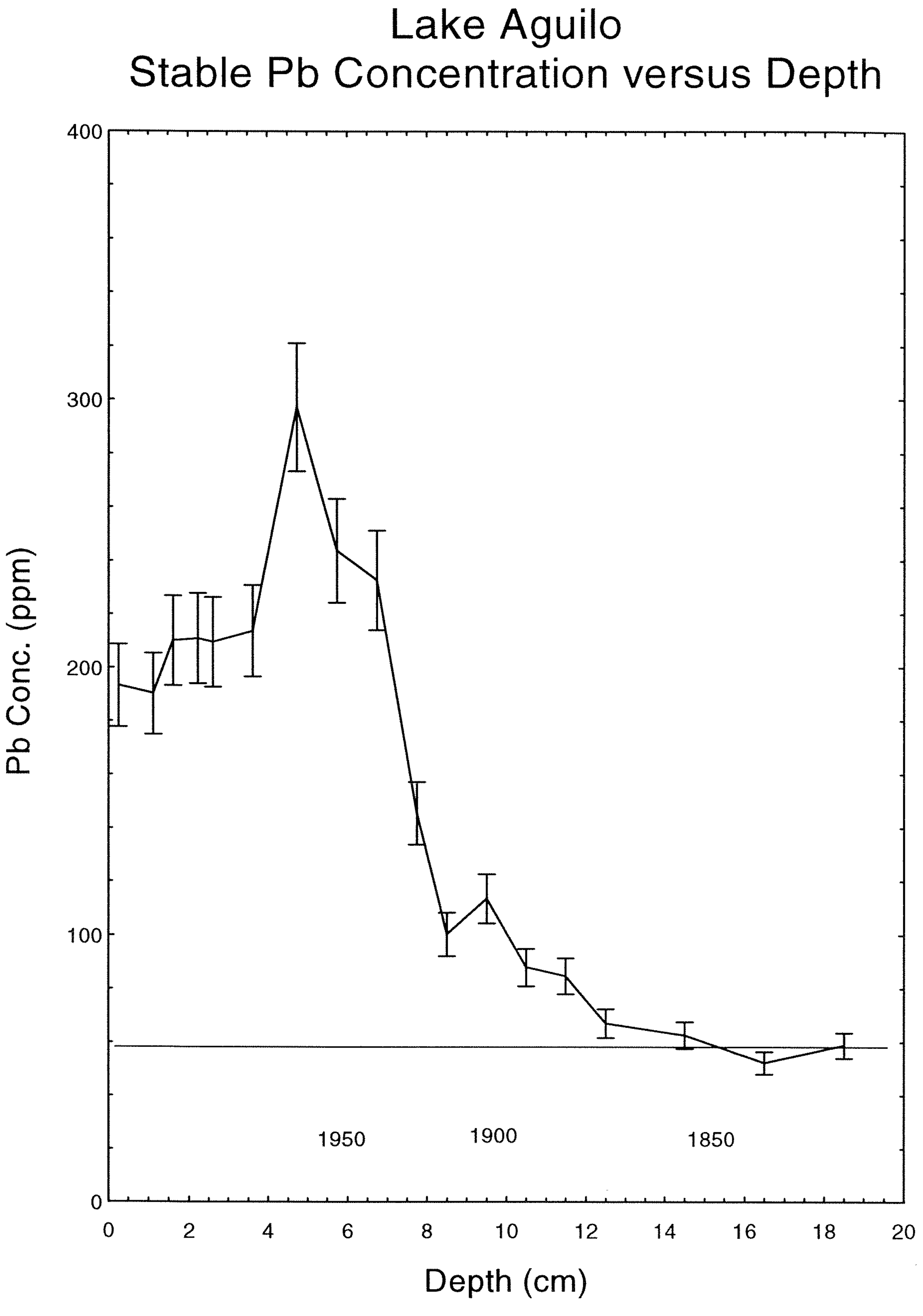


Figure 21. Aguilo, Cd concentration vs. depth

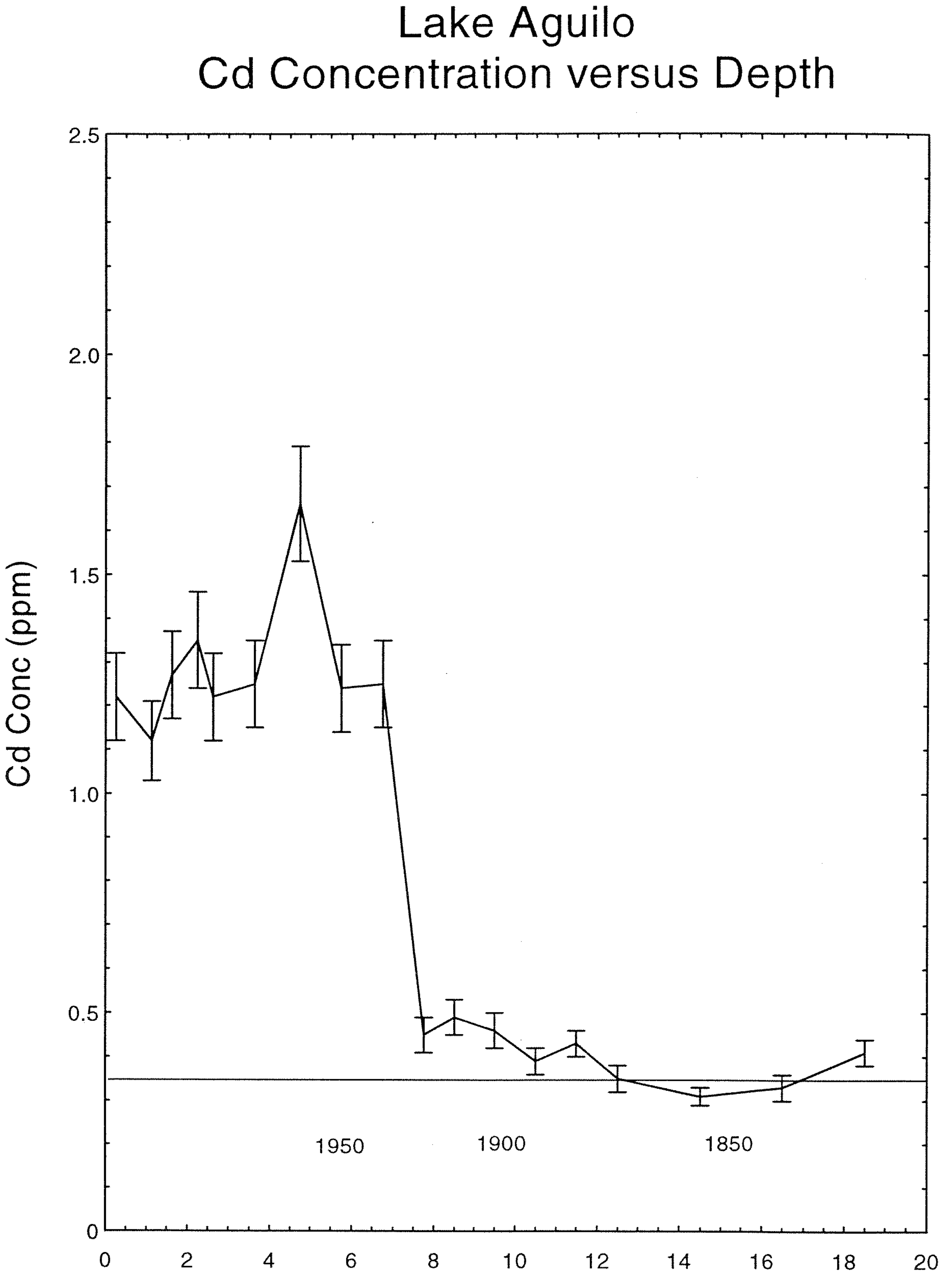


Figure 22. Trace metal/^{210}Pb inventory ratio

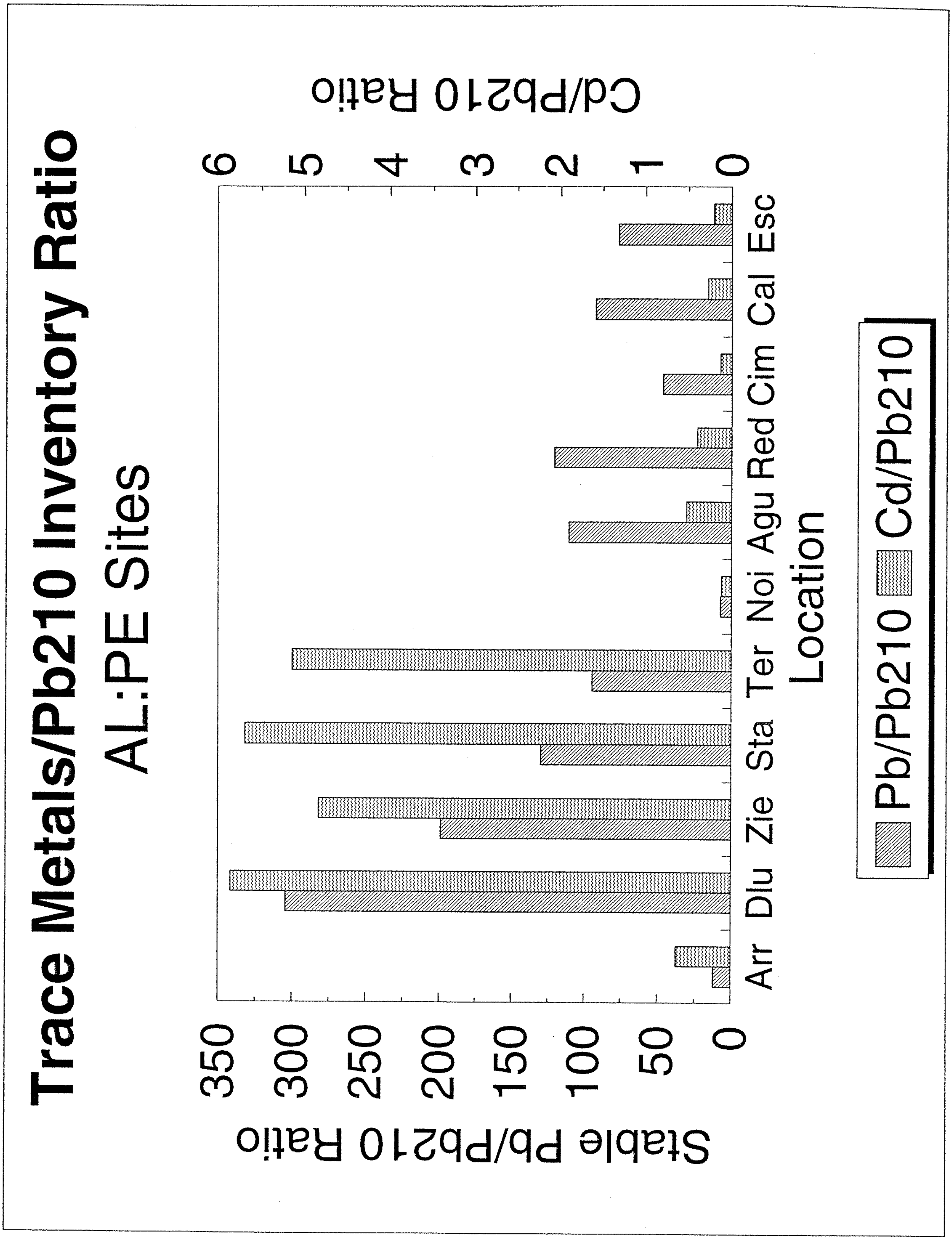


Figure 23. SCP/^{210}Pb inventory ratio

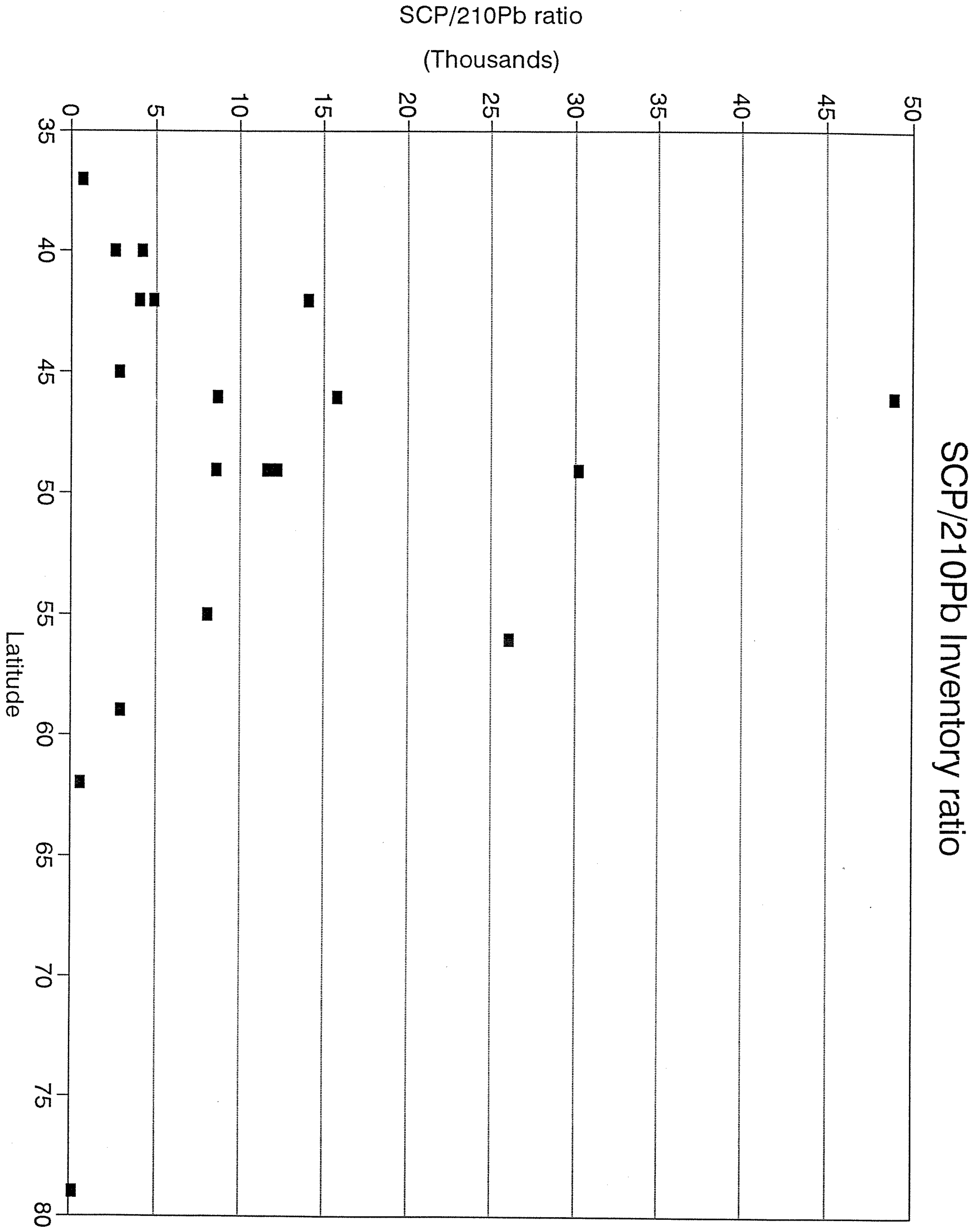


Figure 24. POC/^{210}Pb inventory ratio

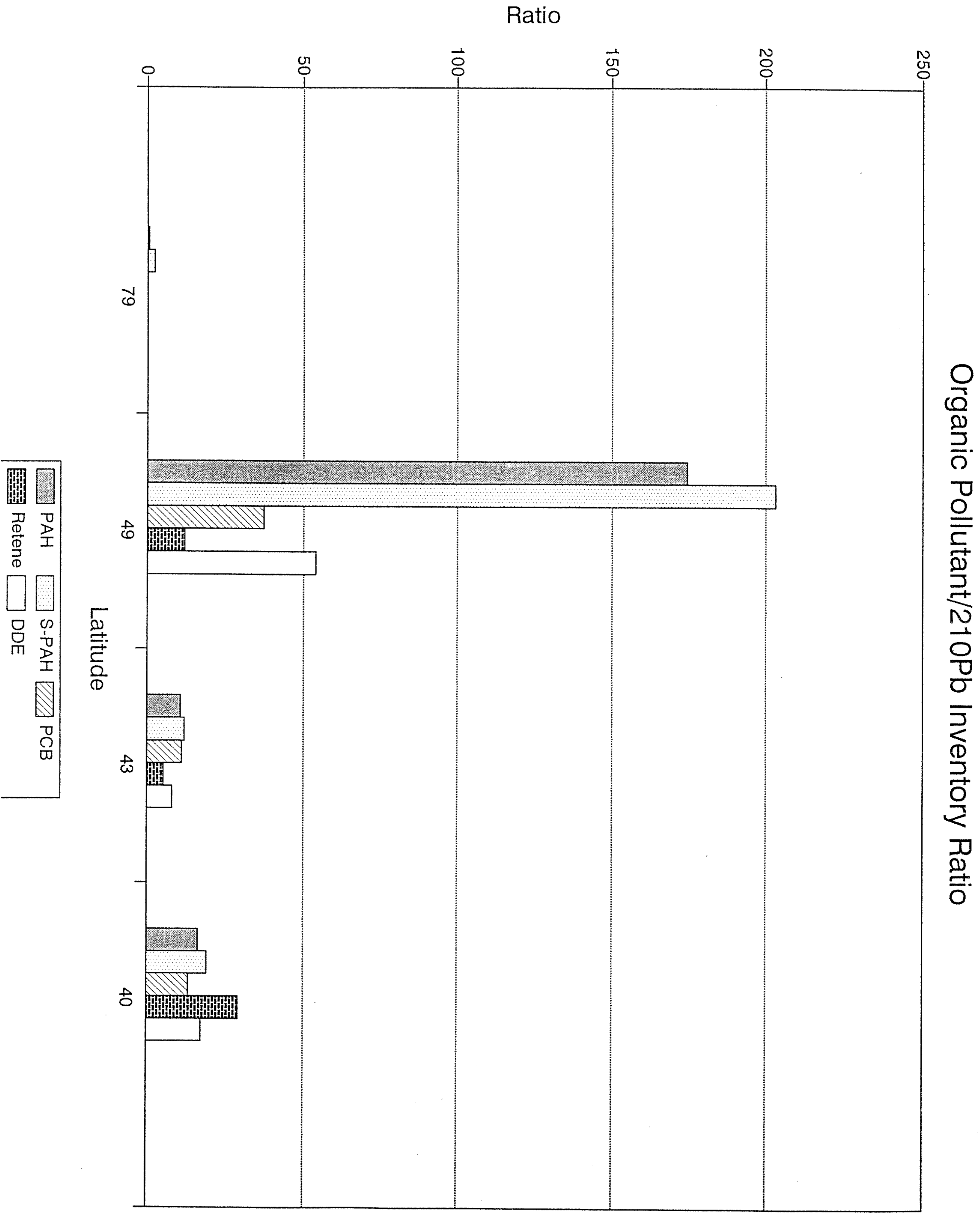
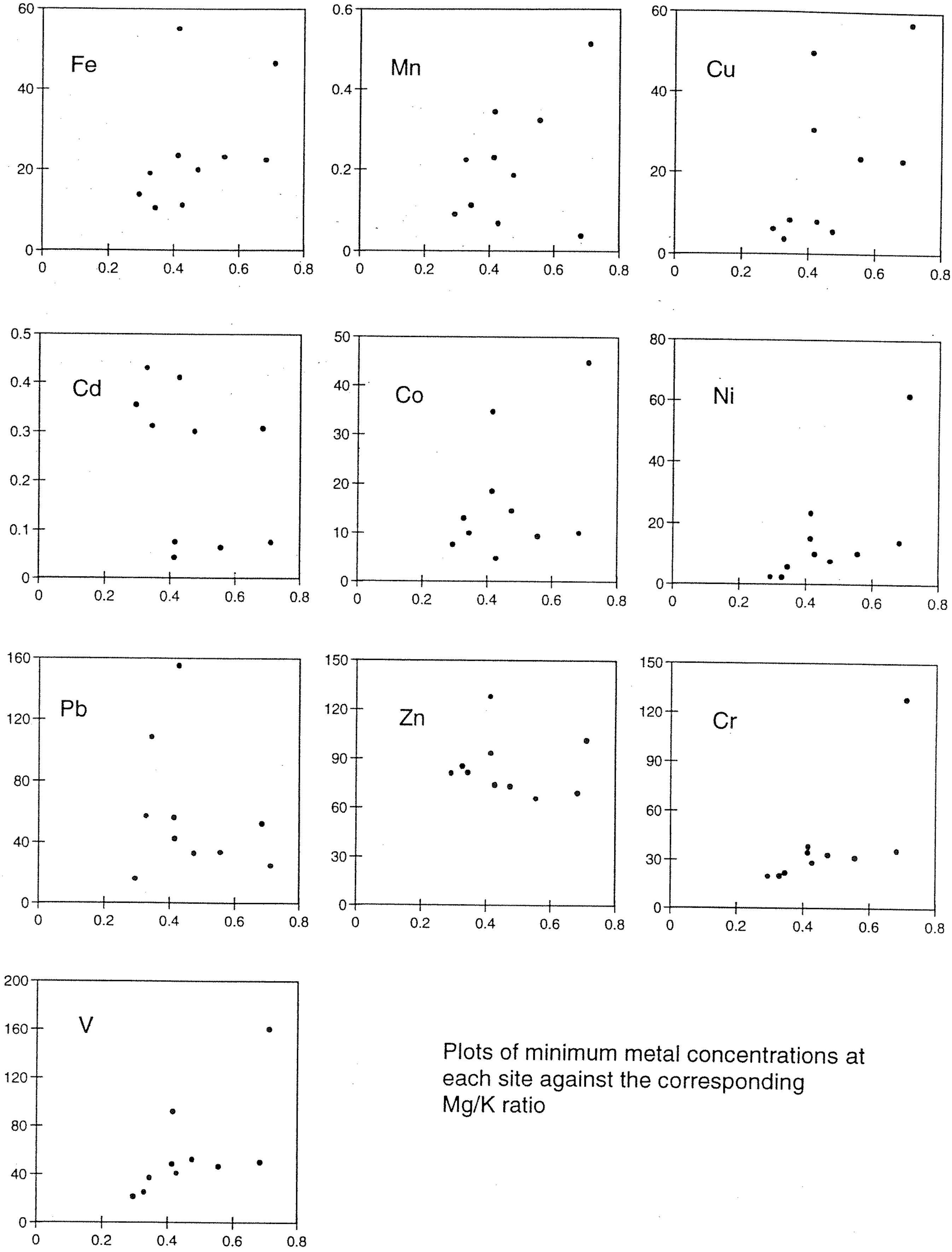


Figure 25. Minimum metal concentration vs. Mg/K



Plots of minimum metal concentrations at each site against the corresponding Mg/K ratio

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

AL:PE 2 report for the period January 1993-June 1995.

Appendix 8B

Physical and Biological Sediment Analyses

Annex Figures

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[2] Institute of Zoology, University of Bergen
[3] Institute for Zoology & Limnology, University of Innsbruck
[4] Institute of Limnology, Austrian Academy of Sciences
[5] Laboratory of Limnology, Universidad Autonoma de Madrid
[6] Department of Hydrobiology, Institute of Zoology, Bratislava
[7] National Institute of Biology, University of Ljublljana
[8] Department of Hydrobiology, Charles University, Prague

Figure 1. ARSJ 93/1 %DW & %LOI

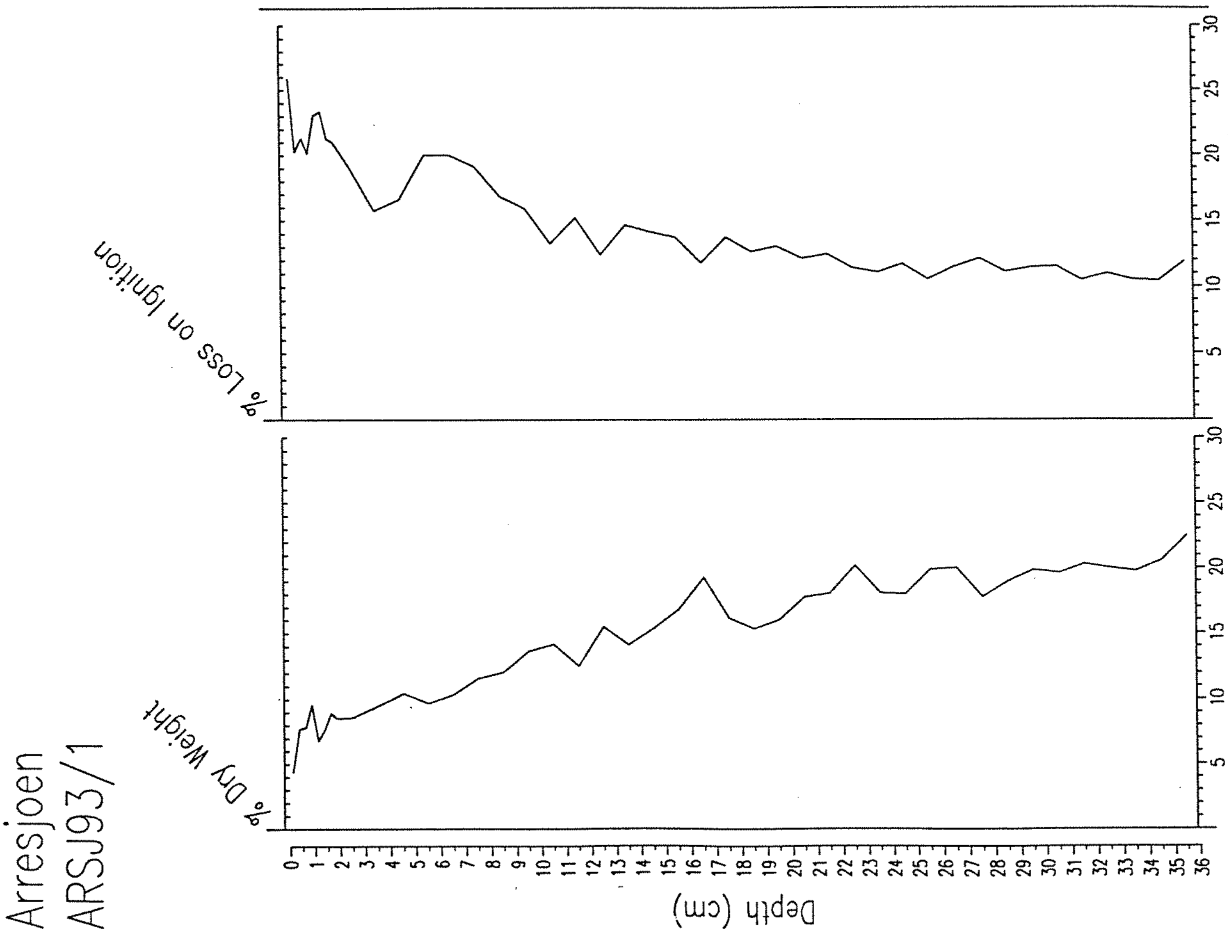


Figure 2. ARSJ 93/2 %DW & %LOI

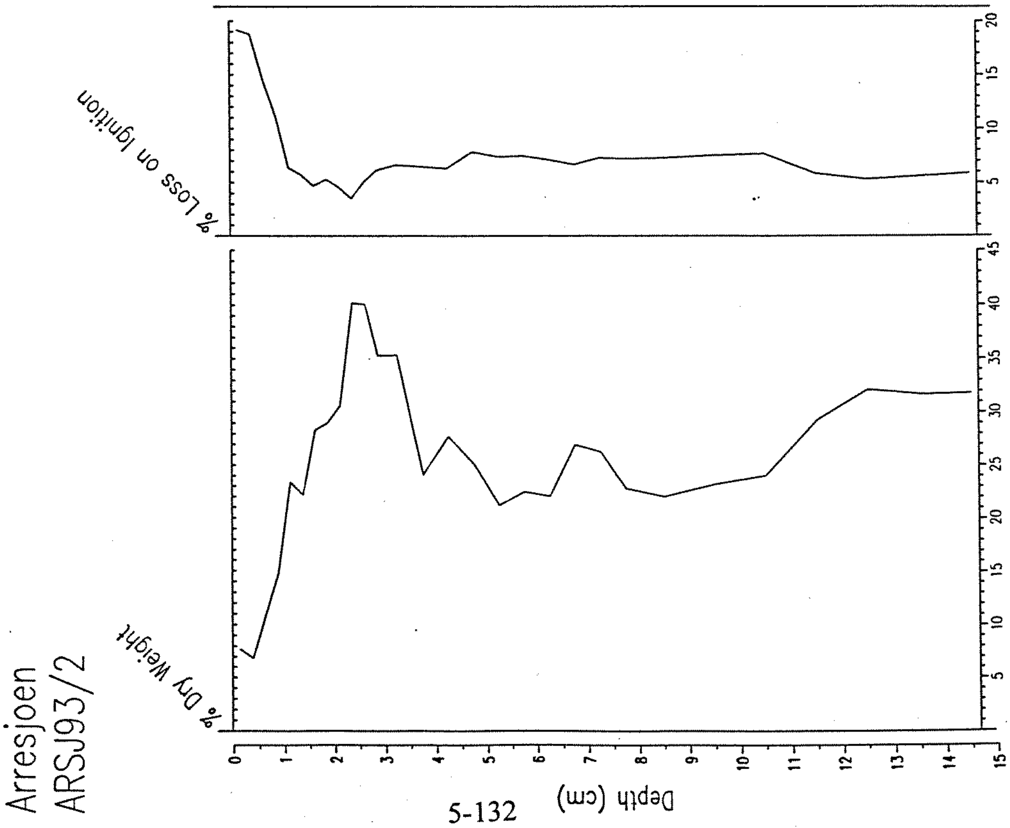


Figure 3. ARSJ 93/3 %DW & %LOI

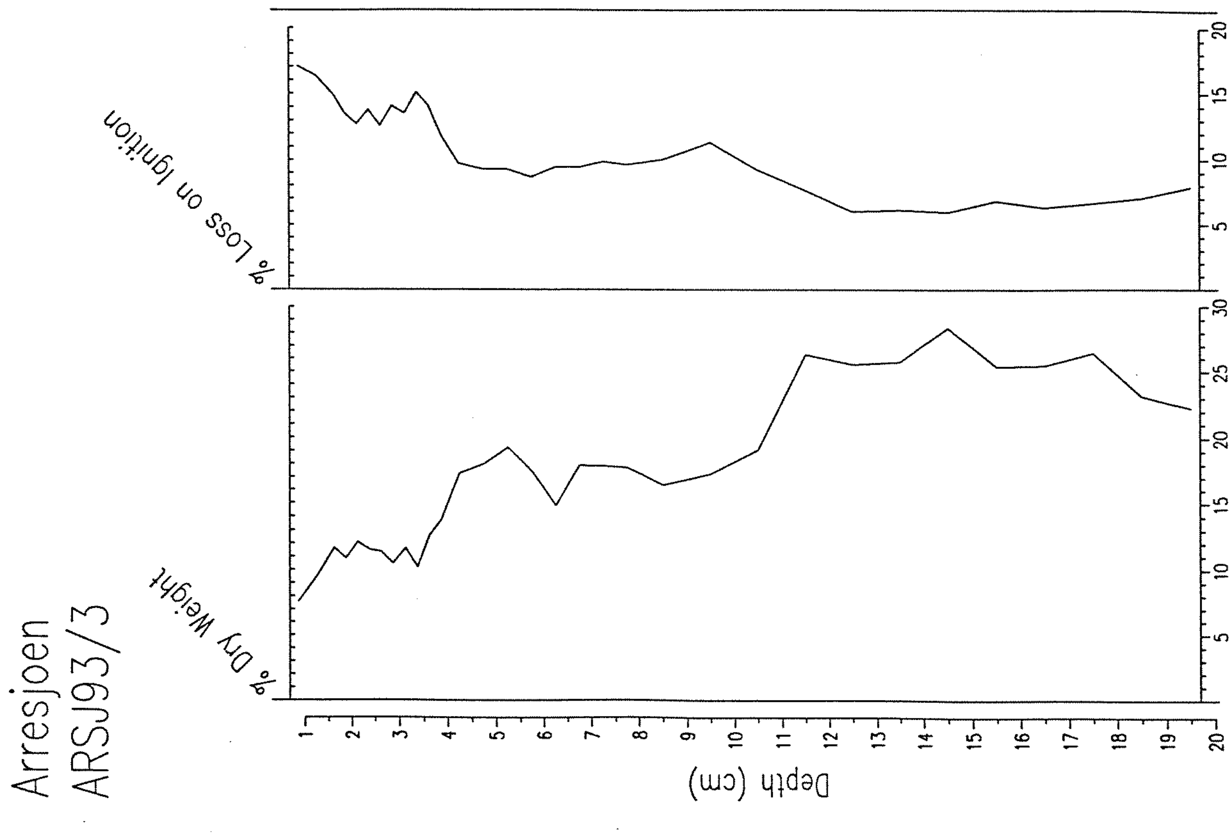


Figure 4. ARSJ 93/4 %DW & %LOI

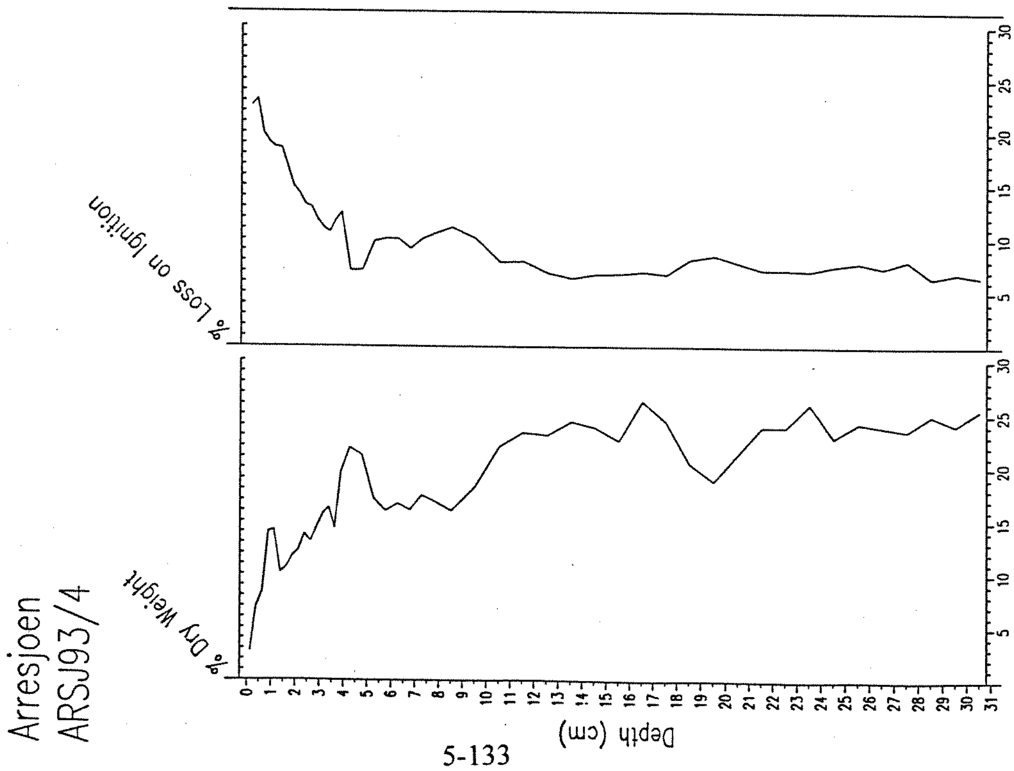


Figure 5. Birgervatnet 1 %DW & %LOI

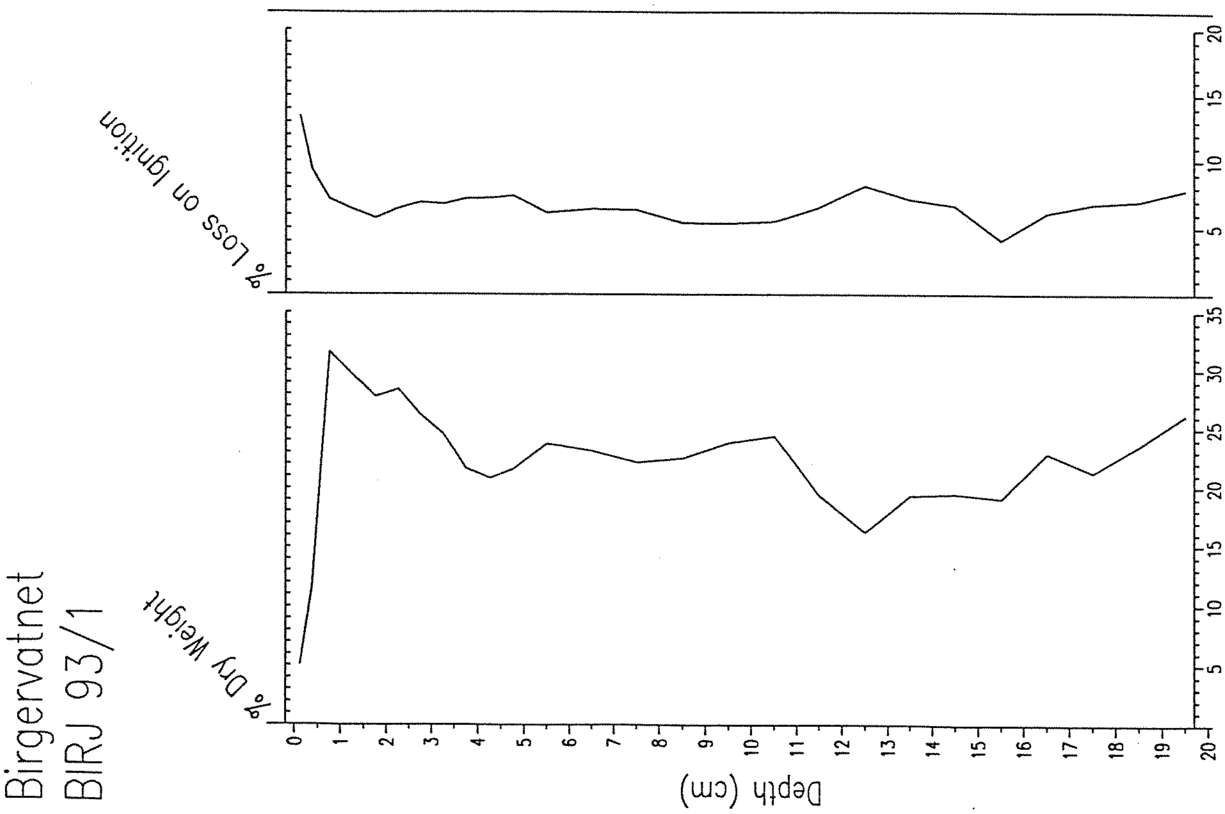


Figure 6. Birgervatnet 2 %DW & %LOI

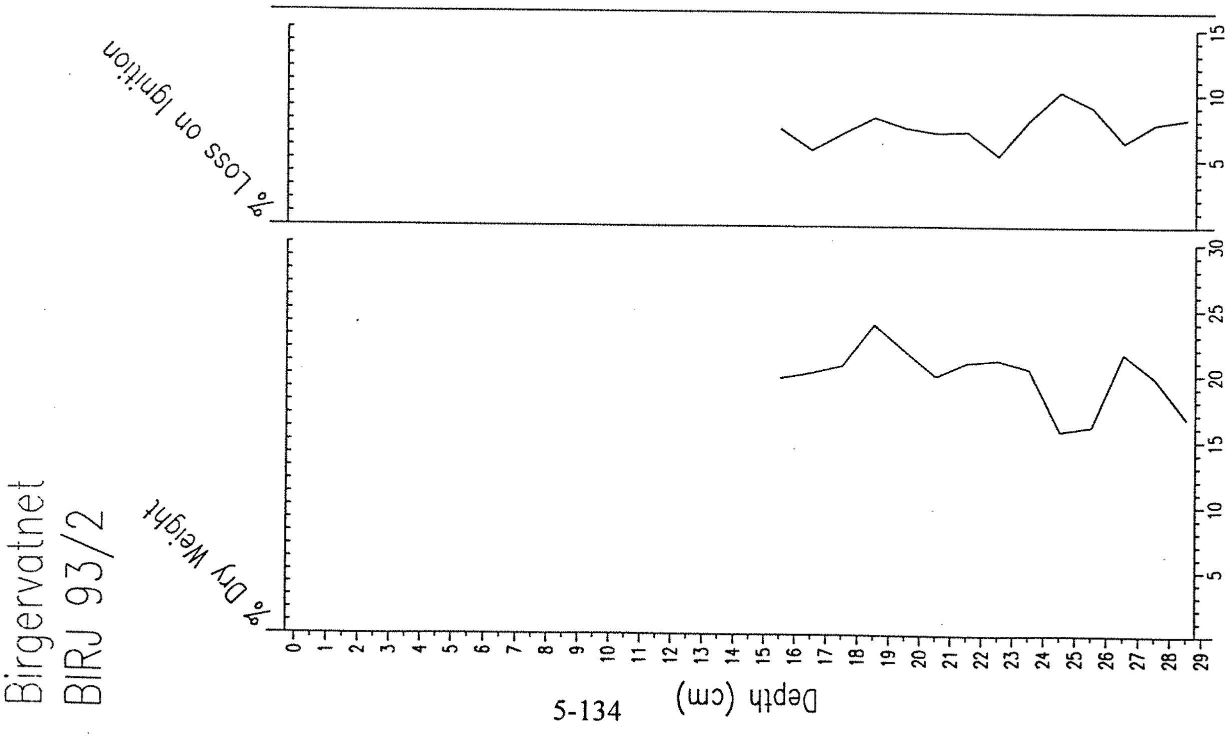


Figure 7. "Scurvy Pond" 1 %DW & %LOI

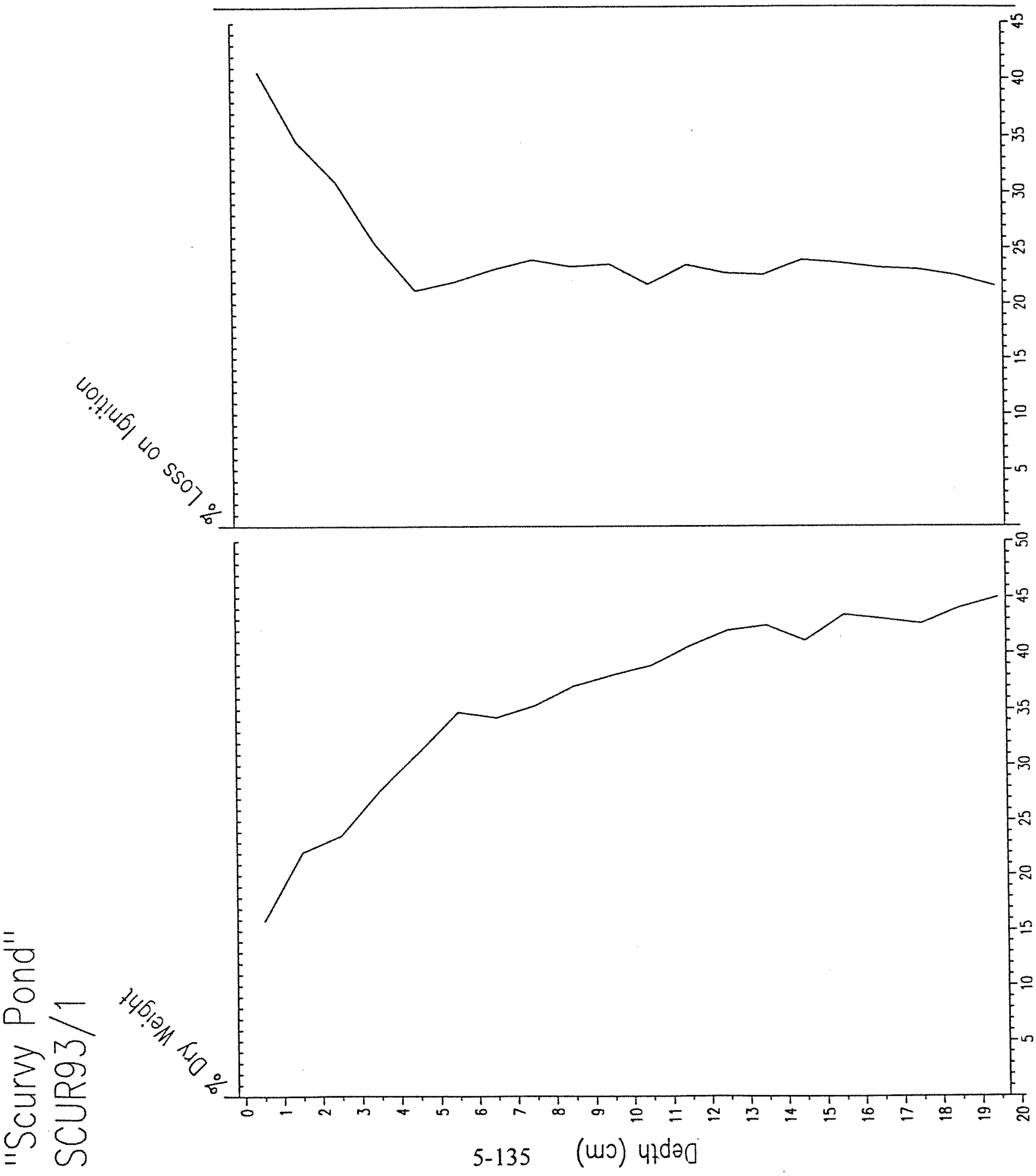


Figure 8. Arresjoen, summary % diatom diagram

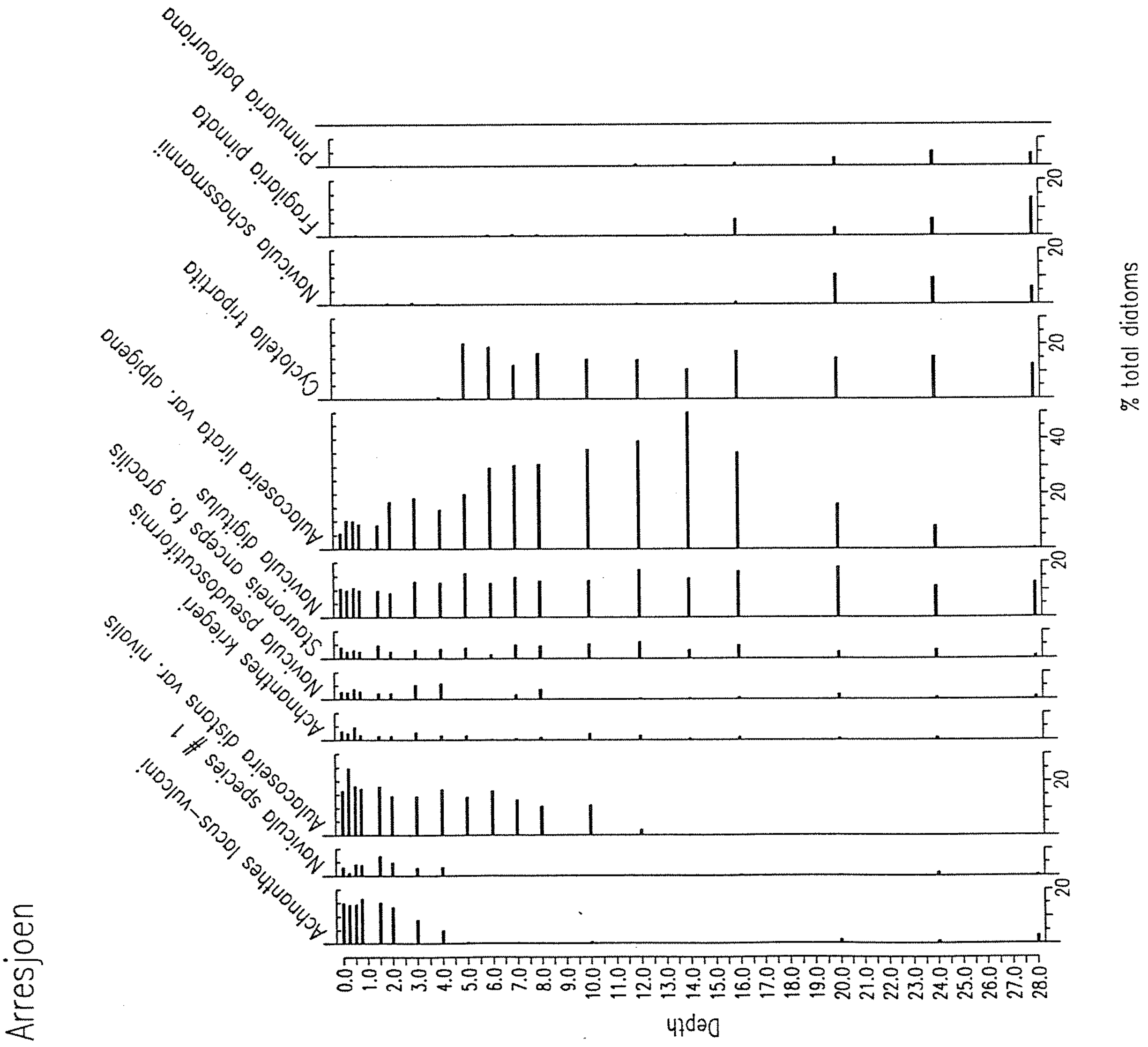


Figure 9. Arresjoen, diatom concentrations

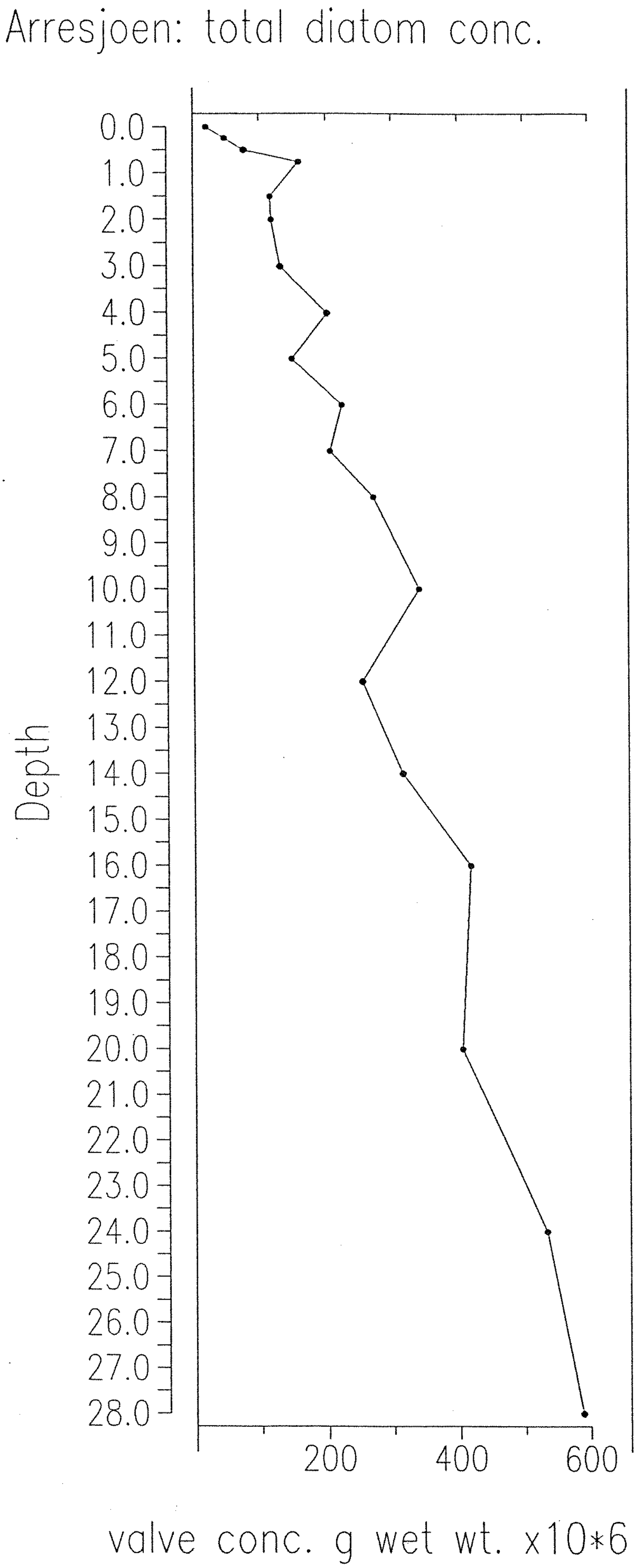


Figure 10. Arresjoen, number of taxa & number of chironomid head capsules

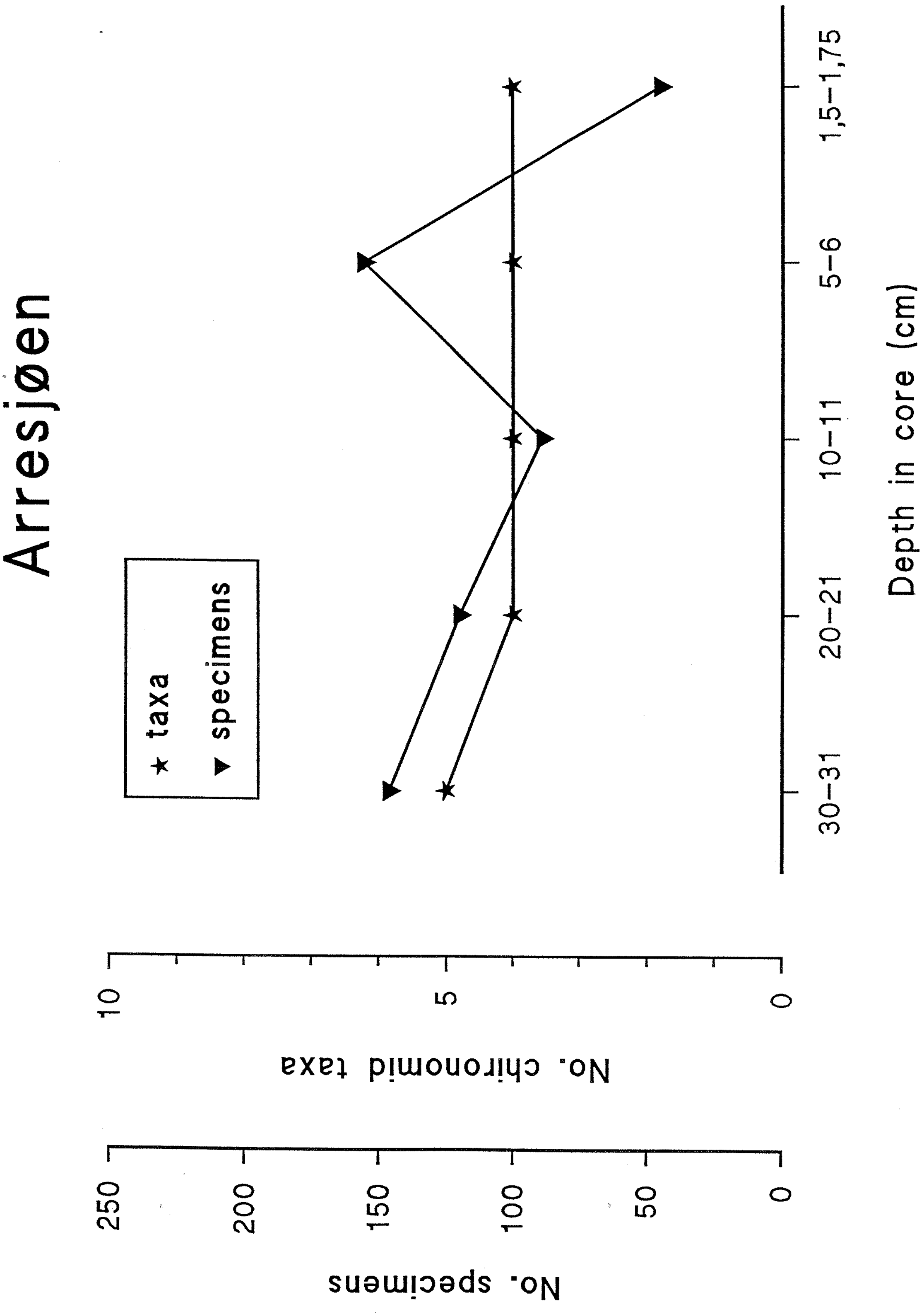


Figure 11. Arresjoen, relative abundances of 2 dominant chironomid species in the core

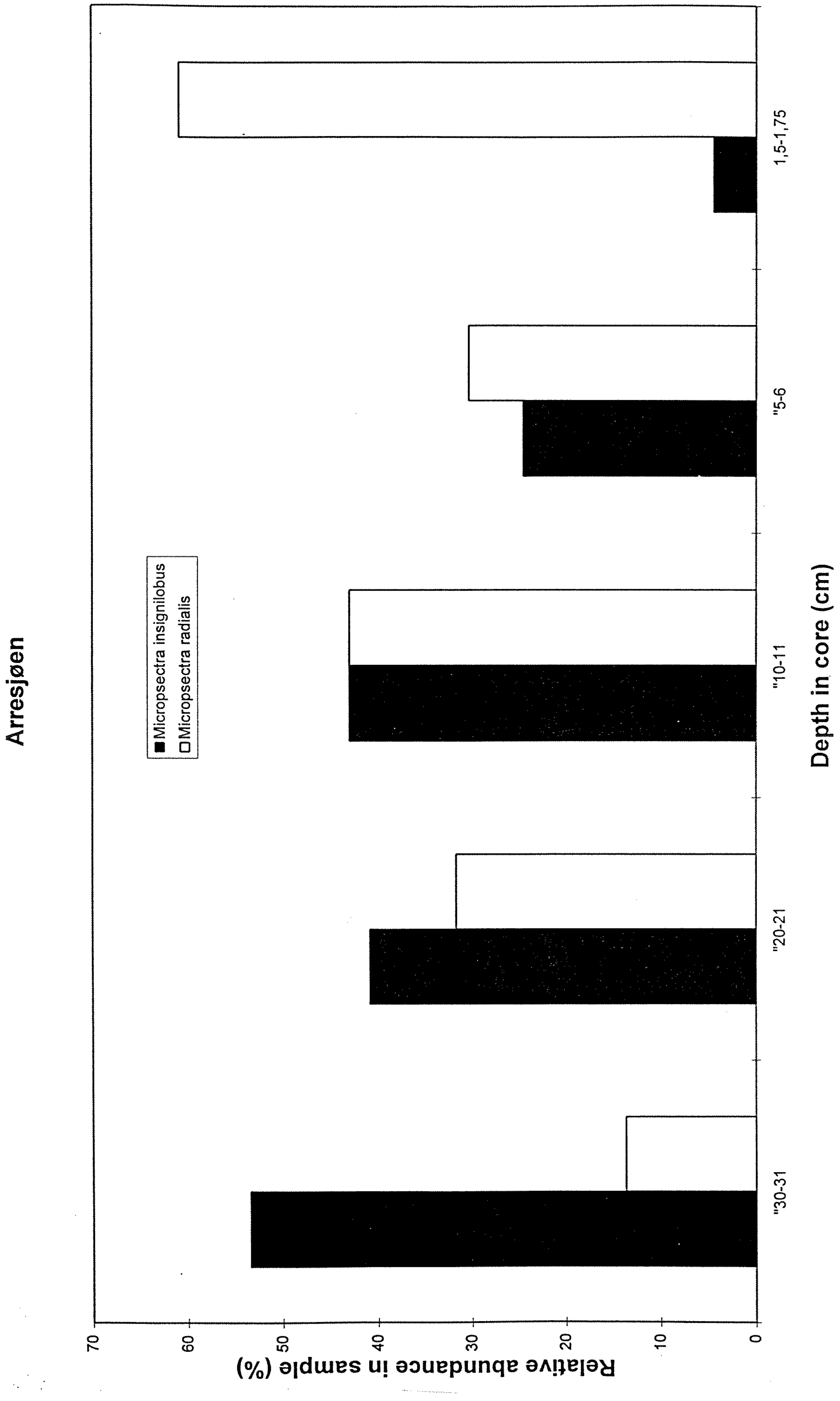


Figure 12. Lake Chuna, summary % diatom diagram

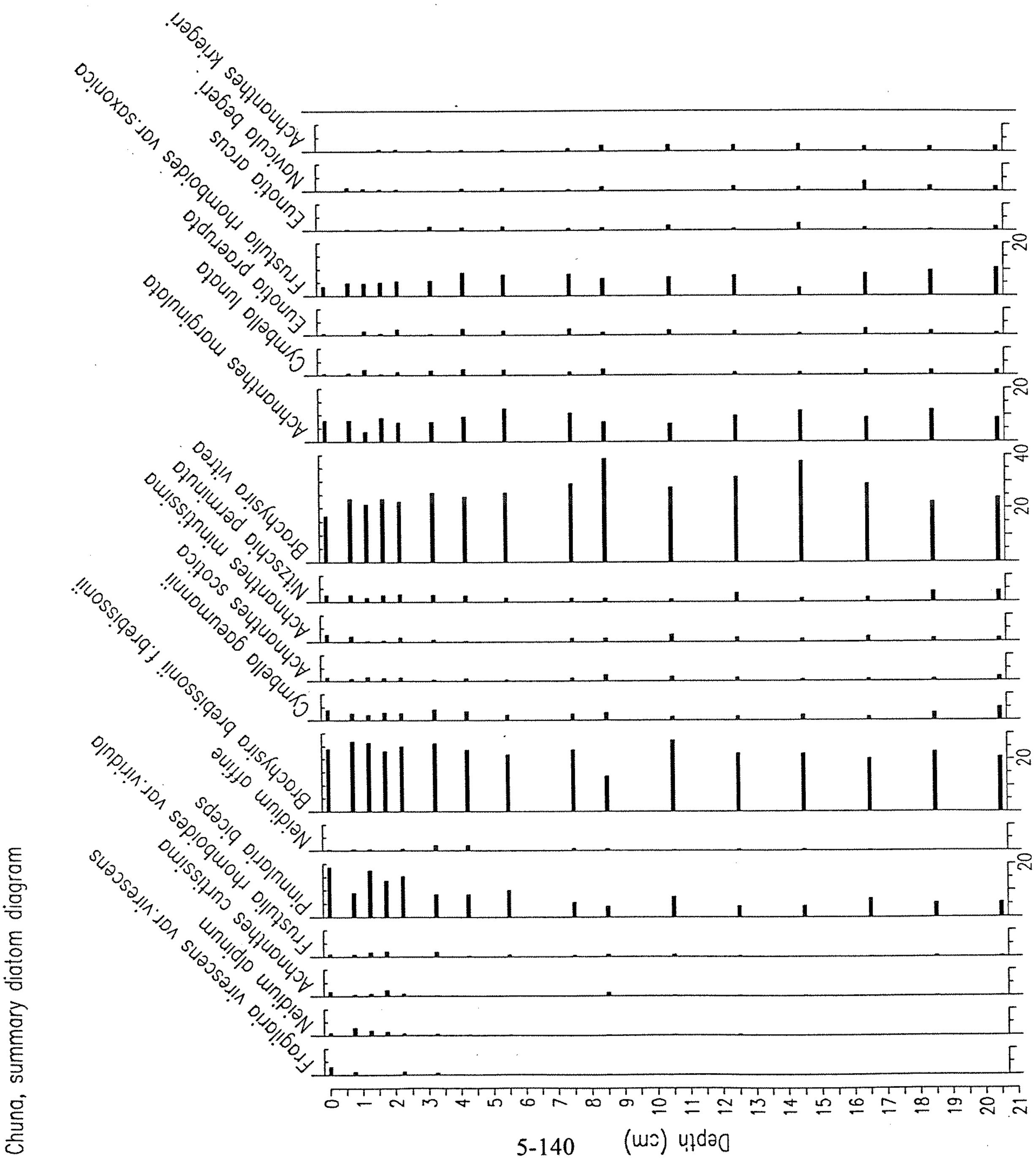


Figure 13. Lough Maam 93/1 %DW & %LOI

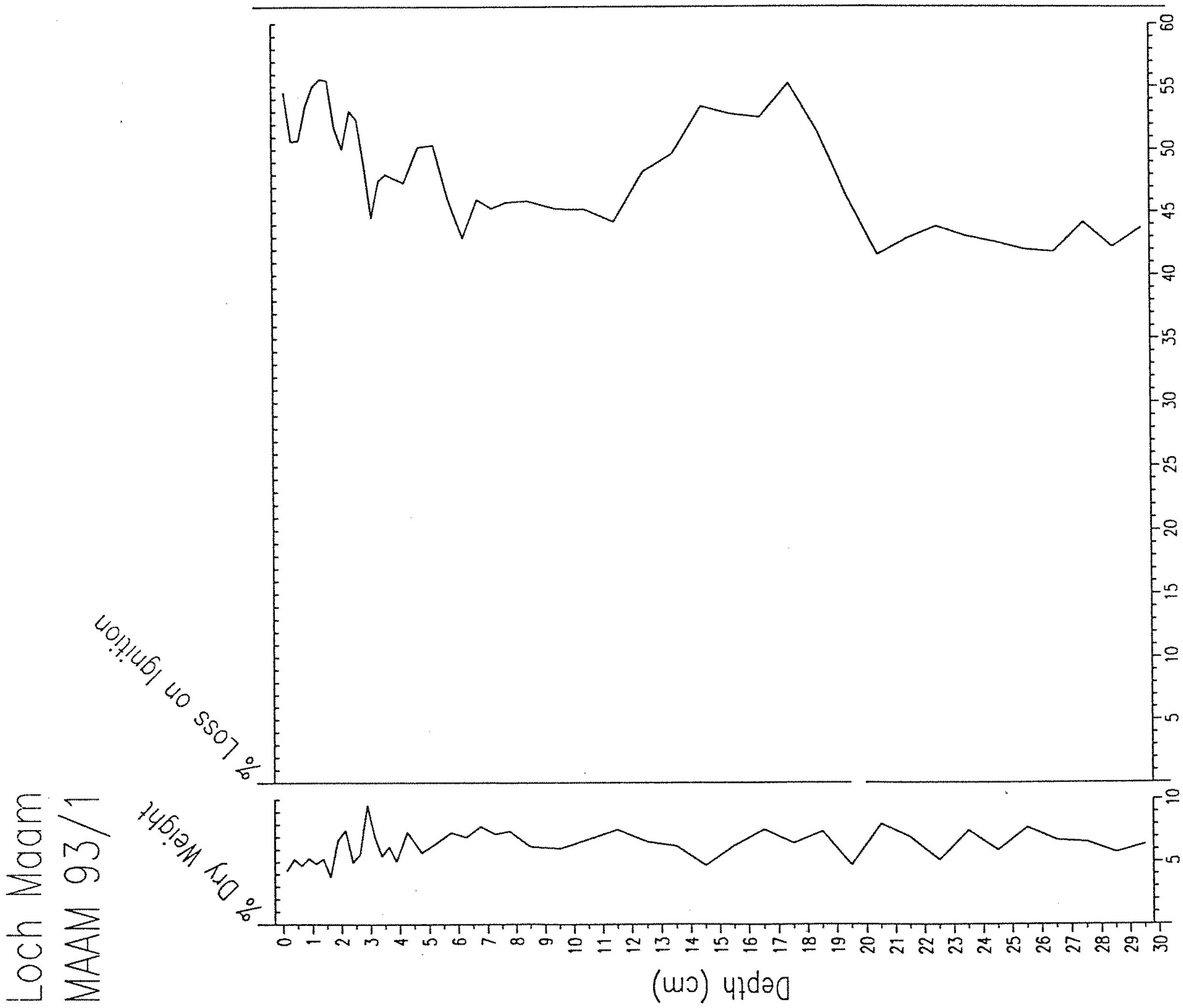


Figure 14. Lough Maam 93/2 %DW & %LOI

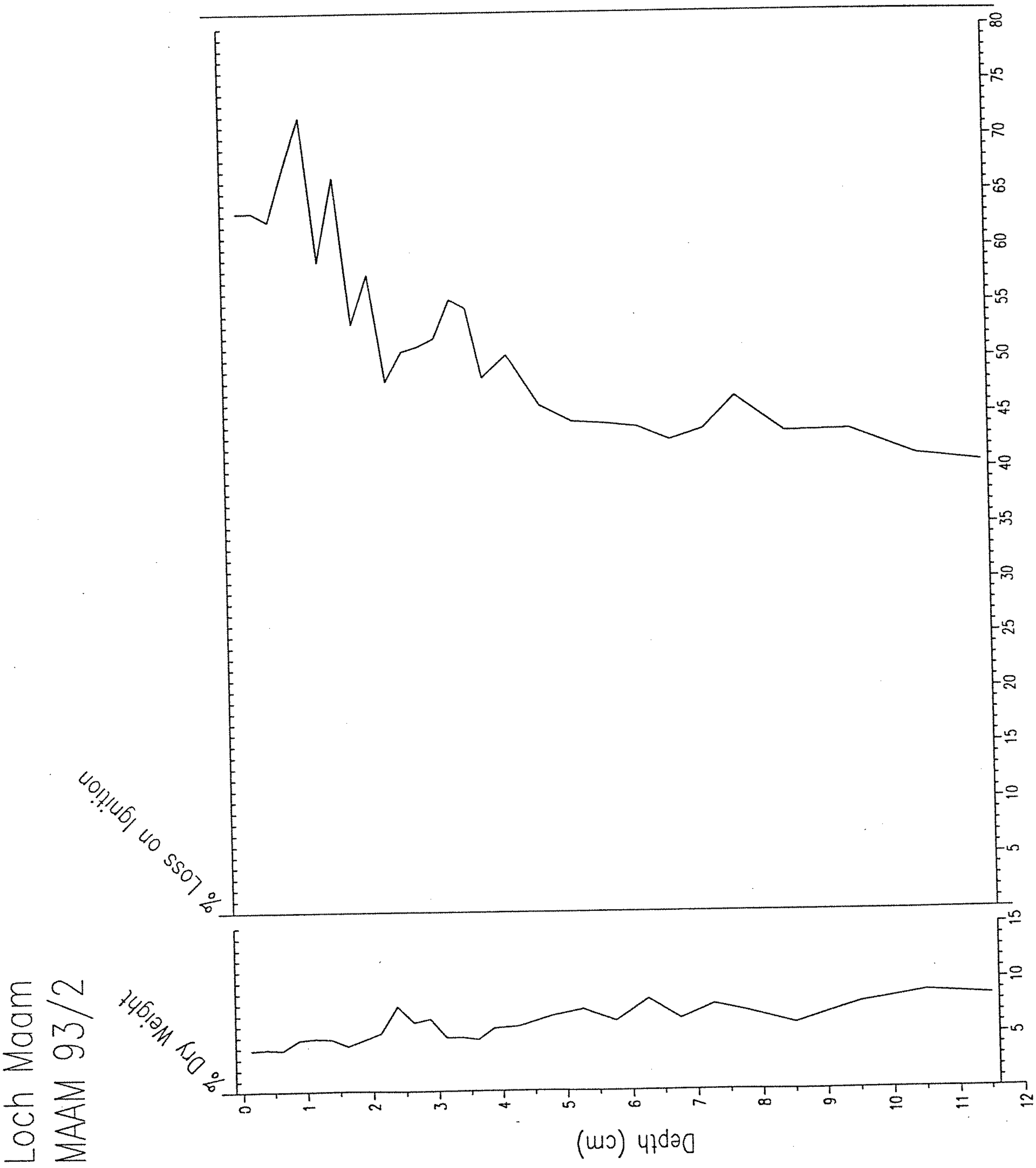


Figure 15. MAAM 93/1, summary % diatom diagram

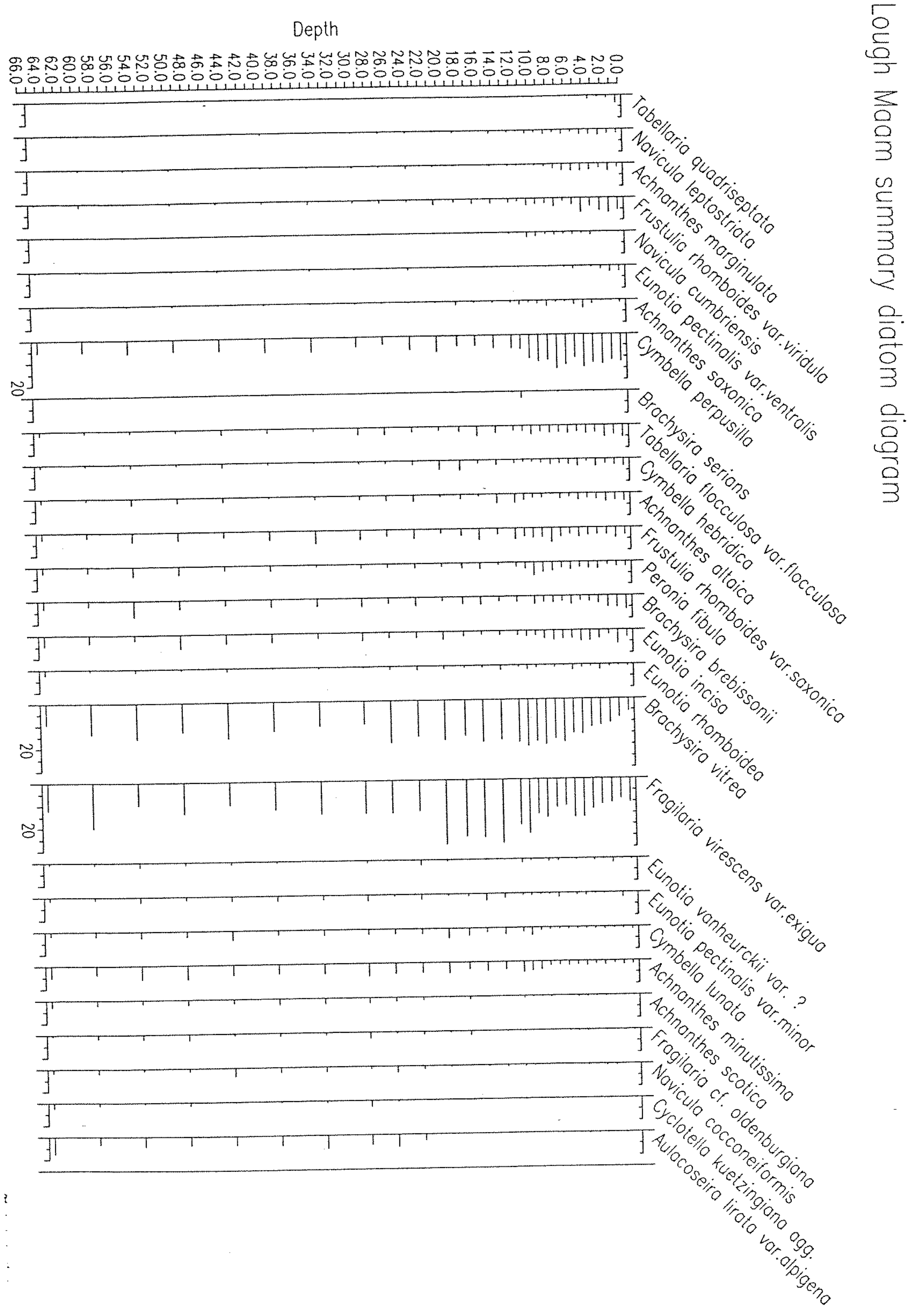


Figure 16. CALD 91/1 %DW & %LOI

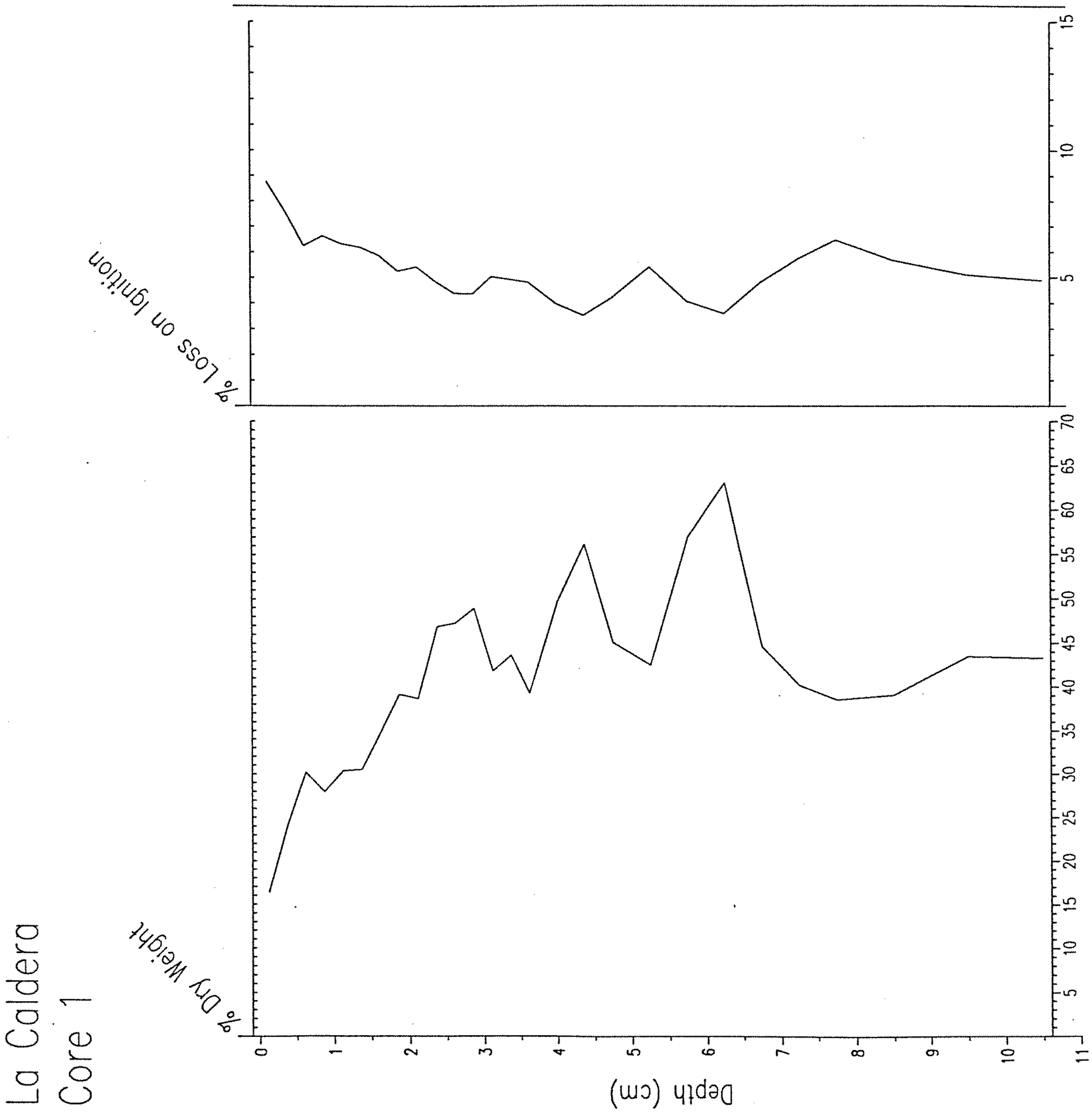


Figure 17. CALD 91/1, summary % diatom diagram

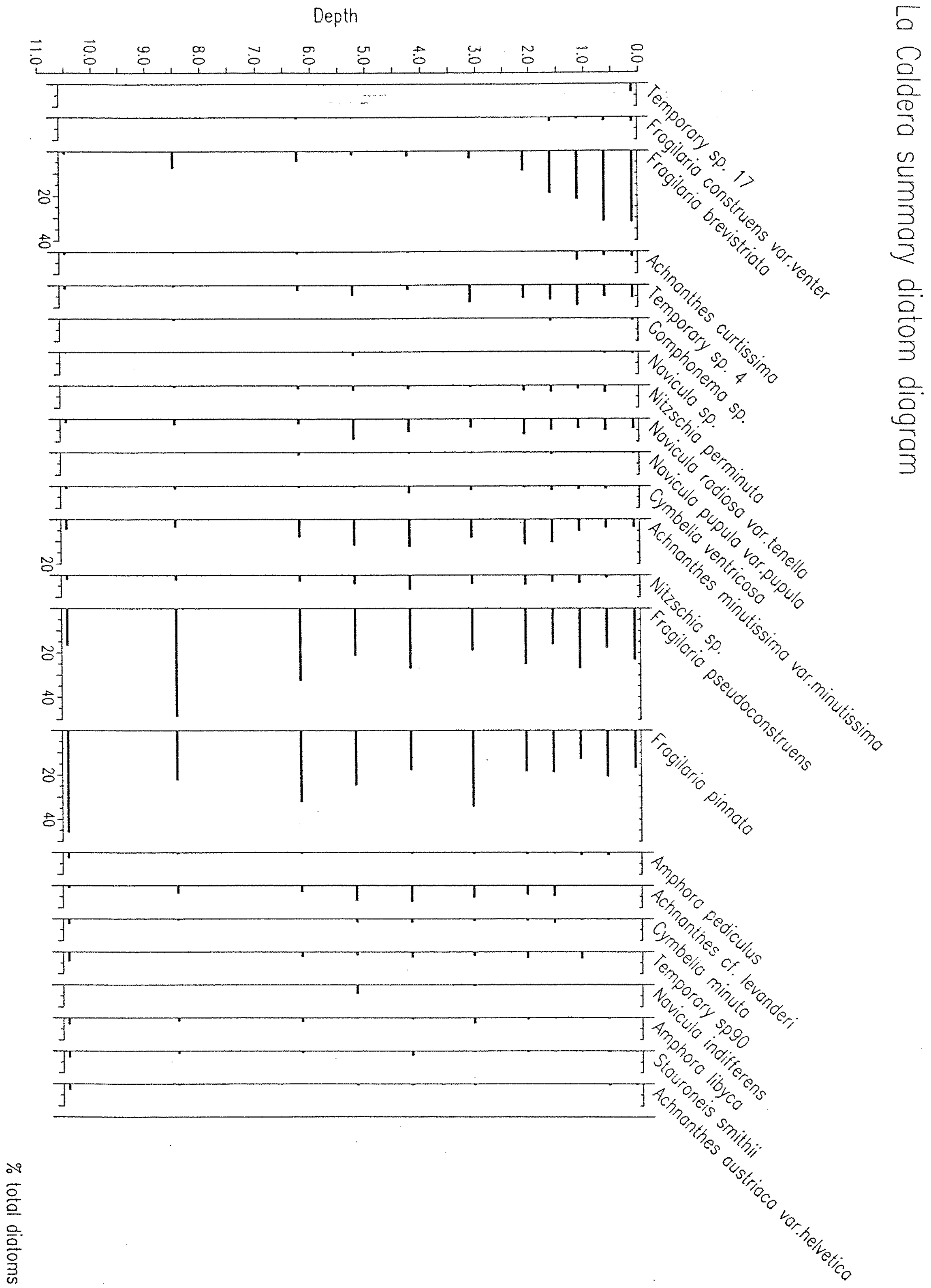


Figure 18a. CIME 93/1 %LOI

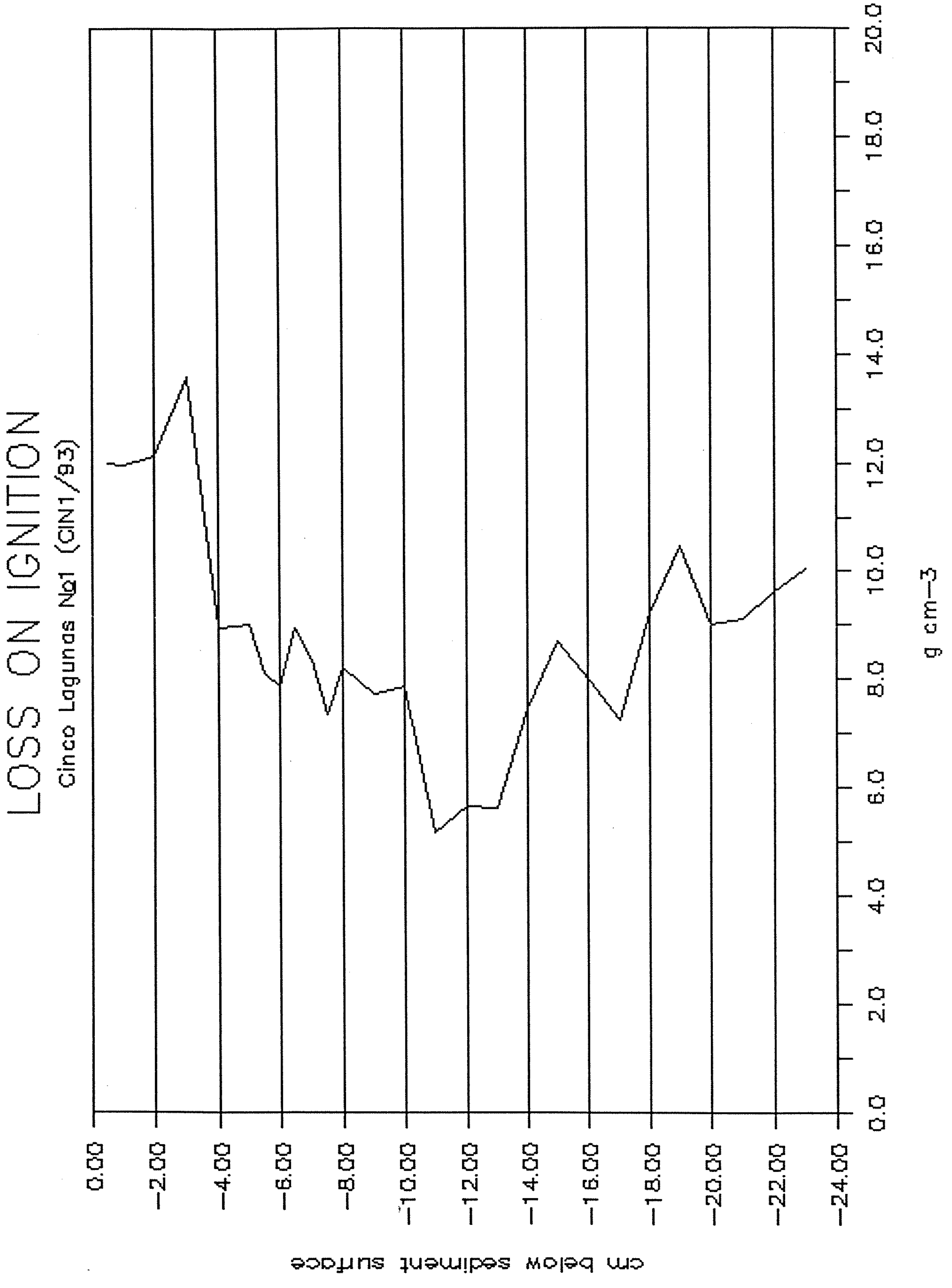


Figure 18b. CIME 93/1 %DW

Figure 19. CIME 93/1 summary % diatom diagram

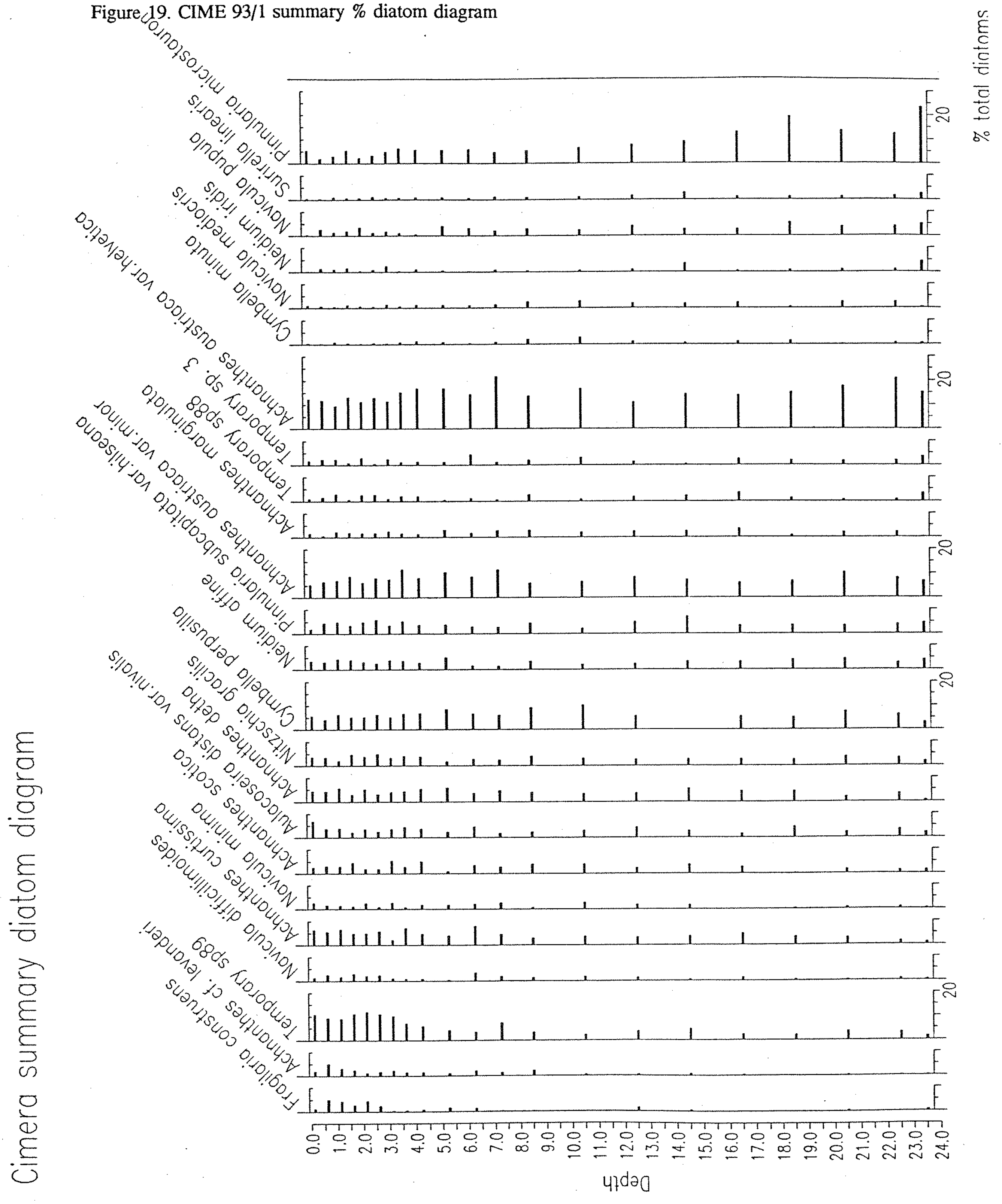


Figure 20. ESCU 93/1 %DW & %LOI

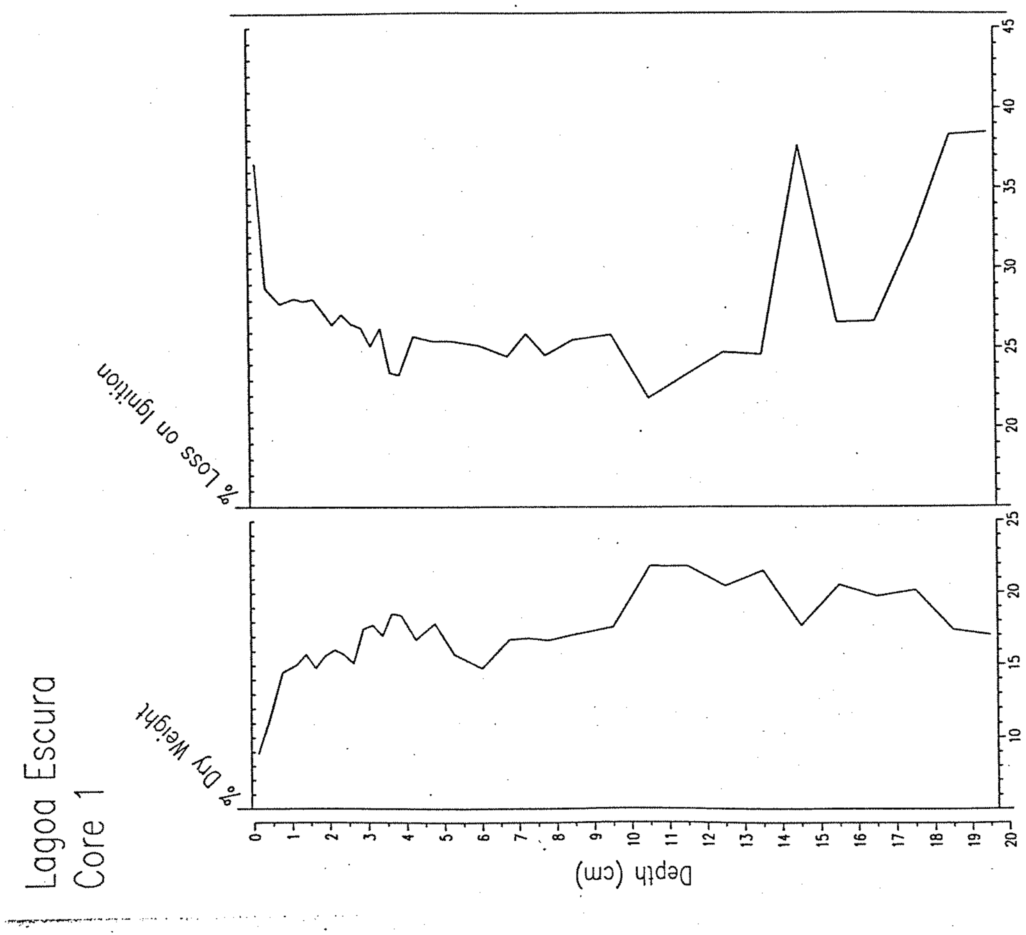


Figure 21. ESCU 93/2 %DW & %LOI

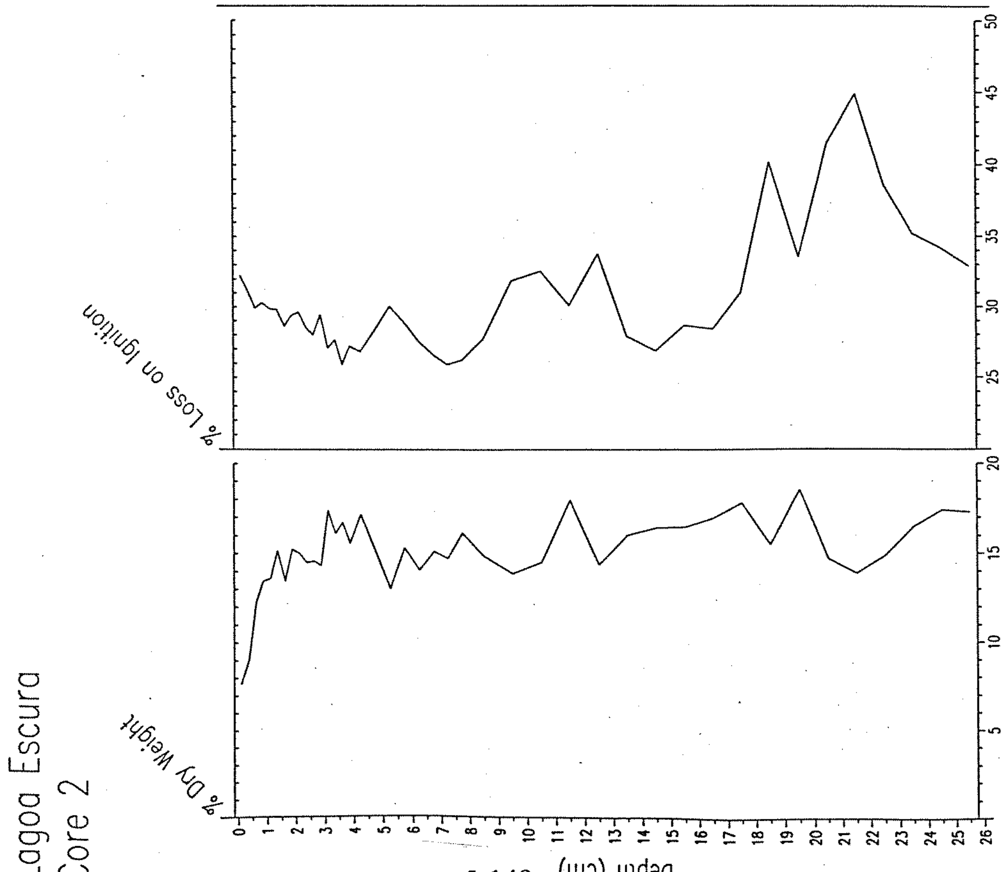


Figure 22. ESCU 93/3 %DW & %LOI

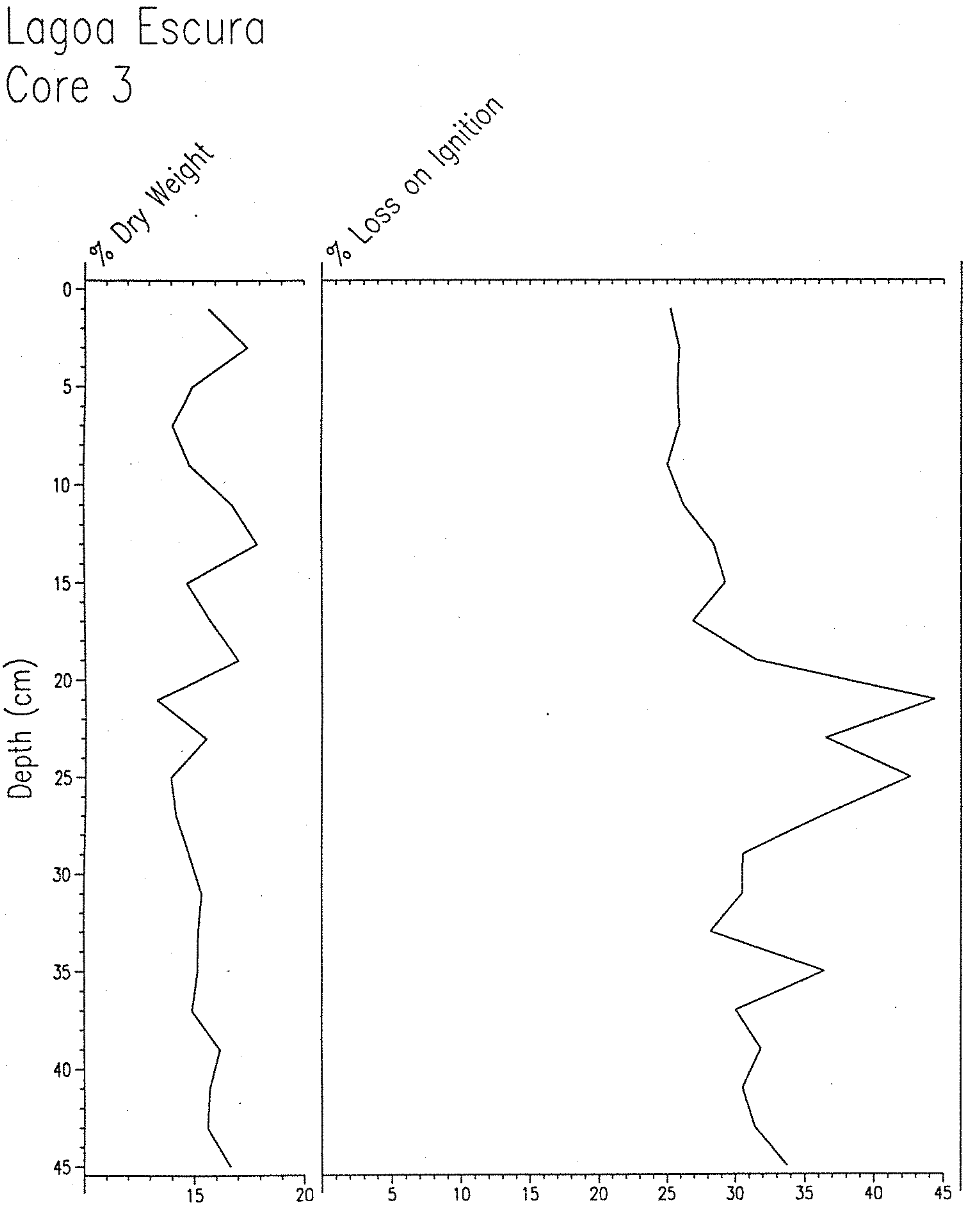


Figure 23. ESCU, summary % diatom diagram

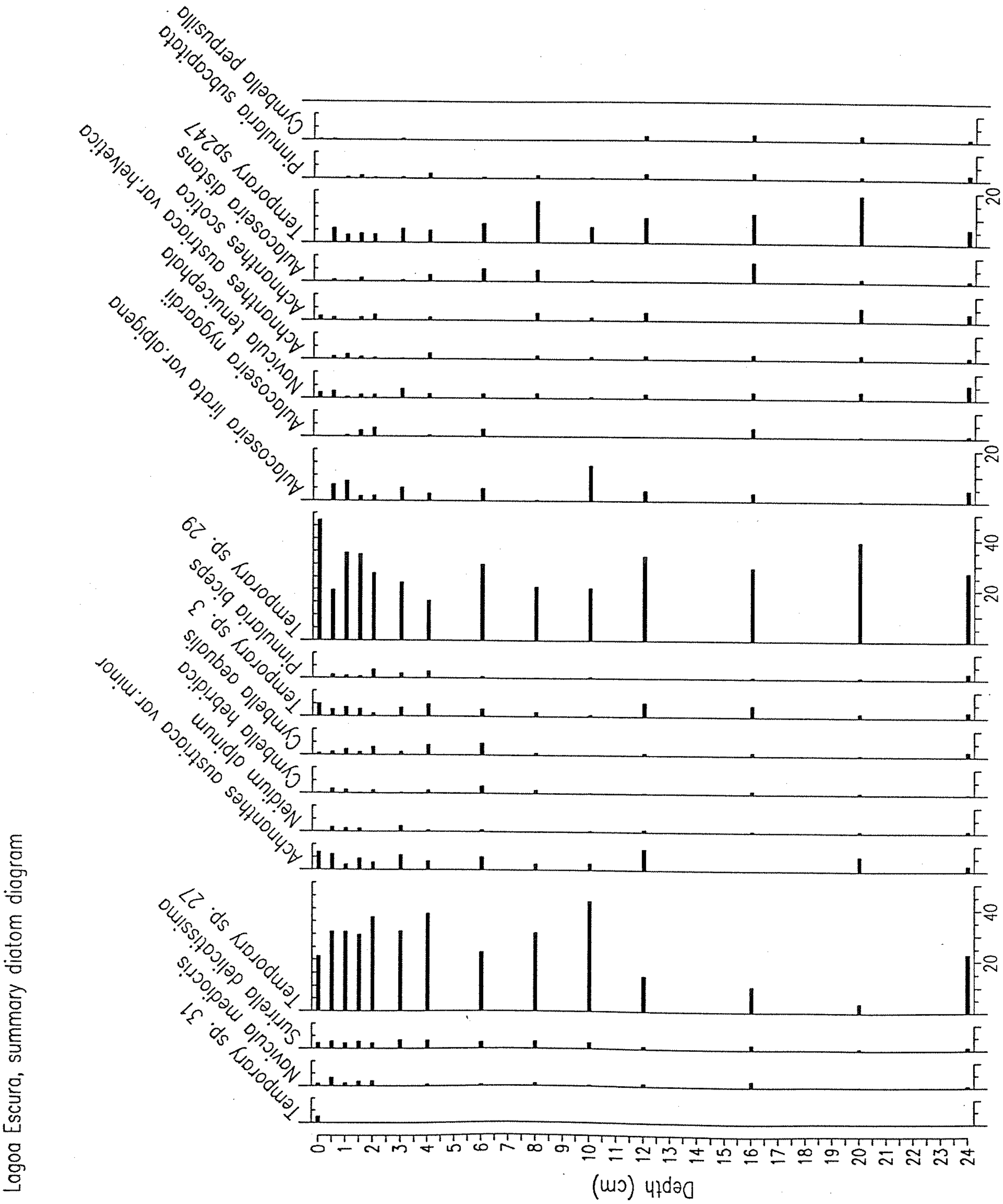


Figure 24. ESCU, number of taxa & number of chironomid head capsules

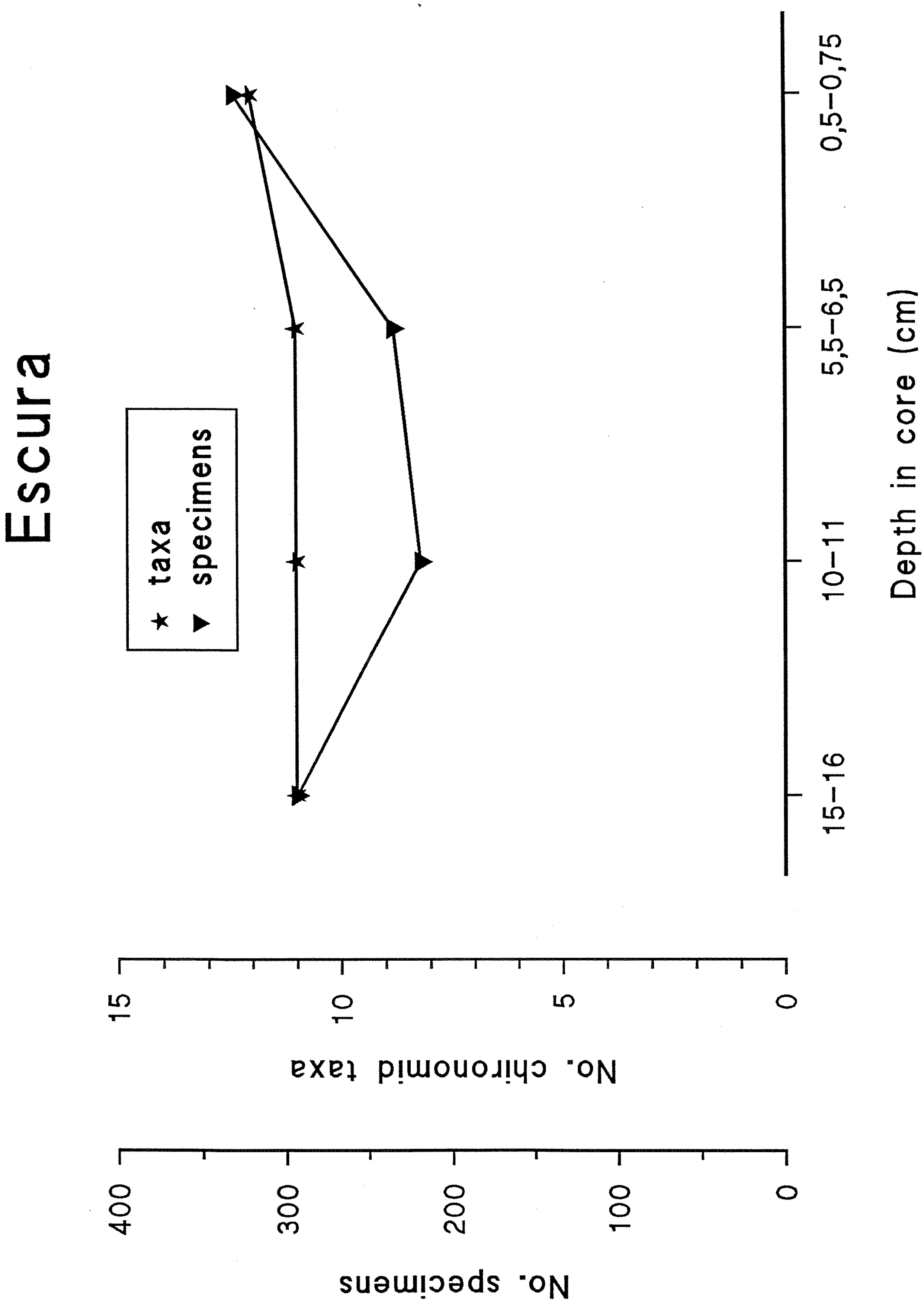


Figure 25. ESCU, relative abundaces of the 2 dominant chironomid species in the core

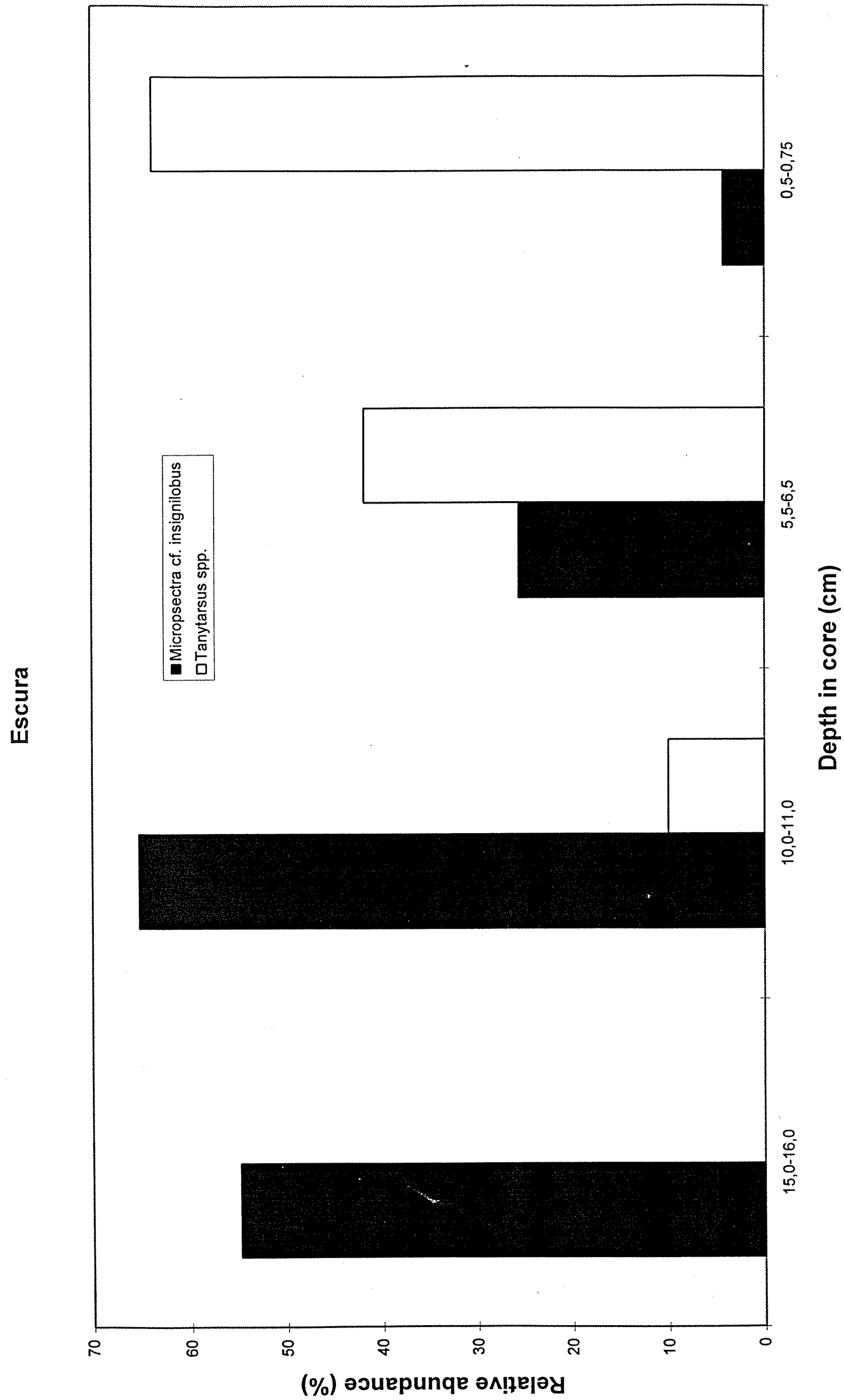


Figure 26. REDO, 93/1 %DW & %LOI

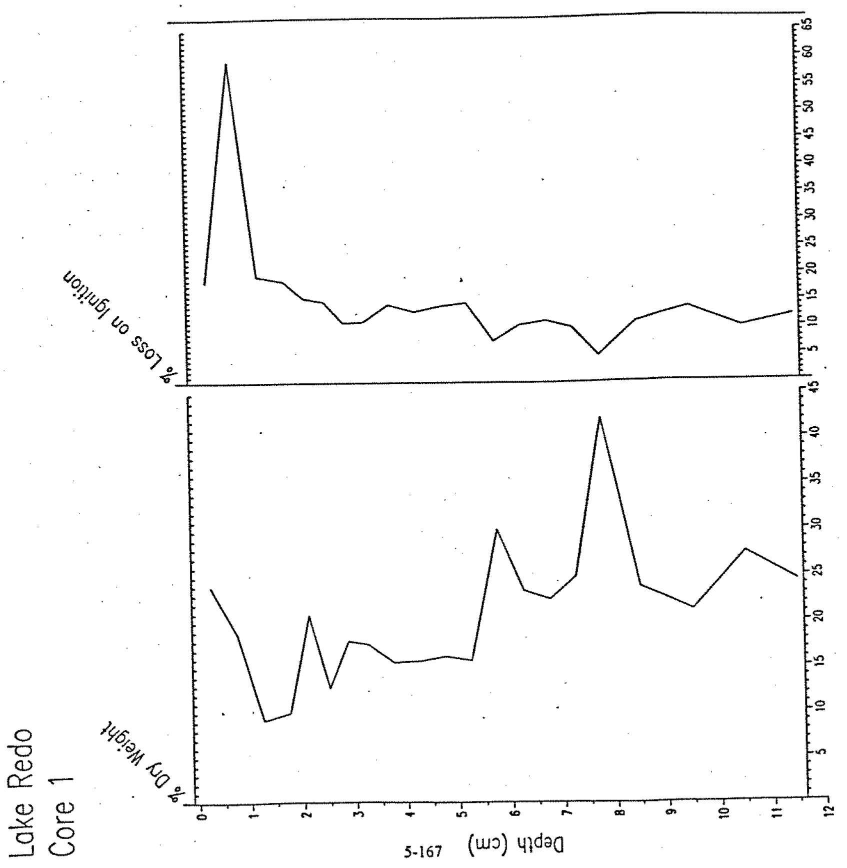


Figure 27. REDO, 93/2 %DW & %LOI

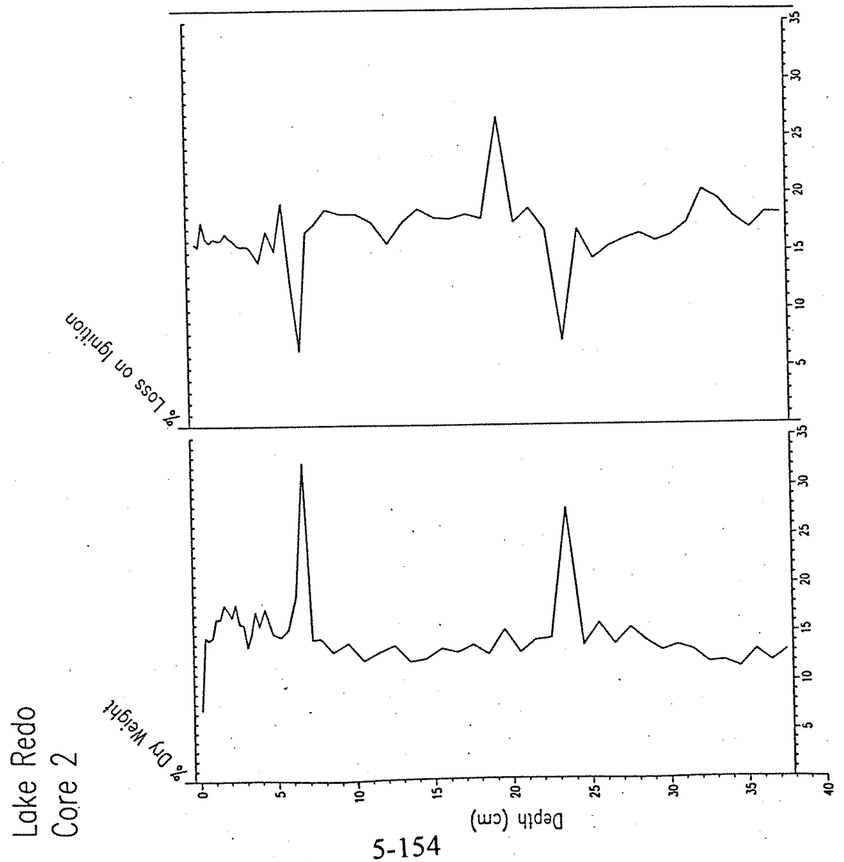


Figure 28. REDO, 93/3 %DW & %LOI

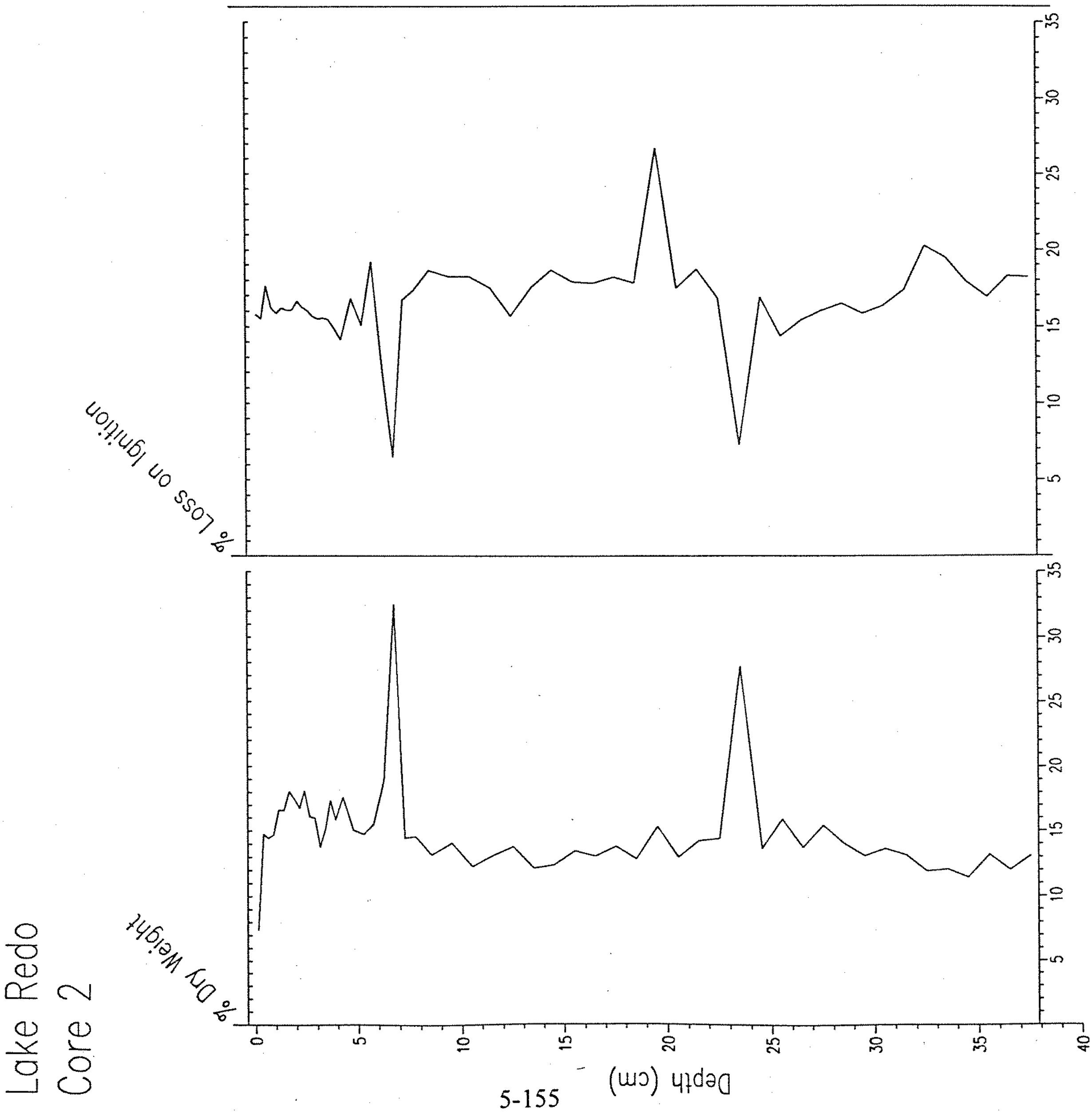


Figure 29. REDO, summary % diatom diagram

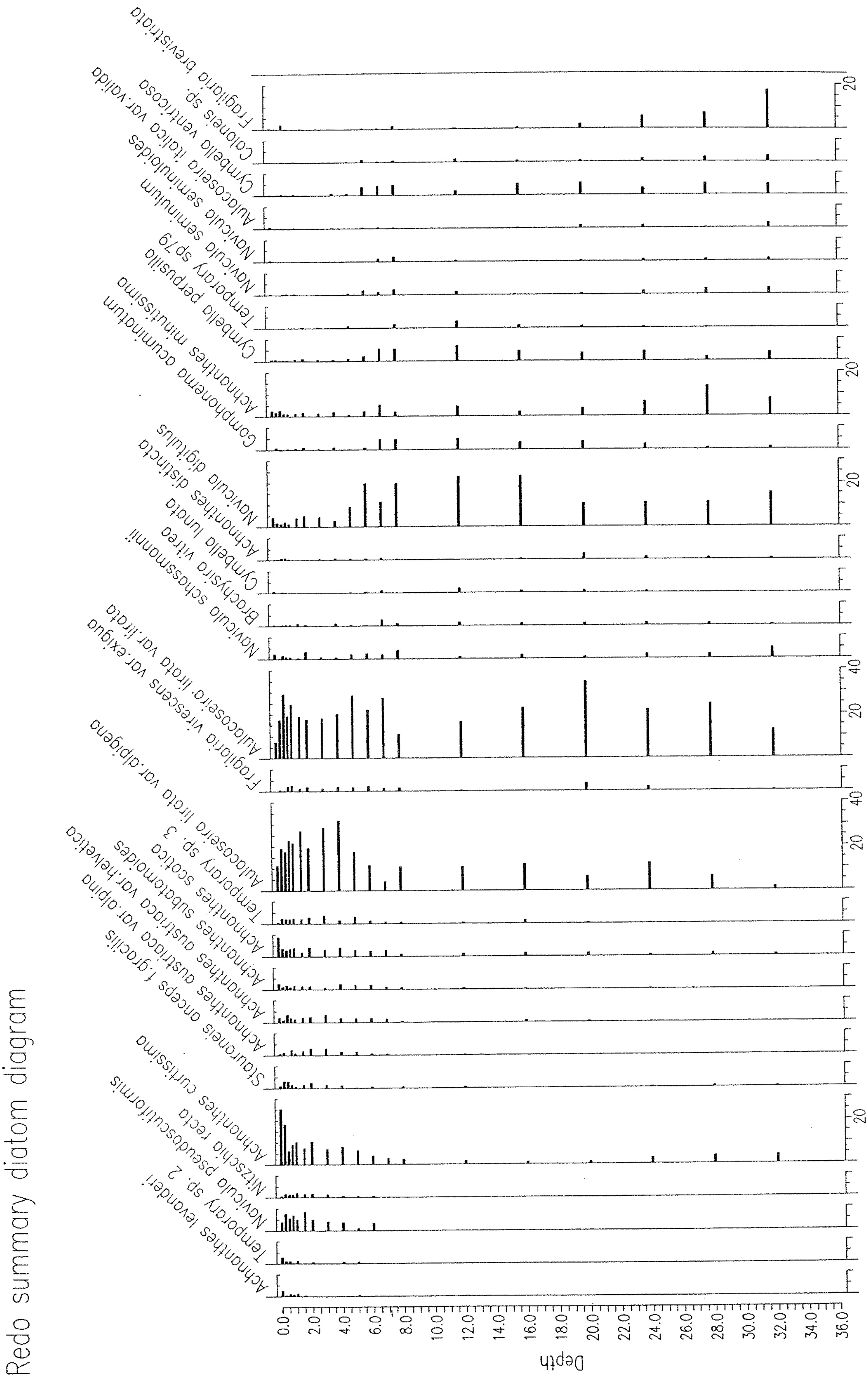


Figure 30. REDO, number of chironomid taxa and individuals recorded in the core

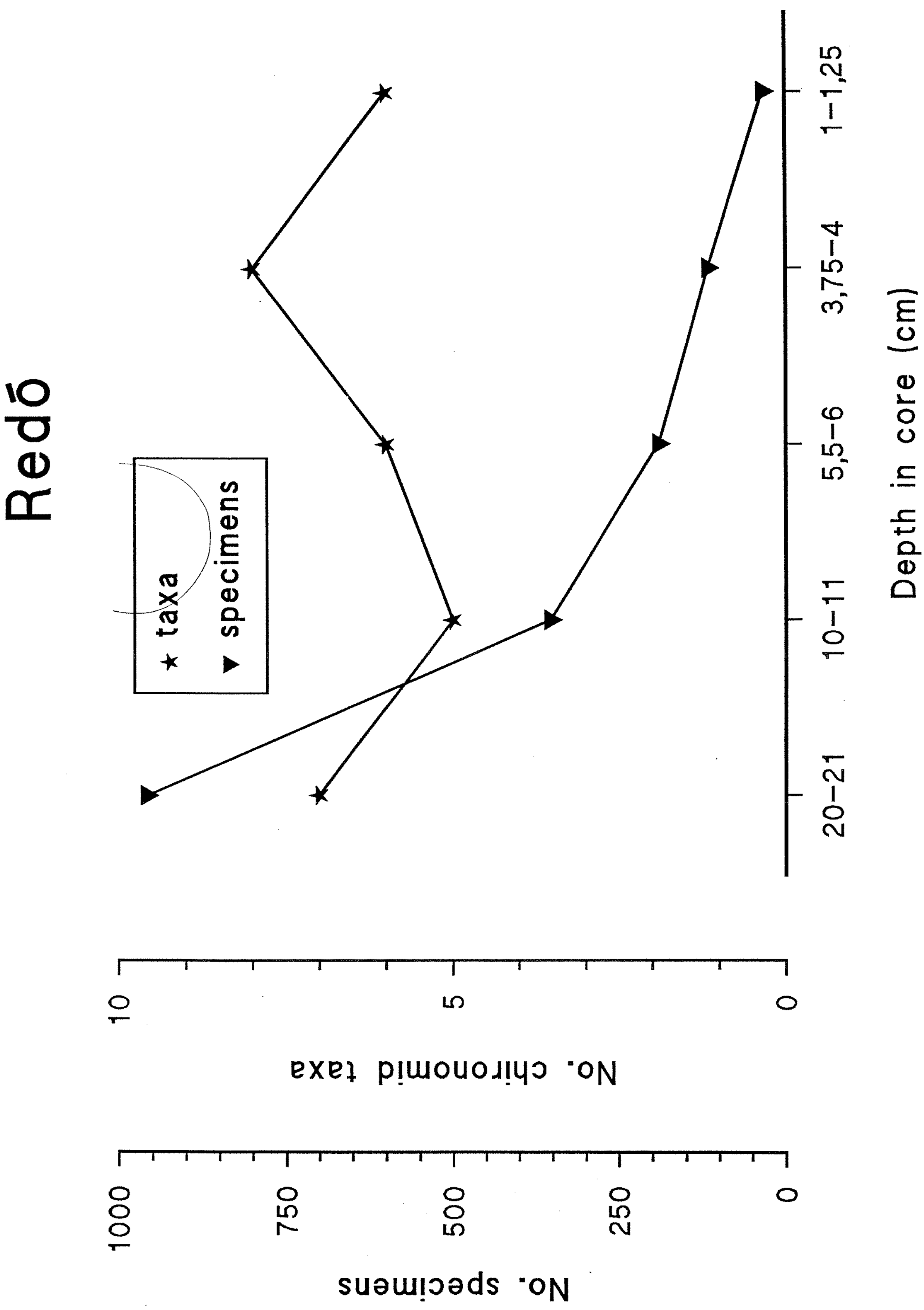


Figure 31. NOIR, 93/1 %DW & %LOI

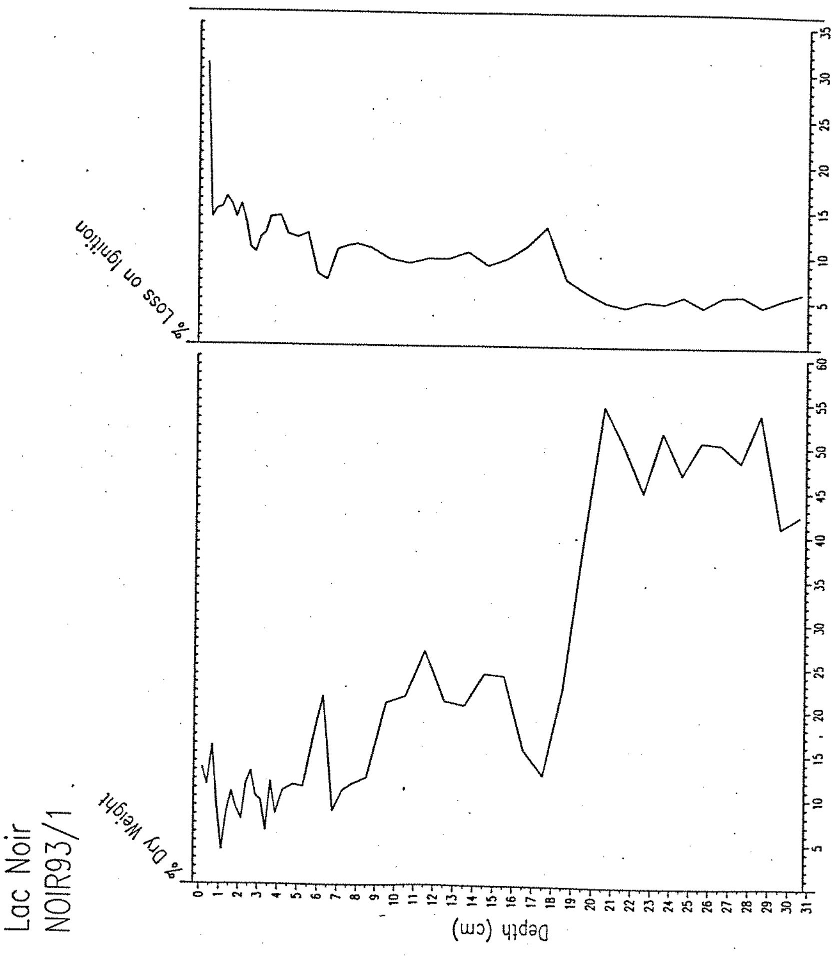


Figure 32. NOIR, 93/2 %DW & %LOI

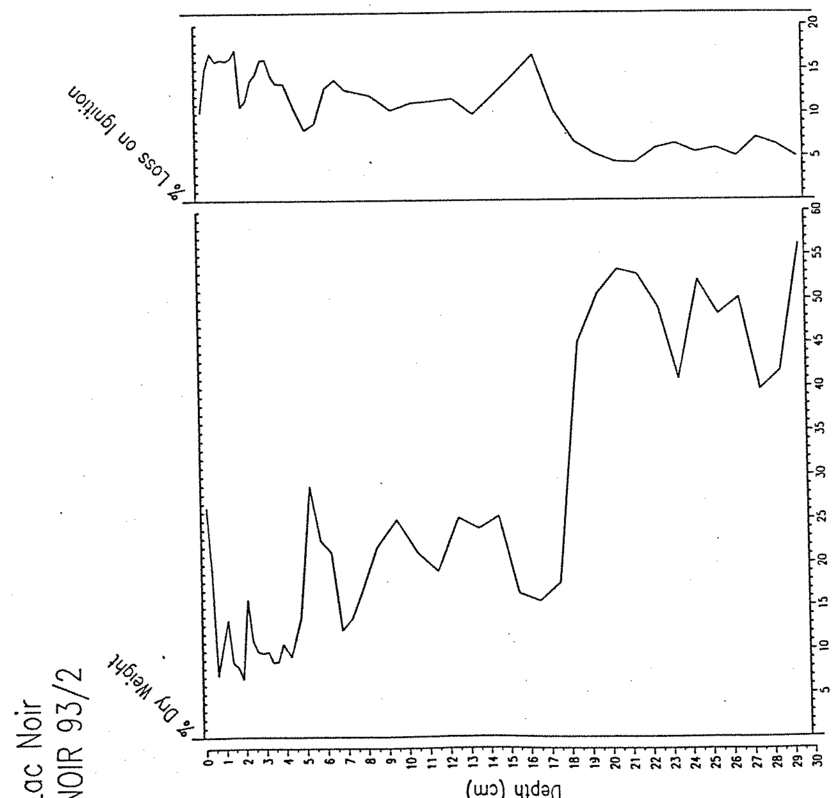


Figure 33. NOIR, 93/3 %DW & %LOI

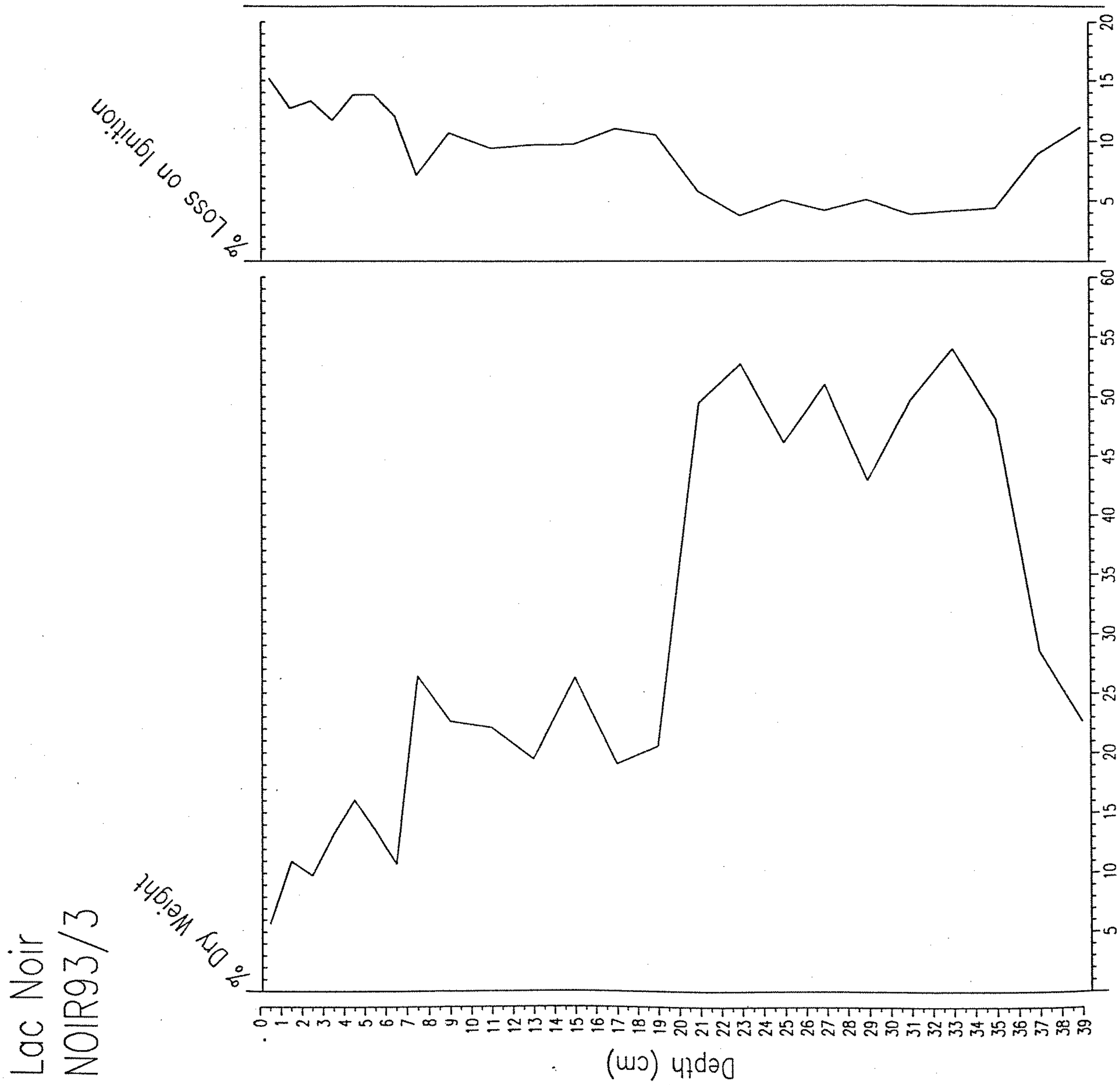


Figure 34. NOIR, summary % diatom diagram

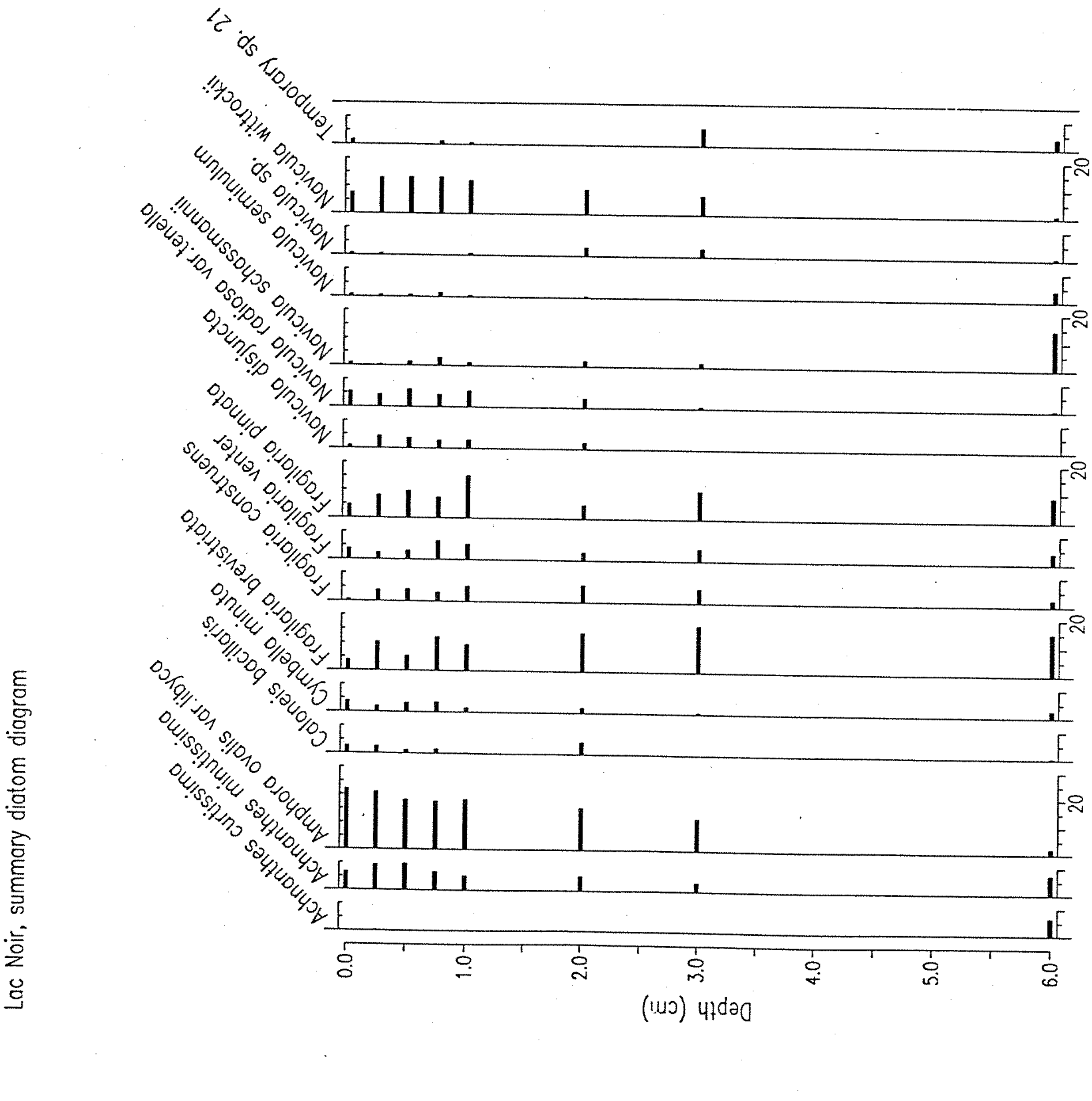


Figure 35. ZKJZ, 94/1 %DW & %LOI

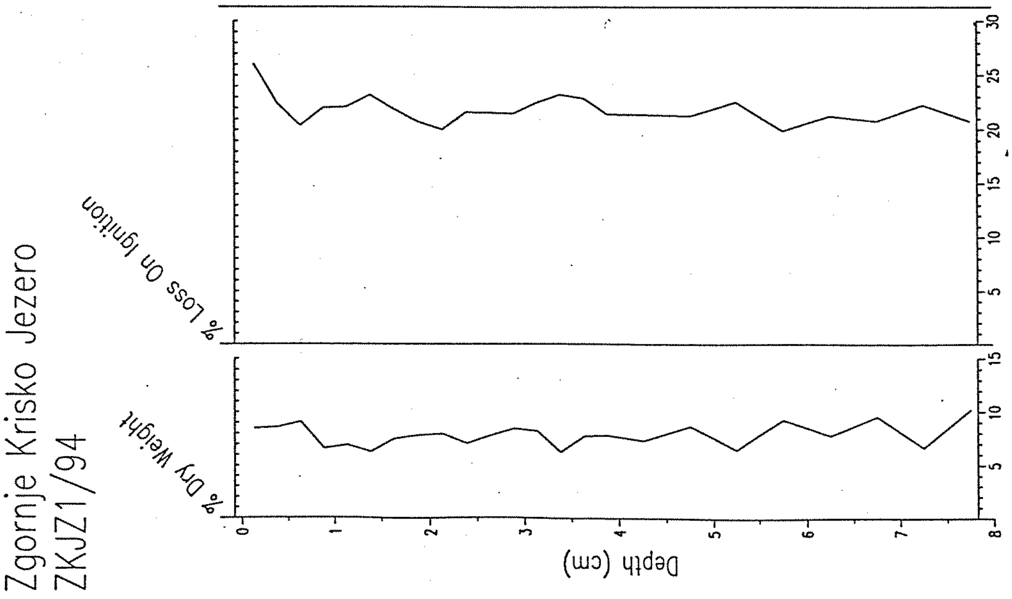


Figure 36. ZKJZ, 94/2 %DW & %LOI

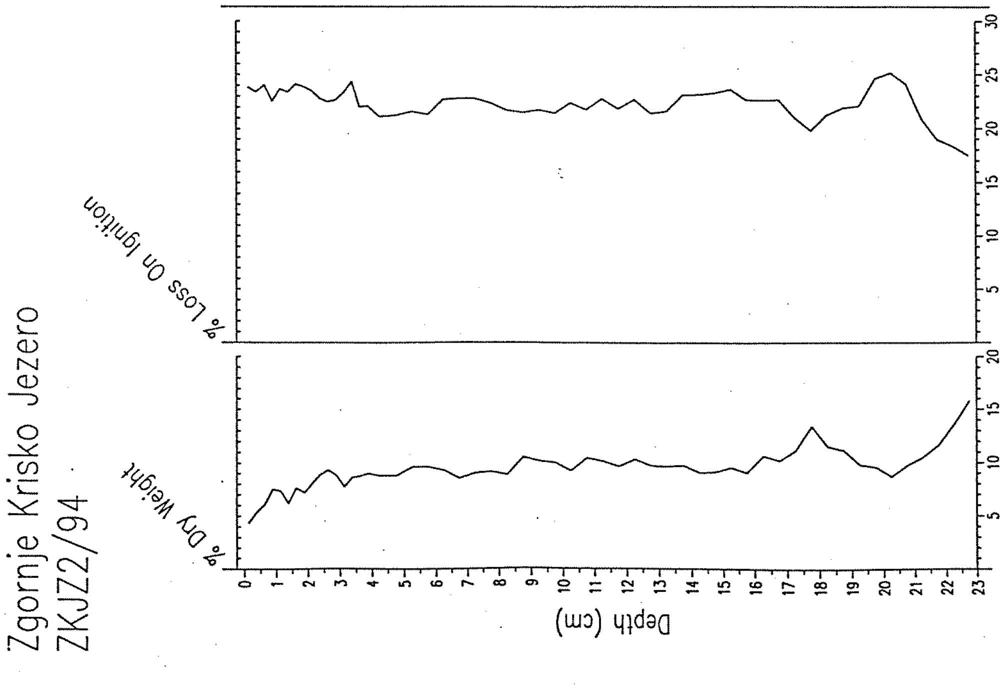


Figure 37. ZKJZ, 94/3 %DW & %LOI

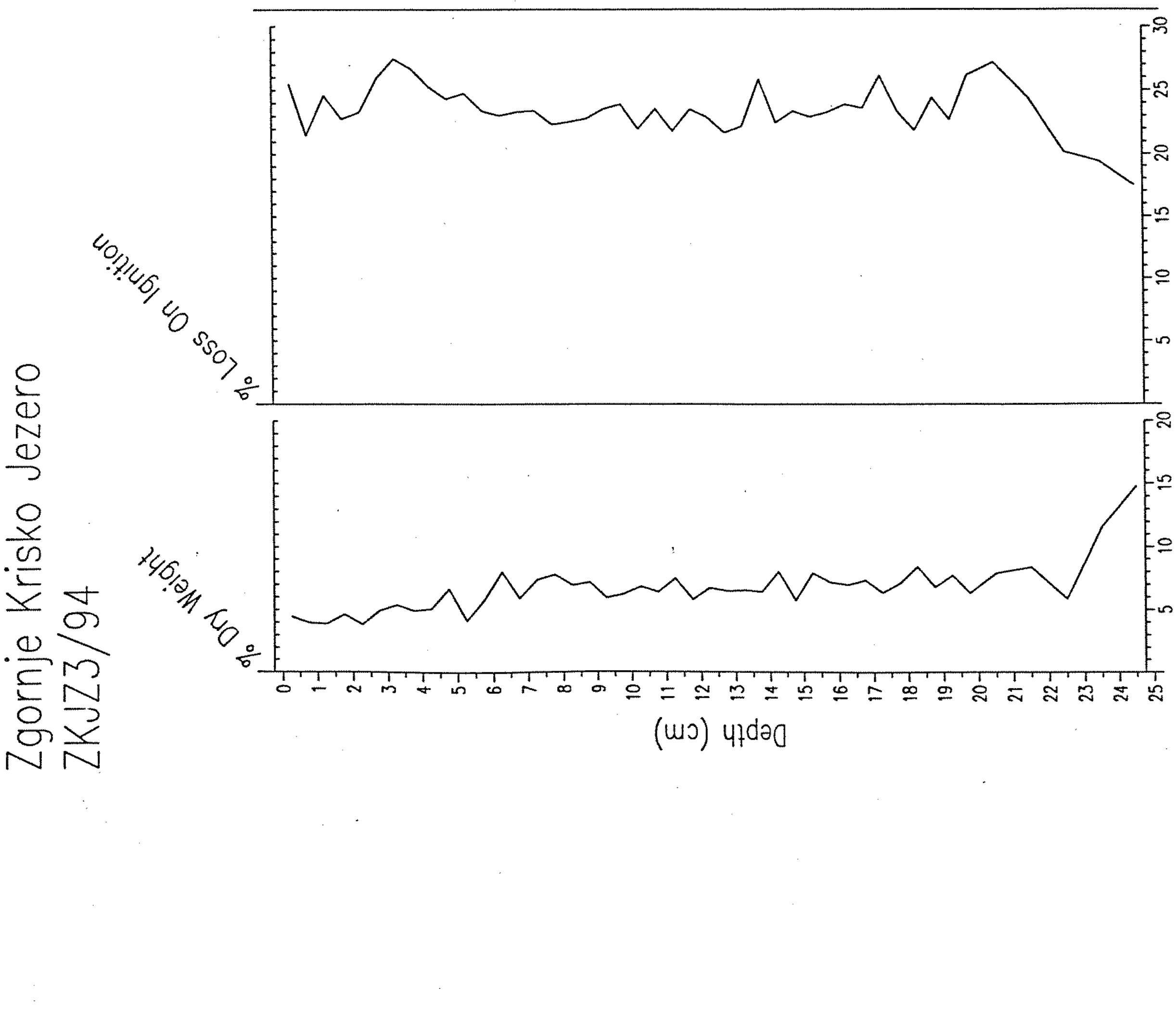


Figure 38. ZKJZ 94/2, summary % diatom diagram

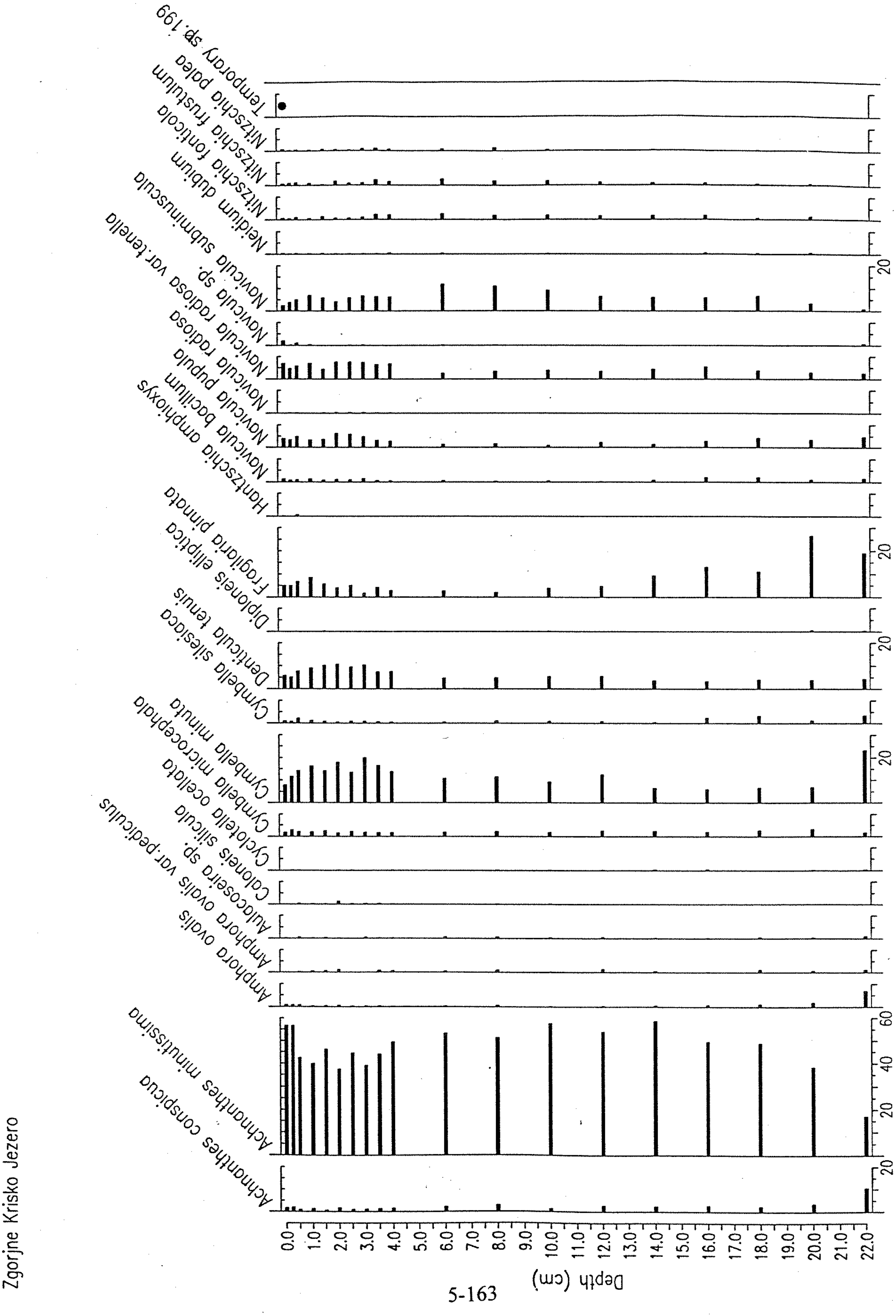
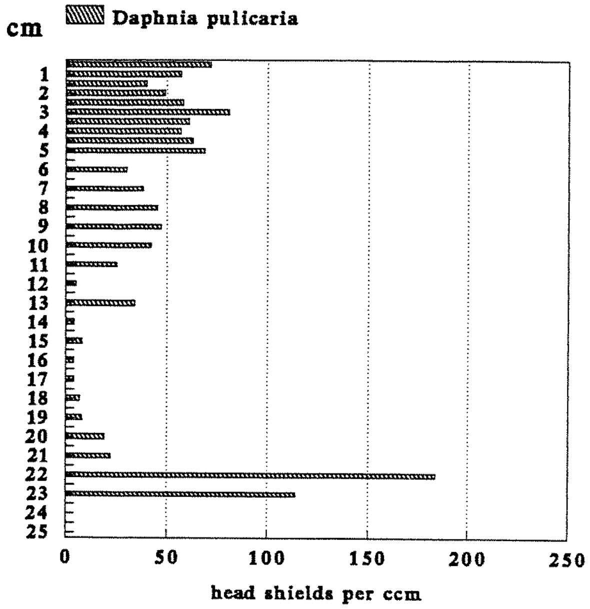


Figure 39. ZKJZ , stratigraphy of the 2 species of cladocerans in the core



Zgornje Krisko jezero
remains of CLADOCERA

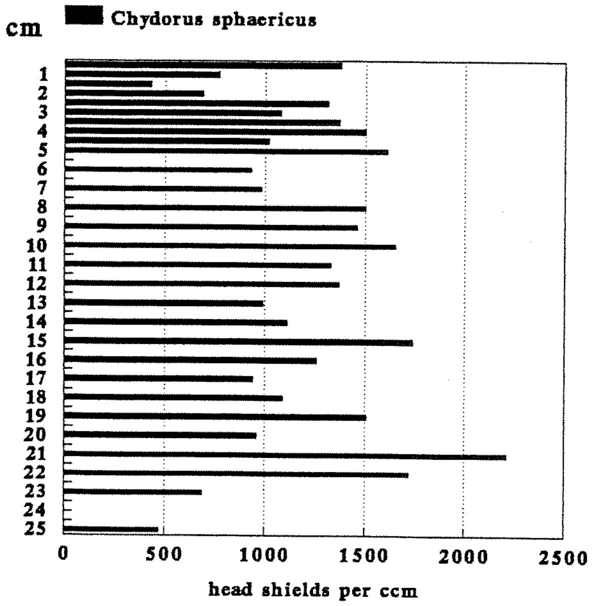


Figure 40. Schwarzsee ob Solden, summary % diatom diagram

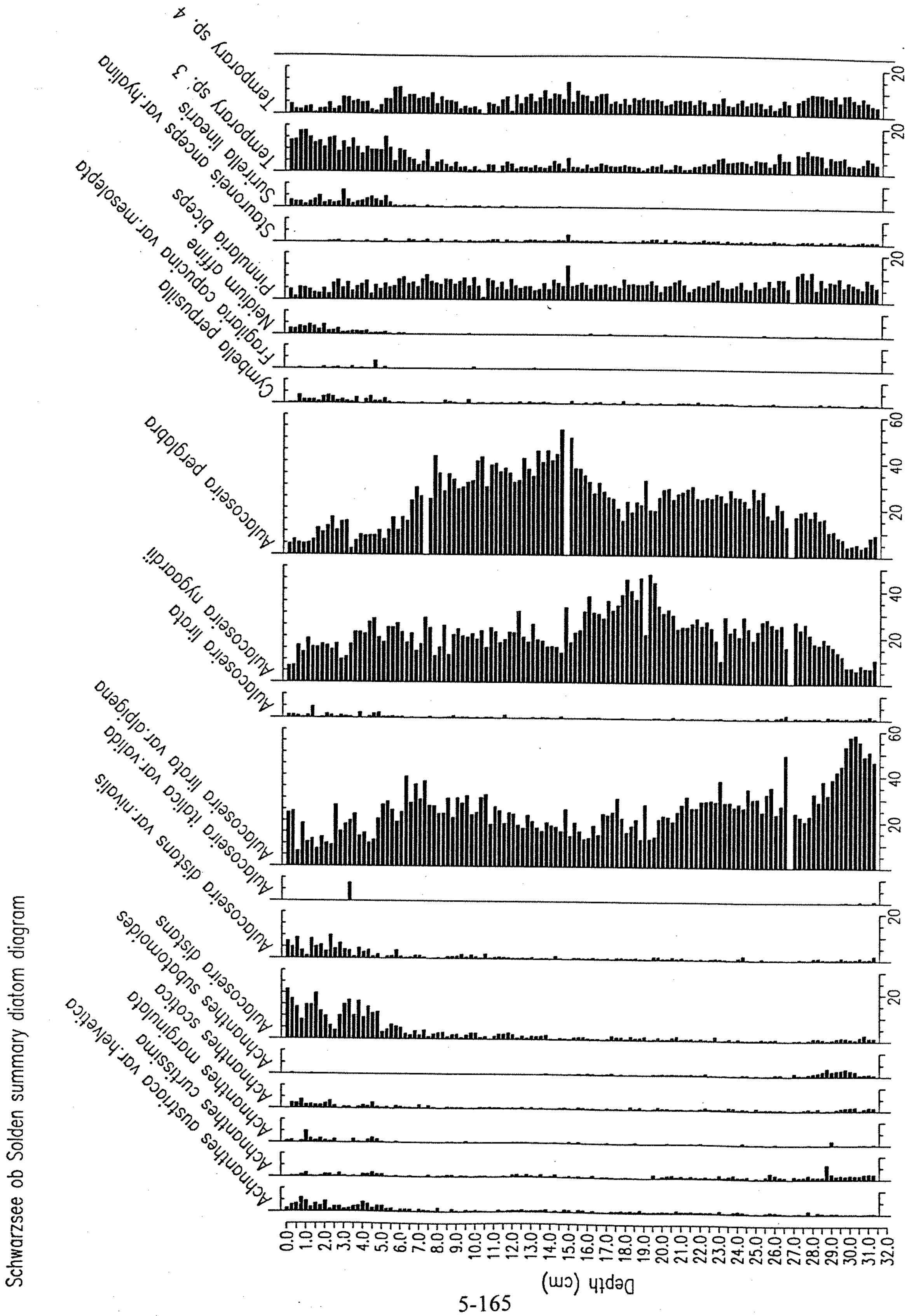


Figure 41. Schwarzsee ob Solden, number of taxa & number of chironomid head capsules

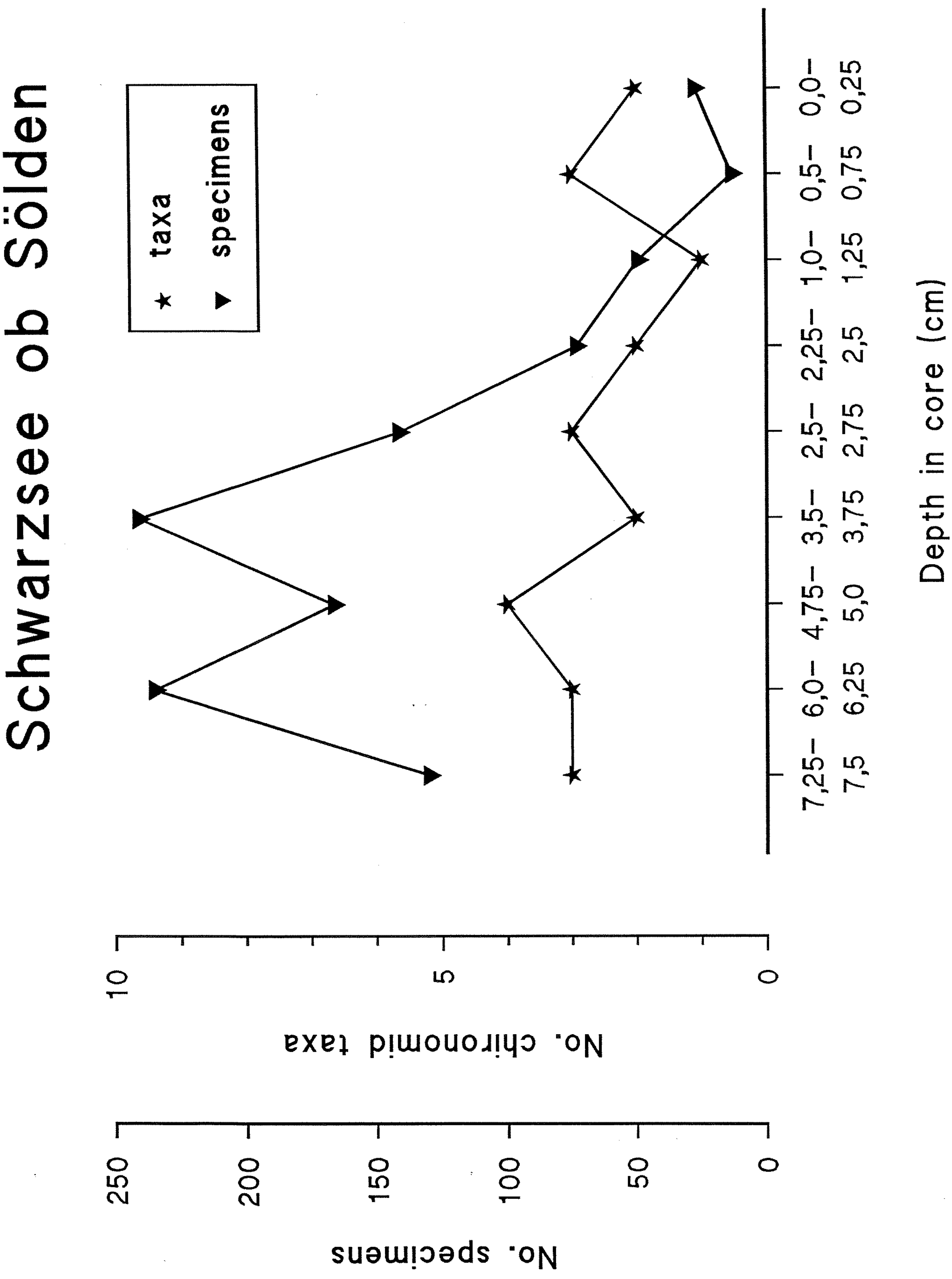


Figure 42. Schwarzsee ob Solden, relative abundances of the 2 dominant chironomid taxa

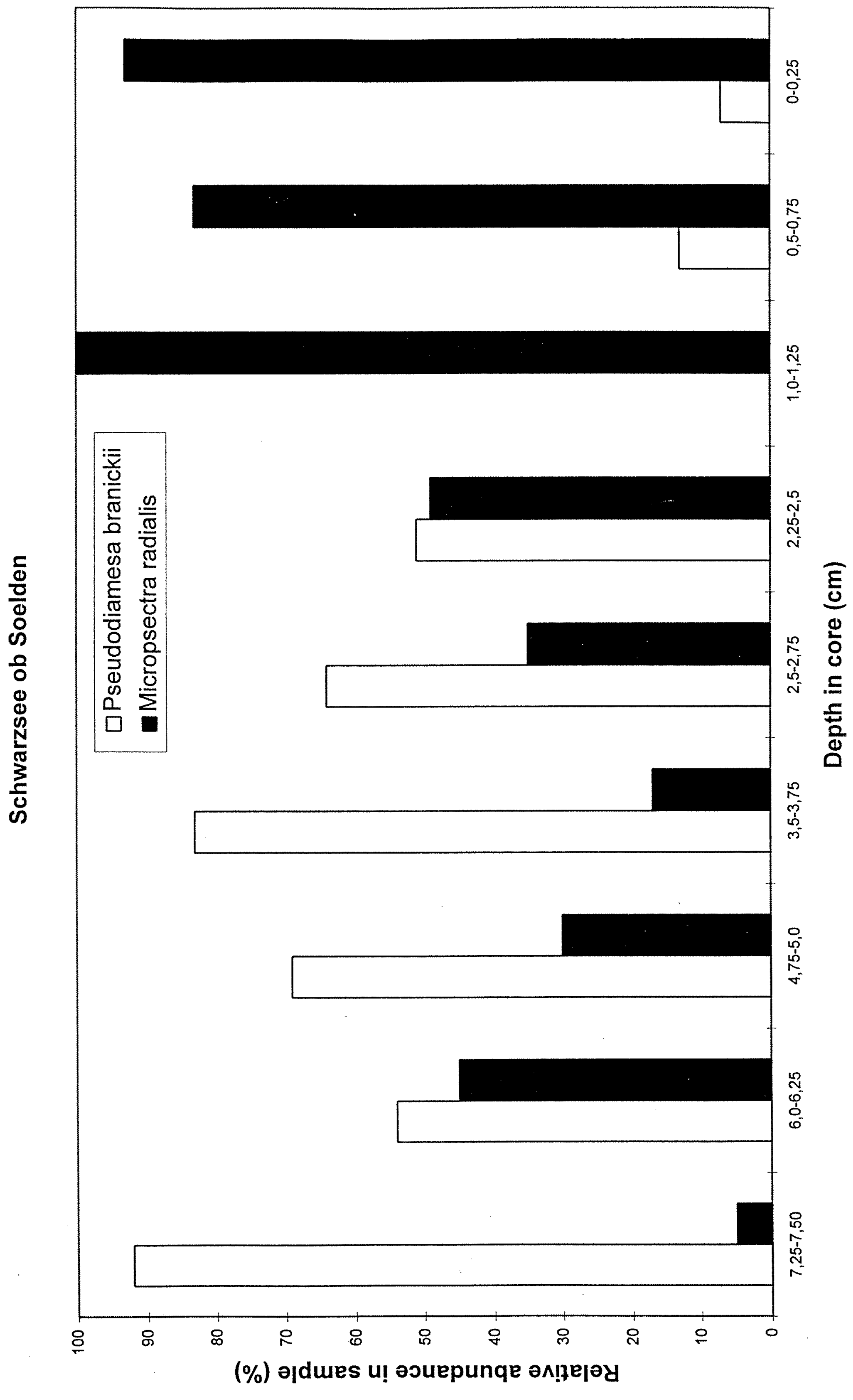


Figure 43. STAR 93/1 %DW & %LOI

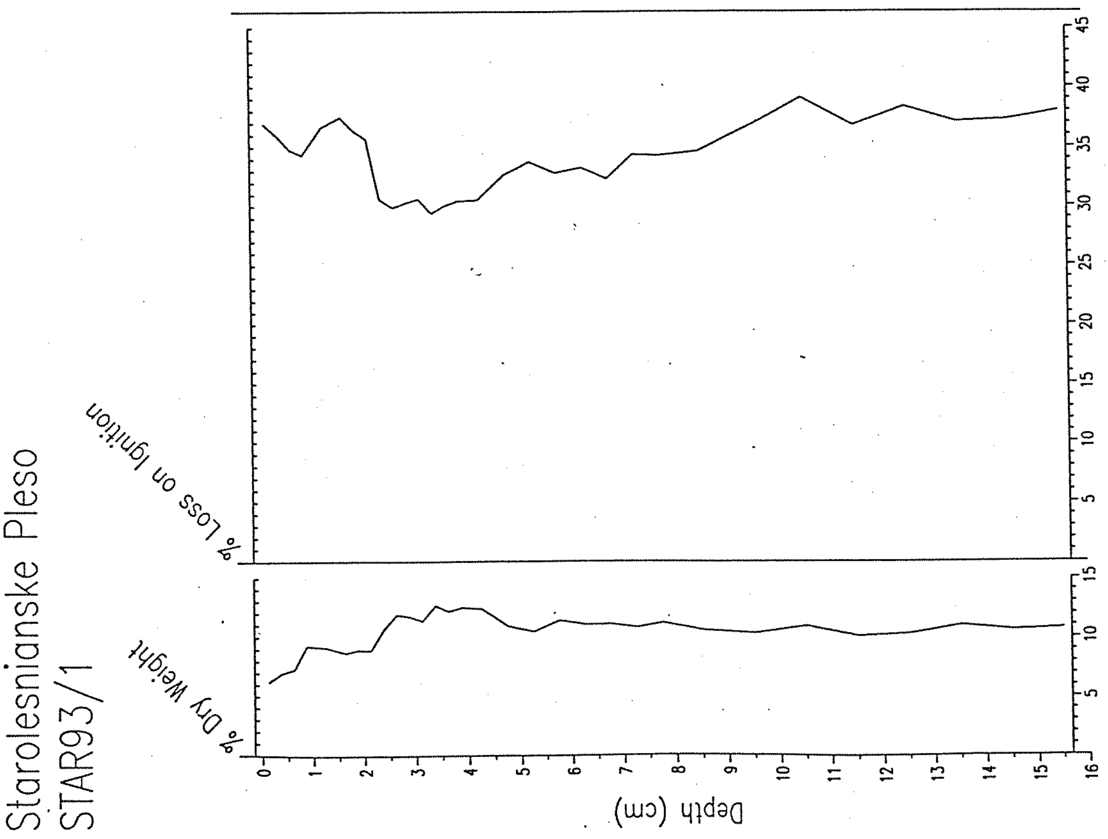


Figure 44. STAR 93/2 %DW & %LOI

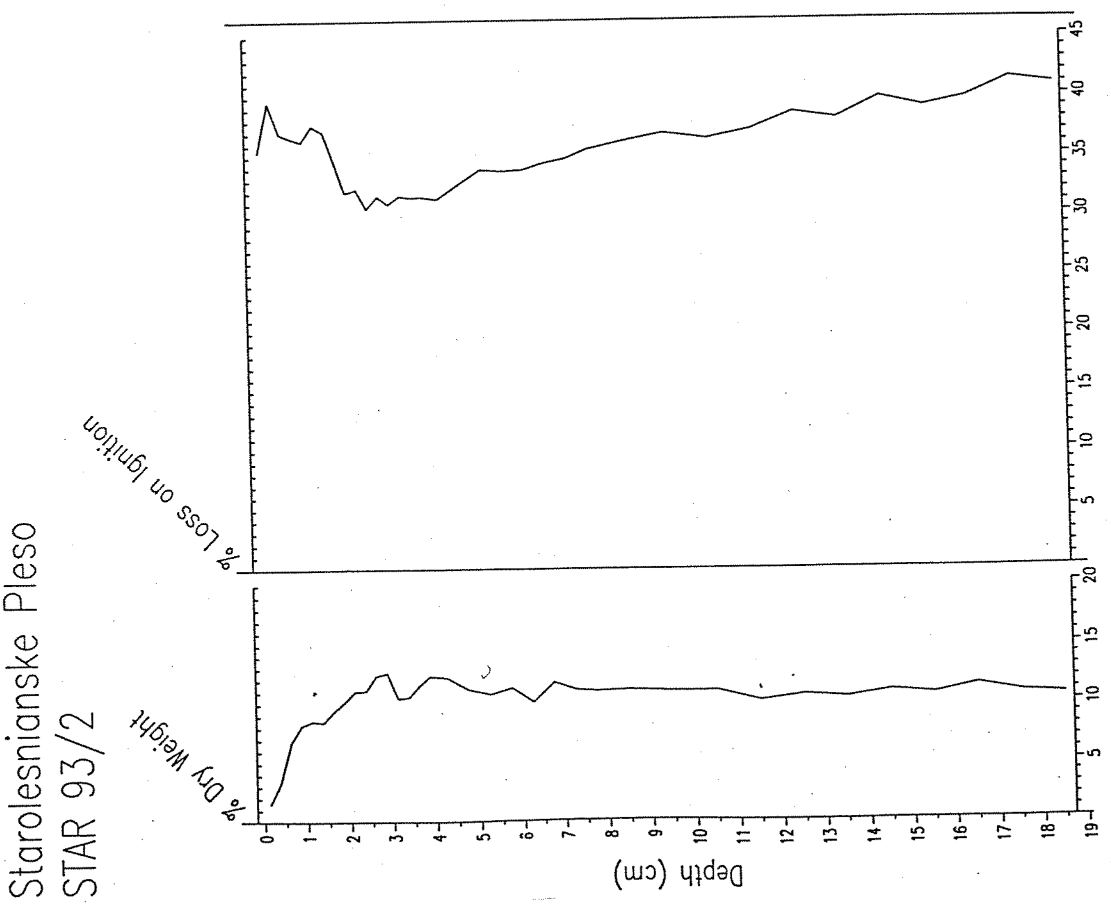


Figure 45. STAR 93/3 %DW & %LOI

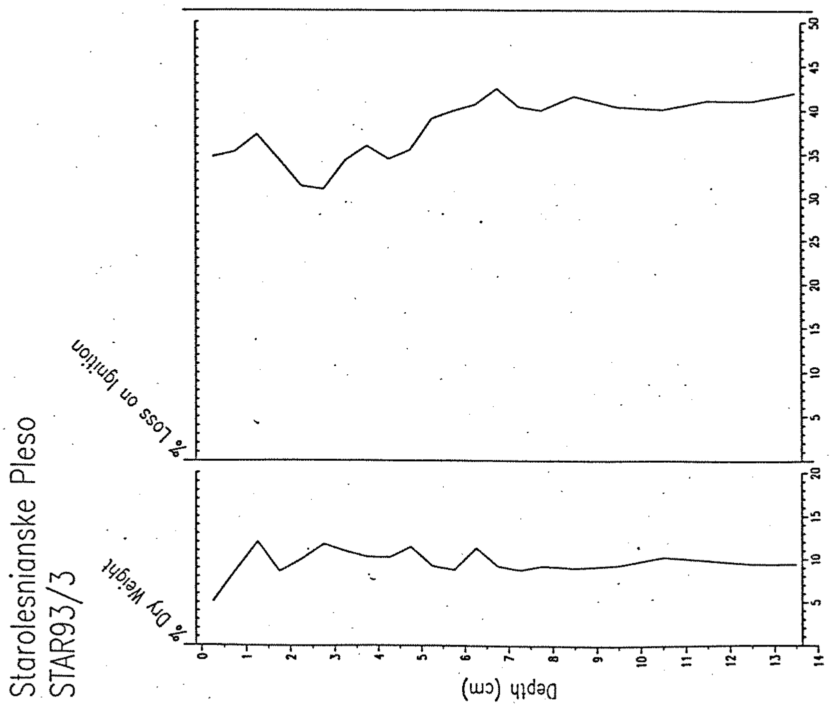


Figure 46. TERI 93/1 %DW & %LOI

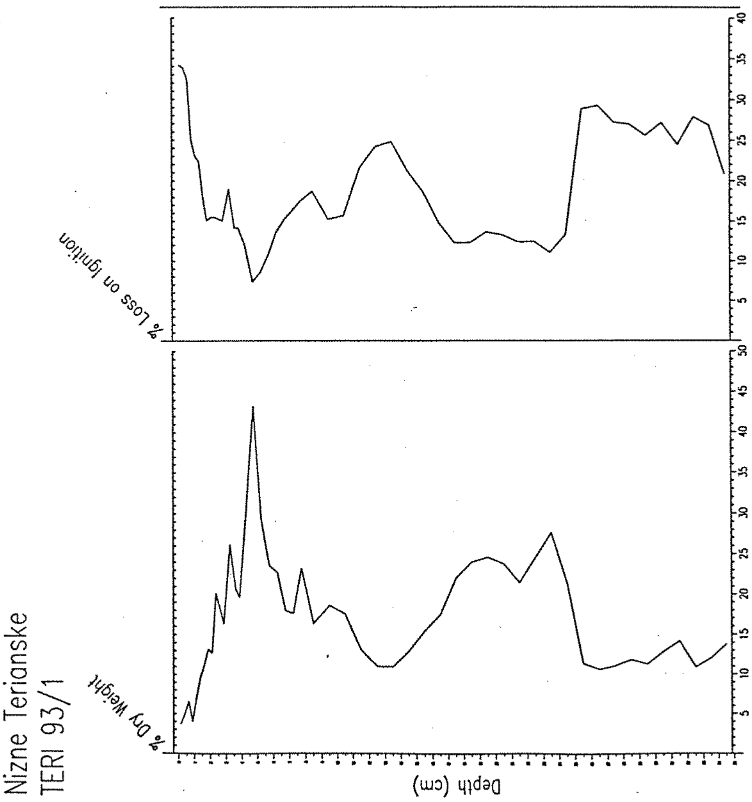


Figure 47. TERI 93/2 %DW & %LOI

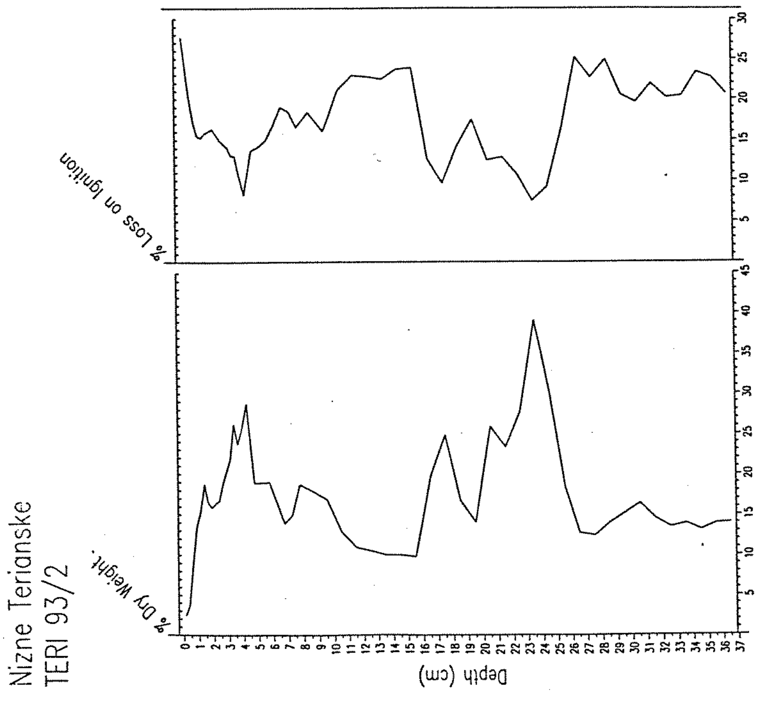


Figure 48. STAR summary % diatom diagram

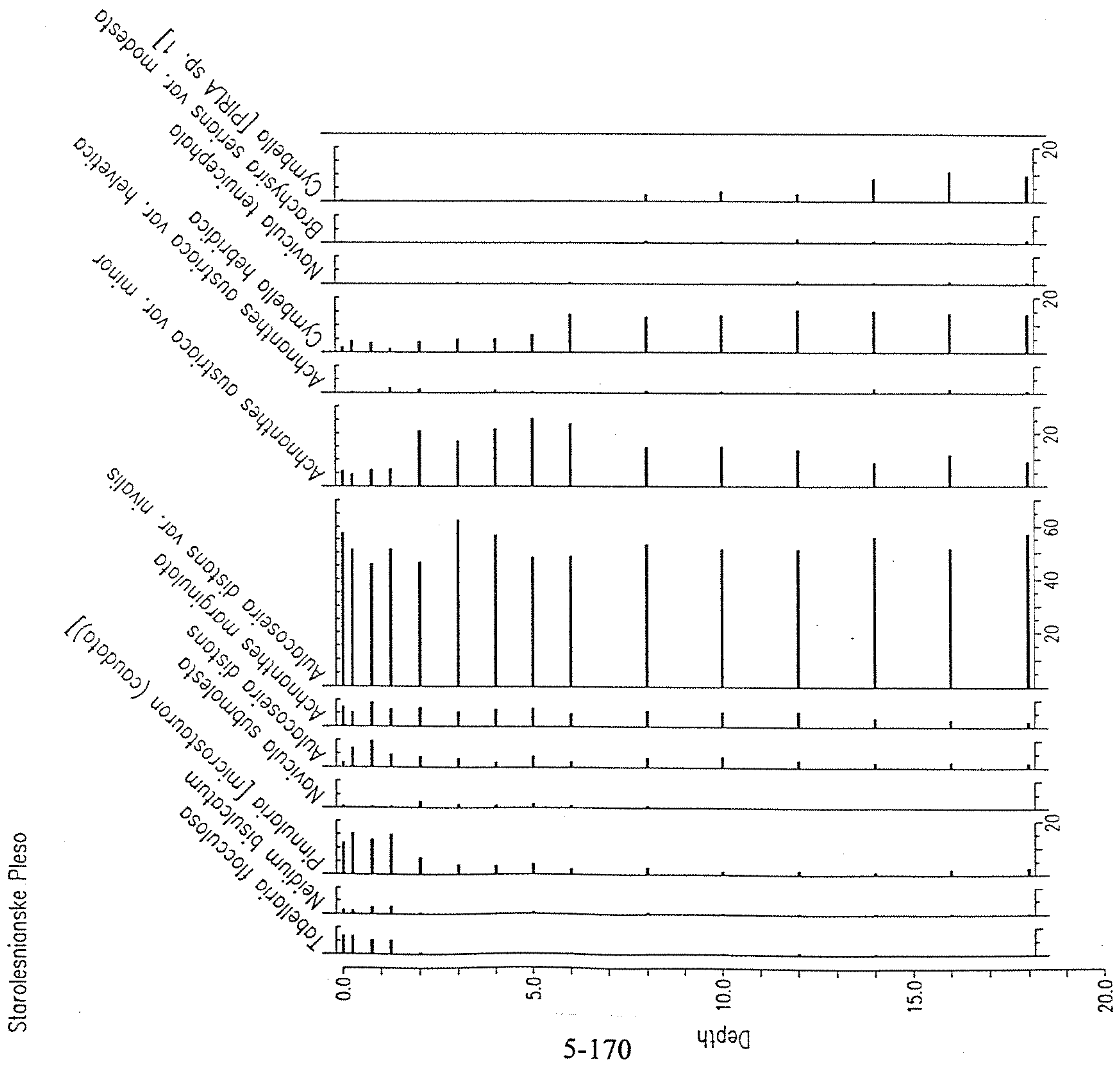


Figure 49. STAR diatom concentrations

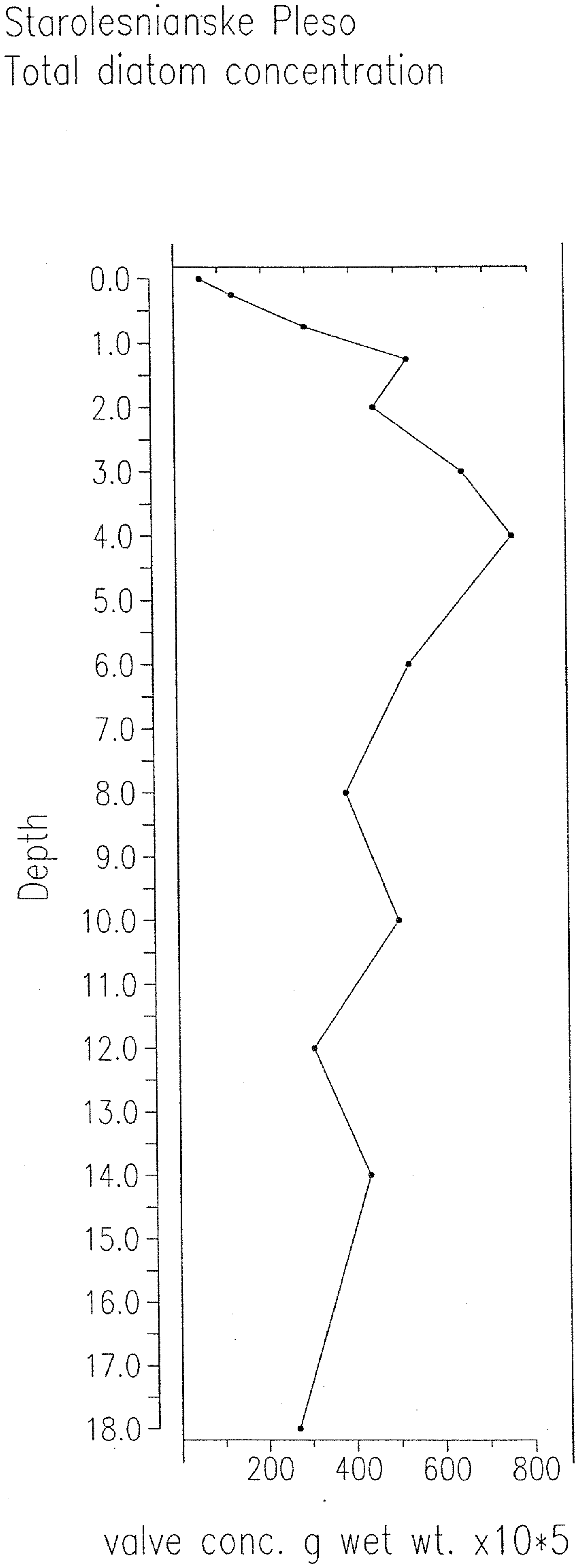


Figure 50. STAR 93/3, remains of 4 species of Cladocera

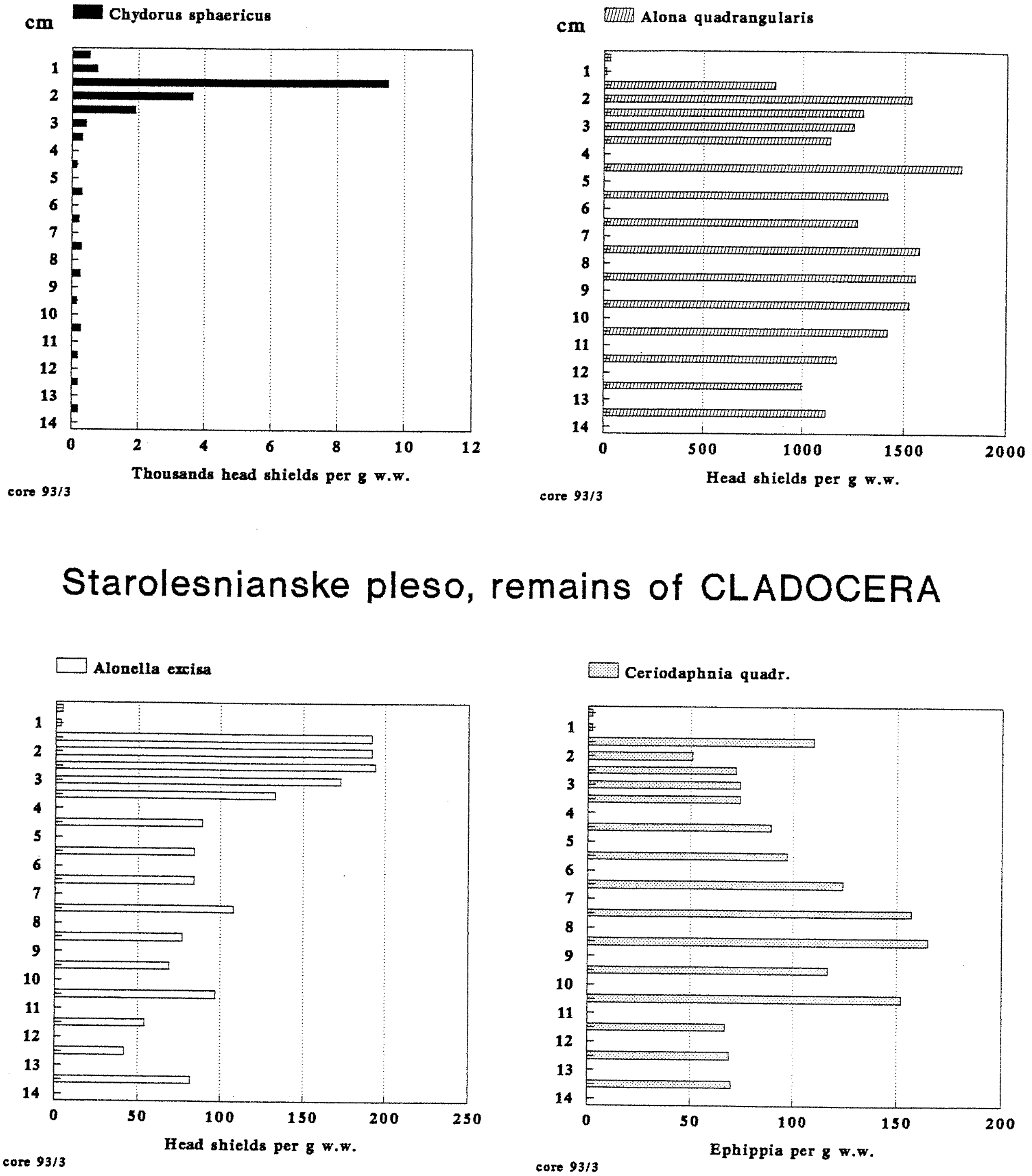
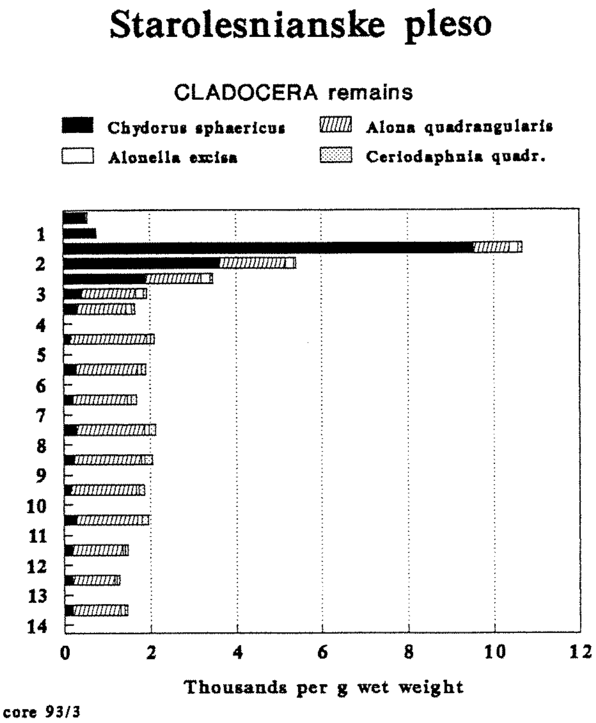


Figure 51. Sum of the remains of Cladocera



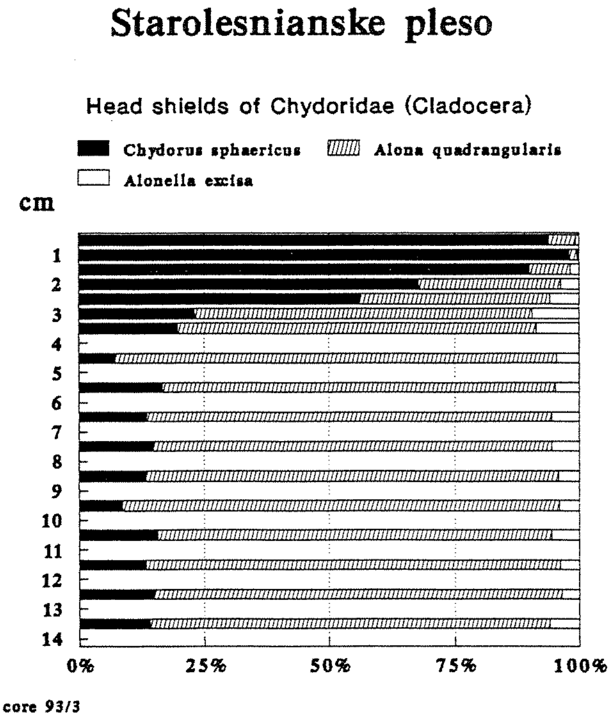


Figure 52. STAR, number of chironomid head capsules and number of species in the core

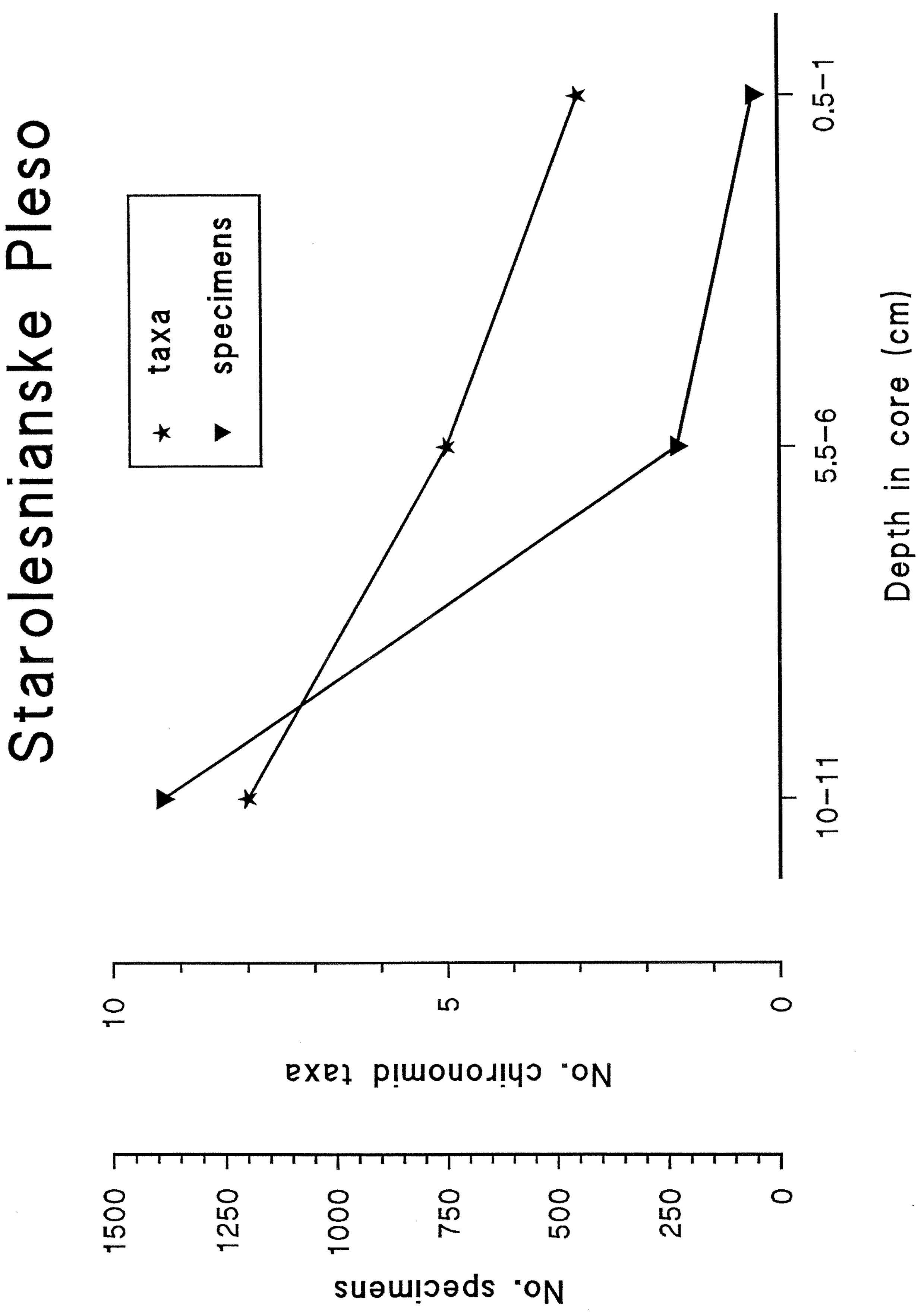


Figure 53. TERI, summary % diatom diagram

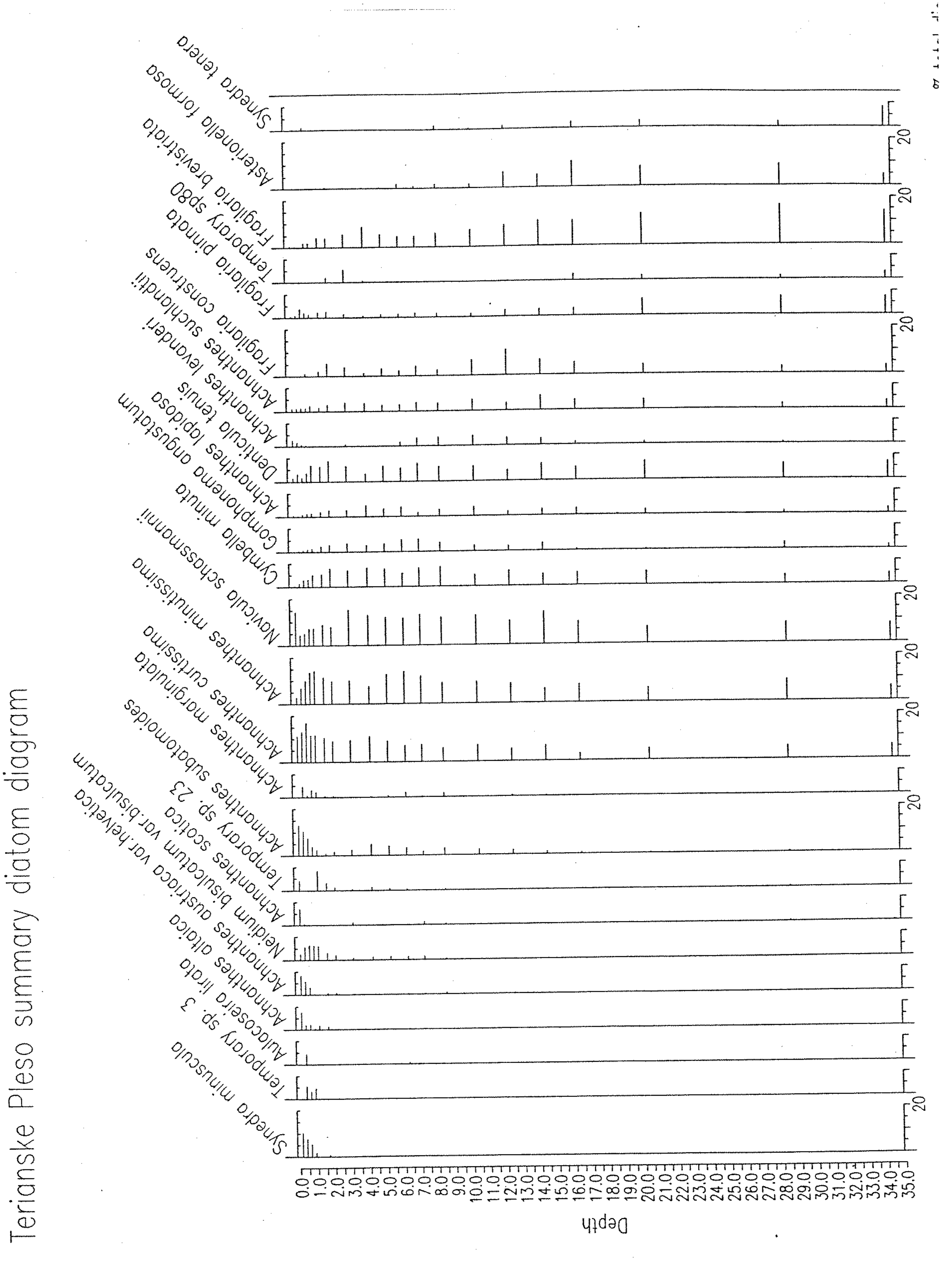
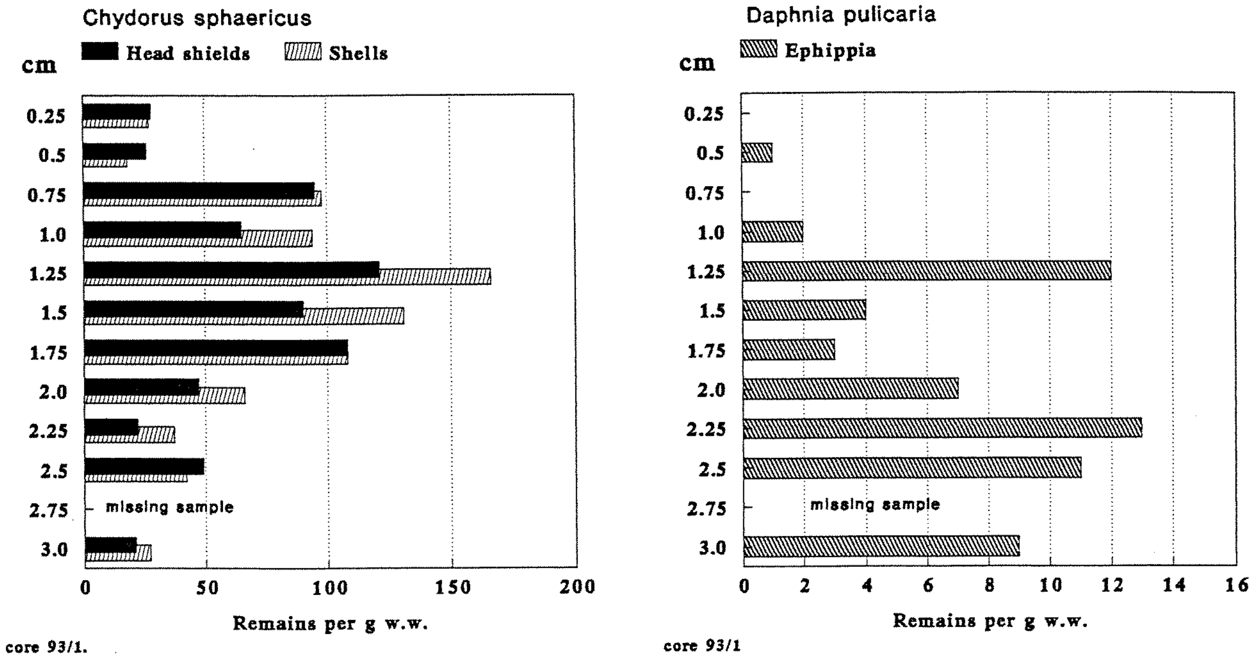


Figure 54. TERI 93/1. Remains of the two species of Cladocera. Sample thickness at the top to the core is 0.25 cm (upper graphs) and for the whole core 1 cm (lower graphs)



Terianske pleso, remains of Cladocera

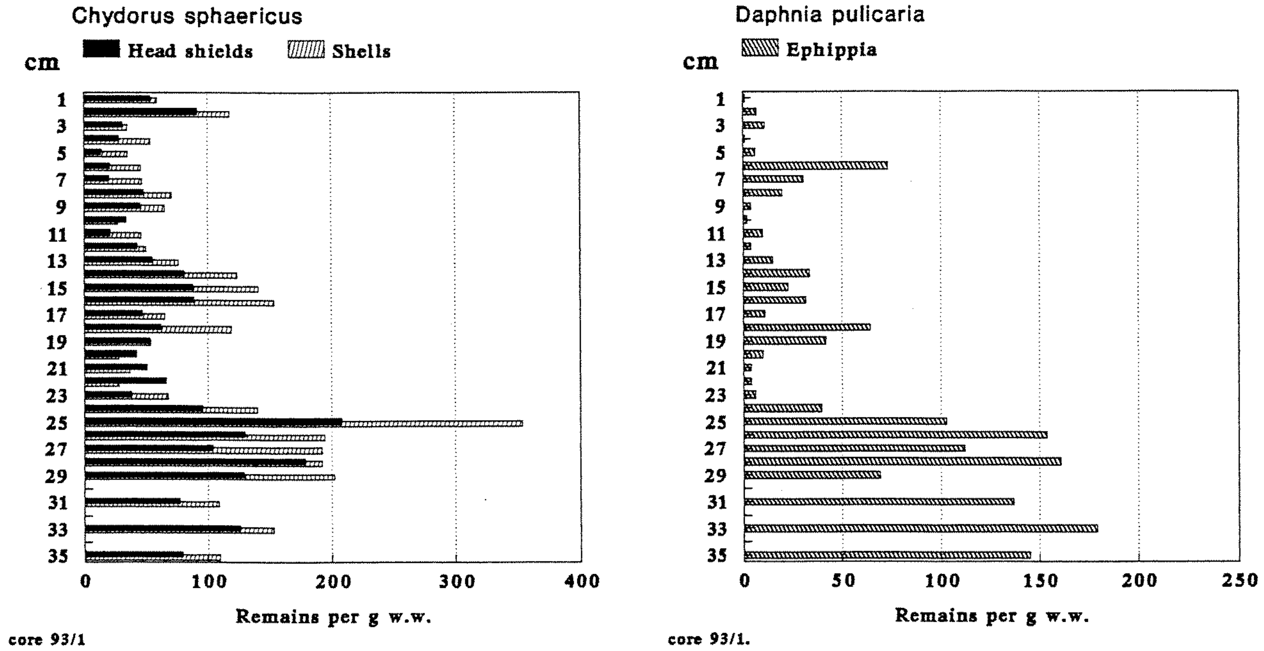


Figure 55. TERI 93/1, core 93/1. Egg capsules of flatworms (Turbellaria Rhabdocoela)

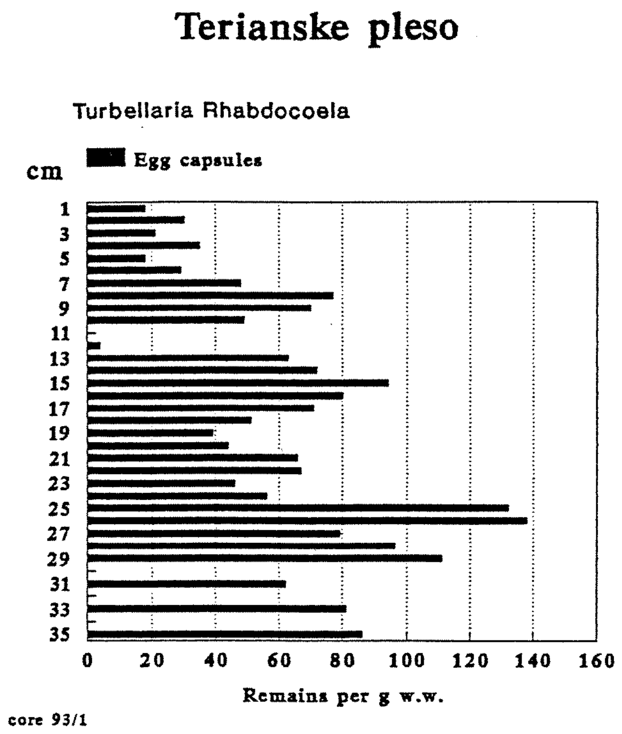


Figure 56. DLUG 93/1 %DW & %LOI

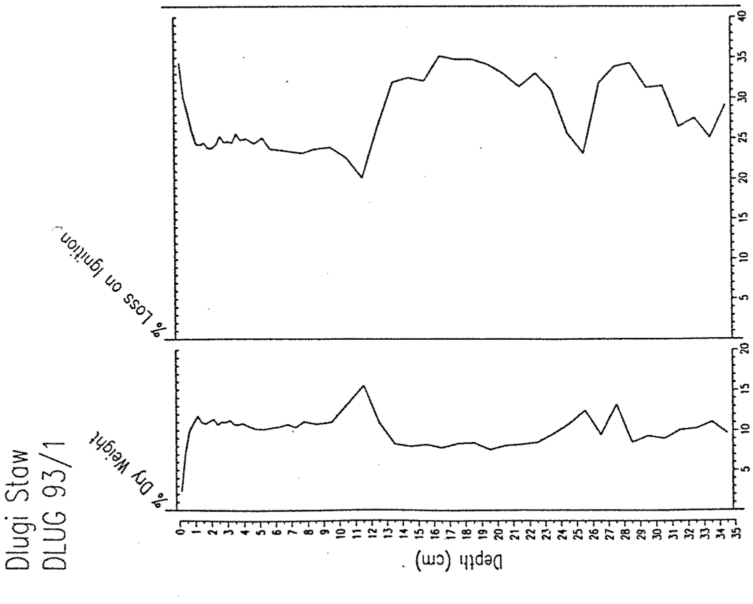


Figure 57. DLUG 93/2 %DW & %LOI

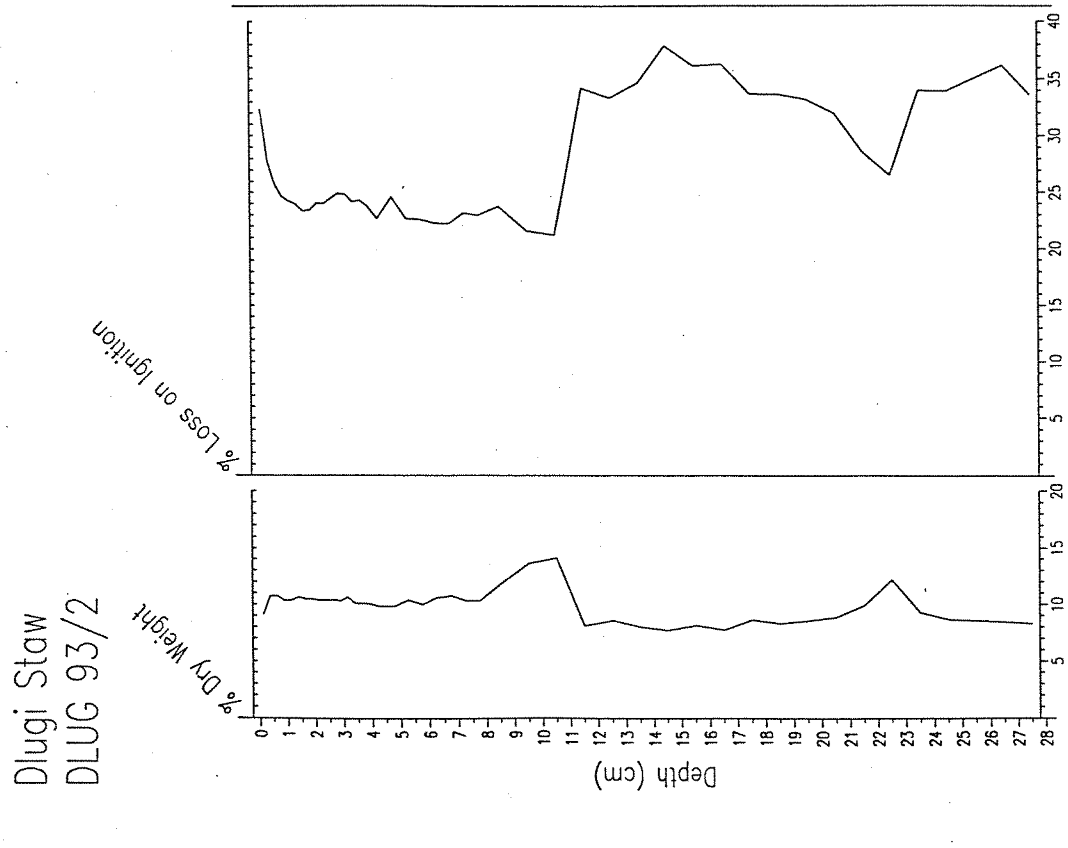


Figure 58. ZIEL 93/1 %DW & %LOI

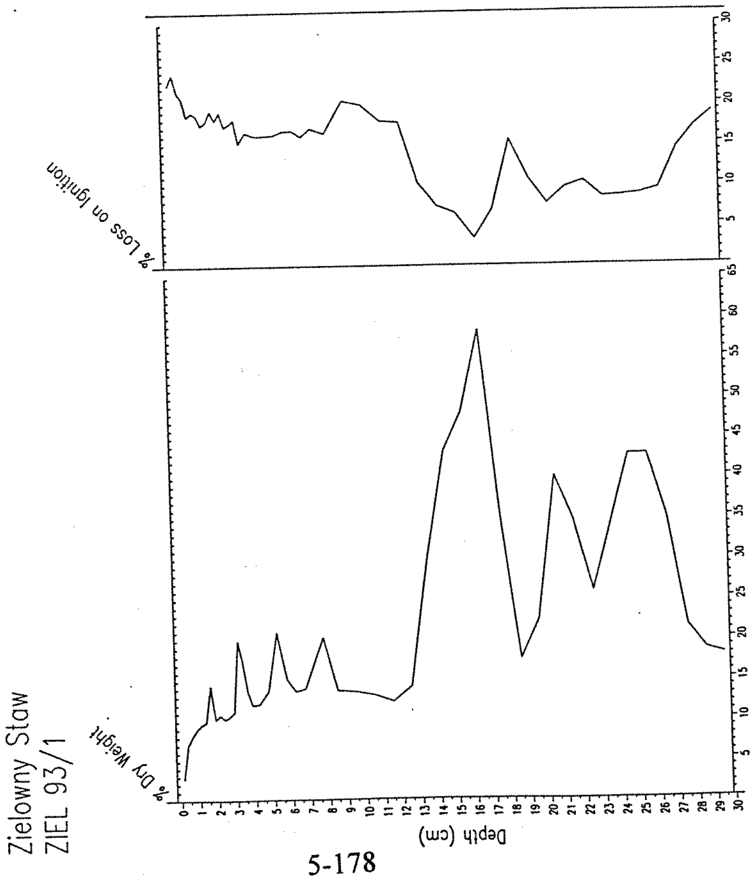


Figure 59. ZIEL 93/2 %DW & %LOI

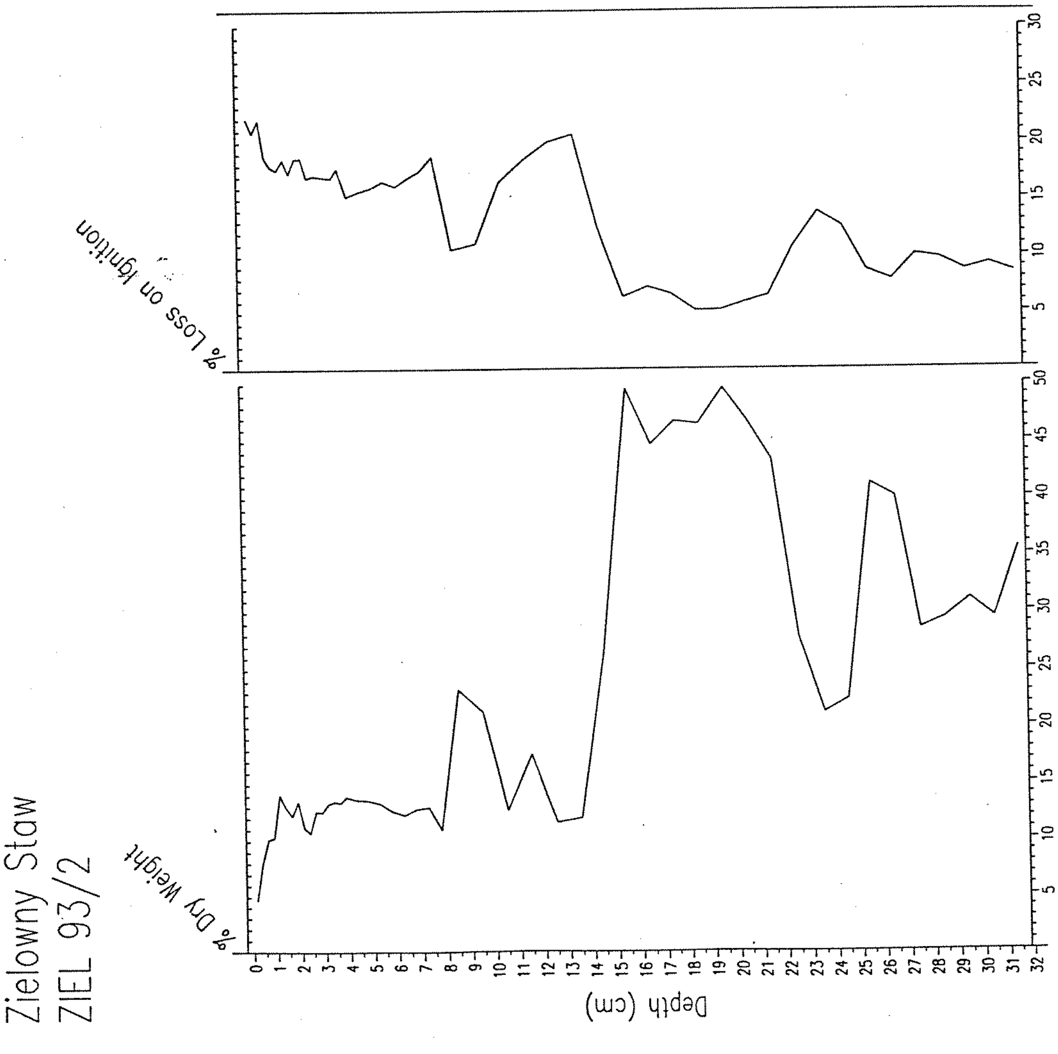


Figure 60. DLUG, summary % diatom diagram

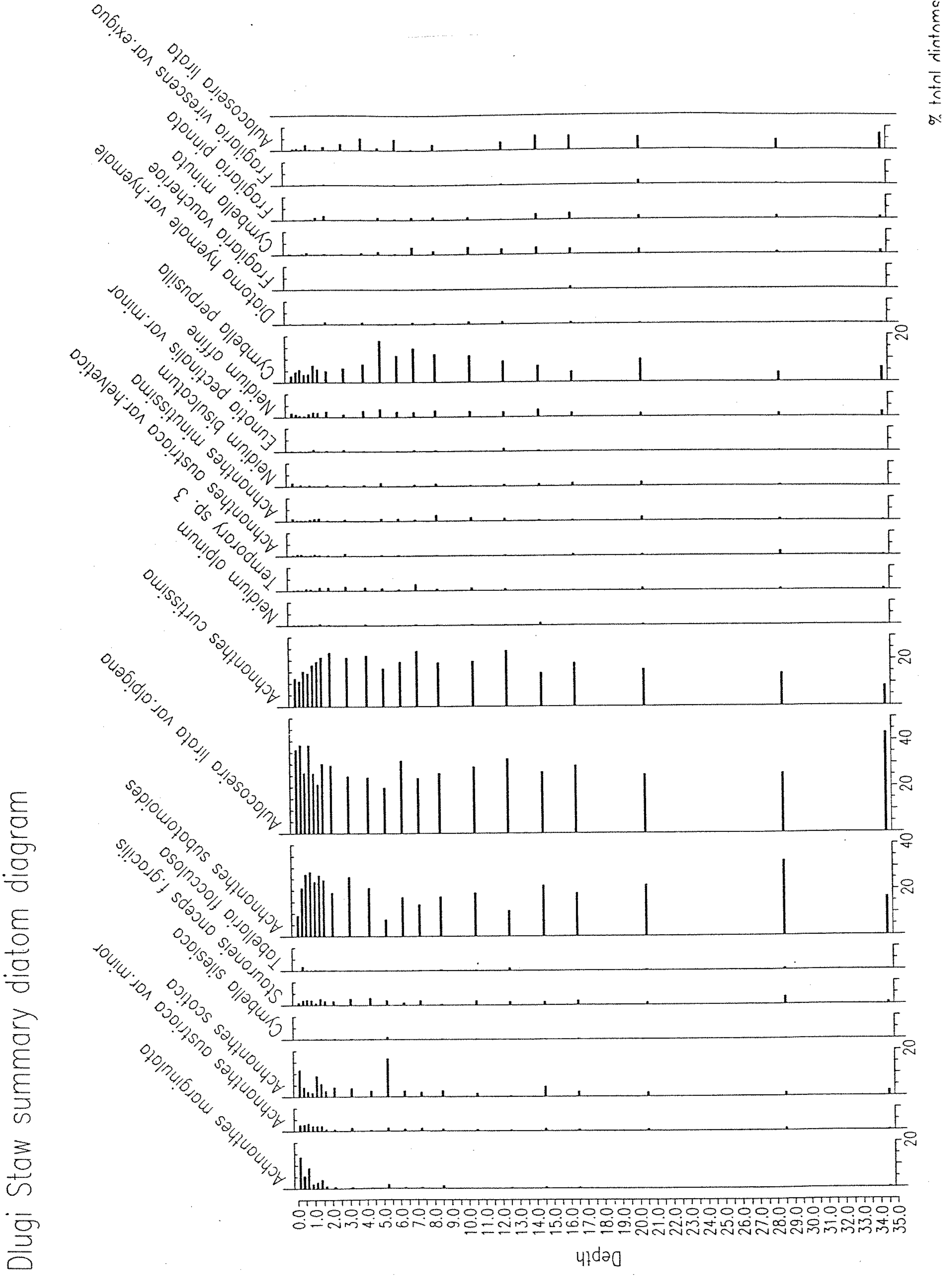


Figure 61. ZIEL, summary % diatom diagram

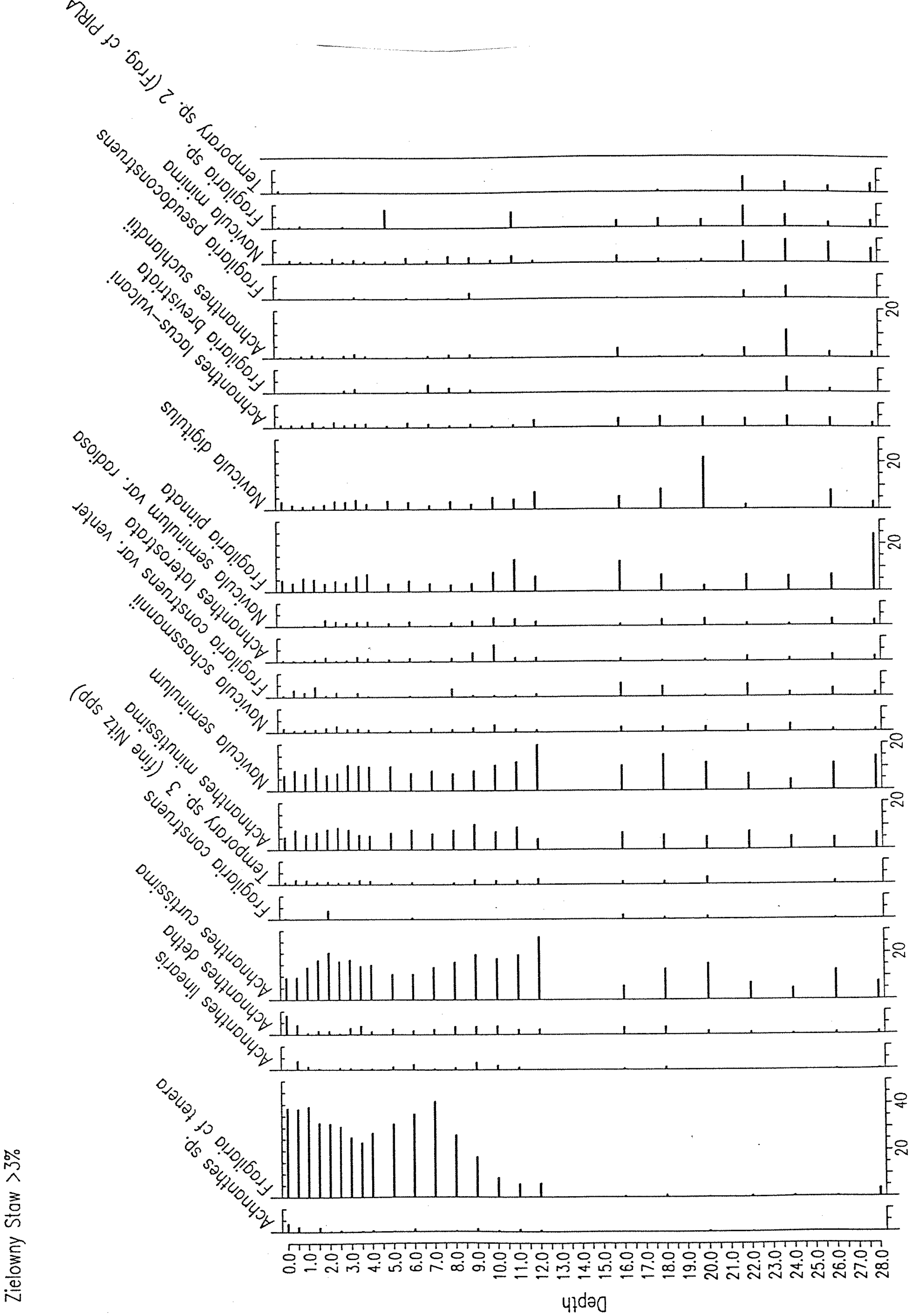


Figure 62. ZIEL, total diatom concentrations

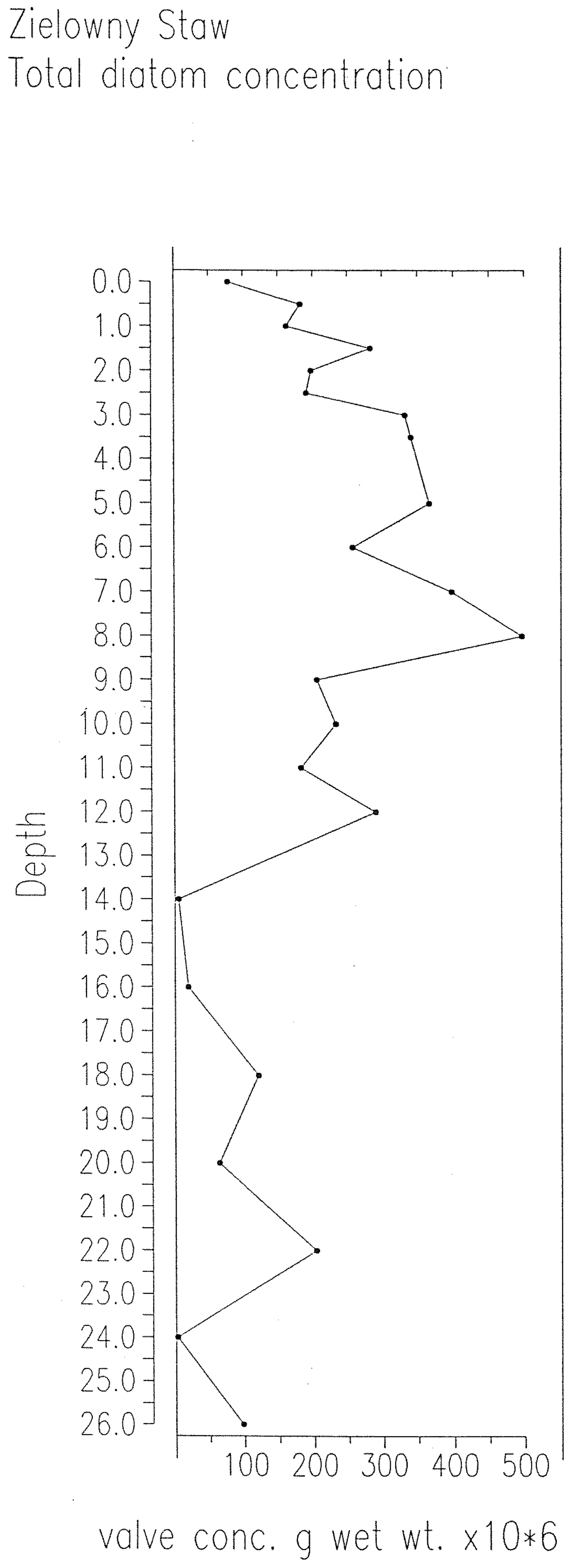
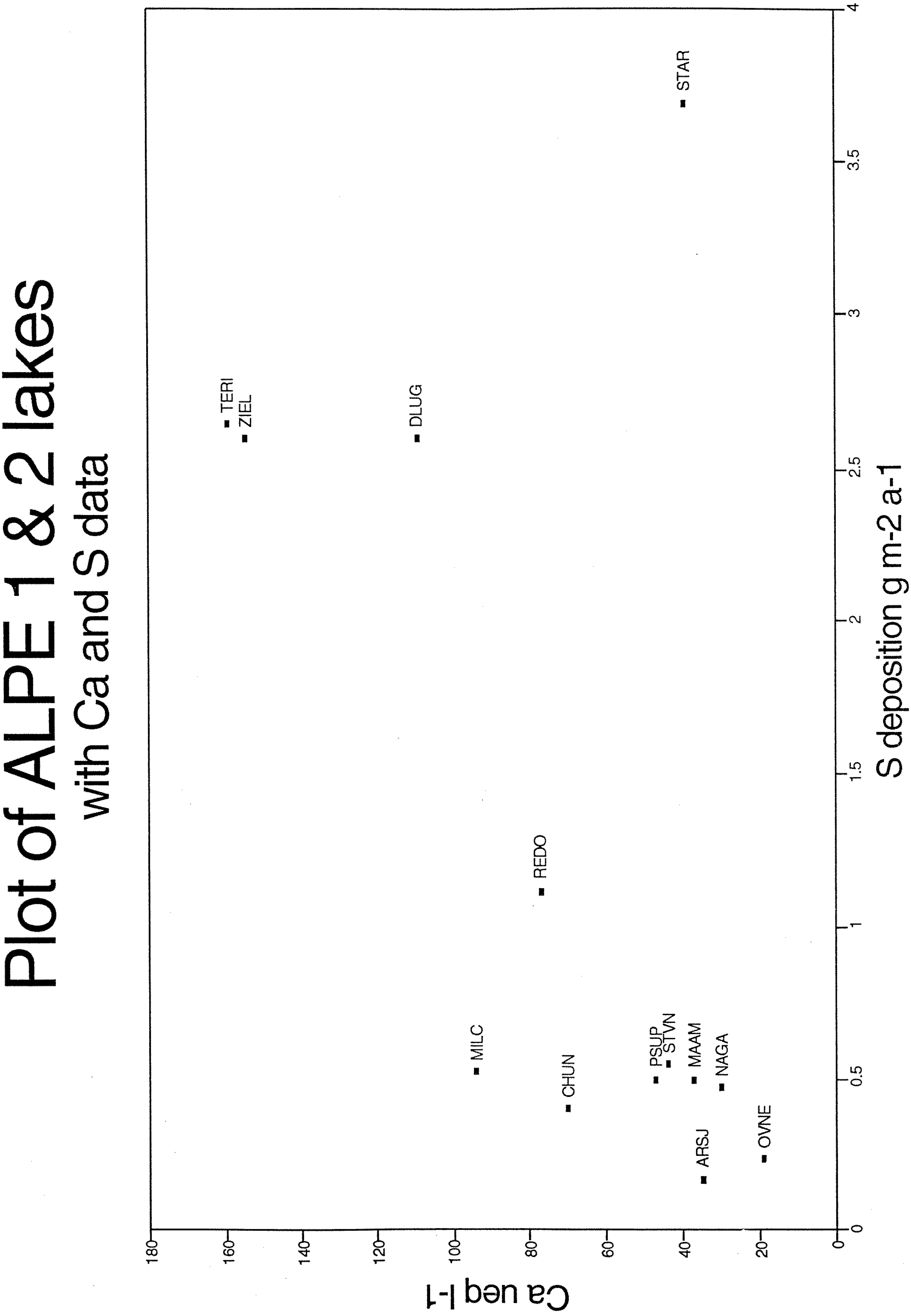


Figure 63. Calcium concentration against sulphur deposition for some ALPE core sites



AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Appendix 9.

AL:PE publications and reports

Publications and reports from the AL:PE project

Papers and conference proceedings

Battarbee, R.W., Wathne, Johannessen, M., B.M., Mosello, R., Patrick, S., Raddum, G.G., Rosseland, B.O., Grimalt, J.O., Catalan, J., Hofer, R., Psenner, R., Schmidt, R., Lami, A., Cameron, N.G., Rose, N.L., Jones, V.J., Birks, H.J.B. 1995. Remote mountain lakes as indicators of environmetal change. In: *Proc.of the SETAC Congress*, Copenhagen, 25-28 June 1995.

Battarbee, R.W., Jones, V.J., Flower, R.J., Appleby, P.G., Rose, N.L., and Rippey, B. 1995. Palaeolimnological Evidence for the Atmospheric Contamination and Acidification of High Cairngorm Lochs, with Special Reference to Lochnagar. *Bot. J. Scotl.* 48(1), pp. 79-87.

Bennion, H. 1995. Surface-sediment diatom assemblages in shallow, artificial, enriched ponds, and implications for reconstructing trophic status. *Diatom Research*, Volume 10 (1), pp. 1-19.

Bennion, H., Wunsam, S., and Schmidt, R. 1995. The validation of diatom-phosphorus transfer functions: an example from Mondsee, Austria. *Freshwater Biology* 34, pp. 271-283.

Boggero, A. A. Barbieri, M. Conedera, A. Marchetto, R. Mosello & G.A. Tartari. 1993. Land cover as a factor influencing the chemistry of mountain lakes in the western Alps. *Verh. Internat. Verein. Limnol.* 25 772-775.

Camarero, L., Catalan, J.,Mosello, R., Marchetto, A., Psenner, R. 1995. Comparison of the chemistry of high altiutde lakes in central, southwest and southeast Europe (Alps, Pyrenees, Pirin). *Limnologica*, 25, pp. 141-156.

Camarero, L., Catalan, J., Pla, S.,Rieradevall, M.,Jiménez, M. Prat, N., Rodríguez, D., Encina, L., Cruz-Pizarro, L., Sáchez Castillo, P., Carillo, P., Toro. M., Grimalt, J., Berdie, L., Fernández, P., Vilanova, R. 1996. Remote Mountain Lakes as Indicators of diffuse acidic and organic pollution in the Iberian Peninsula (AL:PE 2 Studies). *Water, Air and Soil Pollution* (In press).

Camarero, L., Catalan, J., Boggero, A., Marchetto, A., Mosello, R., and Psenner, R. 1995. Acidification in high Mountain Lakes in Central, Southwest, and Southeast Europe (Alps, Pyrennees, Pirin). *Limnologica* 25 (2) pp. 141-156.

Fernandez, P., Vilanova, R., Beride, L., and Grimalt, J.O. 1994. Selectivity effects in semi-polar columns. II. *Journal of chromatography* 688, pp. 363-367.

Galas, J., Dumnicka, E., Kawecka, B., Kownacki, A., Jelonek, M., Stos, P., Wojtan, K. 1996. Ecosystems of some Tatra Lakes - the Polish Participation in the international project AL:PE 2. in: Kownacki, A. (ed.) Tatra National Park. Nature and Man. Vol. 2 Biology. pp. 96-99. Tatra National Park, Polish Soc. of Earth Sciences, Cracow Branch, Krakow - Zakopane.

Galas, J., Dumnicka, E., Kawecka, B., Kownacki, A., Jelonek, M., Stós, P., and Wojtan, K. 1996. Ekosystemy wybranych jezior tatrza~skich - polski udzia| w miTdzynarodowym programie AL:PE 2. (Ecosystems of some Tatra lakes - the Polish participation in the international project ALA:PE 2. In: Kownacki, A. (ed). Tatra National Park, Nature and Man. Vol 2 Biology. pp. 96-99.

Guilizzoni, P., A. Lami & A. Marchetto. 1992. Plant pigment ratios from lake sediments as indicators of recent acidification in alpine lakes. *Limnol. Oceanogr. 37*: 1565-1569.

Guilizzoni, P., A. Marchetto, A. Lami, N.G. Cameron, P.G. Appleby, N.L. Rose, Ø. A. Schnell, C.A. Belis, A. Giorgis, L. Guzzi. (1995). Environmental History of a mountain lake (Lago Paione Superiore, Central Alps, Italy): a multidisciplinary, paleolimnological study. submitted to *Journal of Paleolimnology*.

Hofer, R., Pittracher, H., Koeck, G., Weyrer, S. 1994. Metal accumulaiton by Arctic char (*Salvelinus a. alpinus*) in a remote acid alpine lake. In: R. Mueller and Lloyd (Eds.) Sublethal and chronic pollutants in freshwater fish. FAO Fishing News Books. pp 294-300.

Johannessen, M., R. Mosello and H. Barth (Eds.) 1990. Acidification processes in remote Mountain lakes. Proc. EEC Workshop, Pallanza, Italy, 20-22 June 1989, Air Pollution Research Report 20: 216 pp.

Kopácek, J., Procházková, L., Stuchlík, E., and Blazka, P. 1995. The nitrogen-phosphorus relationship in mountain lakes: Influence of atmospheric input, watershed, and pH. *Limnol. Oceanogr.* 40 (5). pp 930-937.

Köck, G., Hofer, R., and Wögrath, S. 1995. Accumulation of trace metals (Cd, Pb, Cu, Zn) in Arctic char (Salvelinus alpinus) form oligotrophic Alpine lakes: relation to alkalinity. *Can. J. Fish. Aquat. Sci.* 52: 2367-2376.

Köck, G., Triendl, M., and Hofer, R. 1996. Seasonal patterns of metal accumulation in Arctic char (*Salvelinus alpinus)* from an oligotrophic Alpine lake related to temperature. *Can. J. Fish. Aquat. Sci.* **53:** 780-786

Köck, G., Noggler, M., and Hofer, R. 1996. Pb in otoliths and opercula of a Arctic char *(Salvelinus Alpinus)* from oligotrophic lakes. *Wat. Res.* Vol. 30. No. 8. pp. 1919-1923.

Lami, A., A. Marchetto, P. Guilizzoni, A. Giorgis & J. Masaferro. 1994. Paleolimnological records of carotenoids and carbonaceous particles in sediments of some lakes in Southern Alps. *Hydrobiologia* 274: 57-64.

Larsen, J., Birks, H.J.B., Raddum, G. & Fjellheim, A. 1996. Quantitative relationships of invertebrates to pH in Norwegian river systems. *Hydrobiologi*a (in press).

Marchetto, A. 1994. Rescaling species optima estimated by weighted averaging. *J. Paleolimn.* 12: 155-162.

Marchetto, A. & A. Lami. 1994. Reconstruction of pH by chrysophycean scales in some lakes of the Southern Alps. *Hydrobiologia* 274: 83-90.

Marchetto, A., R. Mosello, R. Psenner, A. Barbieri, G. Bendetta, D. Tait & G.A. Tartari. 1994. Evaluation of the level of acidification and the critical loads for Alpine lakes. *Ambio* 23: 150-154.

Marchetto, A., A. Barbieri, R. Mosello and G.A. Tartari. 1994. Acidification and weathering processes in high mountain lakes in Southern Alps. *Hydrobiologia*, 274: 75-81.

Mosello, R., A. Lami, P. Guilizzoni, M. Manca, A.M. Nocentini, A. Pugnetti, A. Boggero, A. Marchetto, G.A. Tartari, R. Bettinetti, M. Bonardi and P. Cammarano. 1993. Limnological studies on two acid sensitive lakes in the Central Alps (Lakes Paione Superiore and Paione Inferiore, Italy). *Mem. Ist.ital. Idrobiol.* 51: 127-146.

Mosello, R., B.M. Wathne and G. Giussani (Eds.). 1992. Limnology on groups of remote lakes: ongoing and planned activities. *Doc. Ist. ital. Idrobiol.*, 32: 128 pp.

Mosello, R., Wathne, B.M., Boggero, A., Marchetto, A. 1995.Research carried out in remote mountain lakes: the AL:PE projects. *Annali di Chimica*, 85: 395-405.

Mosello, R., Wathne, B.M., Lien, L.,Birks, H.J.B. 1995. AL:PE projects: Water chemsitry and critical loads. In: Proc. 5th. Int. Conf. Acidic Deposition, Gothenburg, June 1995. In press in: *Water, Air and Soil Pollution.*

Rose, N.L. 1995. Carbonaceous particle record in lake sediments form the Arctic and other remote areas of the Northern Hemisphere. *Sci. Tot. Environ.*, 160/161, 487-496.

Rose, N.L., Harlock, S., Appleby, P.G., and Battarbee, R.W. 1995. Dating of recent lake sediments in the United Kingdom and Ireland using spheroidal carbonaceous particle (SCP) concentration profiles. *The Holocene,* 5,3 pp. 328-335.

Rose, N.L. 1996. Inorganic fly-ash spheres as pollution tracers. *Environmental Pollution,* Vol. 91, No. 2, pp. 245-252

Rosseland, B.O., Lien, L., Morrison, B., Massabuau, J.-C., Hofer, R., Rodriguez, D., Grimalt, J., Moiseenko, T. 1995. AL:PE Projects. Fish population studies.In: Proc. 5th. Int. Conf. Acidic Deposition, Gothenburg, June 1995.

Schnell, Ø. A. & Raddum G. G. 1993. Past and present fauna of chironomids in remote mountain lakes. Preliminary results from the ALPE 1 project. - In: G.Giussani and C. Callieri (eds), Strategies for Lake Ecosystems Beyond 2000, Proceedings, Stresa, pp. 444 - 447.

Vilanova, R., Fernandez, P., Grimalt, J.O., Appelby, P.G., Rose, N.L., Battarbee, W.R. 1995. The use of high mountain lake sedimentary records for the study of the European environmental change. In: J.O. Grimalt and C. Dorronsoro (eds.) Organic geochemistry: Developments and applications to energy, climate, environment and human history. A.I.G.O.A. Donostia. pp. 575-577.

Wathne, B.M., Fjellheim, A., Johannessen, M., Raddum, G.G., Rosseland, B.O., Battarbee, R.W., Patrick, S., Mosello, R. 1991. AL:PE: Acidification of mountain Lakes: Palaeolimnology and Ecology. In: Proc. Conf. Limnology of Mountain Lakes, Stará Lesná, Czechoslovakia. July 1991.

Wathne, B.M. 1992. Acidification of mountain lakes:palaeolimnology and ecology. The AL:PE Project. In Mosello, R., Wathne, B.M., Guissani, G. (Eds.) Limnology on groups of remote lakes: ongoing and planned activities. *Doc. Ist. Ital. Idrobiol.* 32:7-22. 1992.

Wathne, B.M., Rosseland, B.O. 1993. Norsk Miljøovervåking som grunnlag for internasjonale samarbeidsprosjekt. I: Stordal, F. og Fløisand, I.(Eds.). Tilførsler og virkninger av lufttransporterte forurensninger (TVLF): Forskning og overvåking. Sammendrag av foredrag og postere fra møte på Olavsgaard Hotell 2.-3. desember 1991. NILU OR 26/93.

Wathne, B.M., Battarbee, R.W., Johannessen, M., Mosello, Patrick, S., R., Raddum, G.G., Rosseland, B.O., Lien, L., Tait, D., Massabuau, J.-C., Blake, G. 1993. The AL:PE projects, first results and further plans. *Mem. Ist. Ital. Idrobiolo.* 52: 341-354.

Wathne, B.M., Raddum, G.G., Cameron, N., Lien, L., Patrick, S.T. 1993. AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology, Remote Mountain Lakes as Indicators of Air Pollution and Climate Change. In: Proc. Int. Symp. On The Ecological Effects Of Arctic Airborne Contaminanats. Reikjavik, Island October 1993.

Wathne, B.M. Partick, S.T., Monteith, D., and Barth, H. (Eds.) 1995. AL:PE PROJECT PART 1: AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology. AL:PE 1 Report for the periode April 1991 - April 1993. Ecosystems Research Report No 9. European Commission, D-G XII, Brussels 296pp.

Wathne, B.M., Battarbee, R.W., Patrick, S., Johannessen, M., Cameron, N.G., Rosseland, B.O., Raddum, G.G., Fott, J., Mosello, R., Birks, H.J.B. 1995. AL:PE 1 Acidification of mountain Lakes: Palaeolimnology and Ecology, AL:PE 2 Remote mountain lakes as indicators of air pollution and climate change. In: Proc. 5th. Int. Conf. Acidic Deposition, Gothenburg, June 1995.

Wathne, B.M., Raddum, G.G. 1996. AL:PE Prosjektet: Remote mountain lakes as indicators of air pollution and climate change. In: Føisand, I. and Løbersli, E. (Eds.) Lufttransporterte forurensninger - Tilførsler, virkninger og tålegrenser. Sammendrag av foredrag og postere fra møte på Klækken Hotell, Hønefoss, 22. - 24. januar 1996. Miljøverndepartementet Fagrapport 77. NILU OR 2/96.

AL:PE Reports

Moiseenko, T., Dauvalter, V. Kagan, L., Vandysh, O., Yakovlev, V., Lukin, A., Kashulin, N., Kudravceva; L. AL:PE 2. The Ecosystem of Kola Mountain Lakes. Early response indicators of atmospheric pollution. Report -1/1994. Institute of the North Industrial Ecology Problems (INEP).

Moiseenko, T., Dauvalter, V. Kagan, L., Sharov, A., Landysh, Kashulin, N., O., Yakovlev, V. AL:PE 2. Air Pollution effects on the Mountain Lakes of Kola Northern Russia. Report -2/1995. Institute of the North Industrial Ecology Problems (INEP).

Wathne, B.M. (Ed.): AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Site Information and Investigation Methods. AL:PE Report 1/1992. Norwegian Institute for Water Research, Oslo 1992.

Wathne, B.M. (Ed.): AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Progress Report 1991/92. STEP PROGRAMME. AL:PE Report 2/1992. Norwegian Institute for Water Research, Oslo 1992.

Wathne, B.M. (Ed.): AL:PE 2- Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lkaes as Indicators of Air Pollution and Climate Change. Progress Report 1993. ENVIRONMENT PROGRAMME. AL:PE Report 1/1994. Norwegian Institute for Water Research, Oslo 1994.

Wathne, B.M. (Ed.): AL:PE 2- Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lkaes as Indicators of Air Pollution and Climate Change. Progress Report 1994. ENVIRONMENT PROGRAMME. AL:PE Report 1/1995. Norwegian Institute for Water Research, Oslo 1995.

Wathne, B.M. Rosseland, B.O., Lien, L.: AL:PE - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Part 2 - Utvidelse. Sluttrapport til Norges Forskningsråd. Norwegian Institute for Water Research, Oslo 1996.

AL:PE 2 - Acidification of Mountain Lakes: Palaeolimnology and Ecology. Remote Mountain Lakes as Indicators of Air Pollution and Climate Change

Appendix 10.

AL:PE songs

A hymn dedicated to the scientists working in the AL:PE 2 project.

4th AL:PE Meeting in Innsbruck, Austria, 16-19 March 1994

Song-project leader: Bjørn Olav Rosseland
Co-workers: Brian Morrison and Gunnar Raddum

Song by all: Melody: "My bonnie lies over the ocean"

My AL:PE lake lies in the mountain
My AL:PE lake's far from the sea
The lake's filled with acid and ashes
The problem does really vex me
Pay me!
Pay me!
Please Barth send me money to day - to day
Pay me!
Pay me!
Please Barth send me money to day - to day

Song by Dr. Barth with some help:
Melody: "Where have all the flowers gone"

Where has all my money gone?
Two years passing!
Where has all my money gone?
What have they done?
Where has all my money gone?
Gone to something far beyond
When do results appear?
When do results appear?

Song by all in reply - same melody:

We have data everywhere
Can't you see the disks?
We have data everywhere
We need more time!
We can't give results away
Projects stop and who will pay?
Please give another year!
Please give another year!

End of session - everybody sings joyfully, melody "She'll be coming round the mountain "

You shall have my PC when I die!
You shall have my PC when I die!
It is filled with lots of stories
It concludes with many maybes
You shall have my PC when I die

Singing aye aye yippee yippee aye etc.......

Song for the planning of AL:PE 3

AL:PE meeting, Bergen, Norway, August 22, 1994

(Author: Bjørn Olav Rosseland)

Melody: Edelweiss

ALPE 3
ALPE 3
We are planning your future
If we're wice
Barth don't think twice
raising the money to start you

Bergen is nice - sun is shining bright
shining on your "parents"
AL:PE 3
We will see
Time will show if they'll fund you

AL:PE 3
We must be
very careful to plan you
Not to big
Brüssel think
fewer people should stear you

We, however must still be big
must be high in this topic
Non can now
tell us how
we best deals with this project

Melody: "Yippee aye aye yippee "

We have come to Bergen here today
not to solely work but maybe pray
Our beer is swinging
when we loudly are singing
Yippee aye aye yippee yippee aye etc.......

Another hymn, made in Granada, Spain, February 1995, dedicated to the scientists working in the AL:PE 2 project and hopefully also in an AL:PE 3 project.

Song-project leader: Bjørn Olav Rosseland
Co-worker: Merete Johannessen

Melody: Yesterday

Yesterday
and my troubles seemed so far away
AL:PE 2 report in June we say
We now learnt "June" was yesterday

Please be quick
Send the data files to Bjørn and Rick
If you don't compile the numbers now
no money to your lab will flow

Brüssels is the goal
but their programmes do not fit
TERRI - ELOISE
in the middle we will sit

Yesterday
Now we know tomorrow's here to stay
AL:PE 3 will be a great display,
and previous work not stored away!

Melody: Daisy, Daisy

AL:PE , AL:PE
We have become a team
We have tried to
fulfil a secret dream
The dream was to climb the mountains
and sample mountain fountains
We fish the lake
The fish taste great
and in Brüssel the paid "the steak"

AL:PE, AL:PE
What will the next name be
Roland's crying:
"Not name it AL:PE 3"
To hide that we just continue
We need another issue
Convincing Barth
That this is smart
Then the ECU will pay it's part

Melody: "It's a long way to Tipperary"

We are gathered
here in Granada
for the AL:PE 2 we meet
We report on
the different projects
for the Brüssels to be pleased
We will argue
for the continuance
AL:PE 3 will sure take place
but we need to find the best solutions
so that Barth will give his prays

Melody: Viva Espania

The AL:PE 2 is meeting here
Viva Granada
The reason really why we're here
is beautiful Granada
The city's close to AL:PE site
They argue for Caldera
In spite we all are very nice
Cimera is the site!

This meeting has been a success
Viva Granada
It's Louis and his staff we thank
Viva Espania
Without their hospitality
we all would be suffering
But now we leave and we all smile
Thanks Louis for your time

Another hymn, made in Prague, March 1996, dedicated to the scientists who worked in the AL:PE 2 project and now will be working in MOLAR.

Song-project leader: Bjørn Olav Rosseland

Melody: Edelweis

AL:PE 2
Ending you
Hearts were broken in sorrow
Samples few
none for you
What will happen tomorrow?
Five year's a long time to sample lakes
Felt it last forever
Project done
we went home
Waited for signals from Brussels

Once again
meet your friend
MOLAR now is the reason
Here in Prague
Jan's in charge
preparing the very first season
This time the project has grown so big
packages three were needed
Fingers crossed
No sample lost
Time will show if we succeeded!

Melody: Midnight" (from "Cats")

AL:PE
We have finished our AL:PE
No more data to sample
Bente's finish reports
We're lucky
We still have something else we can do
MOLAR Project
Welcomes you

We will sample
tons of samples
We need lot of equipment's
Labs will test it
and we all will check it
and some even will interpret it!

MOLAR
we will all love the MOLAR
keeps us busy for many
many more years to come
And in three years
when Brussels claims receipt for support
We will give them
"The Report"

End of session - everybody sings joyfully, melody "She'll be coming round the mountain"

The big MOLAR project's started now
What will happen soon we do not know
But one thing is for sure
MOLAR symbols is "unpure"
Named "Big Boobie" project from now on

Singing aye aye yippee yippee aye etc.......

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