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International Cooperative Programme on Assessement and Monitoring of Acidification of Rivers and Lakes

ICP Waters Report 88/2006

Joint Workshop on Confounding Factors in Recovery from Acid Deposition in Surface Waters, 9-10 October 2006, Bergen, Norway; Summary and Abstracts

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REPORT

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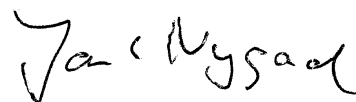| Author(s)	Topic group	Distribution
Brit Lisa Skjelkvåle, NIVA Martin Forsius, SYKE, Finland Richard F. Wright, NIVA Heleen de Wit, NIVA Gunnar G. Raddum, UNIFOB, University of Bergen Anne Merete S. Sjøeng, NIVA	Acid rain Geographical area	Printed NIVA

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Abstract

Environmental factors other than acid deposition – so-called 'confounding factors' – are expected to affect chemical and biological recovery of freshwaters in response to reduced acid deposition. Understanding of fundamental processes that drive ecosystem response to change is necessary for making predictions of the future acidification status of freshwaters. The aim of the workshop was to discuss relations between drivers and responses of different processes that affect recovery. The report contains a workshop summary and abstracts from the presentations.

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Brit Lisa Skjelkvåle
Project manager

Jarle Nygard
Head of research department

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Joint Workshop on Confounding Factors in Recovery from Acid Deposition in Surface Waters, 9-10 October 2006, Bergen, Norway;

Summary and Abstracts

Prepared by
ICP Waters, Norwegian Institute for Water Research
ICP Integrated Monitoring, Finnish Environment Institute

EU-project Eurolimpacs: WP4 - Integrated project to evaluate impacts of global change on European freshwater ecosystems

Oslo, December 2006

Preface

The International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters) was established under the Executive Body of the Convention on Long-range Transboundary Air Pollution at its third session in Helsinki in July 1985. The Executive Body has also accepted Norway's offer to provide facilities for the Programme Centre, which has been established at the Norwegian Institute for Water Research, NIVA. A programme subcentre is established at the Laboratory of Freshwater Ecology and Inland Fisheries at University of Bergen. The ICP Water programme is lead by Berit Kvæven, Norwegian Pollution Control Authority (SFT).

The programme aims are to:
- Assess the degree and geographic extent of the impact of atmospheric pollution, in particular acidification, on surface waters;
- Collect information to evaluate dose/response relationships;
- Describe and evaluate long-term trends and variation in aquatic chemistry and biota attributable to atmospheric pollution.

One of the objectives is to conduct workshops on topics of central interest to the Programme Task Force and the aquatic effects research community.

This workshop on *Confounding Factors in Recovery from Acid Deposition in Surface Waters* is arranged in cooperation with two other international projects with waters and acidification on the agenda; ICP Integrated Monitoring under the Convention on Long-range transboundary air pollution (CLRTAP) and the EU-project Eurolimpacs (WP4 - Integrated project to evaluate impacts of global change on European freshwater ecosystems). We highly appreciate this cooperation.

Part I of this report contains scientific presentations from the Workshop while Part II contains scientific presentations at the ICP Waters Task Force meeting held back-to-back with the Workshop.

Oslo, December 2006

Brit Lisa Skjelkvåle
ICP Waters Programme manager

Contents

Summary of Joint Workshop on Confounding Factors in Recovery from Acid Deposition in Surface Waters, 9-10 October 2006, Bergen Norway

The Workshop on Confounding Factors in Recovery from Acid Deposition in Surface Waters was attended by 52 experts from the following Parties to the Convention on Long-range Transboundary Air Pollution (LRTAP): Canada, the Czech Republic, France, Finland, Germany, Hungary, Italy, Latvia, the Netherlands, Norway, Poland, Russian Federation, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. In addition the Vice Chairman of the Working Group on Effects (WGE) and a member of the United Nations Economic Commission for Europe (UNECE) secretariat also attended.

The Workshop was organised by:
* International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters)
* EU project Eurolimpacs WP4 - Integrated project to evaluate impacts of global change on European freshwater ecosystems
* International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP Integrated Monitoring)

Justification of the Workshop
Environmental factors other than acid deposition – so-called 'confounding factors' – are expected to affect chemical and biological recovery of freshwaters in response to reduced acid deposition. Confounding factors with a regional rather than local occurrence are worthwhile to study in order to grasp their potential effect on the future behaviour of acid-sensitive ecosystems.

* Understanding of fundamental processes that drive ecosystem response to change is necessary for making predictions of the future acidification status of freshwaters
* The outcome of this WS will contribute to give quantitative relations between drivers and responses of different processes that affect recovery
* Output from this workshop will:
  * contribute to improve existing models
  * contribute to a better interpretation of monitoring data
  * give input to the review of the Gothenburg protocol

We have defined confounding factors as:
> *the effects of environmental factors other than acid deposition that affect recovery from acidification of surface waters*

Confounding factors can be classified into three groups:
1. Processes that are not fully understood but nonetheless should be considered as an inherent part of the recovery process (e.g. competition between species).
2. Processes that reduce our ability to detect recovery (e.g. natural climate fluctuations)

3. Processes that could slow, accelerate or counteract recovery in the long term (e.g. climate change, N saturation, exotic species invasion)

The focus of the workshop was largely on point 3 and to lesser extent on point 2.

Confounding factors where climate change is the driver
Climate change is expected to have large impacts on water chemistry and freshwater biology. Changes in large-scale weather patterns and increased temperature can in concert affect regional patterns and timing of precipitation intensity, wind speed and direction, snow cover and other weather variables.

Several possible factors were discussed. Many different effects of climate change can be more or less important in different regions. There is a division between gradual changes vs. extreme events

Extreme events (some examples)
- droughts $\rightarrow$ can give pulses of SO_4 and NO_3 with pH drop
- floods $\rightarrow$ pH and ANC decrease
- floods $\rightarrow$ habitat for aquatic organisms altered with resulting effects on biological recovery
- storms $\rightarrow$ can give acidic seasalt episodes

Long-term gradual changes (some examples)
- increasing temperature $\rightarrow$
    biological effect: increased growth, increased distribution
- long-term increase in precipitation $\rightarrow$ dilution
- changes in snow-cover $\rightarrow$ changed runoff pattern of nitrate
- increased light (UVB) penetration $\rightarrow$ DOC degradation
- changes in ice-cover $\rightarrow$ reduced ice-cover can enhance biological recovery, increased ice-cover can confound biological recovery
- changing wind directions $\rightarrow$ change in which areas receive polluted air masses

Confounding factors where the driver is not clear
Both the fate of organic carbon and nitrogen are important in the process of chemical and biological recovery. The long-term trends in organic carbon and nitrogen are not fully understood and dose-response relationships are still under discussion and research

The reason for the observed increase in DOC in the 1990's is under discussion; possible reasons include:
- climate change (increase in temperature, increase in precipitation)
- decrease in SO_4+Cl deposition
- light (increased solar radiation)

An increase in DOC can be beneficial for the recovery of aquatic biota. Fish can survive better at higher DOC at a given level of total aluminium and ANC, because DOC complexes toxic Al. On the other hand, increased transport of DOC out of the soil will increase transport of metals incl. Hg out of catchments into lakes. This can have a negative effects (but may not affect recovery). DOC is also a source of acidity in freshwaters, and can to some extent counteract the effect of reduced SO_4 deposition on surface water acidity.

Changes in DOC can alter light penetration, primary production, stratification and oxygen consumption as well as oxygen distribution in lakes. High DOC lakes experience normally oxygen depletion in the profundal zone. Oxygen depletion may mask biological recovery processes. In one Swedish lake, recovery was found in the sublittoral zone, while no recovery was seen in the profundal zone of the same lakes (ICP Water results).

Long-term trends in nitrogen show no clear regional general patterns. Results both from ICP Waters and other studies show that most sites show no change, while some show increasing trends and some show decreasing trends. At the nearly constant N-deposition since the mid-1980s we would have expected an increasing N-trend in surface waters, however, the results does not support this expectation. Deposition has been decreasing slightly since the mid-1990s over most areas in Europe (with some exceptions)

Other confounding factors
- insects outbreaks can cause a massive defoliation of trees, and thereby increased leaching of nitrogen. This can lead again to streamwater acidification.
- invasion of new species can confound the local recovery processes due to competiton for food and habitats

Biological recovery is at an early stage of understanding. Full recovery for fish can be defined as a population with a normal age structure. The workshop recommended that:
- biological confounding factors need to be considered in more detail
- lag-time between recovered water chemistry and recovered biology needs to be evaluated

Confounding factors and modelling:
- will be fundamental in possible revision of Gothenburg protocol
- must include assessment of biological lag times
- emissions must be reduced even more strongly and faster if biological lag-times and not only chemical lag-times are taken into account
- more nitrogen research and nitrogen modelling is needed
- more countries should submit TL (target load) -data for surface waters in the next call
- confounding factors, in particular climate may also be included in future TL
- climate patterns such as the North Atlantic Oscillation, Arctic Oscillation, and European Blocking are useful surrogates and integrators of climate data

General recommendations:
- more research is necessary on the importance of climate change for recovery from acidification
- more research is necessary on biological lag-times
- monitoring must continue and biological monitoring must be enhanced
- ICP Water / ICP IM are encouraged to acquire meteorological data for the sites such that temperature, precipitation etc. can also be tested as drivers for observed trends

PART I – Presentations at the Workshop on Confounding factors 9-10 October 2006

1. Opening address

Mari Sæther
Norwegian Ministry of Environment

Dear delegates and colleagues,

On behalf of the Ministry of the Environment it is a great pleasure for me to welcome all of you to this Joint Workshop and ICP Waters Task Force Meeting.

We hope that you will enjoy your stay and find the programme both interesting and useful. In our view, the workshop is a very valuable and promising cooperation between the ICP Waters Programme, The ICP Integrated Monitoring Programme and Eurolimpacs. We look forward to benefit from the new knowledge and ideas that you will come up with.

New knowledge and new ideas are part of a continuing research and monitoring effort but I will argue that it is also particularly important at this point in time.

In the 1990s we had an intensive 10 years of negotiations on regional air pollution and completed a number of new agreements under the LRTAP Convention: the VOC Protocol in 1991, the second sulphur Protocol in 1994, the POP and HM Protocols in 1998 and the Gothenburg Protocol in 1999.

We used all available knowledge and documentation to build the case for these agreements and – with the Gothenburg Protocol - we pushed scientific input, our models and methods to the limits to make use of the effects-based approach in a political instrument.

Since then – there has been a pause. It took too long to see the last three protocols enter into force. We were particularly disappointed over the long time for the Gothenburg Protocol to enter into force and that it is still ratified by too few countries.

The Gothenburg Protocol is now being reviewed – and the case for a possible revision must be made. I hope that the results of your work will underpin and motivate a renewed effort to control acidification and eutrophication of natural ecosystems.

The European focus has turned more towards particulate matter and health effects – probably rightly so.

Still, it is important that the reduction in acid deposition and biological recovery of natural ecosystems gets its fair share of attention in the ongoing review – and in the possible revision of the Gothenburg Protocol.

With our thin soils and acidic bedrock, Norway is not likely to see a complete recovery from acidification anytime soon. Despite emissions reductions much of the southern half of Norway is still suffering from damage. Acid rain has wiped out salmon in 18 of the larger salmon rivers in the southernmost counties of Norway and 9600 fish stocks are extinct.

Monitoring has shown that during the last 15 years there has been a slow improvement in water chemistry and lately also biological recovery. We want to ensure that this positive development continues.

The future recovery may not only be decided by the emission trends for the air pollutants directly involved. It will also be influenced by factors such as climate change. I am looking forward to hearing your discussions on this.

The extensive scientific cooperation under LRTAP is its greatest asset. Not only has it been a key to the successful negotiations on protocols under the Convention. The expert networks that have been built around EMEP and the Effects Group are now being very actively used by the EU in the development of new air pollution strategies and directives.

It is important that we nurture and maintain this expert cooperation. It is also important that it extends beyond Europe. I am therefore very glad that Canada and Russia are represented here in Bergen.

Cooperation under LRTAP contributed decisively to the scientific consensus on the nature of atmospheric dispersion of air pollutants and its effects in Europe and North-America. We believe that the methods and organisation of our cooperation can be a model for other parts of the world. An example of this is the East Asia Acid Deposition Monitoring Network (EANET).

ICP Waters - as one of seven programmes under the Working Group on Effects – is part of this impressive scientific cooperation. ICP Water had its first meeting in 1986 – since then it has made a valuable contribution to our concerted efforts to stop air pollution damage.

I repeat myself – now again is the time for you to provide timely and vital input. The Executive Body at its meeting in (December) 2007 will consider the review of the Gothenburg Protocol and - possibly - initiate negotiations on its revision.

With that in mind I wish you a successful Joint workshop and Task Force meeting. I look forward to your inputs to the review and possible revision of the Gothenburg Protocol.

I hope you will all have an interesting and enjoyable time here in Bergen.

Thank you.

2. Long-term changes in boreal lake and stream chemistry: the role of climate in lake and stream recovery

P. J. Dillon[1], L. A, Molot[2], M. Futter[1] and M. C. Eimers[1]

[1]*Environmental and Resource Studies, Trent University, Peterborough, ON, Canada, K9J 7B8*
[2]*Faculty of Environmental Studies, York University, Toronto, ON, M3J 1P3 Canada*

We have evaluated trends and measured elemental budgets for 8 lakes and 20 sub-catchments over periods ranging from 16 to 28 years. The fluxes are based on continuous hydrologic measurements combined with chemical analyses carried out on at least a bi-weekly basis. Inputs via the atmosphere are estimated based on a 4-station deposition monitoring network in the study area. Over the duration of these studies, sulphate deposition has decreased by 45%; however, N deposition has remained unchanged, and as a result total N deposition now significantly exceeds S deposition. Lake recovery, however, has been modest, as catchment-related processes have led to net output of sulphate from almost all of the catchments. Lake sulphate has decreased, but only about half as much as expected based on the deposition change, and lake alkalinity and pH have improved only marginally. Base cations have also declined in conjunction with the sulphate, while inorganic nitrogen has remained consistently low in both lakes and streams. Because acid deposition is still greater than the critical load at many of these sites, the possibility of recovery of base saturation and improvements in soil water chemistry are limited. In fact, soil pH and base saturation have continued to decline. It is noteworthy, however, that the chemical changes are synchronous; that is the temporal pattern of change is identical in all lakes, as is the pattern in all streams. These patterns have a strong climate signal, notably a drought-related signal that is influenced strongly by the Southern Oscillation Index (SOI).

During the study period, there have been other significant changes in chemical parameters. Dissolved organic carbon (DOC) changed in a non-linear, but again synchronous, fashion. The lake DOC changes were correlated with incident solar radiation and precipitation. Total phosphorus, the critical nutrient in these boreal systems, has also changed very substantially; the declines of up to 65% in the study lakes over 2 decades indicate that lake productivity has dropped substantially. This decline can be only partly attributed to decreasing runoff, and may also be related to changes in the iron and aluminum cycle in the soil.

3. Links between regional scale climate variability and sea salt episodes in the UK.

Don Monteith
UCL Environmental Change Research Centre. UK

Sea salt episodes have a major influence on the water chemistry of acid-sensitive softwater lakes and streams in the western UK, as well as other regions. The temporary displacement of acid cations from catchment soils by marine base cations can result in significant depressions in pH and pulses of inorganic aluminium in runoff. This acidity can reach levels which are potentially toxic to salmonids and, possibly, other aquatic fauna. While these events are infrequent, they therefore have the potential to disrupt the process of biological recovery.

The occurrence of sea salt episodes has been linked to the North Atlantic Oscillation (NAO), an index of oceanicity determined from the difference in sea level atmospheric pressure between two stations situated in Iceland and the Azores (Hurrel 1995; Evans et al. 2001, Hindar et al. 2004). The elevated state of the NAO during the late 1980s and early 1990s resulted in prolonged periods of storminess in the north eastern Atlantic and, consequently, to the substantial and frequent deposition of marine ions on catchments in UK coastal regions. Precipitation on the west coast of the UK during the winter months is also tightly correlated with NAO indices. The approximately decadal scale of variability of the NAO has therefore resulted in decadal scale natural variability in softwater chemistry, and attempts to quantify this link have allowed predictions of future variability (Evans, 2005). While it has been forecast that the NAO is set to intensify in response to global warming (e.g. Hulme et al. 2002), there is no indication that this process is yet underway. While correlations between freshwater indicators of sea salt episodes (e.g. chloride concentration) and the NAO are highly significant there is considerable scatter in relationships.

Preliminary investigations described in this presentation suggest that the Arctic Oscillation (AO) (Thompson and Wallace, 1998), effectively a descriptor of the same climatic phenomenon, but based on observations from multiple stations, is better able to describe variability in chloride concentrations in streams in the western Scotland. Unlike the NAO the AO has intensified gradually since the 1970s. The historical record suggests that the years between 1989 and 1993 experienced perhaps the most persistently elevated AO Index in the past century and by implication the intensity of seasalt episodes over this time may have been unprecedented. Generally, the acidifying effect of episodes on water acidity can be expected to decline as sulphur deposition continues to fall. However a continued ramping of the AO would be expected to slow down the recovery rate. Furthermore, evidence is presented that the extent to which ANC is depressed and H^+ and inorganic aluminium is mobilised by seasalt events in a stream with a managed forested catchment in northwest Scotland, remains unchanged over the last two decades. Increased seasalt deposition into the future here represents a significant threat to water quality and its potential biological significance requires further investigation.

Evans C.D., Monteith D.T. and Harriman R. 2001. Long-term variability in the deposition of marine ions at west coast sites in the UK Acid Waters Monitoring Network: impacts on surface water chemistry and significance for trend determination. Sci. Total Environ. 265: 115–129.

Hindar A, Torseth K., Henriksen A., and Orsolini Y. The significance of the North Atlantic Oscillation (NAO) for sea-salt episodes and acidification-related effects in Norwegian rivers.

Hulme M., Jenkins G.J., Lu X., Turnpenny J.R., Mitchell T.D., Jones R.G., Lowe J., Murphy J.M., Hassell D., Boorman P., McDonald R. and Hill S. 2002. Climate Change Scenarios for the

United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK.

Hurrell J.W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science 269: 676–679.

Thompson, D.W.J., and J.M. Wallace. 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, Geophys. Res. Lett., 25, 1297-1300, 1998.
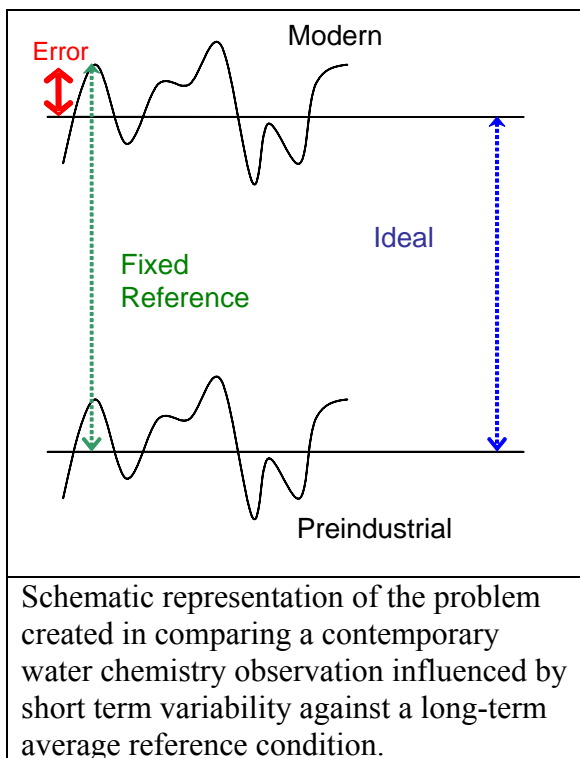
4. Natural variability in acidification status; Now and in the Pre-industrial period

Kevin Bishop Martin Erlandsson and Jens Fölster

Department of Environmental Assessment, Swedish University of Agricultural Sciences
SE-750 07 Uppsala, Sweden

The number of Swedish lakes estimated to be naturally acid (i.e. have a pre-industrial pH less than 6) varies between 12 and 24%, depending on whether national survey data from 1995 or 2000 are used. An important cause of variability in the number of lakes assessed as naturally acid stems from the variability in lake chemistry between sampling occasions. Of the ca 200 Swedish time-series lakes, almost half of these had a pH that was both above and below pH 6 at some point during the last decade.

Climatic variability is an important driver of this variability in contemporary lake chemistry. This can create errors in the assessment of acidification when contemporary measurements are used which are anything less than a long-term average of contemporary conditions (See figure). (A classic example of this is the national lake surveys that have been conducted every 5 years during the last two decades.)

Schematic representation of the problem created in comparing a contemporary water chemistry observation influenced by short term variability against a long-term average reference condition.

As climate change drives climatic variables to new levels and patterns of variability, the acidity status of waters will change. Climate-related changes in DOC are particularly important for the acidity of Swedish surface waters since organic acids are such a major component of the ion balance.

In a stable climate, "static" reference conditions can be used, as in the Water Framework Directive. Given what has been seen of the chemical and biological variability response to short-term climatic variability (much of it natural), and the possibility of long-term, greenhouse gas-related changes in climate, an understanding of how climate affects baseline reference conditions is needed to better understand and interpret anthropogenic effects on our aquatic resources. In particular, we need to better understand the effects on the metrics that are presently being used for assessing good chemical and ecological status. Can we assume, for example, that if climate-induced change results in a positive trend in a reference condition that it will also result in a similar, positive, trend in a stressed condition? Or will different types of stress enhance or mitigate climate effects?

5. Increasing dissolved organic carbon in remote surface waters: Response to climate change or recovery from acidification?

J.L. Stoddard[1*]**, D.T. Monteith**[2*]**, C.D. Evans**[3]**, H.A. de Wit**[4]**, M. Forsius**[5]**, T. Høgåsen**[4]**, D.S. Jeffries**[6]**, A. Wilander**[7]**, B.L. Skjelkvåle**[4]**, J. Vuorenmaa**[5]**, J. Kopácek**[8]**, and J. Vesely**[9]

[1]*U.S. EPA, Corvallis, Oregon, USA;*
[2]*Environmental Change Research Centre, UCL, London, UK;*
[3]*Centre for Ecology and Hydrology, Bangor, UK;*
[4]*Norwegian Institute of Water Research, Oslo, Norway;*
[5]*Finnish Environment Institute, Helsinki, Finland;*
[6]*Environment Canada, Burlington, Ontario, Canada;*
[7]*University of Agricultural Sciences, Uppsala, Sweden;*
[8]*Hydrobiological Institute, Ceske Budejovicé, Czech Republic;*
[9]*Czech Geological Survey, Prague, Czech Republic*

We compiled monitoring data from 505 acid-sensitive monitoring sites on lakes and streams in glaciated regions of northern Europe and North America, and calculated trends in dissolved organic carbon (DOC). For the 1990-2004 time period, five of six regions were dominated by sites with upward trends (334 positive slopes vs. 147 negative slopes; 24 sites had no slope), and 85% of the significant trends (i.e., those with $p < 0.05$) were upward. Increases in DOC, and therefore in organic acids, appear to have retarded chemical recovery in almost all regions; we estimate that increasing trends in alkalinity would be 25% to 100% larger in the absence of increasing DOC concentrations.

Stepwise multiple regression suggested that changes in DOC, both upward and downward, were best predicted by changes in sulfur and seasalt deposition (estimated from changes in surface water SO_4^{2-} and Cl^-); the effect of changing SO_4^{2-} and Cl^- was strongest in the most acid sensitive sites (as indicated by lowest concentrations of seasalt-corrected Ca^{2+} and Mg^{2+}). Changes in air temperature were not strongly related to DOC trends; the multiple regression results suggest that increasing air temperature might result in lower DOC concentrations, once the effects of SO_4^{2-}, Cl^- and CaMg* are accounted for. The relationship between ΔDOC and $\Delta(SO_4^{2-} + Cl^-)$ was very consistent in each of the 6 countries from which data were use (range of coefficients -2.0 to -2.7).

If increasing DOC, which we observe to be widespread, results from decreasing atmospheric deposition of SO_4^{2-} and Cl^-, then higher concentrations of DOC and organic acids should be considered a return to more natural (e.g., reference) pre-acidification conditions.

6. Hydrology controls DOC concentrations in Nova Scotian lakes and rivers

Clair, T.A.
Water Science and Technology Division, Environment Canada, PO Box 6227, Sackville, NB, Canada E4L 1G6

There is currently a debate concerning the controls on medium term changes in dissolved organic carbon (DOC) in lakes and rivers of the western hemisphere. Allochthonous DOC is the product of processes occurring in catchment soils. It's occurrence in streams and eventually lakes is controlled by catchment soil types, the connectivity of soils with drainage waters, and transport by runoff and groundwater processes. We used lake DOC and other chemical data collected from long-term acid rain monitoring networks in Nova Scotia, Canada to assess variations and trends in annual DOC concentrations in relation to DOC analytical methods, acid deposition, sunlight energy, growing season temperature as well as regional precipitation. We found that the best correlation explaining annual lake DOC trends was with growing season light energy. The second most important correlant was runoff. These data emphasize the fact that climatic factors are the most important determinants of DOC concentrations in lakes in our study area. These results are also a reminder that processes controlling DOC in catchment soils must be different from those occurring in lakes. A better understanding of what controls DOC in lakes as well as in catchments will require a multi-compartmental approach.

7. Synchrony of trends in TOC in Swedish streams

Martin Erlandsson * (martin.erlandsson@ma.slu.se)
Kevin Bishop (kevin.bishop@ma.slu.se)
Jens Fölster (jens.folster@ma.slu.se)
Gesa Weyhenmeyer (gesa.weyhenmeyer@ma.slu.se)

Department of Environmental Assessment, Swedish University of Agricultural Sciences, Box 7050, 750 07 Uppsala, Sweden

Several studies have shown increasing trends in TOC the last decades in Northern and Western Europe, as well as North America. In Sweden, we have instead found a clear cyclic pattern for TOC for the studied period of 1965-2004. The study includes 34 Swedish streams. The size of the catchments of the streams ranges from 23 to 26 000 km^2. The streams are distributed all over Sweden, from Skåne in the south to Lappland in the north, and there are boreal as well as alpine and agricultural dominated catchments represented in the study. In spite of this very heterogeneous population, there is a remarkable synchrony between the studied streams. Some of the time-series show an increase in TOC during the period; another pattern is that periods with high or low TOC-concentrations coincide for most of the streams. The general pattern is that most streams show relatively high concentrations around 1985 and 2000, and relatively low concentrations around 1976 and 1992. In this study, we examined potential driving factors for TOC by trying to predict the annual mean TOC for each stream with statistical modelling. The main driving factors behind these patterns are runoff and acidifying deposition, and to a lesser extent the temperature.

8. The influence of climate on concentration of coloured DOC species

Ståle Haaland and Gunnhild Riise
University of Life Sciences (UMB), Department of Plant and Environmental Sciences, Norway

In a forest lake ecosystem, SE-Norway (figure 1), the study of 24 lakes show that the water quality has changed significantly from 1983 to 2005 with decreased concentration of sulphate and increased concentration of coloured dissolved organic carbon (DOC) (figure 2). There is no significant change in pH. Inter annual changes in precipitation is shown to influence the colour of lakes, as increased precipitation generally increases the runoff of coloured DOC species. Changed hydraulic pathways, with increased flow through upper organic horizons are suggested to contribute to the increased colour during high flow events. We have also seen increasing impact of precipitation on the runoff of coloured DOC species, i.e. coloured DOC species are more easily mobilized and exported to the lake ecosystem with time during the investigated period. Simultaneously with increased lake colour, there has been a major reduction in the sulphate deposition, a factor that may influence the pools of DOC available for export. Optical properties of water (i.e. colour) are frequently used to quantify organic matter. The ratio between colour and DOC is, however, not constant. DOC is generally more coloured and acidic during high compared to low flow periods (figure 3). Size separation experiments showed that the content of high molecular weight DOC compounds (nominal molecular weight cut off > 10 kDa) to a large extent could explain the increasing colour of the lakes, as the low molecular weight form (nominal molecular weight < 10kDa) was more or less constant among the studied lakes. Processes contributing to increased mobilization and stabilization of high molecular weight DOC fractions will therefore contribute to increased colour of lakes (e.g. rapid transport of water through upper organic horizons, short lake retention time, and dilution of water solutes).
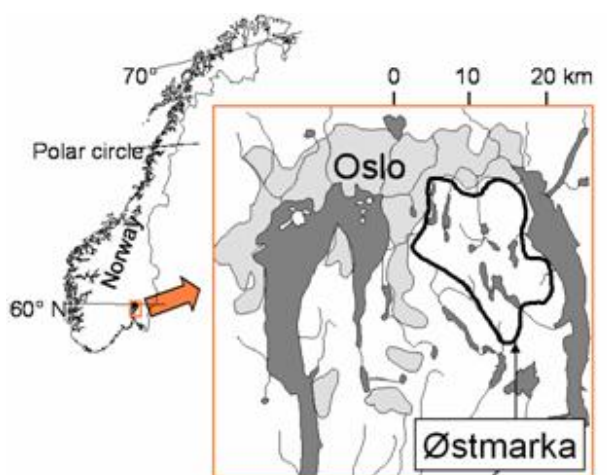

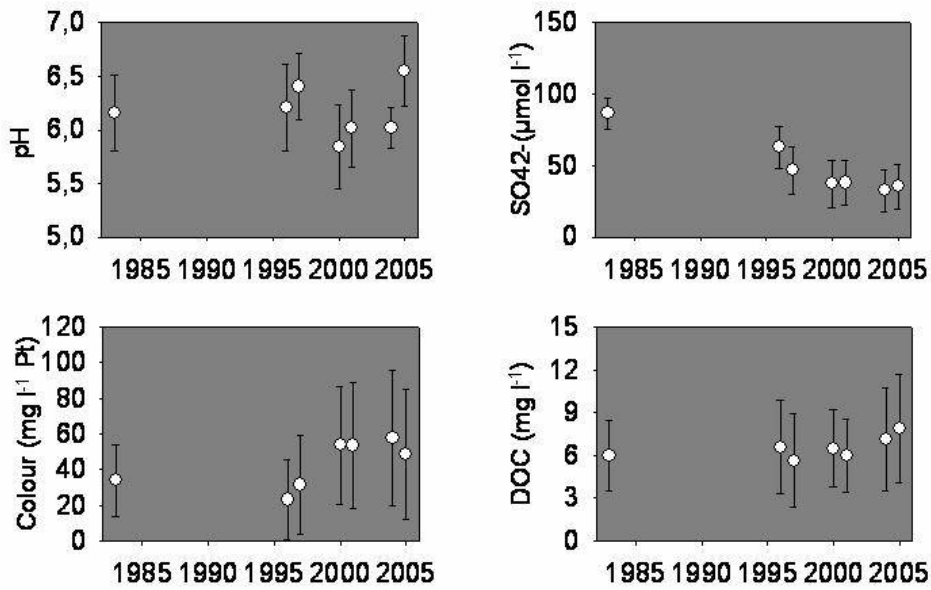Figure 1. The investigated area, Østmarka area, is situated close to Oslo, Norway.

Figure 2. Average sulphate decrease and colour increase in 24 lakes in Østmarka. Standard deviations are shown.
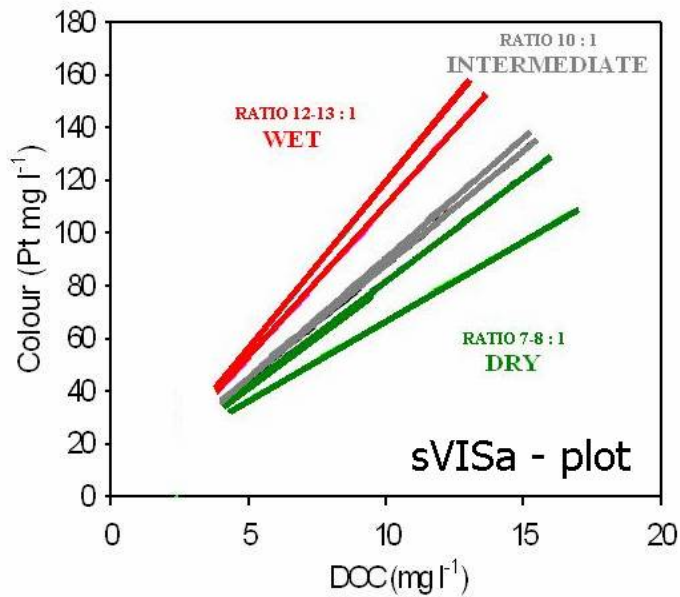

Figure 3. Variations in specific absorbance throughout different precipitation regimes. Wet years tend to have more coloured DOC species.

9. Effects of confounding factors on recovery of invertebrates in acidified waters

Gunnar G. Raddum[*] **and Arne Fjellheim**

*Department of Biology, University of Bergen, Thormøhlensgt. 49, N-5006
Bergen, Norway, e-mail: gunnar.raddum@zoo.uib.no. phone: + 47 55582236 / 95770067*

The main drivers on invertebrate communities during acidification are toxic effects on the organisms. During recovery the toxicity of the water disappears and the damaged communities are increasingly subjected to the physical and non toxic chemical environment as well as biotic interactions. Due to the dynamic nature of ecological processes it is difficult to predict the pathways and the end target of biological recovery after acidification. The processes are controlled by many factors acting together and many of them can be classified as "confounding factors". The processes during recovery are seldom the opposite of those in action during acidification.

Since all communities have a natural variability and develop continuously over time, the pre-acid community will not exist and can not be the target. However, we need to have expectations for the recovery. This is necessary for detecting unforeseen effects and for defining confounding factors.

Reduction of acidifying components has in large areas resulted in reversal of the chemistry associated with acidification, most pronounced in areas with thin soil cover. In areas with thick soil cover, the chemical recovery of surface water is delayed due to high accumulation of acid components in these soils.

Confounding factors associated with climate change are either due to physical factors like increased - or decreased flow, which directly affect the invertebrates through their drift patterns. Densities of invertebrates that are sensitive to strong water currents will be reduced during increased flow, while low flow will favour the same species. The flow will also modify the substrate of the river, the habitat for benthic animals. Changes in the substrate caused by changes in flow patterns will have a major influence on the invertebrate communities. The most dramatic effect will take place during catastrophic flow where the whole bottom substrate comes in movement. Increased water temperature can increase the distribution area of species restricted by the temperature. Increased water temperature of 1-2 °C is found to change the life cycle of some insects with 2 month earlier emergence. Warming will enhance primary production in general, which in turn will increase the abundance of invertebrates.

Warming increases precipitation and events with stormy weather. This will in turn increase the seasalt inputs. High input of seasalt have resulted in setbacks or depressed recovery both chemically and biologically. Sensitive organisms have been wiped out during such episodes, resulting in severe setbacks of the recovery process. At the start of the recovery process, such events will cause an "on -off" situation of the presence of sensitive species for several years.

When the chemical improvements have come so far that the seasalt do not produce toxic water, a stable development of sensitive species will take place.

Warming changes mineralization, nutrition flux, carbon and base cations release to surface water. These factors influences productivity and can change the invertebrate community. Many invertebrates have critical limits to Ca concentrations. Changes in this parameter can therefore exclude or allow development of Ca-sensitive species. Increased DOC is generally observed during recovery. DOC detoxifies water by inactivating Al. Tolerance limits of many sensitive invertebrates therefore increase when DOC concentrations increase. However, DOC alters light penetration, primary production, stratification, oxygen consumption as well as oxygen distribution in lakes. Lakes with high DOC normally experience oxygen depletion in the profundal. Oxygen depletion will mask any biological recovery process. Example: In Swedish lakes recovery was found in the sublittoral zone, while no recovery was seen in the profundal zone of the same lakes where oxygen was depleted.

10. Fish under Recovery: Interactions between ANC and density-dependent processes affect the recovery of fish populations after acidification

Thrond O Haugen[1]*, Trygve Hesthagen[2], Torstein Kristensen[1], Richard F. Wright[1], Bjørn Olav Rosseland[1,4], B. Jack Cosby[3], and Arthur J. Bulger[3]

[1]*Norwegian Institute of Water Research, Gaustadalléen 21, 0421 Oslo, Norway*
[2]*NINA, Oslo, Norway*
[3]*University of Virginia, USA*
[4]*UMB, Ås, Norway*

The decrease in acid deposition during the 1980s and 1990s has largely halted the acidification process in Norway, and since about 1990 many lakes and streams have undergone chemical recovery. Despite this improvement in water chemistry the extent of damage to brown trout populations has continued to expand. Dynamic models like MAGIC that link acid deposition to surface water acidification has been used since 1980s to explain the observed lag time between acid deposition and water chemistry response. Dynamic models for biological response, however, are lacking, and there is an urgent need for such models to evaluate when, where and to what extent biological recovery can be expected. In this project, we develop a dynamic biological response model for brown trout populations in Norwegian lakes undergoing recovery from acidification. The model consists of three sub models that reflect key demographic processes 1) survival, 2) maturation and 3) recruitment under influence of density-dependent factors and ANC. The sub-models are parameterized by fitting statistical models (generalized linear and additive models) to an extensive time series (1977–2005) of brown trout survey data from lake S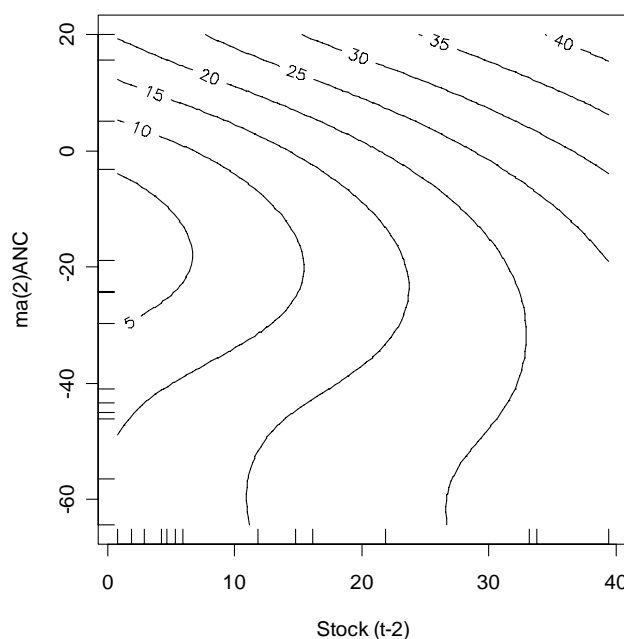audlandsvatnet. The data series included information about age structure (based on ageing from scales), which allowed for detailed analyses of survival and recruitment. Catch per unit effort was used as proxy for population density in the models and ANC values were derived from outputs from the MAGIC model.

1) The survival process (age>2) was shown to be positively and linearly influenced by ANC and negatively (linearly) influenced by the density of trout; 2) The probability of being a first-time spawner was shown to be negatively influenced by ANC, but no effect of trout density was found. 3) The recruitment process was shown to be influenced by a highly significant non-linear interaction effect between number of spawners and ANC (Fig), where number of age-2 recruits for a

Fig. *Estimated (from binomial GAM) number of age-2 recruits as function of spawning stock at time t-2 and the moving average of ANC from time time t-2 to t.*

given number of spawners was almost twice as high at ANC levels above zero compared to ANC values below -50.

By combining the three sub-models into a population dynamic model (Leslie matrix model where both dimensions and elements of the transition matrix vary in time as functions of ANC and the prevailing population size) the population age structure and density could be reconstructed from the initial 1977 situation up to present using the MAGIC-derived ANC-values only as an external driver. The reconstructed population corresponded very well with the historical data ($r = 0.84$, $p<0.001$). Hence, this project has, in addition to providing explicit estimates of combined effects from density and ANC on demographic processes in brown trout, constructed a population dynamic model that seem suitable for modelling the acidification recovery process of brown trout populations in Norway.

11. Nitrogen runoff at ICP Waters sites 1990-2005: Increasing importance of confounding factors?

Øyvind Kaste*, Heleen de Wit, Tore Høgåsen, Brit Lisa Skjelkvåle

ICP Waters Programme Centre, Norwegian Institute for Water Research, Oslo, Norway
* Corresponding author (oka@niva.no)

There is a large spatial variation in NO_3^- concentrations between the different regions included in the ICP Waters Programme. The highest concentrations appear in eastern and western central Europe (ECE and WCE) and in the Alps. There has been a slight increase in the number of sites with mean concentrations of NO_3^- below 5 $\mu eq\ L^{-1}$, from 34% in 1990-93 to 41% in 2002-05. The frequency of sites with NO_3^- concentrations greater than 50 $\mu eq\ L^{-1}$ (only occurring in Central European sites) has remained surprisingly stable during the study period (16%). This might indicate that sites within this group are chronically disturbed by other factors or N sources than atmospheric deposition (e.g. agriculture). About 65% of the ICP Water sites have NH_4^+ concentrations below 2 $\mu eq\ L^{-1}$, and about 90% show concentrations below 5 $\mu eq\ L^{-1}$. There are only small differences between the time periods 1990-93, 1996-99 and 2002-05 with respect to NH_4^+ concentrations.

The importance of NO_3^- in acidification relative to SO_4^{2-} in surface waters can be quantified by the concentration of NO_3^- divided by the sum of non-marine SO_4^{2-} and NO_3^- (the 'N-acidification ratio' - NAR). Given the large reduction in SO_4^{2-} deposition since 1990, there has been a surprisingly little change in NAR-values at the ICP Waters sites up to now. The main reason for this is that many sites have experienced decreasing NO_3^- concentrations during the same period. At 6% of the sites, most of them located in Germany and Italy, NO_3^- was a more important factor than SO_4^{2-} in the acidification of surface waters (NAR > 0.5) during the period 2002-05. This was an increase compared to the earlier period, 1990-93.

The results from the ICP Water Programme support the general picture that increased TIN concentrations occurs in catchments receiving N deposition above certain thresholds. Catchment N retention capacity is highly variable among sites, depending on landscape characteristics, site history and different types of disturbance. When comparing the periods 1990-93, 1996-99 and 2002-05, there was a successive reduction in TIN concentrations in precipitation. In most cases this was followed by a corresponding decrease in TIN runoff concentrations.

Altogether there were 55 sites with sufficient data for trend analysis of both N deposition and NO_3^- runoff during the period 1994-2004 (54 sites covering the period 1990-2001). At most sites, there were no clear trends, neither in N deposition or NO_3^- runoff. During the earliest period (1990-2001) there were more sites with significantly decreasing trends in N deposition than in the period 1994-2004. Only four sites in 1990-2001 and two sites in 1994-2004 show decreasing trends in both N deposition and NO_3^- runoff. Diverging (opposite) trends can indicate that NO_3^- runoff is regulated by other driving forces (confounding factors) than deposition.

12. Regional differences in nitrogen deposition trends

Lars R. Hole[1], Heleen de Wit[2] and Wenche Aas[1]

[1]*Norwegian Inst. for Air Research (NILU),* www.nilu.no
[2]*Norwegian Inst for Water Research (NIVA),* www.niva.no

Future climate change with more precipitation and higher air temperatures in Norway will affect the nitrogen cycle. The REGCLIM project (regclim.met.no) has recently published scenarios for the period 2071-2100 suggesting that the annual precipitation in Southern Norway can increase with between 0.2 and 19.6% while the winter precipitation can increase with 2.0 to 35.6% compared to the present situation.

The CLUE project was established to better understand climate change effects on the N cycle in Norway in a combination of field experiments and model studies including coupling to regional climate models (www.umb.no/ipm/forskning/clue/).

According to Hanssen-Bauer (2005) the annual precipitation in Norway has increased in 9 of 13 regions with a 15-20% increase in north-western regions. The same study shows that there is a correlation between the North Atlantic Oscillation index (NAOI) and winter air temperature in all regions and a correlation between NAOI and winter precipitation in the western regions. However, this correlation varies with time. One explanation may be that the atmospheric circulation over Norway is not only dependent on NAOI but also on the position of the Icelandic low.

Regional nitrate deposition gradients are partly caused by large differences in annual precipitation (a factor of 10). South-West Norway has the highest precipitation and consequently the highest deposition, while dry deposition dominates in the north and along the Swedish border.

Precipitation data from seven monitoring stations were tested with the nonparametric Mann-Kendall as a two-tailed test (Gilbert, 1987). Secondly the estimate for the slope of a linear trend was calculated with the nonparametric Sen's method (Sen, 1968).

Results
- There is a significant increase in both summer and winter precipitation at some stations. No stations show a significant decrease
- Because 1990 was the warmest (and consequently one of the wettest) year on record in Norway, there are few significant trends in precipitation in 1990-2003.
- There are significant reductions in nitrate concentration in precipitation at several stations, particularly at the driest station (Langtjern).
- For reduce nitrogen there are negative trends at the wettest station (Haukeland). The positive trend at Tustervann could be explained by changes in local farming activities.
- NAOI is best correlated with nitrate deposition at the coastal stations (Haukeland and Skreådalen). This is particularly true in winter.

- The European blocking index is strongest (and negatively) correlated with winter nitrate deposition at the drier sites.
- Increasing precipitation seems to compensate for decreasing nitrate concentrations at several sites in the south (Birkenes, Storgama and Langtjern).
- More detailed statistical analysis is in progress as part of the CLUE project. (www.umb.no/ipm/forskning/clue/).

13. Synchronous trends in NO$_3$ export from N-saturated river catchments in northwestern Italy and their relationship with climate variables

Michela Rogora* and Rosario Mosello

CNR Institute of Ecosystem Study, L.go Tonolli 50, I-28922 Verbania Pallanza, Italy
* E-mail: m.rogora@ise.cnr.it

Long-term trends (1978-2005) of NO$_3$ concentrations in river water were investigated for 10 rivers draining forested catchments in northwestern Italy. This area is affected by high N deposition (20-25 kg N ha^{-1} y^{-1} as the sum of NO$_3$-N and NH$_4$-N). This deposition has not changed significantly in the last two decades and is causing N saturation of terrestrial catchments (Rogora *et al.*, 2001).

All the river catchments classified for medium-high stage of N saturation (levels 2-3 of the Stoddard's classification). We also evaluated the seasonality of NO$_3$ concentrations and its change in time during the study record. Both the increasing NO$_3$ levels and the limited seasonal pattern in recent years pointed to an aggrading level of N saturation with time.

Single trends were analysed for significance and magnitude; then statistical techniques for the detection of common trends were applied to the dataset in order to identify common pattern in NO$_3$ time series. Significant positive trends ($p < 0.0001$) were found for all rivers except one. Trend slopes were between 0.30 and 2.16 μeq L^{-1} y^{-1}, corresponding to an overall increase of 8 and 60 μeq L^{-1}, respectively.

Synchronous patterns of NO$_3$ export were found for 8 rivers. The main common trend extracted from the 8 time series was used to test relationships with: i) temperature, ii) precipitation, and iii) N deposition data series. All the rivers with positive NO$_3$ trends showed high correlations with temperature. Correlation increased with addition of a lag of 2-4 months between temperature and NO$_3$. This result indicates that NO$_3$ concentrations in rivers are partly controlled by temperature during the previous 2-4 months. Increasing temperature may affect biological processes, leading to increased release of N to surface waters in excess of that taken up by plants or immobilised in the soil (Wright *et al.*, 1998).

No significant correlations were found between NO$_3$ and precipitation amount or N deposition. Nevertheless, precipitation amount played a role in the temporal pattern of NO$_3$: rainy periods usually led to a temporary decrease in concentration due to dilution. On the other hand prolonged droughts such as those occurred in autumn-winter of 1999, 2001 and 2003, were followed by strong NO$_3$ pulses in river water. It has been observed that extended period of droughts are frequently followed by high NO$_3$ export (e.g. Murdoch *et al.*, 2000). We hypothesised that rain falling after prolonged dry periods leached previously stored N from soil, which caused temporary NO$_3$ increases. The rapid flushing of runoff water during storms prevented the interaction with soil and vegetation, limiting N retention.

Our findings suggest that rates of N mineralisation and nitrification rather than deposition fluxes are the main factors controlling NO$_3$ leaching in the study catchments. Most regional climate models predict a further increase of temperature and a higher frequency of extreme events such as drought and heavy rainfall in the next decades (IPCC, 2001). These variations

may exacerbate the effect of elevated N deposition and increase NO_3 leaching to surface waters.

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14. Climate affects long-term trends in streamwater nitrate concentrations and fluxes in south Norway

Heleen de Wit[1*] and Lars Hole[2]

[1] *Norwegian Institute for Water Research (NIVA), Gaustadalléen 21, 0349 Oslo, Norway*
2 *Norwegian Institute for Air Research (NILU), P.O. Box 100, N-2027 Kjeller, Norway*
* *Corresponding author: heleen.de.wit@niva.no; phone +47 2218 5100 fax +47 2218 5200*

Controls of streamwater nitrate in mountainous and forested catchments are not thoroughly understood. Nitrate fluxes and concentrations show large interannual variation and both upward and downward trends (see Table under), apparently little affected by trends in N deposition. Here, time series of nitrate in four small acid-sensitive catchments in south Norway were studied with the aim to identify likely drivers of long-term changes in streamwater nitrate. The two inland catchments showed a highly significant downward trend in fluxes and concentrations while the two coast-near catchments showed a less distinct, but significant, upward trend in nitrate. The most distinct trends were found in winter and spring. Empirical models (built by stepwise multiple regression using climatic variables, N deposition and hydrology as explaining variables) explained between 45% and 61% of the variation in weekly nitrate concentrations, and described both upward and downward seasonal trends tolerably well. Key explaining variables were snow depth, discharge, and temperature and N deposition for the inland catchments. Of these, only snow depth, temperature and discharge showed a long-term trend. The significant decrease in snowdepth related to the distinct decreases in spring nitrate concentrations in the inland catchments. The catchment with the clearest upward trend in nitrate had a significantly altered distribution of discharge within the year, where winter discharge increased whereas discharge in the remaining seasons decreased. The analysis suggests that climate warming has affected snow cover and winter discharge which have led to decreases in nitrate concentrations in area with medium N deposition, whereas a low N deposition catchment released more nitrate under similar changes in climate.

	period	n	NO3-flux p<	g N /m2/yr sen-slope	NO3 conc p<	µg N /L/yr sen-slope
Birkenes	1973-2005	31	n.s.	1.6	n.s.	0.5
	excl. '86-'91*	24	*	2.8	n.s.	1.0
Langtjern	1974-2002	30	***	-0.4	****	-0.6
Storgama	1975-2005	30	**	-3.7	****	-3.6
Kårvatn	1978-2005	27	*	0.4	***	0.7

*These years were excluded because nitrate was affected by a small harvest in part of the catchment

15. Modelling seasonal nitrate concentrations with MAGIC

R. F. Wright[1] and B. J. Cosby[2]

[1] *Norwegian Institute for Water Research (NIVA), Gaustadalléen 21, 0349 Oslo, Norway*
[2] *University of Virginia, USA*

NO_3 concentrations in streamwater typically show a marked seasonal pattern, low in summer and high in winter. The pattern is the result of the seasonal cycle of biological activity largely driven by temperature. Year-to-year variations in temperature cause variations in snow accumulation and melting. Climate change may alter the magnitude and/or timing of seasonal cycle of NO_3 leaching. Here we used MAGIC at a monthly timestep to attempt to simulate the seasonal pattern and year-to-year variations in NO_3 in streamwater at Storgama, Norway. This site is part of the Norwegian national monitoring programme and has a 30-year record of meteorological data, precipitation chemistry, and streamwater discharge and chemistry.

For the soil nitrogen processes in MAGIC we assumed temperature dependence described by Q_{10} functions. (Q_{10} describes the change in rate with a $10^{\circ}C$ change in temperature). The Q_{10} of gross mineralization was assumed to be smaller than the Q_{10} for immobilisation. Thus net mineralization of N is larger in the cold months and smaller in the warm months. In addition N uptake by plants was assumed to occur during the summer months and litterfall in the autumn. To simulate accumulation and loss of N in the snowpack we also used temperature dependence.

MAGIC was calibrated to the year 1990, mid-point of the record 1974-2004. Model goodness-of-fit to both monthly mean concentrations of NO_3 and monthly flux of NO_3 was evaluated by 5 measures, including efficiency (Efficiency $eff = 1 - (sumsq / n) / \mathrm{var}$).

The results show that MAGIC with monthly time steps and seasonal variations for the N cycle successfully explain about 35% of the variance in concentration and 70% in flux. Addition of the snowmelt routine had only a small improvement in the efficiency. MAGIC was unable to simulate the observed long-term decrease in NO3 concentrations at Storgama, probably because the long-term N retention on MAGIC is assumed governed by the C/N in soil organic matter. Additional work is necessary to fully evaluate the effect of warm vs. cold winters on NO3 in streamwater at Storgama and other sites.

16. The influence of climate change (scenarios HadAM3 B2 and ECHAM4/OPYC3 A2) on recovery from acidification at Lysina catchment, Czech Republic

Jakub Hruška[1], Jan Turek[2], Pavel Krám[1], and Jiří Kopáček[2]

[1]*Czech Geological Survey, Klárov 3, 118 21 Prague, Czech Republic*
[2]*Biological Center, Institute of Hydrobiology AS CR, České Budějovice, Czech Republic*

Two climatic scenarios from the global circulation models HadAM3 B2 (HAB2) and ECHAM4/OPYC3 A1 (ECA2) were applied to estimate future trends (2070-2090) of streamwater chemistry and hydrology at the Lysina catchment, western Czech Republic. HAB2 and ECA2 predict temperature increase from present-day 5.0 to 5.8 C and 8.4 C, respectively, precipitation change from 983 to 1012 mm and 904 mm, respectively, and runoff decrease from 450 mm to 392 mm and 329 mm, respectively. As a result, SO_4 concentrations will decrease relative to the predicted lowest concentrations in 2010 by about 20% in 2090. NO_3 will increase significantly from about 15 µeq/L in 2010 to 80 µeq/L (no climate change) or ca 90 µeq/L in 2090 (both climate predictions). Consequently, pH will decrease from 4.15 (2020) to 4.05 in 2090 (no climate change and ECA2) or 4.02 (HAB2). Total Al will rise from 25 µmol/L to 35 µmol/L (no climate change) or 40 µmol/L (both scenarios). ANC will decrease from −10 µeq/L (2020) to − 60 µeq/L (no climate change) or −70 µeq/L (both scenarios). Soil base saturation will decrease slightly (from 5.5 % to 5%) under both climate scenarios. The scenario of no climate change will result in negligible increase from 5.5% to 5.6%.

Hydrological changes will affect streamwater chemistry only slightly; the most important will be nitrogen dynamics. This will depend not only on climate change scenario, but also on forest management and N deposition trends.

PART II – Presentations at the ICP Waters TF meeting 11-12 October 2006

17. Estimation of long-term trends in water chemistry in Kola Peninsula, northwestern Russia

Tatyana Moiseenko[1] and Natalia Gashkina[2]

[1]*Institute of Water Problems of Russian Academy of Sciences, 3 Gubkina St., GSP-1, Moscow 119991, Russia*
[1]*tayana@ aqua.laser.ru, corresponding member of Russian Academy of Sciences*
[2]*gashkina@aqua.laser.ru*

Within the "Survey Lakes" project every five years investigations in lakes are carried out in the Kola Peninsula, northwestern Russia. This region suffers from long-term atmospheric pollution of sulphur and metals caused by the copper-nickel metallurgical plants "Pechenganickel" and "Severonickel".

Water chemistry has improved for the lakes suffering highest pollution loads (within 10 km from the plants). This is shown by decreasing concentrations of sulphate, nickel and copper in waters of these lakes. In the past decade there their critical loads have not been exceeded.

Geological conditions largely predefine the vulnerability of lakes to acidification. This is shown by values of critical load exceedences.

We measure decreasing concentrations of sulphate, nickel and copper also in lakes located far from the plants. This suggests a regional decrease in sulphate and metal loads in the area of Kola North. Nevertheless there is no increase of pH, probably because of increasing organic anion concentrations. A regional consequence is the decreasing concentrations of calcium and magnesium (as a result of their accumulation by humus in the catchment) and an increasing mobility of aluminium.

We conclude that the decreasing of deposition of sulphur and heavy metals in Kola North has led to improvements in water chemistry in proximity of the plants and also in the whole region.

18. Temporal and spatial assessment of water quality around copper-nickel smelters on Kola Peninsula

Natalia Gashkina[1] and Tatyana Moiseenko[2]

Institute of Water Problems of Russian Academy of Sciences,
3 Gubkina St., GSP-1, Moscow 119991, Russia
[1]tayana@ aqua.laser.ru, corresponding member of Russian Academy of Sciences
[2]gashkina@aqua.laser.ru

The Kola North situated above Artic Circle within two geographical zones (tundra and taiga) is very vulnerable to anthropogenic impacts. Large smelters operated by the "Pechenganickel" and "Severonickel" companies (Fig. 1) have emitted pollutants for more than 60 years (Moiseenko, 1994). In the 1980s emission of pollutants reached a maximum. The main pollutants were nickel, copper and sulphate. The annual emission of SO_2, Ni and Cu was 516000, 2460 and 1600 t, respectively. The annual sulphur deposition was above 1 gS/m^2 over 30% of the territory, while in the industrial regions it reached to 10 gS/m^2. Since 1990, as a result of the economic crisis in Russia, anthropogenic pressure has decreased. The recent recovery of the economy goes on simultaneously with technological modernization and tighter control of pollutant emissions to the atmosphere.

To determine the influence of these changes on water chemistry, the results of survey lakes in 1990-1992, 1995, 2000 and 2005 were used. In 1995 the research was carried out throughout the Kola North (460 lakes) as a part of project "Survey Lakes 1995" (Henriksen et al., 1998). In 2000 and 2005 partial monitoring of western part of the Kola North (100 lakes) was repeated using the same selection and sampling methods. From a previous lake survey in 1990-1992 only 40 lakes conform to sampling method and are included in consecutive monitoring.

Analytical methods were almost identical through the study (sulphate was analysed by ion chromatography since 1995). Accuracy of the methods is documented by international intercomparison tests (Hovind, 2001). Acid neutralizing capacity of water (ANC), critical loads (CL) and their exceedences (CLex) were calculated using method of Henriksen et al. (1992).

In the period of anthropogenic load fall from 1990 to 1995 a decrease in concentrations of the main pollutants in lake waters occurred, but its magnitude varied spatially. In the local zones of intensive load considerable reductions of Ni and Cu concentrations were observed in the lakes near "Severonickel" smelter, but not in the lakes near "Pechenganickel" smelter (fig. 2). In 1990 the percentage of lakes with Ni and Cu concentrations above high level (10 µg/l) was 20% and 7%, whereas in 1995 it was 10% and 2%, respectively (fig. 3). It seems that the Ni deposition had slightly more local behaviour than Cu. This is perhaps why the only a reduction of Cu concentration was detected in lakes of remote regions. However, the decrease in anthropogenic load had an effect on the common regional level of pollutants. Whereas in 1990 the percentage of lakes with Ni and Cu concentration below 1 µg/l was 20% and 2%, in 1995 it was 55% and 65%, respectively (fig. 3). The decrease of SO_4 was gradual and

prolonged (fig. 3). First (1995) it was in the tundra zone, especially in its remote region (fig. 4a). This region, with geological formations resistant to chemical weathering, thin soil and poorly developed vegetation, has low solute contents in the lakes. Here the decline of SO_4 was significant and larger than the decline in base cations, which led to an ANC increase (fig. 4b). As a response to the sulphate reduction, decreases of critical load exeedences were observed (fig. 5b). In the lakes near the "Severonickel" smelter the improvement in lake chemistry was first revealed in ANC (1995), then in SO_4 and Clex (2000), which implies very slow rate of decline of base cations.

In the period of industrial impact stabilization since 2000 changes have continued. SO_4 concentrations in the lakes have continued to decline (fig. 3). For the last decade the decline in sulphate has caused a decrease of base cations (fig. 8a). However, other parameters connected with sulphate concentrations and their deposition did not show significant changes. Values of critical load exceedence stayed at about same level (fig. 5a). In response in some of the lakes near "Severonickel" smelter in 2000 we can see some decrease of critical load exeedences (fig. 5b). One would expect this to be reflected in pH values, but there is no tendency of increased pH. The percentage of lakes with pH below 6 was 16.5%, 9%, 12.5% in 2005, 2000, 1995, respectively, whereas only 5% in 1990 (fig. 7a). In recent years there has been some reduction of pH values in lakes spread throughout Kola North especially in taiga (fig. 6a). This coincides with increases in organic anion (fig. 6b). In the period of industrial impact stabilization concentrations of organic anions in the lakes increased and were higher than in the period of anthropogenic load fall (fig. 7b). In recent years elevation of organic anion content in lake waters has led to pH decrease and Al increase (fig. 9). There is no decreasing trend of copper for last decade especially in high and low ranges of values (fig. 3a), which is due to activation of its migration in more acidic water and with organic mater (fig. 10a). This same situation can be seen in nickel distribution, but only in low range of values (fig. 3b). The mechanism of nickel activation is not as evident as for copper (fig. 10b). We can definitely conclude that nickel decreases along with sulphate (fig. 8b).

Conclusions

In the period of intensive anthropogenic load decrease:
- improvement of water quality on many parameters in the lakes near "Severonickel" smelter
- only minor improvement of water quality in the lakes near "Pechenganickel" smelter

In the period of stabilization of anthropogenic load:
- common regional consequence of sulphate decline is decrease in base cations;
- increased elevation of organic anion concentration in water of many lakes has led to following consequences:
  - pH decrease and Al increase
  - mobilisation of Cu and partially Ni (both of which have accumulated in soil during the long period of smelter operations)

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Figure 1. Location of Ni-Cu smelters.
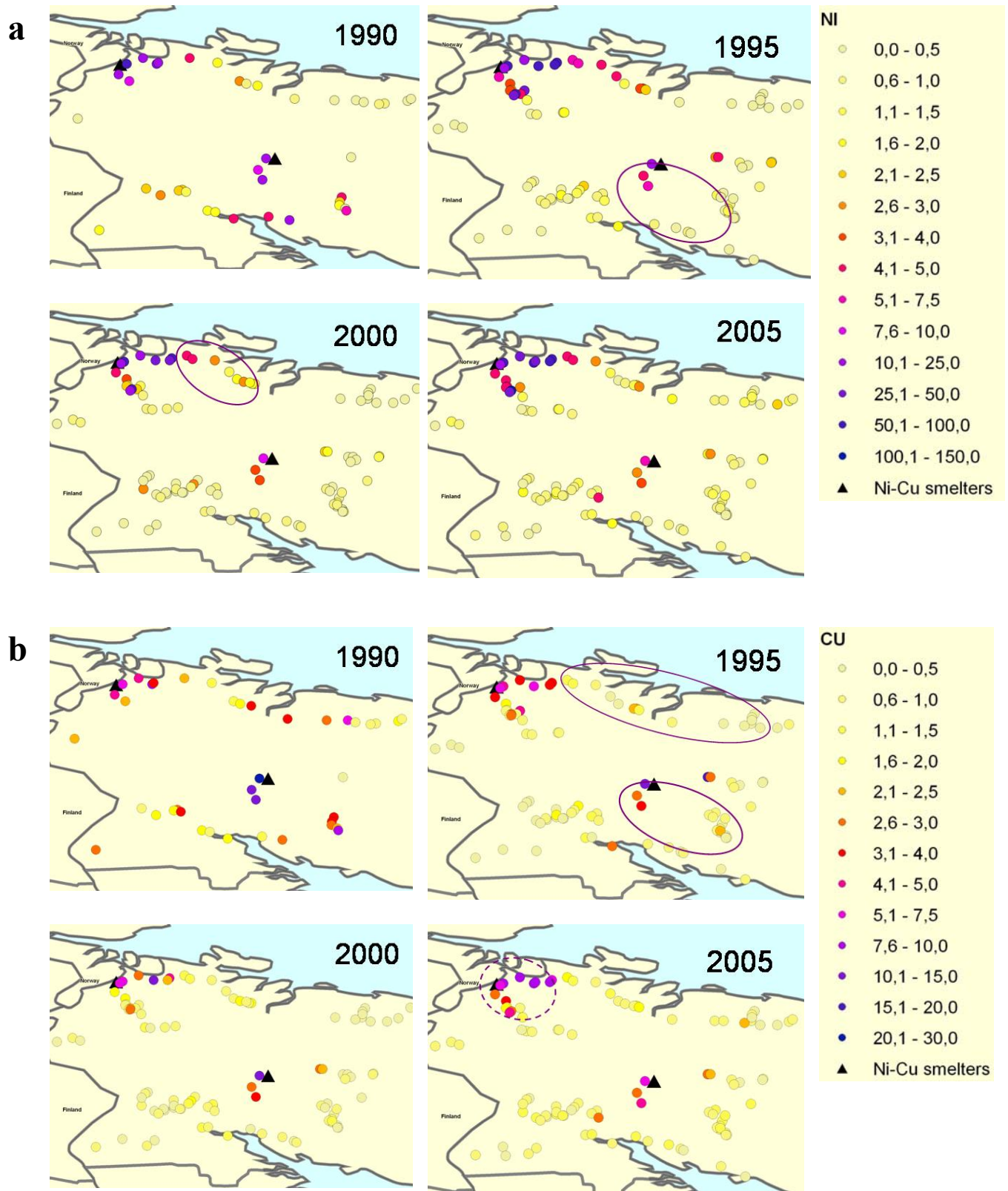
Figure 2. Distribution of Ni (a), µg/l, and Cu (b), µg/l, in water of Kola North lakes in 1990, 1995, 2000 and 2005 years (Here and in figures 4, 5 and 6, zones of decrease and increase are segregated full and dashed lines accordingly).
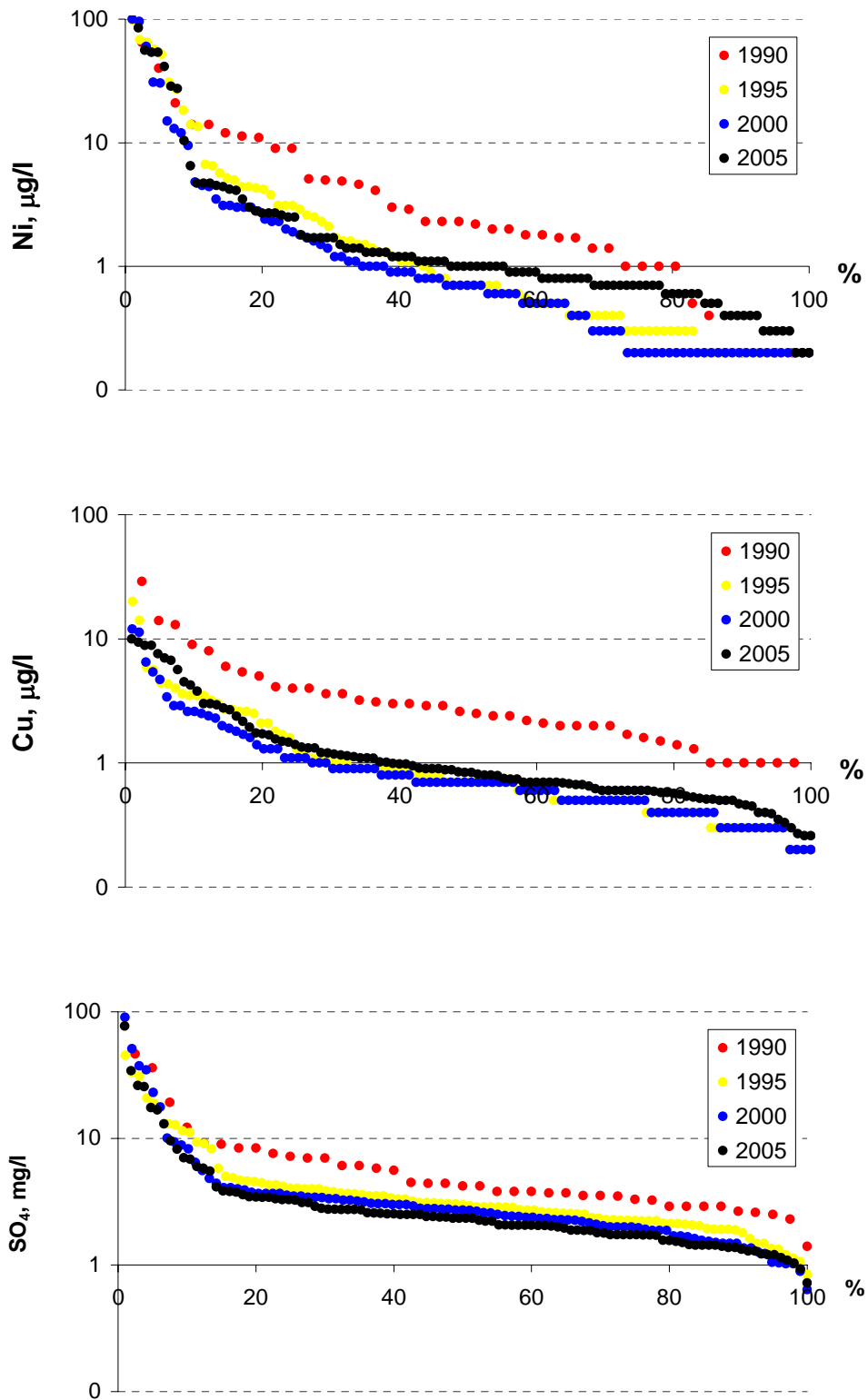
Figure 3. Distribution in decreasing order of Ni, Cu and SO₄ in water of Kola North lakes on years.
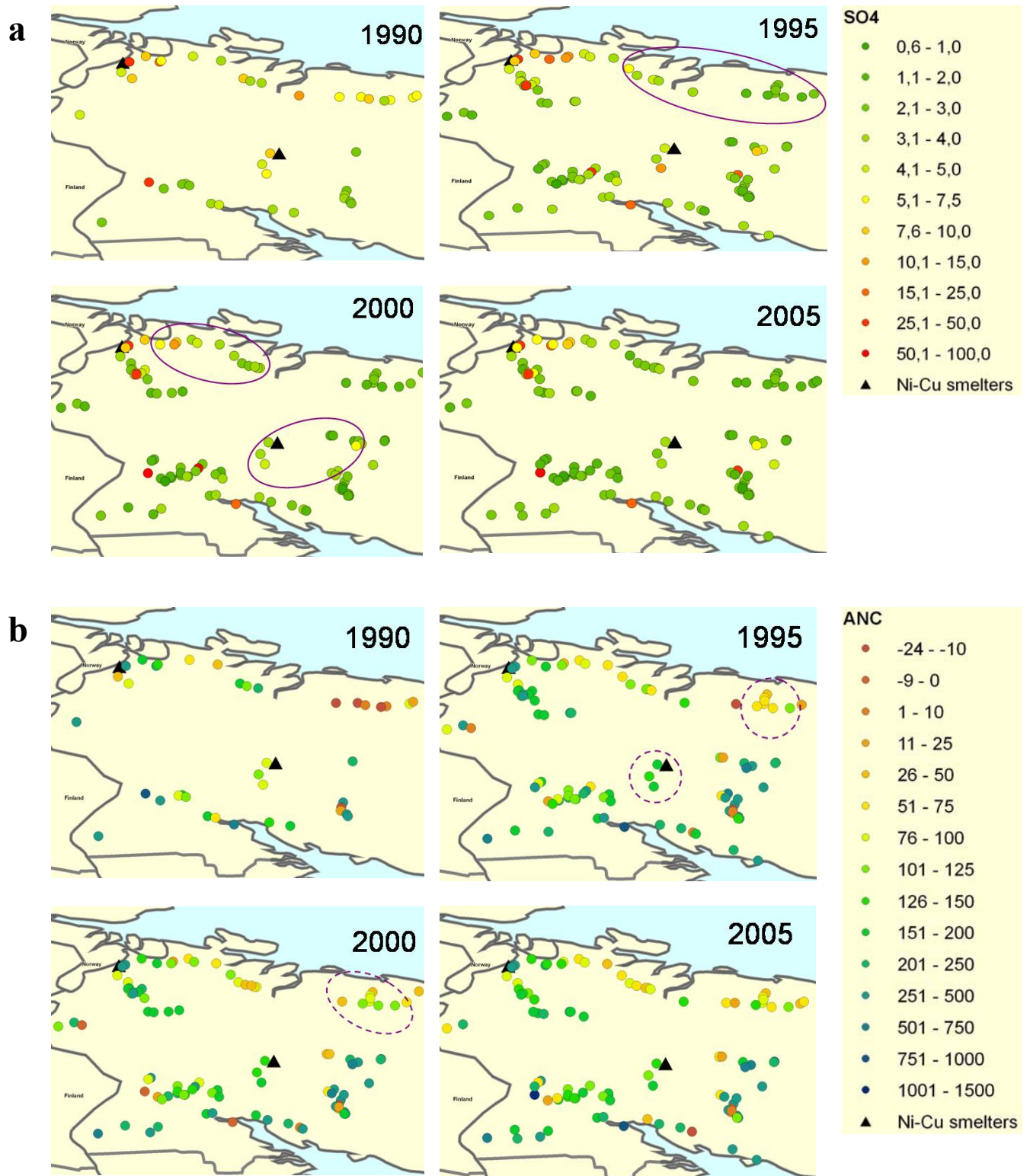
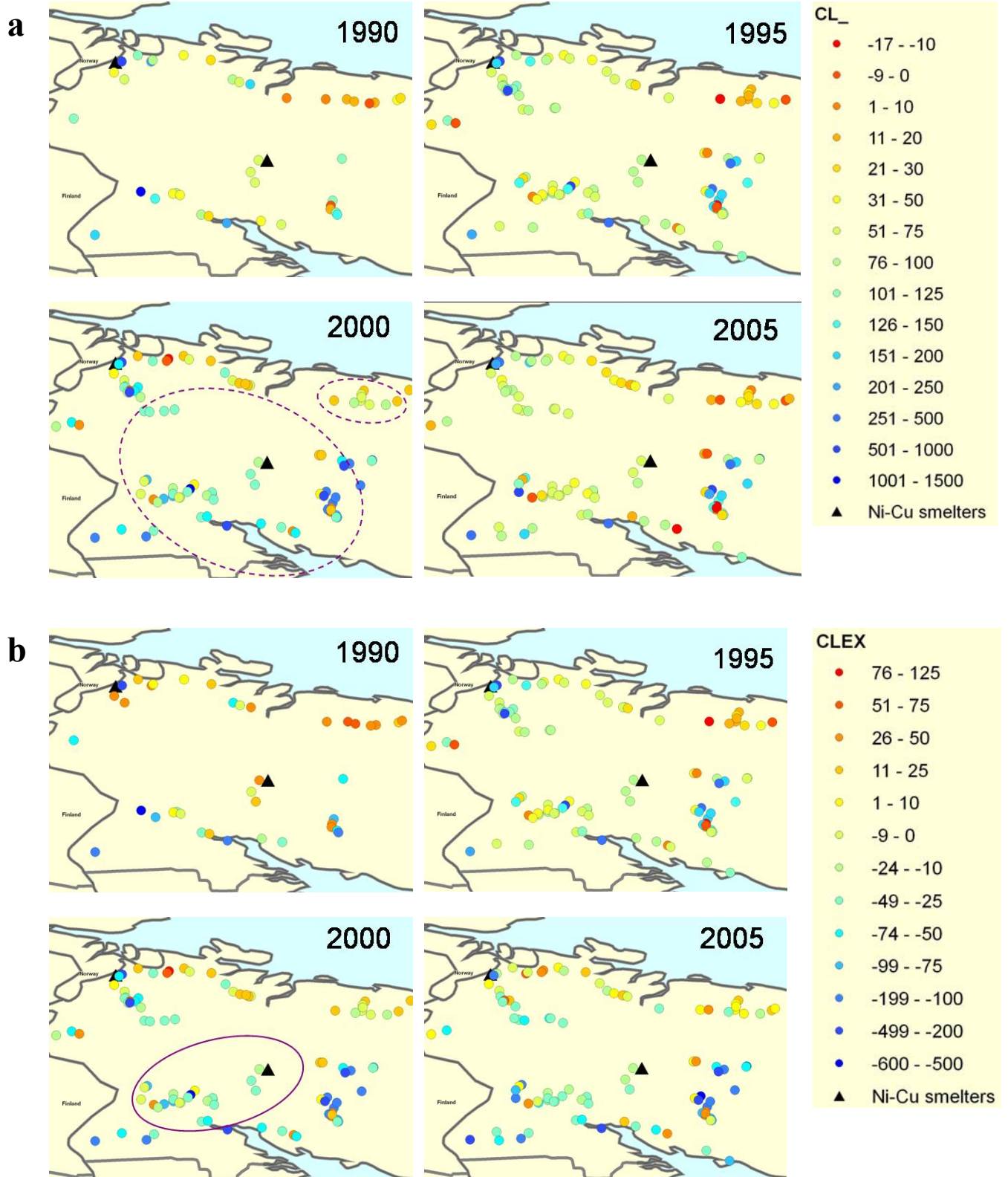**Figure 4.** Distribution of SO$_4$ (a), mg/l, and ANC (b), µeq/l, in water of Kola North lakes in 1990, 1995, 2000 and 2005 years.

Figure 5. Distribution of CL (a), eq/m^2/yr, and CLex (b), eq/m^2/yr, in water of Kola North lakes in 1990, 1995, 2000 and 2005 years.
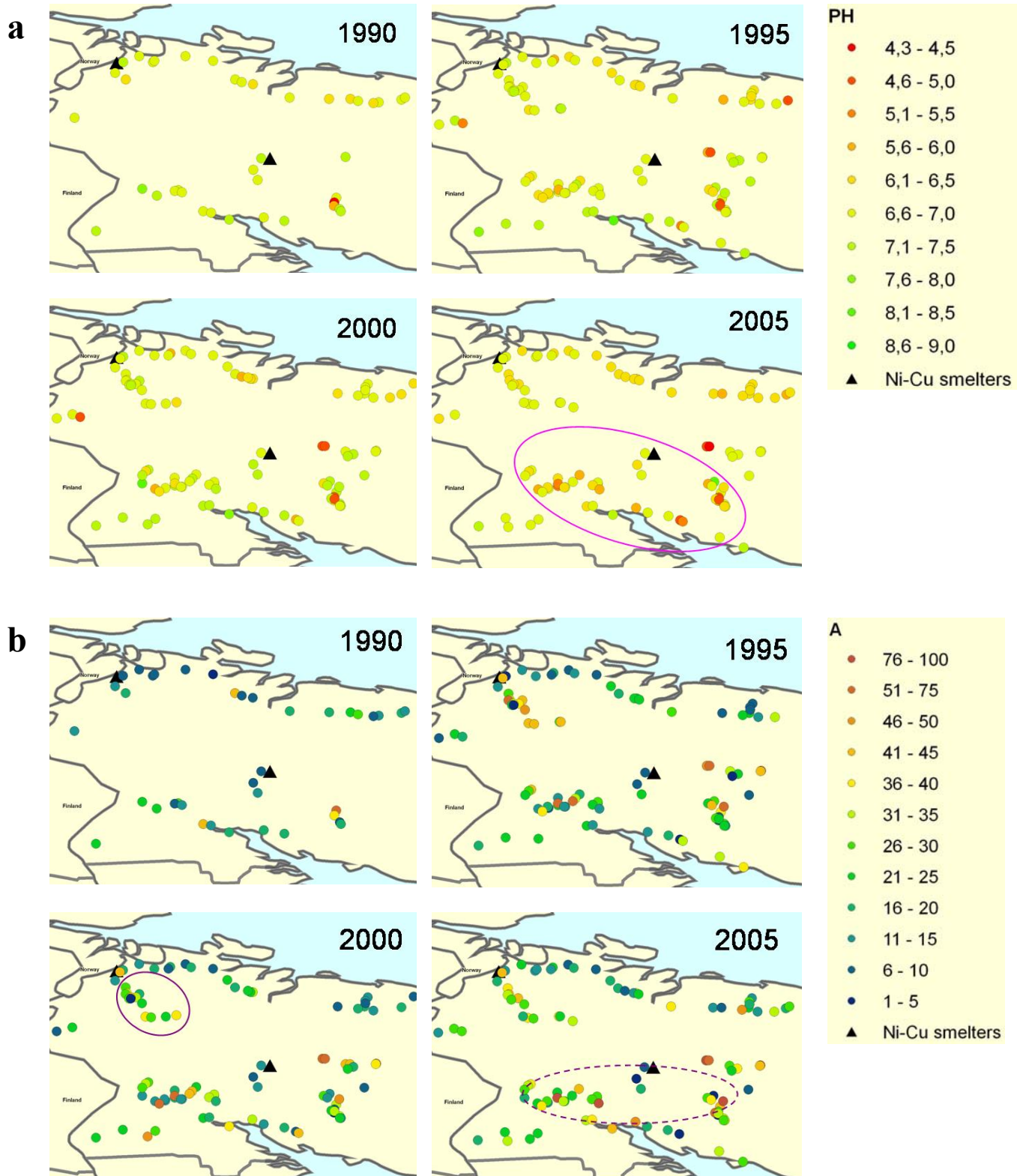
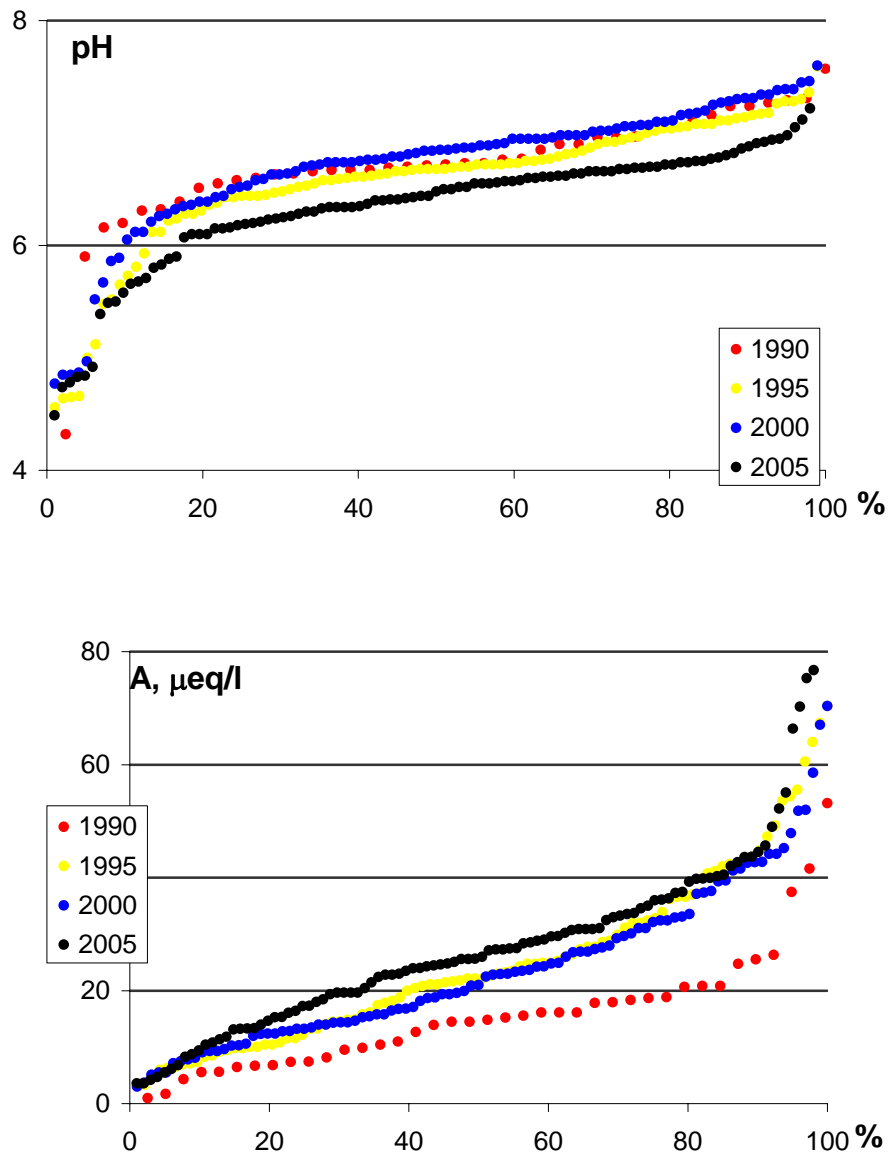**Figure 6.** Distribution of pH (a) and A (b), μeq/l, in water of Kola North lakes in 1990, 1995, 2000 and 2005 years.
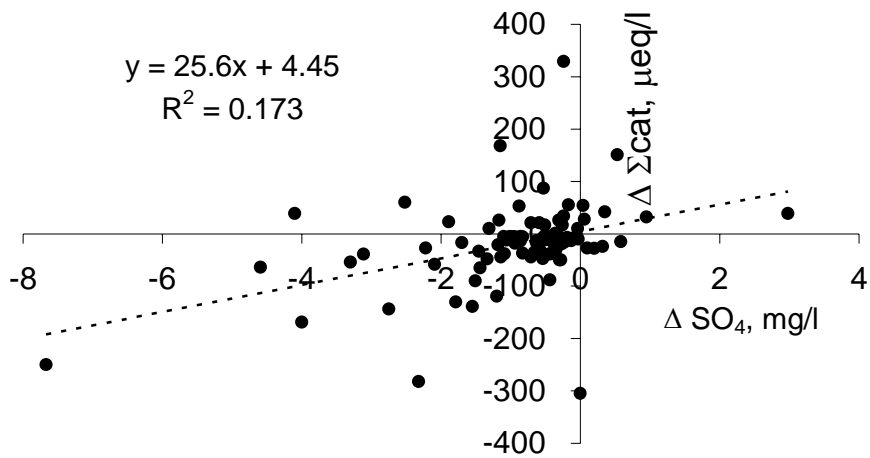
Figure 7. Distribution in increasing order of pH and A in water of Kola North lakes on years.

a

y = 25.6x + 4.45
R^2 = 0.173

Δ Σcat, µeq/l

Δ SO$_4$, mg/l

400
300
200
100
-100
-200
-300
-400

-8   -6   -4   -2   0   2   4

b

in the cases of organic anion decreasing

Δ Ni, µg/l

4
2
-2
-4
-6
-8

-8,0   -6,0   -4,0   -2,0   0,0   2,0   4,0

Δ SO$_4$, mg/l

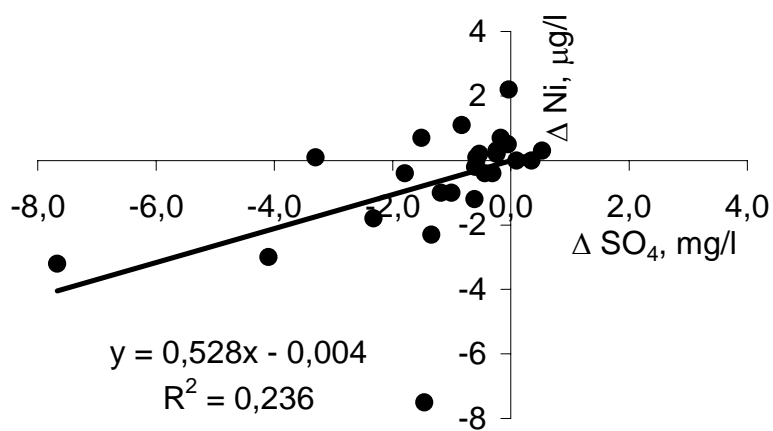y = 0,528x - 0,004
R^2 = 0,236

Figure 8. Changing of base cations and Ni in dependence of sulphates changing in water of Kola North lakes for last decade
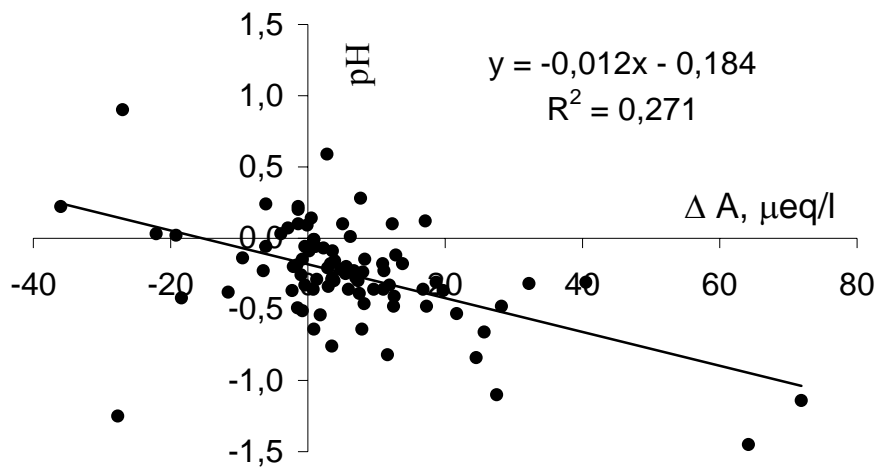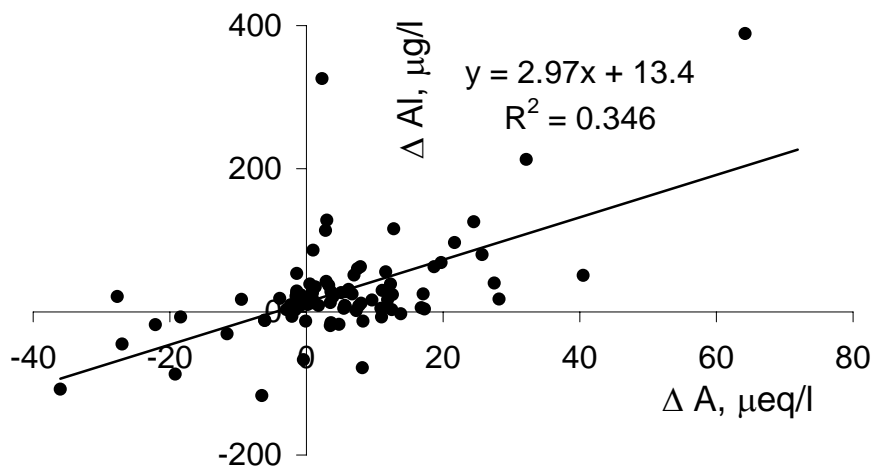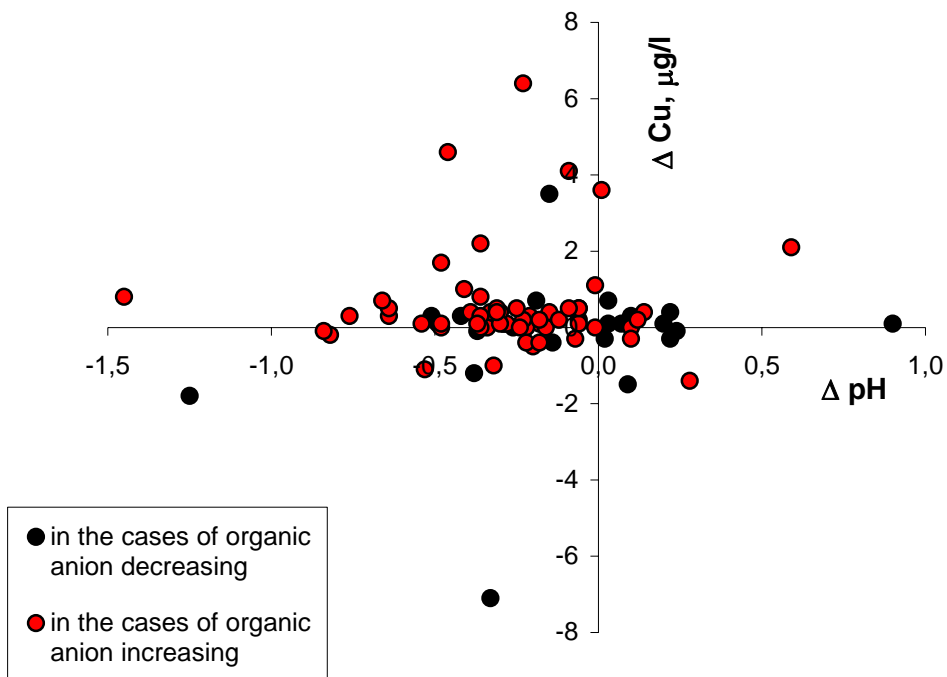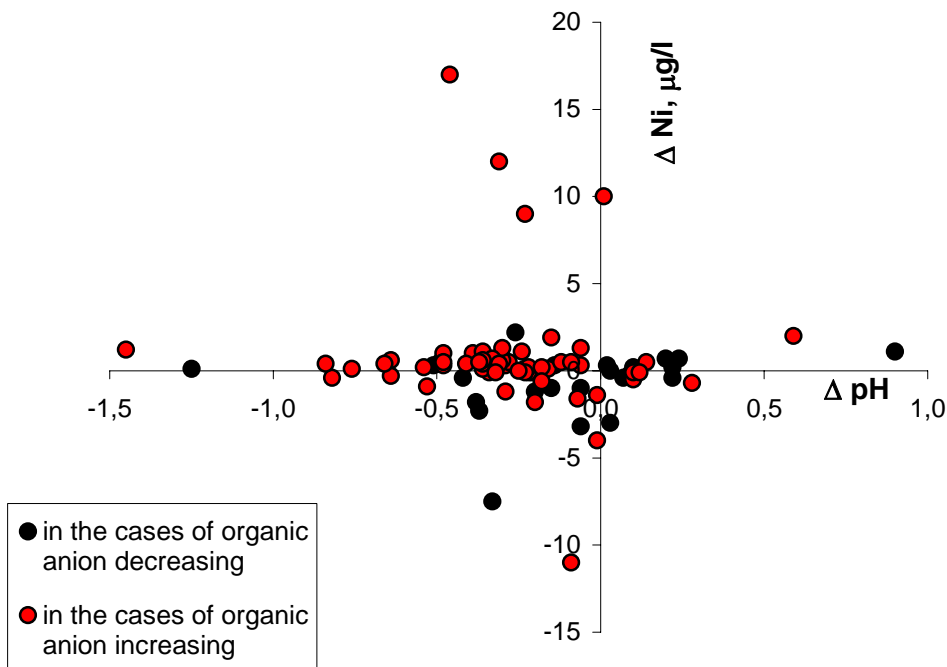
a

b

Figure 9. Changing pH and Al in dependence of organic anion changing in water of Kola North lakes for last decade

a

b

Figure 10. Changing Cu and Ni in dependence of pH changing for last decade

Appendix A. Programme

**Programme for the joint workshop on "Confounding factors in recovery from acid deposition in surface waters",
Scandic Hotel Bergen 9-10th October 2006.**

Monday October 9th

**Welcome and introduction
Chair: Brit Lisa Skjelkvåle**

1. Welcome to Bergen	Arne S. Svindland Managing Director, UNIFOB University of Bergen Research Company
2. Opening address	Mari Sæther Norwegian Ministry of Environment
3. Introduction and goals	Brit Lisa Skjelkvåle, Norway

**Session 1: Climatic factors
Chair: Martin Forsius**

1. Key Note speaker:
The role of climate in acidification recovery in Canada   Peter Dillon, Canada

2. Confounding effects of climate variability on recovery   Don Monteith, UK
from acidification: evidence from the UK

3. Natural variability in acidification status; Now and in the   Kevin Bishop, Sweden
Pre-industrial period

**Session 2: Organic Carbon
Chair: Martin Forsius**

1. Increasing dissolved organic carbon in remote surface   John Stoddard, USA
waters: A response to climate change and return to pre-
acidification conditions?

2. Controls on DOC concentrations in acidification in   Tom Clair, Canada
acidified Nova Scotian lakes and rivers

3. The influence of organic anions on the acidification   Jussi Vuorenmaa, Finland
recovery of Finnish lakes

4. Synchrony of trends in TOC in Swedish streams   Martin Erlandsson, Sweden

5. The influence of climate on concentration of coloured   Ståle Haaland, Norway
DOC species

Tuesday October 10th

Session 3: Biologic recovery
Chair: Rachel Helliwell

1. Key Note speaker: Effect of confounding factors on recovery of invertebrates in acidified waters	Gunnar Raddum, Norway
2. Species- and cohort specific mortality of Atlantic salmon and brown trout caused by a sea salt episode; a setback for the recovery from acidification in a south Norwegian river	Bjørn T. Barlaup, Norway
3. Interactions between climate and density-dependent processes affect the recovery of fish populations after acidification	Thrond Haugen, Norway

Session 4: Nitrogen
Chair: Rachel Helliwell

1. New assessment of N inputs and leaching at European and North-American ICP Waters sites	Øyvind Kaste, Norway
2. Regional differences in nitrogen deposition trends	Lars Hole, Norway

12:00-13:00 Lunch

Session 4: Nitrogen continues
Chair: Merete Ulstein
13:00-16:00

3. Links between the sulphur, dissolved organic carbon and nitrogen cycles: Is sulphur deposition a confounding factor for nitrogen leaching	Chris Evans, UK
4. Synchronous trends in NO3 export from N-saturated river catchments in North Western Italy and their relationship with climate variables	Michela Rogora, Italy
5. Climate controls of nitrate concentrations in 30-years time series in four acid-sensitive catchments in south Norway	Heleen de Wit, Norway
6. Modelling seasonal nitrate concentrations with MAGIC	Dick Wright, Norway
7. The influence of climate change (scenarios HadAM3 B2 and ECHAM4/OPYC3 A2) on recovery from acidification at Lysina catchment	Jakub Hruška, Czech Republic

Session 5: Discussion and conclusions
Chair: Dick Wright
16:00-17:00

Appendix B. Participiants

Mr. **Vladimir Abakumov**
Institute of Global Climate and Ecology
Glebovskaia 20b
Moscow, 107258
Russia

Ms. **Kari Austnes**
The Norwegian university of life sciences (UMB)
P.O. Box 5003
N-1432 Aas
Norway
kari.austnes@umb.no

Mr. **Bjørn T. Barlaup**
LFI-Unifob, University for Bergen
Thor Møhlensgate 49
N-5006 Bergen
Norway
bjorn.barlaup@bio.uib.no

Mr. **Kevin Bishop**
Swedish University of Upsala (SLU)
Department of Environmental Assessment
Box 7050,
SE 750 07 Uppsala
Sweden
kevin.bishop@ma.slu.se

Mr. **Tom Clair**
Aquatic Ecosystem Impacts Research Division
Environment Canada
17 Waterfowl Lane
PO Box/ CP 6227
Sackville, NB, E4L 1G6
Canada
tom.clair@ec.gc.ca

Mr. **Luca Colombo**
Ufficio protezione aria, Sezione protezione aria,
acqua e suolo
Via C. Salvioni 2a
6500 Bellinzona
Switzerland
luca.colombo@ti.ch

Mr. **Jack Cosby**
University of Virginia
Department of Environmental Sciences,
Charlottesville, Va, 22903
USA
bjc4a@virginia.edu

Mr. **Peter Dillon**
Trent University
1600 West Bank Drive
Peterborough On Canada K9J 7B8
Canada
pdillon@trentu.ca

Mr. **Lars Eriksson**
SLU
Institutionen för miljöanalys
P.O.Box 750
SE-750 07 Uppsala
Sweden
lars.eriksson@ma.slu.se

Mr. **Martin Erlandsson**
Swedish University of Upsala (SLU)
Department of Environmental Assessment
Box 7050,
SE-750 07 Uppsala
Sweden
martin.erlandsson@ma.slu.se

Mr. **Christopher Evans**
CEH Bangor
Deiniol Road, Bangor,
LL57 2UP
UK
cev@ceh.ac.uk

Mr. **Arne Fjellheim**
LFI/UNIFOB Stavanger museum
Musegt. 16
N-406 Stavanger
Norway
arne.fjellheim@stavanger.museum.no

Mr. **Martin Fosius**
Finnish Environment Institute (SYKE)
P.O. Box 140
FI-00251 Helsinki
Finland
martin.forsius@ymparisto.fi

Mr. **Jens Fölster**
Sveriges Lantbruksuniversitet
SLU
P.O.Box 7050
SE-750 07 Uppsala
Sweden
jens.folster@ma.slu.se

Ms. **Natalia Gashkina**
Russian Academy of Sciences
Institute of Water Problems
Gubkina St. 3
Moscow GSP-1 119991
Russia
gashkina@aqua.laser.ru

Mr. **Heinz-Detlef Gregor**
Federal Environmental Agency
Bismarckplatz 1
14193 Berlin
Germany
heinz-detlef.gregor@uba.de

Mr. **Godtfred Anker Halvorsen**
LFI – University of Bergen
Thor Møhlensgt. 49
N-5006 Bergen
Norway
godtfred.halvorsen@zoo.uib.no

Mr. **Thrond Haugen**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
thrond.haugen@niva.no

Ms. **Rachel Helliwell**
Macaulay Institute, Aberdeen
Craigiebuckler, Countersswells Road, Aberdeen,
AB15 8QH
UK
r.helliwell@macaulay.ac.uk

Mr. **Lars Hole**
Norwegian Institute for Air Research (NILU)
P.O. Box 100
Instituttveien 18
N-2027 Kjeller
Norway
lrh@nilu.no

Ms. **Inga Honavko**
Latvian Hydrometeorological Agency
165 Maskavas str.
LV-1019 Riga
Latvia
epoc@lvgma.gov.lv

Mr. **Jacub Hruška**
Czech Geological Survey Praha
Klárov 3, 118 21 Prague,
Czech republic
hruska@cgu.cz

Mr. **Mike Hutchins**
CEH Wallingford
Maclean Building,
Crowmash Gifford, Wallingford,
OX10 8BB, UK
mihu@ceh.ac.uk

Mr. **Ståle Haaland**
The Norwegian university of life sciences (UMB)
P.O. Box 5003
N-1432 Aas
Norway
staale.haaland@umb.no

Mr. **Matti Johansson**
United Nations Economic Commission for Europe
(UNECE)
Bureau 350, Palais des Nations
CH-1211 Geneva 10
Switzerland
matti.johansson@unece.org

Mr. **Øyvind Kaste**
Norwegian Institute for Water Research, Grimstad
Televeien 3,
N-4879 Grimstad,
Norway
oeyvind.kaste@niva.no

Mr. **Jiří Kopáček**
Biological center ASCR, Hydrobiological Institute
Na Sádkách 7, 370 05 Čedské Budějovice,
Czech Republic
jkopacek@hbu.cas.cz

Ms. **Berit Kvaeven**
Norwegian Pollution Control Authority
P.O. Box 8100 Dep
N-0032 Oslo
Norway
berit.kvaven@sft.no

Mr. **Balázs Laszlo**
Budapest University of Technology & Economics
Müegyteni okp. 3 4V Building
H-1111, Budapest
Hungary
balazs@vkkt.bme.hu

Ms. **Anne Christine Le Gall**
INERIS
Modelisation and Economic Analysis Unit
Chronic Risk Division
Parc Technologique ALATA, Bp. No 2.
60 550 Verneuil en Halatte
France
anne-christine.le-gall@ineris.fr

Mr. **Vladimir Majer**
Czech Geological Survey - Dept. Geochemistry
Geologicka 6,
CZ-152 00 Prague 5
Czech Republic
majer@cgu.cz

Ms. **Tatyana Moiseenko**
Institute of Water Problems RAS
Gubkina 3
Moscow GSP 1, 119991
Russia
tatyana@aqua.laser.ru

Mr. **Filip Moldan**
Swedish Environmental Research (IVL), Gothenburg
Box 5302
SE-400 14 Göteborg,
Sweden
filip.moldan@ivl.se

Mr. **Don Monteith**
Environmental Change Research, UCL
Pearson Building, Gower street
London – WCIE GBP
United Kingdom
dmonteit@geog.ucl.ac.uk

Mr. **Gunnar G.G. Raddum**
LFI - University of Bergen
Thor Møhlensgt 49
N-5006 Bergen
Norway
gunnar.raddum@zoo.uib.no

Ms. **Michela Rogora**
CNR Institute of Ecosystem Study
L.go Tonolli 50
1 28922 Verbania Pallanza
Italy
m.rogora@ise.cnr.it

Mr. **Bjørn Olav Rosseland**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
bjorn.rosseland@umb.no

Ms. **Dorota Rzychon**
Institute for Ecology of Industrial Areas
7 Kossutha str
40-833 Katowice
Poland
rzychon@ietu.katowice.pl

Mr. **Steinar Sandøy**
The Norwegian Directorate for nature management
Tungslette 2
N-7026 Trondheim
Norway
steinar.sandoy@dirnat.no

Ms. **Brit Lisa Skjelkvåle**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
brit.skjelkvaale@niva.no

Ms. **Anne Merete Smelhus Sjøeng**
Norwegian Institute for Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
annemerete.sjoeng@niva.no

Ms. **Sandra Steingruber**
Ufficio protezione aria, Sezione protezione aria,
acqua e suolo
Via C. Salvioni 2a
6500 Bellinzona
Switzerland
sandra.steingruber@ti.ch

Ms. **Stanita Stivrina**
Latvian Hydrometeorological Agency
165 Maskavas str.
LV-1019 Riga
Latvia
epoc@lvgma.gov.lv

Mr. **John Stoddard**
U.S. Environmental Protection Agency
200 SW 35th Str.
Corvallis, Oregon 97333
USA
stoddard.john@epa.gov

Ms. **Mari Sæther**
Postboks 8013 Dep
N-0030 Oslo
Norway
mari.sather@md.dep.no

Ms. **Merete J. Ulstein**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
merete.ulstein@niva.no

Mr. **Milan Vana**
Czech Hydrometeorological Institute
Kosetice Observatory, 394 22 Kosetice,
Czech Republic
vanam@chmi.cz

Mr. **Jussi Vuorenmaa**
Finnish Environment Institute (SYKE)
P.O. Box 140
FIN-00251 Helsinki
Finland
jussi.vuorenmaa@ymparisto.fi

Ms. **Heleen de Wit**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
heleen.de.wit@niva.no

Mr. **Adam Worsztynowicz**
Institute for Ecology of Industrial Areas
7 Kossutha str
40-833 Katowice
Poland
worsz@ietu.katowice.pl

Mr. **Rick Wortelboer**
National Institute for Public Health and the
Environment-RIVM
P.O. Box 303
3720 AH Bilthoven
The Netherlands
rick.wortelboer@mnp.nl

Mr. **Richard Wright**
Norwegian Institute of Water Research (NIVA)
Gaustadalléen 21
N-0349 Oslo
Norway
richard.wright@niva.no