Swedish University of Agricultural Sciences
ICP IM Programme Centre
ICP IM Annual Reports, 33
2024

# 33rd Annual Report 2024

## Convention on Long-range Transboundary Air Pollution

## International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems

*James Kurén Weldon (ed.)*

SLU

wge Working Group on Effects of the Convention on Long-range Transboundary Air Pollution

Clean Air 40 YEARS

**Editor:** James Kurén Weldon, Swedish University of Agricultural Sciences
**Publisher:** Swedish University of Agricultural Sciences, ICP IM Programme Centre
**Year of publication:** 2024
**Place of publication:** Uppsala
**Illustration:** Lysina IM site, Czechia. Thanks to Pavel Krám
**Title of series:** Annual Report of the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems
**Number:** 33
**ISBN:** **978-91-8046-631-8**
**DOI:** **https://doi.org/10.54612/a.71s9imh34k**

# Abstract

The Integrated Monitoring Programme (ICP IM) is part of the effect-oriented activities under the 1979 Convention on Long-range Transboundary Air Pollution, which covers the region of the United Nations Economic Commission for Europe (UNECE). The main aim of ICP IM is to provide a framework to observe and understand the complex changes occurring in natural/semi natural ecosystems. This report summarizes the work carried out by the ICP IM Programme Centre and several collaborating institutes. The emphasis of the report is in the work done during the programme year 2022/2023 including:

- A short summary of previous data assessments
- A status report of the ICP IM activities, content of the IM database, and geographical coverage of the monitoring network
- A report on long-term trends in vegetation indices at IM sites
- Workplan for the next period
- Analysis of changes in tree species at the heavily disturbed IM site Aneboda (Sweden)
- National Reports on ICP IM activities

**Keywords:** Integrated Monitoring, ecosystems, small catchments, air pollution

# Abbreviations

| | |
|---|---|
| AMAP | Arctic Monitoring and Assessment Programme |
| ANC | Acid neutralising capacity |
| CCE | Coordination Centre for Effects |
| CDM | Centre for Dynamic Modelling (previously JEG DM), a body under ICP M&M |
| CL | Critical Load |
| CNTER | Carbon-nitrogen interactions in forest ecosystems |
| ECE | Economic Commission for Europe |
| eLTER RI | European Research Infrastructure that LTER Europe is building after being adopted by the 2018 ESFRI Roadmap. The RI is built by the two Horizon 2020 projects “eLTER PPP” (Preparatory Phase Project) and “eLTER PLUS” (Advanced Community project) |
| EMEP | Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe |
| EU | European Union |
| EU LIFE | EU’s financial instrument supporting environmental and nature conservation projects throughout the EU |
| Horizon 2020 | H2020, EU Research and Innovation programme |
| ICP | International Cooperative Programme |
| ICP Forests | International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests |
| ICP IM | International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems |
| ICP Materials | International Cooperative Programme on Effects on Materials |
| ICP M&M | ICP Modelling and Mapping, International Cooperative Programme on Modelling and Mapping of Critical Loads and Levels and Air Pollution Effects, Risks and Trends |
| ICP Waters | International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes |
| ICP Vegetation | International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops |
| ILTER | International Long Term Ecological Research Network |
| IM | Integrated Monitoring |
| JEG | JEG DM, Joint Expert Group on Dynamic Modelling. Now under the acronym CDM |
| LRTAP Convention | Convention on Long-range Transboundary Air Pollution |
| LTER Europe | European Long-Term Ecosystem Research Network |
| LTER Network | Long Term Ecological Research Network |
| NFP | National Focal Point |
| SLU | Swedish University of Agricultural Sciences |
| TF | Task Force |
| Task Force on Health | Joint Task Force on the Health Aspects of Air Pollution |
| UNECE | United Nations Economic Commission for Europe |
| WGE | Working Group on Effects |

# Contents

# Preface

Welcome to the 33rd Annual Report, produced by the Programme Centre at the Swedish University of Agricultural Sciences. This year's Task Force meeting was held in Prague, Czechia. We thank our Czech colleagues for hosting a successful meeting! Minutes of the TF meeting may be downloaded from the IM website (link below). The cover photo for this year's report is of the Lysina site in Czechia (thanks to Pavel Krám for that).

Our German colleagues have kindly offered to host the 2025 Task Force Meeting in Dessau-Rosslau, from April 23 to 25. More information will of course be sent out nearer the time, but for now please save the date.

As well as the usual updates, this edition of the annual report includes a feature on the long-term trends in vegetation indices at sites where the VG subprogramme is undertaken, a summary of a study looking at the development in tree species at the heavily disturbed Swedish site Aneboda, and a new logo for ICP IM.

Finally, a note on our move to open data. Almost all countries have now provided an agreement on open publication (or in a few cases a verbal agreement with the document to follow shortly), so thank you all for your engagement in this important question. We are now in a good position to move forward with the data paper and publication of the database.

James Kurén Weldon, on behalf of the Programme Centre

The Programme Centre team is as follows:

James Kurén Weldon – Head of Programme Centre
Karin Eklöf – Evaluation of heavy metals data
Martyn Futter – Senior researcher, with focus on modelling
Hampus Markensten – Validation of incoming data, updating the database, and handling data excerpts
Pernilla Rönnback – Database manager/administrator

The current co-chairs of IM, Ulf Grandin and Salar Valinia are also in Sweden, facilitating close co-operation with the Programme Centre.

The website for IM can be found at www.slu.se/en/icp-im and a PDF version of the monitoring manual can be downloaded from this link, as well as minutes of meetings and previous editions of this report.

# Comprehensive summary

## Background and objectives of ICP IM

Integrated monitoring of ecosystems means physical, chemical, and biological measurements over time of different ecosystem compartments simultaneously at the same location. In practice, monitoring is divided into several compartmental subprogrammes which are linked by the use of the same parameters (cross-media flux approach) and/or same or close stations (cause-effect approach).

The International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM, http://www.slu.se/en/icp-im) is part of the Effects Monitoring Strategy under the Convention on Long-range Transboundary Air Pollution (LRTAP Convention). The main objectives of the ICP IM are:

- To monitor the biological, chemical, and physical state of ecosystems (catchments/plots) over time in order to provide an explanation of changes in terms of causative environmental factors, including natural changes, air pollution and climate change, with the aim to provide a scientific basis for emission control.
- To develop and validate models for the simulation of ecosystem responses and use them (a) to estimate responses to actual or predicted changes in pollution stress, and (b) in concert with survey data to make regional assessments.
- To carry out biomonitoring to detect natural changes, in particular to assess effects of air pollutants and climate change.

The full implementation of the ICP IM will allow ecological effects of heavy metals, persistent organic substances, and tropospheric ozone to be determined. A primary concern is the provision of scientific and statistically reliable data that can be used in modelling and decision making. The ICP IM sites (mostly forested catchments) are located in undisturbed areas, such as nature reserves or comparable areas. The ICP IM network presently covers forty-eight sites from fifteen countries. The international Programme Centre is located at the Swedish University of Agricultural Sciences, in Uppsala. The present status of the monitoring activities is described in detail in Chapter 1 of this report. A manual detailing the protocols for monitoring each of the necessary physical, chemical, and biological parameters is applied throughout the programme (Manual for Integrated Monitoring 1998, and updated versions, which can be downloaded from the website).

## Assessment activities within the ICP IM

Assessment of data collected in the ICP IM framework is carried out at both national and international levels. Key tasks regarding international ICP IM data have been:

- Input-output and proton budgets
- Trend analysis of bulk and throughfall deposition and runoff water chemistry
- Assessment of responses using biological data
- Dynamic modelling and assessment of the effects of different emission / deposition scenarios, including confounding effects of climate change processes
- Assessment of concentrations, pools, and fluxes of heavy metals
- Calculation of critical loads for sulphur and nitrogen compounds, and assessment of critical load exceedance, as well as links between critical load exceedance and empirical impact indicators
- Evaluation and reporting of ICP IM data in relation to the revision process of the Gothenburg Protocol

## Conclusions from international studies using ICP IM data

### Input-output and proton budgets, C/N interactions

Ion mass budgets have proved to be useful for evaluating the importance of various biogeochemical processes that regulate the buffering properties in ecosystems. Long-term monitoring of mass balances and ion ratios in catchments/plots can also serve as an early warning system to identify the ecological effects of different anthropogenically derived pollutants, and to verify the effects of emission reductions.

The most recent results from ICP IM studies are available from the study of Vuorenmaa et al. (2017). Site-specific annual input-output budgets were calculated for sulphate ($SO_4$) and total inorganic nitrogen ($TIN = NO_3\text{-}N + NH_4\text{-}N$) for 17 European ICP IM sites in 1990–2012. Temporal trends for input (deposition) and output (runoff water) fluxes and net retention/net release of $SO_4$ and TIN were also analysed. Large spatial variability in the input and output fluxes of $SO_4$ and TIN reflects important gradients of air pollution effects in Europe, with the highest deposition and runoff water fluxes in southern Scandinavia, Central and Eastern Europe and the lowest fluxes at more remote sites in northern European regions. A significant decrease in the total (wet + dry) non-marine $SO_4$ deposition and bulk deposition of TIN was found at 90% and 65% of the sites, respectively. Output fluxes of non-marine $SO_4$ in runoff decreased significantly at 65% of the sites, indicating positive effects of international emission abatement actions in Europe during the last 25 years. Catchments retained $SO_4$ in the early and mid-1990s, but this shifted towards a net release in the late 1990s, which may be due to the mobilisation of legacy S pools accumulated during times of high atmospheric $SO_4$ deposition. Despite decreased deposition, TIN output fluxes and retention rates showed a mixed response with both decreasing (9 sites) and increasing (8 sites) trend slopes, but trends were rarely significant. In general, TIN was strongly retained in the catchments not affected by natural disturbances. The long-term annual variation in net releases for $SO_4$ was explained by variations in runoff and $SO_4$ concentrations in deposition, while a variation in TIN concentrations in runoff was mostly associated with a variation of the TIN retention rate in catchments. Net losses of $SO_4$ may lead to a slower recovery of surface waters than those predicted by the decrease in $SO_4$ deposition. Continued enrichment of N in catchment soils poses a threat to terrestrial biodiversity and may ultimately lead to higher TIN runoff through N saturation or climate change. Continued monitoring and further evaluations of mass balance budgets are thus needed.

### Summary of earlier results from ICP IM studies

The first results of input-output and proton budget calculations were presented in the 4th Annual Synoptic Report (ICP IM Programme Centre 1995) and the updated results regarding the effects of N deposition were presented in Forsius et al. (1996). Data from selected ICP IM sites were also included in European studies for evaluating soil organic horizon C/N-ratio as an indicator of nitrate leaching (Dise et al. 1998, MacDonald et al. 2002). Results regarding the calculation of fluxes and trends of S and N compounds were presented in a scientific paper prepared for the Acid Rain Conference, Japan, December 2000 (Forsius et al. 2001). A scientific paper regarding calculations of proton budgets was published in 2005 (Forsius et al. 2005).

The budget calculations showed that there was a large difference between the sites regarding the relative importance of the various processes involved in the transfer of acidity. These differences reflected both the gradients in deposition inputs and the differences in site characteristics. The proton budget calculations showed a clear relationship between the net acidifying effect of nitrogen processes and the amount of N deposition. When the deposition increases also N processes become increasingly important as net sources of acidity.

A critical deposition threshold of about 8–10 kg N $ha^{-1}$ $yr^{-1}$, indicated by several previous assessments, was confirmed by the input-output calculations with the ICP IM data (Forsius et al. 2001). The output flux of nitrogen was strongly correlated with key ecosystem variables like N deposition, N concentration in organic matter and current year needles, and N flux in litterfall (Forsius et al. 1996). Soil organic horizon C/N-ratio seems to give a reasonable estimate of the annual export flux of N for European forested sites receiving throughfall deposition of N up to about 30 kg N $ha^{-1}$ $yr^{-1}$. When stratifying data based on C/N ratios less than or equal to 25 and greater than 25, highly significant relationships were observed between N input and nitrate leached (Dise et al. 1998, MacDonald et al. 2002, Gundersen et al. 2006). Such statistical relationships from intensively studied sites can be efficiently used in conjugation with regional monitoring data (e.g., ICP Forests and ICP Waters data) in order to link process level data with regional-scale questions.

An assessment on changes in the retention and release of S and N compounds at the ICP IM sites was prepared for the 21st Annual Report (Vuorenmaa et al. 2012). Updated and revised data were included in the continuation of the work in the 22nd and 23rdAnnual Reports (Vuorenmaa et al. 2013, 2014). The relationship between N deposition and organic N loss and the role of organic nitrogen in the total nitrogen output fluxes were derived in Vuorenmaa et al. (2013).

Sulphur budgets calculations indicated a net release of S from many ICP IM sites, indicating that the soils are releasing previously accumulated S. Similar results have been obtained in other European plot and catchment studies.

The reduction in deposition of S and N compounds at the ICP IM sites, as a result of the implementation of the “Protocol to Abate Acidification, Eutrophication and Ground-level Ozone” of the LRTAP Convention (“Gothenburg protocol”), was estimated for the year 2010 using transfer matrices and official emissions. Continued implementation of the protocol will further decrease the deposition of S and N at the ICP IM sites in western and north-western parts of Europe, but in more eastern parts the decrease will be smaller (Forsius et al. 2001).

Results from the ICP IM sites were also summarised in an assessment report prepared by the Working Group on Effects of the LRTAP Convention (WGE) (Sliggers & Kakebeeke 2004, Working Group on Effects 2004).

ICP IM contributed to an assessment report on reactive nitrogen ($N_r$) of the WGE. This report was prepared for submission to the TF on Reactive Nitrogen and other bodies of the LRTAP Convention to show what relevant information has been collected by the ICP programmes under the aegis of the WGE to allow a better understanding of $N_r$ effects in the ECE region. The report contributed relevant information for the revision of the Gothenburg Protocol. A revised Gothenburg Protocol was successfully finalised in 2012. A new revision process of the Protocol is currently ongoing in 2021-2023, and ICP IM is again contributing.

It should also be recognised that there are important links between N deposition and the sequestration of C in the ecosystems (and thus direct links to climate change processes). These questions were studied in the CNTER-project in which data from both the ICP IM and EU/Intensive Monitoring sites were used (Gundersen et al. 2006). A summary report of the CNTER-results on C/N -interactions and nitrogen effects in European forest ecosystems was prepared for the WGE meeting 2007 (ECE/EB.AIR/WG.1/2007/10).

## Trend assessments

Empirical evidence on the development of environmental effects is of central importance for the assessment of success of international emission reduction policy. In order to assess the impacts of air pollution and climate change in the environment, a long-term integrated monitoring approach in remote unmanaged areas including physical, chemical, and biological variables is needed. Vuorenmaa et al. (2018) evaluated long-term trends (1990–2015) for deposition and runoff water chemistry and fluxes, and climatic variables at 25 ICP IM sites in Europe that commonly belong also to the LTER Europe/ILTER networks. The trend assessment was published in a special issue in Science of the Total Environment with the title: "International Long-Term Ecological Research (ILTER) network". The recent results from trend assessment at IM sites confirm that emission abatement actions are having their intended effects on precipitation and runoff water chemistry in the course of successful emission reductions in different regions in Europe. Concentrations and deposition fluxes of xSO4, and consequently acidity in precipitation, have substantially decreased in IM areas. Inorganic N (TIN) deposition has decreased in most of the IM areas, but to a lesser extent than that of xSO4. Substantially decreased xSO4 deposition has resulted in decreased concentrations and output fluxes of xSO4 in runoff and decreasing trends of TIN concentrations in runoff – particularly for NO3 – are more prominent than increasing trends. In addition, decreasing trends appeared to strengthen over the course of emission reductions during the last 25 years. TIN concentrations in runoff were mainly decreasing, while trends in output fluxes were more variable, but trend slopes were decreasing rather than increasing. However, decreasing trends for S and N emissions and deposition and deposition reduction responses in runoff water chemistry tended to be more gradual since the early 2000s. Air temperature increased significantly at 61% of the sites, while trends for precipitation and runoff were rarely significant. The site-specific variation of xSO4 concentrations in runoff was most strongly explained by deposition. Climatic variables and deposition explained the variation of TIN concentrations in runoff at single sites poorly, and as yet there are no clear signs of a consistent deposition-driven or climate-driven increase in TIN exports in the catchments.

Vuorenmaa et al. (2018) reported that the IM sites are located in areas with very different N deposition, and it is obvious that not all potential drivers were included in the empirical model in the study, and further analysis with specific landscape and soil data is needed to elucidate the variation in inorganic N concentrations in runoff at IM sites.

Vuorenmaa et al. (2020) carried out a first analysis on the impact of internal catchment N-related parameters on TIN leaching. A significant negative correlation was found between the annual change of TIN concentrations and fluxes in runoff, and mean TIN fluxes in throughfall, tot N concentrations and N/P-ratios in foliage and litterfall, and tot N concentrations and fluxes in soil water. A significant positive correlation was found between the mean concentrations and fluxes of TIN in runoff and mean TIN deposition in throughfall and mean tot N concentrations and N/P-ratios in foliage and litterfall. Using multiple regression analysis, the annual change in TIN concentrations and fluxes and mean TIN concentrations and fluxes in runoff were dominantly explained by mean tot N concentrations in foliage (R-squares 0.88–0.97). Discriminant analysis was applied with sites having significant decrease in TIN concentrations in runoff and sites having no significant decrease as the dependent dichotomy variable (classes). The foliage N/P-ratio distinguished between two trend classes, and the sites with no significant decrease exhibited higher N/P-ratio than the sites with significant decrease. Since majority of sites showed downward trend slope in TIN concentrations (76%) and fluxes (69%), these results mean that the most N-affected sites with the highest N deposition to the forest floor and highest N concentrations in foliage, litterfall, runoff water and soil water, showed the most pronounced decreases of TIN in runoff. Decrease of TIN in concentrations and fluxes in runoff was also pronounced at sites where decreasing trend of TIN in bulk deposition was highest.

## Summary of earlier trend studies from IM

First results from a trend analysis of monthly ICP IM data on bulk and throughfall deposition as well as runoff water chemistry were presented in Vuorenmaa (1997). ICP IM data on water chemistry were also used for a trend analysis carried out by the ICP Waters and results were presented in the Nine-Year Report of that programme (Lükewille et al. 1997).

Calculations on the trends of N and S compounds, base cations and hydrogen ions were made for 22 ICP IM sites with available data across Europe (Forsius et al. 2001). The site-specific trends were calculated for deposition and runoff water fluxes using monthly data and non-parametric methods. Statistically significant downward trends of SO4, NO3 and NH4 bulk deposition (fluxes or concentrations) were observed at 50% of the ICP IM sites. Sites with higher N deposition and lower C/N-ratios clearly showed higher N output fluxes, and the results were consistent with previous observations from European forested ecosystems. Decreasing SO4 and base cation trends in runoff waters were commonly observed at the ICP IM sites. At some sites in the Nordic countries decreasing NO3 and H+ trends (increasing pH) were also observed. The results partly confirmed the effective implementation of emission reduction policy in Europe. However, clear responses were not observed at all sites, showing that recovery at many sensitive sites can be slow and that the response at individual sites may vary greatly.

Data from ICP IM sites were also used in a study of the long-term changes and recovery at nine calibrated catchments in Norway, Sweden, and Finland (Moldan et al. 2001, RECOVER: 2010 project). Runoff responses to the decreasing deposition trends were rapid and clear at the nine catchments. Trends at all catchments showed the same general picture as from small lakes in Scandinavia.

It was agreed at the ICP IM Task Force meeting in 2004 that a new trend analysis should be carried out. The preliminary results were presented in Kleemola (2005) and the updated results in the 15th Annual Report (Kleemola & Forsius 2006). Statistically significant decreases in SO4 concentrations were observed at a majority of sites in both deposition and runoff/soil water quality. Increases in ANC (acid neutralising capacity) were also commonly observed. For NO3 the situation was more complex, with fewer decreasing trends in deposition and even some increasing trends in runoff/soil water.

Results from several ICPs and EMEP were used in an assessment report on acidifying pollutants, arctic haze and acidification in the arctic region prepared for the Arctic Monitoring and Assessment Programme (AMAP, Forsius & Nyman 2006, www.amap.no). Sulphate concentrations in air showed generally decreasing trends since the 1990s. In contrast, levels of nitrate aerosol were increasing during the arctic haze season at two stations in the Canadian arctic and Alaska, indicating a decoupling between the trends in sulphur and nitrogen. Chemical monitoring data showed that lakes in the Euro-Arctic Barents region are showing regional scale recovery. Direct effects of sulphur dioxide emissions on trees, dwarf shrubs and epiphytic lichens were observed close to large smelter point sources.

A trend assessment using monthly ICP IM data (Vuorenmaa et al. 2018) was preceded by corresponding trend evaluations for the periods 1993–2006 and 1990–2013 (Vuorenmaa et al. 2009, 2016, respectively). Moreover, trends for annual input and output fluxes of SO4 and TIN were evaluated for the period 1990–2012 (Vuorenmaa et al. 2017). These results clearly showed the regional-scale decreasing trends of SO4 in deposition and runoff/soil water, and suggested that IM catchments have increasingly responded to the decreases in S emissions and depositions of SO4 since the early 1990s. Decreased nitrogen emissions also resulted in decrease of inorganic N deposition, but to a lesser extent than that of SO4, and trends in TIN fluxes in runoff were highly variable due to complex processes in terrestrial catchment that are not yet fully understood. Besides, the net release of SO4 in forested catchments fuelled by the mobilisation of legacy S pools, accumulated during times of high atmospheric sulphur deposition, may delay the recovery from acidification. The more efficient retention of inorganic N than SO4 results in generally higher leaching fluxes of SO4 than those of inorganic N in European forested ecosystems. SO4 thus remains the dominant source of actual soil acidification despite the generally lower input of SO4 than inorganic N. Critical load calculations for Europe also indicated exceedances of the N critical loads over large areas. Long-term trends for deposition and runoff variables were for the first time evaluated together with climatic variables (precipitation, runoff water volume and air temperature) at IM sites by Vuorenmaa et al. (2016). Many study sites exhibited long-term seasonal trends with a significant increase in air temperature, precipitation, and runoff particularly in spring and autumn, but annual trends were rarely significant. It was concluded that the sulphur and nitrogen problem thus clearly requires continued attention as a European air pollution issue, and further long-term monitoring and trend assessments of different ecosystem compartments and climatic variables are needed to evaluate the effects, not only of emission reduction policies, but also of changing climate.

An assessment on changes in the retention and release of S and N compounds at the ICP IM sites was prepared for the 21st Annual Report (Vuorenmaa et al. 2012). Updated and revised data were included in the continuation of the work in the 22nd and 23rdAnnual Reports. The role of organic nitrogen in mass balance budget was derived and trends of S and N in fluxes were analysed (Vuorenmaa et al. 2013, 2014).

## Detected responses in biological data

The effect of pollutant deposition on natural vegetation, including both trees and understorey vegetation, is one of the central concerns in the impact assessment and prediction. Recent studies using ICP IM data on dose-response relationships showed a weak recovery of epiphytic lichen communities in Sweden despite improvements in air quality (Weldon & Grandin, 2021) and found a relationship between increasing levels of nitrogen deposition and increased dominance of nitrophyllic bryophytes in forest understory, but no effect on species richness (Weldon et al., 2022).

In 2010, the Task Force meeting decided upon a new reporting format for biological data. The new format was based on primary raw data, and not aggregated mean values as before. All countries were encouraged to re-report old data in the new format. This was successful and as a result, the full potential of the biological data from the ICP Integrated Monitoring network could be utilised to raise and answer research question that the old database could not. As a direct consequence, Dirnböck et al. (2014) utilised the re-reported long-term monitoring data from 28 Integrated Monitoring sites to analyse the effect by nitrogen deposition on temporal trends in plant species cover and diversity. In many European countries airborne nitrogen coming from agriculture and fossil fuel burning exceeds critical thresholds and threatens the functioning of ecosystems. One effect is that high levels of nitrogen stimulate the growth of only a few plants that outcompete other, often rare, species. As a consequence, biodiversity declines. Though this is known to happen in natural and semi-natural grasslands, it has never been shown in forest ecosystems where management is a strong, mostly overriding determinant of biodiversity. Dirnböck et al. (2014) found that at sites where nitrogen deposition exceeded the critical load, the cover of forest plant species preferring nutrient-poor soils (oligotrophic species) significantly decreased whereas plant species preferring nutrient-rich soils (eutrophic species) showed – though weak – an opposite trend. These results show that airborne nitrogen has changed the structure and composition of forest floor vegetation in Europe. Plant species diversity did not decrease significantly within the observed period, but the majority of newly established species was found to be eutrophic. Hence it was hypothesised that without reducing nitrogen deposition below the critical load forest biodiversity will decline in the future.

### Summary of earlier work on biological data from IM

The first assessment of vegetation monitoring data at ICP IM sites with regards to N and S deposition was carried out by Liu (1996). Vegetation monitoring was found useful in reflecting the effects of atmospheric deposition and soil water chemistry, especially regarding sulphur and nitrogen. The results suggested that plants respond to N deposition more directly than to S deposition with respect to vegetation indices.

De Zwart (1998) carried out an exploratory analysis of possible causes underlying the aspect of forest damage at ICP IM sites, using multivariate statistics. These results suggested that coniferous defoliation, discolouration, and lifespan of needles in the diverse phenomena of forest damage are for respectively

18%, 42% and 55% explained by the combined action of ozone and acidifying sulphur and nitrogen compounds in air.

As a separate exercise, the epiphytic lichen flora of 25 European ICP IM monitoring sites, all situated in areas remote from local air pollution sources, was statistically related to measured levels of SO2 in air, NH4+, NO3– and SO42– in precipitation, annual bulk precipitation, and annual average temperature (van Herk et al. 2003, de Zwart et al. 2003). It was concluded that long distance transport of nitrogen air pollution is important in determining the occurrence of acidophytic lichen species and constitutes a threat to natural populations that is strongly underestimated so far.

## Dynamic modelling and assessment of the effects of emission/deposition scenarios

In a policy-oriented framework, dynamic models are needed to explore the temporal aspect of ecosystem protection and recovery. The critical load concept, used for defining the environmental protection levels, does not reveal the time scales of recovery. Priority in the ICP IM work is given to site-specific modelling. The role of ICP IM is to provide detailed and consistent physical and chemical data and a long time-series of observations for key sites against which model performance can be assessed and key uncertainties identified (see Jenkins et al. 2003). ICP IM participates also in the work of the Joint Expert Group on Dynamic Modelling (JEG) of the WGE. Since September 2019, this expert group has reorganised into an international designated centre under the International Cooperative Programme on Modelling and Mapping, under the name Centre for Dynamic Modelling (CDM).

Dynamic vegetation modelling at ICP IM sites has been conducted with contributions from ICP M&M, ICP Forests, and the LTER Europe network. The VSD+ model was applied to simulate soil chemistry at 26 sites in ten countries throughout Europe (Holmberg & Dirnböck 2015, 2016, Dirnböck et al. 2018a, 2018b, Holmberg et al. 2018). Simulated future soil conditions improved under projected decrease in deposition and current climate conditions: higher pH, BS, and C: N at 21, 16 and 12 of the sites, respectively. Dirnböck et al. (2018b) found, however, that a release from eutrophication is not expected to result from the decrease in N deposition under current legislation emission (CLE) reduction targets until 2030. Weldon (2024) compared modelled (VSD+/PROPS) and observed vegetation at the Swedish IM sites and found the models performed better with vascular plants than with mosses and lichens.

Dynamic models have also previously been developed and used for the emission/deposition and climate change scenario assessment at several selected ICP IM sites (e.g., Forsius et al. 1997, 1998a, 1998b, Posch et al. 1997, Jenkins et al. 2003, Futter et al. 2008, 2009). These models are flexible and can be adjusted for the assessment of alternative scenarios of policy importance. The modelling studies have shown that the recovery of soil and water quality of the ecosystems is determined by both the amount and the time of implementation of emission reductions. According to the models, the timing of emission reductions determines the state of recovery over a short time scale (up to 30 years). The quicker the target level of reductions is achieved, the more rapidly the surface water and soil status recover. For the long-term response (> 30 years), the magnitude of emission reductions is more important than the timing of the reduction. The model simulations also indicate that N emission controls are very important to enable the maximum recovery in response to S emission reductions. Increased nitrogen leaching has the potential to not only offset the recovery predicted in response to S emission reduction, but further to promote substantial deterioration in pH status of freshwaters and other N pollution problems in some areas of Europe.

Work has also been conducted to predict potential climate change impacts on air pollution related processes at the sites. The large EU-project Euro-limpacs (2004–2009) studied the global change impacts on freshwater ecosystems. The institutes involved in the project used data collected at ICP IM and ICP Waters sites as key datasets for the modelling, time-series, and experimental work of the project. A modelling assessment on the global change impacts on acidification recovery was carried out in the project

(Wright et al. 2006). The results showed that climate/global change induced changes may clearly have a large impact on future acidification recovery patterns and need to be addressed if reliable future predictions are wanted (decadal time scale). However, the relative significance of the different scenarios was largely determined by site-specific characteristics. For example, changes in sea-salt deposition were only important at coastal sites and changes in decomposition of organic matter at sites which are already nitrogen saturated.

In response to environmental concerns, the use of biomass energy has become an important mitigation strategy against climate change. A summary report on links between climate change and air pollution effects, based on results of the Euro-limpacs project, was prepared for the WGE meeting 2008 (ECE/EB.AIR/WG.1/2008/10). It was concluded that the increased use of forest harvest residues for biofuel production is predicted to have a significant negative influence on the base cation budgets causing re-acidification at the study catchments. Sustainable forestry management policies would need to consider the combined impact of air pollution and harvesting practices.

## Pools and fluxes of heavy metals

The work to assess spatial and temporal trends on concentrations, stores, and fluxes of heavy metals at ICP IM sites is led by Sweden. In 26th Annual Report data on Pb, Cd, Hg, Cu and Zn from countries in the ICP IM were presented (Åkerblom & Lundin 2017). These data were used for establishment of background heavy metal concentrations in forested compartments and risk assessments of heavy metals.

The results presented by Eklöf et al. (2024) showed decreasing trends were observed in 15% (Hg), 39% (Pb) and 45% (Cd) of the watercourses during the period of evaluation. Decreasing trends were mainly observed between 2000 and 2005 for Hg and between 2000 and 2015 for Pb and Cd. For the last five years of the studied time period (2015–2020), more watercourses showed significant increasing, rather than decreasing Hg, Pb and Cd trends. This was interpreted as a legacy effect of metals still retained in catchment soils. The overall negative trends during the earlier part of the study period were likely driven by declining deposition of metals over Europe, especially for Pb and Cd.

In many national studies on ICP IM sites, detailed site-specific budget calculations of heavy metals (including Hg) have improved the scientific understanding of ecosystem processes, retention times and critical thresholds. ICP IM sites are also used for dynamic model development of these compounds. For the future evaluation of emission reductions of heavy metals to the atmosphere site-specific long-term trends for fluxes of heavy metals (primarily for Cd, Pb, and Hg and depending on availability of data, also Cu and Zn) will be analysed in deposition (input) and runoff (output), using available long-term monthly data collected across ICP IM sites in Europe. This will be done to see if fluxes of heavy metals in deposition and runoff respond to changes in emission reductions in Europe. Reduction in heavy metal emissions is hypothesised to be reflected in decreasing heavy metal concentrations (Åkerblom & Lundin 2015), taking into account climatic variation over time and between regions also in decreasing heavy metal fluxes. Temporal trend analysis in heavy metal fluxes will provide a detailed understanding of responses in heavy metal mass balances to emission reductions and give indication on possible change in retention of heavy metals in catchments over time. This overview will also provide an estimate on the significance in heavy metal mass balances over time and identify uncertainties in the mass balances and needs for improvements.

Input-output budgets of Hg help to explain the increase or no change in Hg concentrations in the upper-most forest soil mor-layer despite the general decrease in atmospheric deposition (Åkerblom & Lundin 2015). One process that is not accounted for in ICP IM programme is the land-atmosphere exchange of Hg. The phenomenon of land-atmosphere exchange has been known for a long time, but it has been quantified only recently due to the development of micrometeorological systems for continuous measurements (Osterwalder et al. 2016). In the case of mass balance calculations for Hg new evidence has shown that land-atmosphere exchange during a 2-year study over a peatland can be more than double the flux in stream runoff (Osterwalder et al. 2017). Based on natural Hg stable isotope studies in podzols and histosols, significant Hg re-emission from organic soil horizons occurred (Jiskra et al. 2015). These novel observations and knowledge about processes that govern land-atmosphere exchange of Hg calls for methods and approaches to account for this important flux in the catchment cycle of Hg within ICP IM.

The objective of the aluminium (Al) contribution of Krám and Kleemola in the 28th Annual Report (2019) was to collect and present recently available information about Al fractions from the Integrated Monitoring (IM) database and stimulate the IM National Focal Points to checkout and add not yet reported Al fractions data to the IM database for a publication in peer-reviewed journal. Aluminium (Al) does not belong to the group of so-called heavy metals and is not transferred in large quantities by atmospheric deposition to forest catchments like most of the heavy metals. However, elevated inputs of strong acids from the anthropogenic atmospheric deposition to sensitive sites could mobilize Al from soils and stream sediments in a form of potentially toxic Al fractions to surface waters (Gensemer & Playle 1999). Different fractions of aqueous Al have very different toxicity levels for aquatic biota. Modified methods of the original Al fractionation procedure of Driscoll (1984) were applied and reported from fourteen IM catchments. Total monomeric Al ($Al_m$) and organic monomeric Al ($Al_o$, sometimes called non-labile Al) were measured in surface water by a colorimetry method. The $Al_o$ was separated using a strong cation exchange resin, the method utilized charge exclusion by ion exchange. Potentially toxic inorganic monomeric Al ($Al_i$, sometimes called labile Al) was calculated as the difference between $Al_m$ and $Al_o$. The ICP IM database contains relevant data about Al fractions in surface runoff from fourteen catchments so far. These catchments belong to seven countries: Finland (5), Norway (3), United Kingdom (2), Czech Republic (1), Estonia (1), Sweden (1) and Switzerland (1). Distinct patterns were evident in runoff waters of these catchments. The highest $Al_i$ values were detected at CZ02 (median 340 $\mu g\ L^{-1}$) and at SE04 (median 210 $\mu g\ L^{-1}$). Very high $Al_i$ concentrations were measured at NO01 and NO03 (median 170 $\mu g\ L^{-1}$ and 130 $\mu g\ L^{-1}$, respectively). Slightly elevated $Al_i$ values were documented at GB02, EE02, FI01 and FI02. The remaining IM catchments (GB01, FI03, FI04, FI05, NO02 and CH02) showed very low $Al_i$ concentrations in runoff water. Fast additions of missing $Al_i$ values from catchments with available, but not reported $Al_i$ data to the IM database is advisable (Krám & Kleemola 2019).

## Summary of earlier work on heavy metals

Preliminary results on concentrations, fluxes and catchment retention were reported to the Working Group on Effects in 2001 (document EB.AIR/WG.1/2001/10). The main findings on heavy metals budgets and critical loads at ICP IM sites were presented by Bringmark (2011). Input/output budgets and catchment retention for Cd, Pb and Hg in the years 1997–2011 were determined for 14 ICP IM catchments across Europe (Bringmark et al. 2013). Litterfall plus throughfall was taken as a measure of the total deposition of Pb and Hg (wet + dry) on the basis of evidence suggesting that, for these metals, internal circulation is negligible. The same is not true for Cd. Excluding a few sites with high discharge, between 74 and 94% of the input, Pb was retained within the catchments; significant Cd retention was also observed. High losses of Pb (>1.4 mg m−2 yr−1) and Cd (>0.15 mg m−2 yr−1) were observed in two mountainous Central European sites with high water discharge. All other sites had outputs below or equal to 0.36 and 0.06 mg m−2 yr−1, respectively, for the two metals. Almost complete retention of Hg, 86–99% of input, was reported in the Swedish sites. These high levels of metal retention were maintained even in the face of recent dramatic reductions in pollutant loads. In the Progress report on heavy metal trends at ICP IM sites (Åkerblom & Lundin 2015) temporal trends were seen in forest floor with decreasing concentrations for Cd and Pb while Hg did not change. An increase in heavy metal concentrations was also seen in deeper mineral soil horizon indicating a translocation of heavy metals from upper to deeper soil horizons.

### Calculation of critical loads and their exceedance, relationships to effect indicators

The critical load (CL) methodology has been a key science-based tool for assessing the environmental consequences of air pollution. Critical loads are deposition thresholds used to describe the sensitivity of ecosystems to atmospheric deposition. Critical loads for eutrophication and acidification were computed using a long-term dataset of intensively studied forested ecosystem ICP Integrated Monitoring sites (n = 17) in northern and central Europe (Forsius et al. 2021). The sites belong to the ICP Integrated Monitoring and eLTER networks. The link between the site-specific calculations and time-series of CL exceedances and measured site data was evaluated using long-term measurements (1990–2017) for bulk deposition, throughfall and runoff water chemistry. Novel techniques for presenting exceedances of CLs and their temporal development were also developed. Concentrations and fluxes of sulphate, total inorganic nitrogen (TIN) and acidity in deposition substantially decreased at the sites. Decreases in sulphur (S) deposition resulted in statistically significant decreased concentrations and fluxes of sulphate in runoff and decreasing trends of TIN in runoff were more common than increasing trends. The temporal developments of the exceedance of the CLs indicated the more effective reductions of S deposition compared to nitrogen (N) at the sites. There was a relation between calculated exceedance of the CLs and measured runoff water concentrations and fluxes, and most sites with higher CL exceedances showed larger decreases in both TIN and $H^+$ concentrations and fluxes. Sites with higher cumulative exceedance of eutrophication CLs (averaged over 3 and 30 years) generally showed higher TIN concentrations in runoff. The results provided evidence on the link between CL exceedances and empirical impacts, increasing confidence in the methodology used for the European-scale CL calculations. The results also confirm that emission abatement actions are having their intended effects on CL exceedances and ecosystem impacts.

In Holmberg et al. (2013) empirical impact indicators of acidification and eutrophication were determined from stream water chemistry and runoff observations at ICP IM catchments. The indicators were compared with exceedances of critical loads of acidification and eutrophication obtained with deposition estimates for the year 2000. Empirical impact indicators agreed well with the calculated exceedances. Annual mean fluxes and concentrations of acid neutralising capacity (ANC) were negatively correlated with the exceedance of critical loads of acidification. Observed leaching of nitrogen was positively correlated with the exceedances of critical loads (Holmberg et al. 2013). This study was revisited with new data on N concentrations and fluxes (Holmberg et al. 2017). For most sites, there was an improvement visible as a shift towards less exceedance and lower concentrations of total inorganic nitrogen (TIN) in runoff. At most of the sites both the input and the output flux of TIN decreased between the two observation periods 2000–2002 and 2013–2015. Data from the ICP IM provide evidence of a connection between modelled critical loads and empirical monitoring results for acidification parameters and nutrient nitrogen.

## Planned activities

- Maintenance and development of central ICP IM database at Swedish Agricultural University (SLU).
- Continued assessment of the long-term effects of air pollutants to support the implementation of emission reduction protocols, including:
  - Assessment of trends.
  - Calculation of ecosystem budgets, empirical deposition thresholds and site-specific critical loads.
  - Dynamic modelling and scenario assessment.
  - Comparison of calculated critical load exceedances with observed ecosystem effects.
- Calculation of pools and fluxes of heavy metals at selected sites.
- Assessment of cause-effect relationships for biological data, particularly vegetation.

- Coordination of work and cooperation with other ICPs, particularly regarding dynamic modelling (all ICPs), cause-effect relationships in terrestrial systems (ICP Forests, ICP Vegetation), and surface waters (ICP Waters).
- Cooperation with other external organisations and programmes, particularly the International Long Term Ecological Research Network (ILTER, www.ilter.network, Mirtl et al. 2018).
- Participation in projects with a global change perspective.

## References

Åkerblom, S. & Lundin, L. 2015. Progress report on heavy metal trends at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 24th Annual Report 2015. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 31/2015, pp. 32–36.

Åkerblom, S. & Lundin, L. 2017. Report on concentrations of heavy metals in important forest ecosystem compartments. In: Kleemola, S. & Forsius, M. (Eds.) 26th Annual Report 2017. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 24/2017, pp. 36–42.

Bringmark, L. 2011. Report on updated heavy metal budgets and critical loads. In: Kleemola, S. & Forsius, M. (Eds.) 20th Annual Report 2011. ICP Integrated Monitoring. The Finnish Environment 18/2011, pp. 33–35. Finnish Environment Institute, Helsinki.

Bringmark, L., Lundin, L., Augustaitis, A., Beudert, B., Dieffenbach-Fries, H., Dirnböck, T., Grabner, M-T., Hutchins, M., Krám, P., Lyulko, I., Ruoho-Airola, T. & Váňa, M. 2013. Trace Metal Budgets for Forested Catchments in Europe – Pb, Cd, Hg, Cu and Zn. Water, Air, and Soil Pollution, 224: 1502, 14p.

Dirnböck, T., Grandin, U., Bernhard-Römermann, M., Beudert, B., Canullo, R., Forsius, M., Grabner, M.-T., Holmberg, M., Kleemola, S., Lundin, L., Mirtl, M., Neumann, M., Pompei, E., Salemaa, M., Starlinger, F., Staszewski, T. & Uzięblo, A. K. 2014. Forest floor vegetation response to nitrogen deposition in Europe. Global Change Biology 20: 429–440.

Dirnböck, T., Holmberg, M. & Pröll, G. 2018a. Progress report on dynamic soil-vegetation modelling. In: Kleemola, S. & Forsius, M. (Eds.). 27th Annual Report, International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems. Reports of the Finnish Environment Institute 20/2018: 30–33.

Dirnböck, T., Pröll, G., Austnes, K., Beloica, J., Beudert, B., Canullo, R., De Marco, A., Fornasier, M.A., Futter, M., Goergen, K., Grandin, U., Holmberg, M., Lindroos, A.J., Mirtl, M., Neirynck, J., Pecka, T., Nieminen, T.M., Nordbakken, J.F., Posch, M., Reinds, G.J., Rowe, E., Salemaa, M., Scheuschner, T., Starlinger, F., Uzięblo, A.K., Valinia, S., Weldon, J. Wamelink, W. & Forsius, M. 2018b. Currently legislated decreases in nitrogen deposition will yield only limited plant species recovery in European forests. Environmental Research Letters 13 (2018) 125010.

Dise, N.B, Matzner, E. & Forsius, M. 1998. Evaluation of organic horizon C:N ratio as an indicator of nitrate leaching in conifer forests across Europe. Environmental Pollution 102, S1: 453–456.

Driscoll, C.T. 1984. A procedure for the fractionation of aqueous aluminum in dilute acidic waters. International Journal of Environmental Analytical Chemistry 16: 267–284.

Eklöf, K. *et al.* 2024. 'Trends in mercury, lead and cadmium concentrations in 27 European streams and rivers: 2000-2020', *Environmental pollution.* https://doi.org/10.1016/j.envpol.2024.124761.

.

Forsius, M., Kleemola, S. & Vuorenmaa, J. 1996. Assessment of nitrogen processes at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 5th Annual Report 1996. UNECE ICP Integrated Monitoring. The Finnish Environment 27, pp. 25–38. Finnish Environment Institute, Helsinki.

Forsius, M., Alveteg, M., Bak, J., Guardans, R., Holmberg, M., Jenkins, A., Johansson, M., Kleemola, S., Rankinen, K., Renshaw, M., Sverdrup, H. & Syri, S. 1997. Assessment of the Effects of the EU Acidification Strategy: Dynamic modelling on Integrated Monitoring sites. Finnish Environment Institute, Helsinki. 40 p.

Forsius, M., Alveteg, M., Jenkins, A., Johansson, M., Kleemola, S., Lükewille, A., Posch, M., Sverdrup, H. & Walse, C. 1998a. MAGIC, SAFE and SMART model applications at Integrated Monitoring Sites: Effects of emission reduction scenarios. Water, Air, and Soil Pollution 105: 21–30.

Forsius, M., Guardans, R., Jenkins, A., Lundin, L. & Nielsen, K.E. (Eds.) 1998b. Integrated Monitoring: Environmental assessment through model and empirical analysis – Final results from an EU/LIFE-project. The Finnish Environment 218. Finnish Environment Institute, Helsinki, 172 p.

Forsius, M., Kleemola, S., Vuorenmaa, J. & Syri, S. 2001. Fluxes and trends of nitrogen and sulphur compounds at Integrated Monitoring Sites in Europe. Water, Air, and Soil Pollution 130: 1641–1648.

Forsius, M., Kleemola, S. & Starr, M. 2005. Proton budgets for a monitoring network of European forested catchments: impacts of nitrogen and sulphur deposition. Ecological Indicators 5: 73–83.

Forsius, M. & Nyman, M. (Eds.) 2006. AMAP assessment 2006: acidifying pollutants, arctic haze, and acidification in the Arctic. Oslo, Arctic Monitoring and Assessment Program (AMAP). 112 p. www.amap.no.

Futter, M., Starr, M., Forsius, M. & Holmberg, M. 2008. Modelling long-term patterns of dissolved organic carbon concentrations in the surface waters of a boreal catchment. Hydrology and Earth System Sciences 12: 437–447.

Forsius, M., Posch, M., Holmberg, M., Vuorenmaa, J., Kleemola, S., Augustaitis, A., Beudert, B., Bochenek, W., Clarke, N., de Wit, H., Dirnböck, T., Frey, J., Grandin, U., Hakola, H., Kobler, J., Krám, P., Lindroos, A-J., Löfgren, S., Pecka, T., Rönnback, P., Skotak, K., Szpikowski, J., Ukonmaanaho, L., Valinia, S., Váňa, M. 2021. Assessing critical load exceedances and ecosystem impacts of anthropogenic nitrogen and sulphur deposition at unmanaged forested catchments in Europe. Science of the Total Environment 753.

Futter, M.N., Forsius, M., Holmberg, M. & Starr, M. 2009. A long-term simulation of the effects of acidic deposition and climate change on surface water dissolved organic carbon concentrations in a boreal catchment. Hydrology Research 40: 291–305.

Gensemer, R.W. & Playle, R.C. 1999. The bioavailability and toxicity of aluminum in aquatic environments. Critical Reviews in Environmental Science and Technology 29: 315–450.

Gundersen, P., Berg, B., Currie, W. S., Dise, N.B., Emmett, B.A., Gauci, V., Holmberg, M., Kjønaas, O.J., Mol-Dijkstra, J., van der Salm, C., Schmidt, I.K., Tietema, A., Wessel, W.W., Vestgarden, L.S., Akselsson, C., De Vries, W., Forsius, M., Kros, H., Matzner, E., Moldan, F., Nadelhoffer, K. J., Nilsson, L.-O., Reinds, G.J., Rosengren, U., Stuanes, A.O. & Wright, R.F. 2006. Carbon-Nitrogen Interactions in Forest Ecosystems – Final Report. Forest & Landscape Working Papers no. 17–2006, Danish Centre for Forest, Landscape and Planning, KVL. 62 p.

van Herk, C. M., Mathijssen-Spiekman, E. A. M. & de Zwart, D. 2003. Long distance nitrogen air pollution effects on lichens in Europe. The Lichenologist 35 (4): 347–359.

Holmberg, M., Vuorenmaa, J., Posch, M., Forsius, M., Lundin, L., Kleemola, S., Augustaitis, A., Beudert, B., de Wit, H.A., Dirnböck, T., Evans, C.D., Frey. J., Grandin, U., Indriksone. I., Krám, P., Pompei, E., Schulte-Bisping, H., Srybny, A. & Vána, M. 2013. Relationship between critical load exceedances and empirical impact indicators at Integrated Monitoring sites across Europe. Ecological Indicators: 24:256–265.

Holmberg, M. & Dirnböck, T. 2015. Progress report on dynamic vegetation modelling at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 24th Annual Report 2015. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 31/2015, pp. 23–27.

Holmberg, M. & Dirnböck, T. 2016. Dynamic vegetation modelling at ecosystem monitoring and research sites. In: Kleemola, S. & Forsius, M. (Eds.) 25th Annual Report 2016. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 29/2016, pp. 27–33.

Holmberg, M., Vuorenmaa, J., Posch, M., Kleemola, S., Augustaitis, A., Beudert, B., de Wit, H.A, Dirnböck, T., Frey, J., Forsius, M., Hakola, H., Kobler, J., Krám, P., Lundin, L. & Váňa, M. 2017. Relationship between critical load exceedances and empirical impact indicators at IM sites - Update 2017. In: Kleemola, S. & Forsius, M. (Eds.) 26th Annual Report 2017. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 24/2017, pp. 29–35.

Holmberg, M., Aherne, J., Austnes, K., Beloica, J., De Marco, A., Dirnböck, T., Fornasier, M.F., Goergen, K., Futter, M., Lindroos, A.J., Krám, P., Neirynck, J., Nieminen, T.M., Pecka, T., Posch, M., Rowe, E.C., Scheuschner, T., Schlutow, A., Valinia, S. & Forsius, M. 2018. Modelling study of soil C, N and pH response to air pollution and climate change using European LTER site observations. Science of the Total Environment 640-641: 387-399.

ICP IM Programme Centre 1995. Assessment of nitrogen processes on ICP IM sites. In: 4th Annual Synoptic Report 1995, UNECE ICP Integrated Monitoring, pp. 19–61. Finnish Environment Agency, Helsinki.

Jenkins, A., Larssen, T., Moldan, F., Hruška, J., Krám, P. & Kleemola, S. 2003. Dynamic modelling at Integrated Monitoring sites – Model testing against observations and uncertainty. The Finnish Environment 636. Finnish Environment Institute, Helsinki. 37 p.

Jiskra, M., Wiederhold, J. G., Skyllberg, U., Kronberg, R. M., Hajdas, I. & Kretzschmar, R. 2015. Mercury deposition and re-emission pathways in boreal forest soils investigated with Hg isotope signatures. Environ. Sci. Technol. 49, (12), 7188-7196.

Kleemola, S. 2005. Trend assessment of bulk deposition, throughfall and runoff water chemistry at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 14th Annual Report 2005. ICP Integrated Monitoring. The Finnish Environment 788, pp. 32–37. Finnish Environment Institute, Helsinki.

Kleemola, S. & Forsius, M. 2006. Trend assessment of bulk deposition, throughfall and runoff water/ soil water chemistry at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 15th Annual Report 2006. ICP Integrated Monitoring. The Finnish Environment 30/2006, pp. 22–48. Finnish Environment Institute, Helsinki.

Krám, P. & Kleemola, S. 2019. Aluminium fractions in surface waters draining catchments of ICP Integrated Monitoring network. In: Kleemola, S. & Forsius, M. (eds.). 28th Annual Report 2019. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 33/2019, pp. 31–36.

Liu, Q. 1996. Vegetation monitoring in the ICP IM programme: Evaluation of data with regard to effects of N and S deposition. In: Kleemola, S. & Forsius, M. (Eds.) 5th Annual Report 1996. UNECE ICP Integrated Monitoring. The Finnish Environment 27, pp. 55–79. Finnish Environment Institute, Helsinki.

Lükewille, A., Jeffries, D., Johannessen, M., Raddum, G., Stoddard, J. & Traaen, T. 1997. The nine-year report: Acidification of surface water in Europe and North America. Long-term developments (1980s and 1990s). Norwegian Institute for Water Research, Oslo. NIVA Report 3637–97.

MacDonald, J.A., Dise, N.B., Matzner, E., Armbruster, M., Gundersen, P. & Forsius, M. 2002. Nitrogen input together with ecosystem nitrogen enrichment predict nitrate leaching from European forests. Global Change Biology 8: 1028–1033.

Manual for Integrated Monitoring 1998. Finnish Environment Institute, ICP IM Programme Centre, Helsinki, Finland. Original version (https://helda.helsinki.fi/handle/10138/242414), updated version: www.syke.fi/nature/icpim > Manual for Integrated Monitoring.

Mirtl, M., Borer, E.T., Djukic, I., Forsius, M., Haubold, H., Hugo, W., Jourdan, J., Lindenmayer, D., McDowell, W.H., Muraoka, H, Orenstein. D.E., Pauw, J.C., Peterseil, J., Shibata, H., Wohner, C., Yu, X. & Haase, P. 2018. Genesis, goals, and achievements of Long-Term Ecological Research at the global scale: A critical review of ILTER and future directions. Science of the Total Environment 626: 1439–1462.

Moldan, F., Wright, R.F., Löfgren, S., Forsius, M., Ruoho-Airola, T. & Skjelkvåle, B.L. 2001. Long-term changes in acidification and recovery at nine calibrated catchments in Norway, Sweden, and Finland. Hydrology and Earth System Sciences 5: 339–349.

Osterwalder, S., Bishop, K., Alewell, C., Fritsche, J., Laudon, H., Åkerblom, S. & Nilsson, M. B. 2017. Mercury evasion from a boreal peatland shortens the timeline for recovery from legacy pollution. Scientific Reports 7, 16022.

Osterwalder, S., Fritsche, J., Alewell, C., Schmutz, M., Nilsson, M. B., Jocher, G., Sommar, J., Rinne, J. & Bishop, K. 2016. A dual-inlet, single detector relaxed eddy accumulation system for long-term measurement of mercury flux. Atmos. Meas. Tech. 9, (2), 509-524.

Posch, M., Johansson, M. & Forsius, M. 1997. Critical loads and dynamic models. In: Kleemola, S. & Forsius, M. (Eds.) 6th Annual Report 1997. UN ECE ICP Integrated Monitoring. The Finnish Environment 116, pp. 13–23. Finnish Environment Institute, Helsinki.

Sliggers, J. & Kakebeeke, W. (Eds.) 2004. Clearing the Air: 25 years of the Convention on Long-range Transboundary Air Pollution. Geneva, United Nations Economic Commission for Europe.167 p.

Vuorenmaa, J. 1997. Trend assessment of bulk and throughfall deposition and runoff water chemistry at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 6th Annual Report 1997. UN ECE ICP Integrated Monitoring. The Finnish Environment 116, pp. 24–42. Finnish Environment Institute, Helsinki.

Vuorenmaa, J., Kleemola, S. & Forsius, M. 2009. Trend assessment of bulk deposition, throughfall and runoff water/soil water chemistry at ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds.) 18th Annual Report 2009. ICP Integrated Monitoring. The Finnish Environment 23/2009, pp. 36–63. Finnish Environment Institute, Helsinki.

Vuorenmaa, J. et al. 2012. Interim report: Sulphur and nitrogen input-output budgets at ICP Integrated Monitoring sites in Europe. In: Kleemola, S. & Forsius, M. (Eds.) 21st Annual Report 2012. ICP Integrated Monitoring. The Finnish Environment 28/2012, pp.23–34. Finnish Environment Institute, Helsinki.

Vuorenmaa, J. et al. 2013. Sulphur and nitrogen input-output budgets at ICP Integrated Monitoring sites in Europe. In: Kleemola, S. & Forsius, M. (Eds.) 22nd Annual Report 2013. ICP Integrated Monitoring. Reports of the Finnish Environment Institute 25/2013, pp. 35–43.

Vuorenmaa, J. et al. 2014. Sulphur and nitrogen input-output budgets at ICP Integrated Monitoring sites in Europe in 1990-2012. In: Kleemola, S. & Forsius, M. (Eds.) 23rd Annual Report 2014. ICP Integrated Monitoring. Reports of the Finnish Environment Institute 23/2014, pp. 28–35.

Vuorenmaa, J., Augustaitis A., Beudert, B., Clarke, N., de Wit H., Dirnböck, T., Forsius, M., Frey, J., Indriksone, I., Kleemola, S., Kobler, J., Krám, P., Lindroos, A.-J., Lundin L., Marchetto, A., Ruoho-Airola, T., Schulte-Bisping, H., Srybny, A., Tait, D., Ukonmaanaho, L. & Váňa M. 2016. Trend assessments for deposition and runoff water chemistry concentrations and fluxes and climatic variables at ICP Integrated Monitoring sites in 1990-2013. In: Kleemola, S. & Forsius, M. (Eds.). 25th Annual Report, International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems. Reports of the Finnish Environment Institute 29/2016: 34–51.

Vuorenmaa, J., Augustaitis, A., Beudert, B., Clarke, N., de Wit, H.A., Dirnböck, T., Frey, J., Forsius, M., Indriksone, I., Kleemola, S., Kobler, J., Krám, P., Lindroos, A.-J., Lundin, L., Ruoho-Airola, T., Ukonmaanaho, L. & Váňa, M. 2017. Long-term sulphate and inorganic nitrogen mass balance budgets in European ICP Integrated Monitoring catchments (1990-2012). Ecological Indicators 76: 15–29.

Vuorenmaa, J. Augustaitis, A., Beudert, B., Bochenek, W., Clarke, N., de Wit, H., Dirnböck, T., Frey, J., Hakola, H., Kleemola, S., Kobler, J., Krám, P., Lindroos, A.-J., Lundin, L., Löfgren, S., Marchetto, A., Pecka, T., Schulte-Bisping, H., Skotak, K., Srybny, A., Szpikowski, J., Ukonmaanaho, L., Váňa, M., Åkerblom, S. & Forsius, M. 2018. Long-term changes (1990–2015) in the atmospheric deposition and runoff water chemistry of sulphate, inorganic nitrogen, and acidity for forested catchments in Europe in relation to changes in emissions and hydrometeorological conditions. Science of the Total Environment 625:1129–1145.

Vuorenmaa, J. et al. 2020. Long-term changes in the inorganic nitrogen output in European ICP Integrated Monitoring catchments. In: Kleemola, S. & Forsius, M. eds. 29th Annual Report 2020. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 31/2020, pp. 36–47.

Weldon, J. & Grandin, U. 2021. Weak recovery of epiphytic lichen communities in Sweden over 20 years of rapid air pollution decline. The Lichenologist 53(2): 203–213.

Weldon, J., Merder, J., Ferretti, M., Grandin, U. 2022. Nitrogen deposition causes eutrophication in bryophyte communities in central and northern European forests. Annals of Forest Science 79(24).

Weldon, J 2024. Modelling forest biodiversity and recovery from acidification. Sveriges lantbruksuniversitet, SLU Institutionen för vatten och miljö: Rapport 2024:2 2024.

Working Group on Effects 2004. Integrated Monitoring of Ecosystems. In: Review and assessment of air pollution effects and their recorded trends. Report of the Working Group on Effects of the Convention on Long-range Transboundary Air Pollution, pp. 30–33. Geneva, United Nations Economic Commission for Europe.

Wright, R.F., Aherne, J., Bishop, K., Camarero, L., Cosby, B.J., Erlandsson, M., Evans, C.D., Forsius, M**.,** Hardekopf, D., Helliwell, R., Hruška, J., Jenkins, A., Kopáček, J., Moldan, F., Posch, M. & Rogora, M. 2006. Modelling the effect of climate change on recovery of acidified freshwaters: Relative sensitivity of individual processes in the MAGIC model. Science of the Total Environment 365: 154–166.

de Zwart, D. 1998. Multivariate gradient analysis applied to relate chemical and biological observations. In: Kleemola, S. & Forsius, M. (Eds.) 7th Annual Report 1998. UN ECE ICP Integrated Monitoring. The Finnish Environment 217, pp. 15–29. Finnish Environment Institute, Helsinki.

de Zwart, D., van Herk, K.C.M. & Mathijssen-Spiekman, L.E.A. 2003. Long distance nitrogen air pollution effects on lichens in Europe. In: Kleemola, S. & Forsius, M. (Eds.) 12th Annual Report 2003. UN ECE ICP Integrated Monitoring. The Finnish Environment 637, pp. 32–37. Finnish Environment Institute, Helsinki.

# ICP IM activities, monitoring sites and available data

## Review of the ICP IM activities from June 2023 to June 2024

### Meetings

- Salar Valinia, Ulf Grandin, and James Weldon represented ICP IM at the Ninth Joint Session of the Working Group on Effects and the Steering Body to EMEP, held in Geneva 11–15 September 2023.
- Ulf Grandin and James Weldon represented ICP IM at the joint meeting of EMEP Steering Body and Working Group on Effects Extended Bureau, held in Geneva 27 February – 1 March 2024.
- James Weldon represented ICP IM and gave an online presentation about current activities, at the CDM/CCE/M&M meeting, held in Oslo, Norway 23-25 April 2024.
- The thirty-second meeting of the Programme Task Force on ICP Integrated Monitoring was held in Prague, Czechia (and online), 28–30 May 2024.
- James Weldon and Ulf Grandin took part in the eLTER PPP and PLUS project meeting, held in Sofia, Bulgaria 3 -7 June 2024. Discussions on co-operation between eLTER and the WGE were held.
- James Weldon represented ICP IM and gave an online presentation about current activities, at the ICP Forests Task Force meeting, held in Prague, Czechia, 10–14 June 2024.
- James Weldon represented ICP IM and gave a presentation about current scientific work related to nitrogen deposition, at the XXVI IUFRO World Conference, held in Stockholm, Sweden, 23–29 June 2024.

### Data issues

The National Focal Points (NFPs) reported their results to the ICP IM Programme Centre. The Programme Centre carried out standard check-up of the results and incorporated them into the IM database.

### Scientific work and activities in priority topics

- A scientific paper on Hg and heavy metal trends in concentrations across ICP Integrated Monitoring sites in Europe (Eklöf et al.) was published (2024).
- A report was published on dynamic modelling of the four Swedish sites and modelling of vegetation responses there (2024).

## Activities and tasks planned for 2024–2025

ICP IM activities on the WGE 2024–25 work plan:

- Scientific paper on the effects from deposition on vegetation community stability over time (2024-5)

- Scientific paper on trends in heavy metal fluxes across ICP Integrated Monitoring sites (2024-

25)

- An assessment of the mercury data gathered by the newly installed passive samplers (2024)

- As far as possible, making the ICP IM database accessible, under a "by attribution" licence, and aiming to meet FAIR principles, and by publishing a data paper to explain the IM monitoring infrastructure in more detail (2024-25)

- Scientific paper or report - Update in long-term changes in the atmospheric deposition and runoff water chemistry of sulfate, inorganic nitrogen and acidity (2025)

- Initiate a revision and update of the IM manual. An ad-hoc group will provide recommendations to the TF meeting in an ongoing process that will extend to the next work plan (2024-25)

- Proof of concept for development of above ground vegetation monitoring in ICP IM sites using drone remote sensing (2025). Subject to external funding being approved.

### Other activities

- Maintenance and development of central ICP IM database at Swedish Agricultural University (SLU).
- Arrangement of the 33rd Task Force meeting (2025).
- Preparation of the 34th ICP IM Annual Report (2025).
- Preparation of the ICP IM contribution to assessment reports of the WGE
- Participation in meetings of the WGE and other ICPs

## Published reports and articles 2022–2024

### Evaluations of international ICP IM data and related publications

Eklöf, K. *et al.* (2024) 'Trends in mercury, lead and cadmium concentrations in 27 European streams and rivers: 2000-2020', *Environmental pollution.* https://doi.org/10.1016/j.envpol.2024.124761.

Weldon, J. (ed.), 2021. 31st Annual Report (2022). Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Annual Reports of the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems 31, Uppsala. https://res.slu.se/id/publ/118336

Weldon, J., Merder, J., Ferretti, M., Grandin, U. (2022). Nitrogen deposition causes eutrophication in bryophyte communities in central and northern European forests. Annals of Forest Science 79(24). doi: 10.1186/s13595-022-01148-6

### Evaluations of national ICP IM data and publications of ICP IM representatives

Monteith, D. T., Henrys, P. A., Hruška, J., de Wit, H. A., Krám, P., Moldan, F., . . . Evans, C. D. (2023). Long-term rise in riverine dissolved organic carbon concentration is predicted by electrolyte solubility theory. Science Advances, 9(3), eade3491. doi:10.1126/sciadv.ade3491

Liptzin, D., Boy, J., Campbell, J.L., Clarke, N., Laclauf, J.-P., Godoy, R., Johnson, S.L., Kaiser, K., Likens, G.E., Pihl Karlsson, G., Markewitz, D., Rogora, M., Sebestyen, S.D., Shanley, J.B., Vanguelova, E., Verstraeten, A., Wilcker, W., Worralls, F., McDowell, W.H. (2022). Spatial and Temporal Patterns in Atmospheric Deposition of Dissolved Organic Carbon. Global Biogeochemical Cycles, doi: 10.1029/2022GB007393.

Monteith D.T., Henrys P.A., Hruška J., de Wit H.A., Krám P., Moldan F., Posch M., Raike A., Stoddard J.L., Shilland E.M., Gloria Pereira M., Evans C.D. (2023) Long-term rise in riverine dissolved organic carbon concentration is predicted by lectrolyte solubility theory. *Science Advances*, 9(3): eade3491, 1-11.

Petrash D.A., Krám P., Pérez-Rivera K.X., Buzek F., Čuřík J., Veselovský F., Novák M. (2023) Soil solution data from Bohemian headwater catchments record atmospheric metal deposition and legacy pollution. *Environmental Science and Pollution Research*, doi.org/10.1007s11356-023-25673-7.

Yttri, K. E., Canonaco, F., Eckhardt, S., Evangeliou, N., Fiebig, M., Gundersen, H., Hjellbrekke, A.-G., Lund Myhre, C., Platt, S. M., Prévôt, A. S. H., Simpson, D., Solberg, S., Surratt, J., Tørseth, K., Uggerud, H., Vadset, M., Wan, X., and Aas, W.: Trends, composition, and sources of carbonaceous aerosol at the Birkenes Observatory, northern Europe, 2001–2018, Atmos. Chem. Phys., 21, 7149–7170, https://doi.org/10.5194/acp-21-7149-2021, 2021.

*Reports:*
Austnes, K., Hjermann, D.O., Sample, J.E., Wright, R.F., Kaste, O., de Wit, H. 2022. Nitrogen in surface waters: time trends and geographical patterns explained by deposition levels and catchment characteristics. NIVA-rapport 7728-2022. ICP Waters report 149-2022.

Weldon, J. “Modelling Forest biodiversity and recovery from acidification”, Report 2024:2 (Uppsala, Department of Aquatic Sciences and Assessment of the Swedish University of Agricultural Sciences, 2024).

## Monitoring sites and data

The following countries have continued data submission to the ICP IM database during the period 2016–2022: Austria, Belarus, the Czech Republic, Estonia, Finland, Germany, Ireland, Italy, Lithuania, Norway, Poland, the Russian Federation, Spain, Sweden, and Switzerland.

The number of sites with on-going data submission for at least part of the data years 2015–2022 is 48 from fifteen countries. Sites from Canada, Latvia and United Kingdom only contain older data.

An overview of the data reported internationally to the ICP IM database is given in Table 1.1. Additional earlier reported data are available from sites outside those presented in Table 1.1. and Fig. 1.1. Locations of the ICP IM monitoring sites are shown in Fig. 1.1.

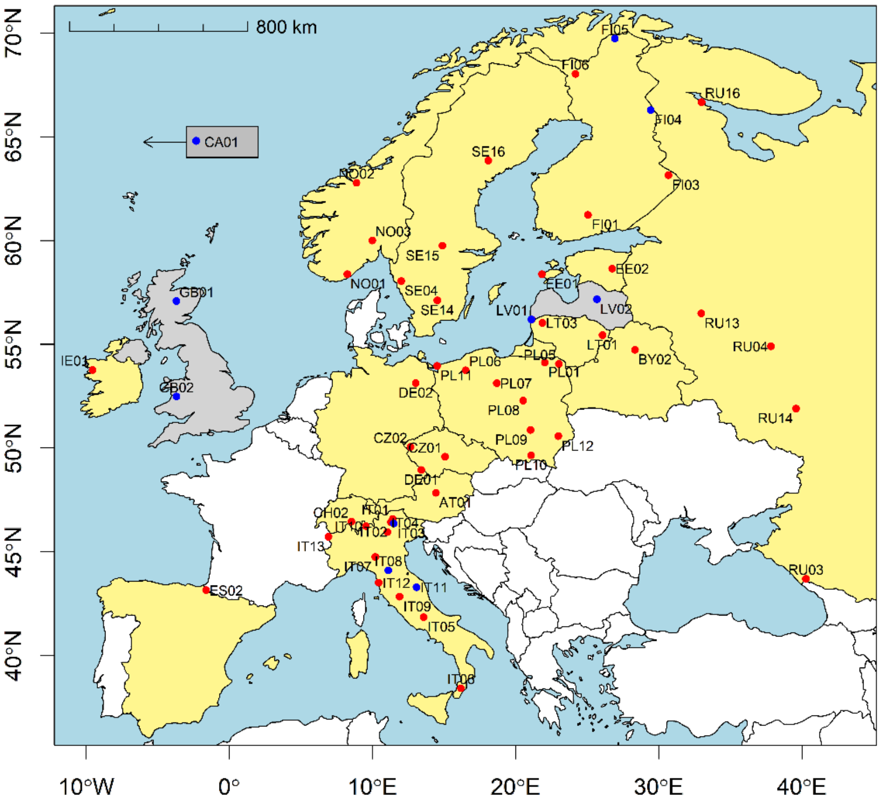

*Figure 1: Location and status of ICP IM sites. For site names, see table 1.1. Red mark: active site. Blue mark: non-active site. Yellow: country with active IM sites. Grey: country with only non-active sites.*

*Table 1.1. Internationally reported data from ICP IM sites (- subprogramme not possible to carry out, * or forest health parameters in former Forest stands/Trees).*

| **AREA** | SUBPROGRAMME | | | | | | | | | | | | | | | * | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AM | AC | PC | MC | TF | SF | SC | SW | GW | RW | LC | FC | LF | RB | LB | FD | VG | BI | VS | EP | AL | MB | BB | BV |
| | meteorology | air chemistry | precipitation chemistry | moss chemistry | throughfall | stemflow | soil chemistry | soil water chemistry | groundwater chemistry | runoff water chemistry | lake water chemistry | foliage chemistry | litterfall | hydrobiology of streams | hydrobiology of lakes | forest damage | vegetation | bioelements | vegetation structure | trunk epiphytes | aerial green algae | microbial decomposition | bird inventory | vegetation inventory |
| AT01 ZÖBELBODEN | 95-22 | 95-22 | 93-22 | | 93-22 | 99-04 | 04 | 93-22 | | 95-22 | | 92-22 | 93-22 | | | | 93 | | | 93-98 | | | | |
| BY02 BEREZINA BR | 89-15 | 89-15 | 89-15 | | | | 95-98 | | | 95-15 | | | | | | | | | | | | | | |
| CH02 LAGO NERO | 15-19 | 15-19 | 15-19 | | | | 18 | 17-19 | | 15-19 | 15-16 | | | | | | 17 | | | | | | | |
| CZ01 ANENSKE POVODI | 89-22 | 89-22 | 89-22 | 89 | 89-22 | | 02-20 | 07-22 | 08-22 | 89-22 | - | | | 07 | | | | | | | | | | |
| CZ02 LYSINA | 67-20 | 93-96 | 90-22 | | 91-22 | | 93 | 90-22 | 89-22 | 89-22 | 91-22 | 94 | 08 | 07 | 11 | | 15 | 94 | | | 14-15 | | 10 | |
| DE01 FORELLENBACH | 90-22 | 90-22 | 90-22 | 90 | 90-22 | 90-05 | 90-11 | 90-22 | 88-22 | 90-22 | - | 90-22 | 90-22 | | | 90-14 | 90-08 | | 00 | 92-95 | | 94-22 | 91-02 | 90-95 |
| DE02 NEUGLOBSOW | 67-22 | 98-22 | 98-22 | | 98-22 | 04-22 | 04-16 | 98-22 | 98-22 | | 98-22 | 06-22 | 04-22 | | | | 04-17 | | | | | 22 | | |
| EE01 VILSANDI | 95-22 | 94-22 | 94-22 | 94-20 | 94-22 | 94-22 | 94-20 | 94-22 | 95-96 | | | 94-22 | 94-22 | | | 94-17 | 94-21 | | | 94-21 | | 94-22 | | 94 |
| EE02 SAAREJÄRVE | 94-22 | 98-22 | 94-22 | 94-21 | 94-22 | 94-22 | 94-20 | 95-22 | 95-21 | 94-22 | 96 | 94-22 | 94-22 | | | 96-17 | 96-22 | 12 | | 94-21 | 94-17 | 96-22 | 98-14 | |
| ES02 BERTIZ | 08-17 | 08-22 | 07-22 | | 07-22 | 08-19 | 10-15 | 07-18 | | 07-22 | | 08-22 | 08-22 | | | 07-12 | 07-21 | | 07 | | | | | |
| FI01 VALKEA-KOTINEN | 88-22 | 94-20 | 88-22 | 88-96 | 89-17 | 89-99 | 88-89 | 89-17 | | 88-22 | 87-22 | 88-17 | 90-16 | | 90-93 | 88-91 | 88-09 | | | 88-97 | | 90 | 87-89 | 87 |
| FI03 HIETAJÄRVI | 88-22 | 93-00 | 88-22 | 89-96 | 89-17 | 89-99 | 88 | 89-17 | 93-22 | 88-22 | 87-22 | 88-17 | 90-16 | | 90 | 88-91 | 90-09 | | | 90-97 | | 90-91 | 87-89 | |
| FI06 PALLASJÄRVI | 13-22 | | 14-22 | | 16-17 | | | 02-17 | 18-22 | 04-22 | 04-22 | 95-17 | 07-16 | | | | | | | | | | 88-89 | |
| IE01 BRACKLOON WOOD | | | 91-16 | | 91-11 | 92-97 | | 91-16 | | | | 91-96 | 91-98 | | | | | | | | | | | |
| IT01 RENON-RITTEN | 90-19 | 93-19 | 93-14 | | 93-13 | 93-13 | 93-11 | 93-13 | | 00-13 | | 93-10 | 00 | | | 92-13 | 09 | | 05-09 | 92 | | 93-11 | | |
| IT03 PASSO LAVAZE | 92-21 | 93-22 | 92-13 | | 94-13 | 94-00 | 93-95 | 95-07 | | 01-13 | | 93-05 | 94 | | | 93-19 | 95-09 | | 99-09 | 92 | | | | |
| IT05 SELVA PIANA | 97-21 | 97-22 | 97-19 | | 97-19 | 97-19 | 95 | 02-08 | | | | 97-19 | | | | 97-19 | 09 | | 99-09 | | | | | |
| IT06 PIANO LIMINA | 99-19 | 97-16 | 97-22 | | 97-22 | 97-21 | 95 | 19-22 | | | | 97-19 | | | | 97-19 | 09 | | 99-09 | | | | | |
| IT07 CARREGA | 97-21 | 97-22 | 97-22 | | 97-22 | 97-00 | 95 | 19-22 | | 98-13 | | 97-19 | | | | 97-19 | 09 | | 99-09 | | | | | |
| IT09 MONTE RUFENO | 97-21 | 97-22 | 97-22 | | 97-22 | 97-00 | 95 | 02-22 | | 97-14 | | 97-19 | | | | 97-19 | 09 | | 99-09 | | | | | |
| IT10 VAL MASINO | 97-19 | 00-15 | 97-15 | | 97-15 | | 95 | 05-07 | | | | 97-05 | | | | 97-09 | 09 | | 99-09 | | | | | |
| IT11 ROTI | | 97-22 | 97-12 | | 97-12 | | 95 | | | | | 97-05 | | | | 97-09 | 09 | | 99-09 | | | | | |
| IT12 COLOGNOLE | 97-01 | 97-15 | 97-15 | | 97-15 | 97-00 | 95 | | | | | 97-05 | | | | 97-09 | 09 | | 99-09 | | | | | |
| IT13 LA THUILE | 97-21 | 97-15 | 09-15 | | 09-15 | | 95 | | | | | 97-05 | | | | 97-09 | | | 99-08 | | | | | |
| LT01 AUKSTAITIJA | 93-13 | 93-19 | 93-19 | 93-20 | 93-19 | | 93-20 | 94-22 | 93-22 | 93-22 | | 06-22 | 99-22 | 12-20 | | 00-22 | 93-22 | 20 | 02-20 | 93-22 | 93-22 | | | 93 |
| LT03 ZEMAITIJA | 90-13 | 95-19 | 95-19 | 06-20 | 95-19 | | 94-20 | 95-22 | 95-22 | 95-22 | | 06-22 | 99-22 | 95-20 | | 00-22 | 94-22 | 20 | 02-20 | 94-22 | 94-22 | | | 94 |
| NO01 BIRKENES | 87-21 | 87-22 | 87-22 | 92 | 89-22 | | 87-11 | 86-22 | 87-88 | 87-22 | | 86-17 | 87-02 | | | 91-18 | 86-18 | | | 86 | | | | |
| NO02 KÅRVATN | 87-91 | 87-22 | 87-22 | 88 | 89-11 | | 89-13 | 89-10 | | 87-22 | | 89-09 | 89-02 | | | 92-10 | 89-09 | | | | | | | |
| NO03 LANGTJERN | | 87-97 | 77-22 | | 86-03 | | 91-13 | 91-03 | | 87-22 | | 86-03 | 87-02 | | | | | | | | | | | |
| PL01 PUSZCZA BORECKA | 06-22 | 16-22 | 16-21 | | 16-22 | 21-22 | 17 | 10-22 | | | 16-22 | | 06-22 | | | | 16 | | | | | | | |
| PL05 WIGRY | 06-22 | 16-22 | 16-22 | | 16-22 | 21-22 | 19 | 06-22 | | 16-22 | | | 05-22 | | | | 16 | | | | | | | |
| PL06 PARSENTA | 10-22 | 16-22 | 94-22 | | 96-22 | 21-22 | | 10-22 | | 94-22 | | | 10-22 | | | | | | | | | | | |
| PL07 POJEZIERZE CHELMINSK | 16-22 | 16-22 | 16-22 | | | | 18 | 20 | | 16-22 | | | | | | | | | | | | | | |
| PL08 KAMPINOS | 09-22 | 16-22 | 16-22 | | 16-22 | 21-22 | 16 | 12-19 | | 21-22 | | | 10-22 | | | | 16 | | | | | | | |
| PL09 LYSOGORY | 05-22 | 16-22 | 16-22 | | 16-22 | 21-22 | | 05-22 | | 16-22 | | | 05-22 | | | | 16 | | | | | | | |
| PL10 BESKIDY | 94-22 | 16-22 | 94-22 | | 02-22 | 21-22 | | 11-22 | | 94-22 | | | 09-22 | | | | 16 | | | | | | | |
| PL11 WOLIN | 16-22 | 16-22 | 16-22 | | 17-22 | 21-22 | 21 | 16-22 | | 16-22 | | | 16-22 | | | | | | | | | | | |
| PL12 ROZTOCZE | 16-22 | 16-22 | 16-22 | | 16-22 | 21-22 | | 16-22 | | 16-22 | | | 16-22 | | | | 16 | | | | | | | |
| PL13 POZNAN-MORASKO | 22 | 22 | 22 | | 22 | 22 | | | | 22 | | | 22 | | | | | | | | | | | |
| PL14 KARKONOSZE | | | | | 22 | 22 | | 22 | | 22 | | | 22 | | | | | | | | | | | |
| RU03 CAUCASUS BR | 89-94 | 89-22 | 89-98 | | | | | | | | | | | | | | | | | | | | | |
| RU04 OKA-TERRACE BR | 89-06 | 89-22 | 89-98 | 90 | | | | | | | | | | 93-99 | | 93-22 | 93-02 | | | 93 | | 94-96 | | |
| RU12 ASTRAKHAN BR | 93-94 | 93-21 | 93-94 | | | | | | | | | | | | | | | | | | | | | |
| RU13 CENTRAL FOREST BR | 93 | 93-94 | 93 | | | | | | | | | | | | | 09-22 | 18-20 | | | | | | | |
| RU14 VORONEZH BR | 94 | 94-22 | 94-98 | | | | | | | | | | | | | | | | | | | | | |
| RU16 VELIKIY ISLAND | | | | 89-90 | | | 89 | 89 | 89 | | | | | | 93-99 | 93-22 | 91-94 | | | 89-94 | 93 | 94-95 | | 91 |
| RU47 KURSK | | | | | | | | | | | | | | | | 18-21 | | | | | | | | |
| RU48 MOSCOW ARBORETUM | | | | | | | | | | | | | | | | 19-22 | | | | | | | | |
| SE04 GÅRDSJÖN F1 | 87-22 | 88-22 | 87-22 | 95 | 87-22 | | 95-10 | 96-22 | 79-22 | 87-22 | | 99-22 | 96-22 | | | 97-01 | 95-22 | 91-20 | 91-20 | 96-21 | 92-22 | 99-22 | | |
| SE14 ANEBODA | 96-22 | 96-22 | 96-22 | 95 | 96-22 | | 96-11 | 99-22 | 96-22 | 96-22 | | 99-22 | 99-22 | | | 97-01 | 82-22 | 96-22 | 06-22 | 97-22 | 97-22 | 99-22 | | |
| SE15 KINDLA | 97-22 | 96-22 | 96-22 | | 96-22 | | 97-12 | 99-22 | 97-22 | 96-22 | | 97-22 | 99-22 | | | 98-01 | 96-22 | 98-18 | 98-18 | 98-18 | 97-22 | 99-22 | | |
| SE16 GAMMTRATTEN | 99-22 | 99-22 | 99-22 | | 99-22 | | 00-18 | 00-22 | 00-22 | 99-22 | | 99-22 | 00-22 | | | 00-01 | 99-22 | 99-19 | 99-19 | 00-20 | 00-22 | 00-22 | | |

## Trend maps

In this section we present maps showing trends in the IM data series, to provide the reader with a quick visual overview of trends across the IM network since 2010, with annual updates as new data become available. We are beginning with trends in throughfall concentrations of $SO_4$, $NH_4$ and $NO_2$ but will expand the coverage in future editions of the annual report to encompass more subprogrammes. At each site trends were analysed using the non-parametric Seasonal Kendall test (Hirsch et al. 1982) applied to monthly data. The magnitude of trend was estimated by the slope estimation method (Sen 1968), which estimates the slope by calculating the median of all between-year differences in the variable of interest. For the analysed parameters, a calculated positive value of test statistics S indicates an increasing slope (increasing values with time), and a negative value indicates a decreasing slope. A statistical significance threshold of $p < 0.05$ was applied to the trend analysis.

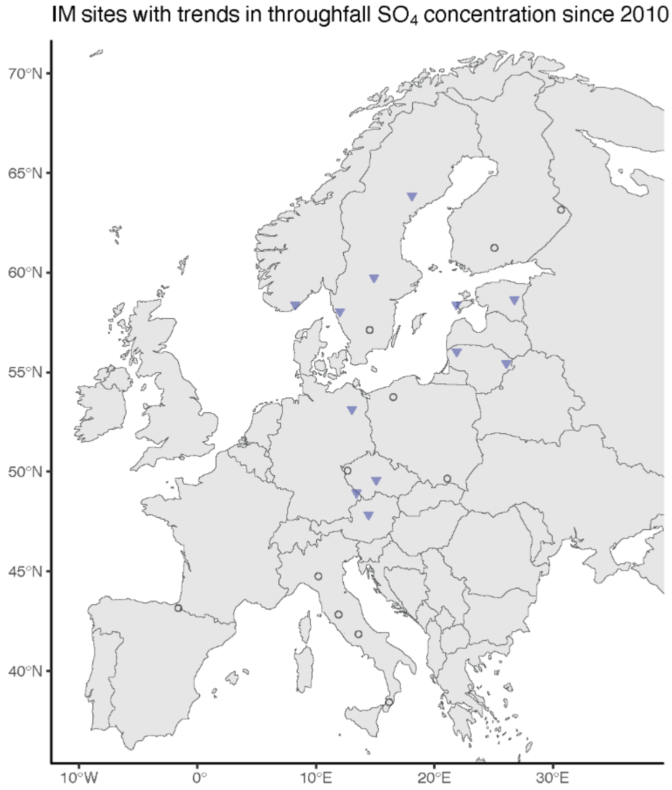

*Figure 2: Trends in throughfall $SO_4$ concentrations since 2010, blue arrows indicate declining trend, and circles sites with no significant trend (Mann Kendall tests)*

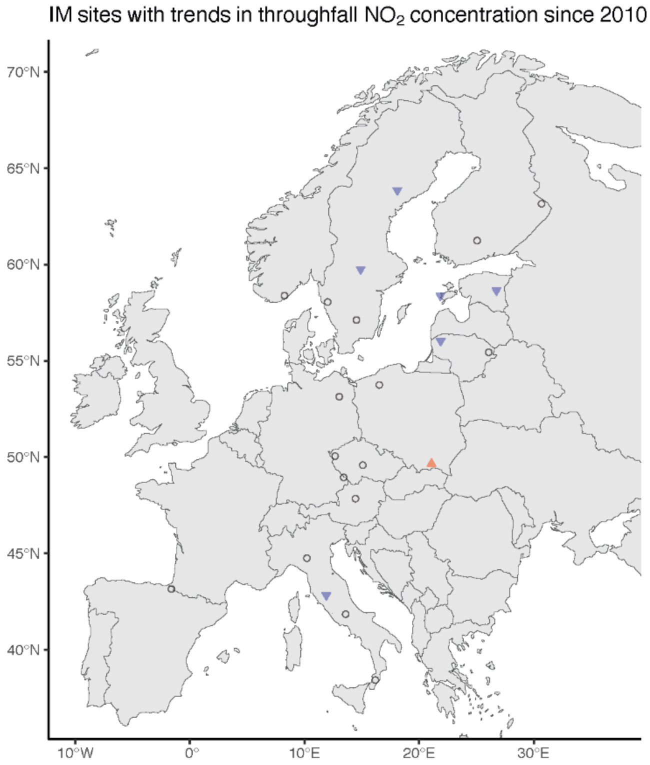

*Figure 3: Trends in throughfall $NO_2$ concentrations since 2010, blue arrows indicate declining trend, red arrows increasing trend (Mann Kendall tests), and circles sites with no trends.*

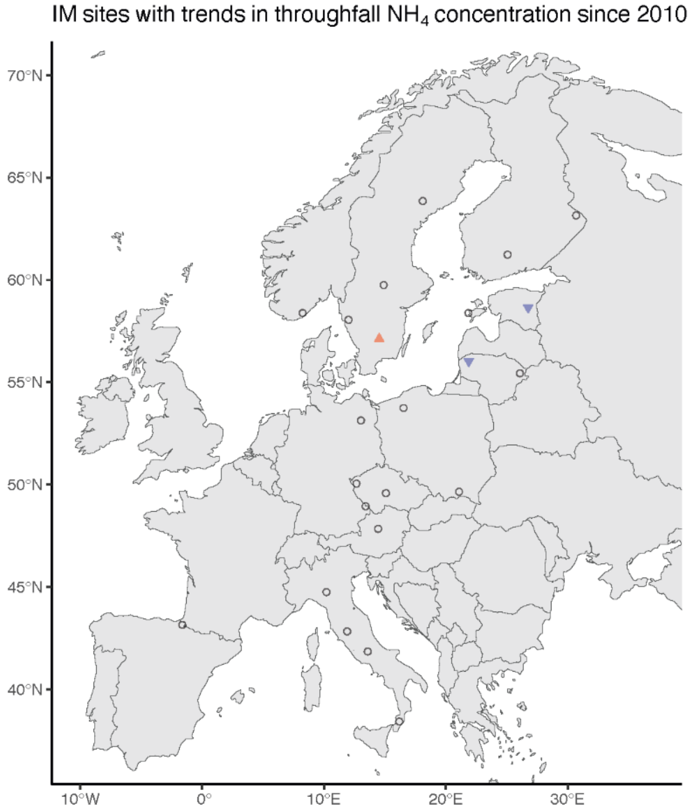

*Figure 4: Trends in throughfall $NH_4$ concentrations since 2010, blue arrows indicate declining trend, red arrows increasing trend (Mann Kendall tests), and circles sites with no trends*

## National Focal Points (NFPs) and contact persons for ICP IM sites

**AT / Austria**
NFP:
Johannes Kobler and Gisela Pröll
Environment Agency Austria
Spittelauer Lände 5
A-1090 Vienna
AUSTRIA
e-mail:
johannes.kobler@umweltbundesamt.at
Gisela.Proell@umweltbundesamt.at

**BY / Belarus**
NFP:
Anatoly Srybny
Berezinsky Biosphere Reserve
P. O Domzheritzy
Lepel District
Vitebskaya oblast, 211188
BELARUS
e-mail: srybny@vitb.pogoda.by

**CZ / Czech Republic**
NFP:
Adéla Holubová
Czech Hydrometeorological Institute
Košetice Observatory
CZ-394 22 Košetice
CZECH REPUBLIC
e-mail: adela.holubova@chmi.cz

**Contact for site CZ02:**
Pavel Krám
Czech Geological Survey
Department of Geochemistry
Klarov 3
CZ-118 21 Prague 1
CZECH REPUBLIC
e-mail: pavel.kram@geology.cz

**CH / Switzerland**
NFP:
Luca Colombo and Fabio Lepori
Institute of Earth Sciences
University of Applied Sciences and Arts of Southern Switzerland, SUPSI
Campus Trevano, 6952 Canobbio
SWITZERLAND
e-mail: luca.colombo@supsi.ch
fabio.lepori@supsi.ch

**DE / Germany**
NFP:
Thomas Scheuschner
Federal Environment Agency
Air Pollution and Terrestrial Ecosystems
Wörlitzer Platz 1
D-06844 Dessau-Roßlau
GERMANY
e-mail: thomas.scheuschner@uba.de

**Contact for site DE01:**
Angelika Kölbl
Nationalparkverwaltung Bayerischer Wald
Sachgebiet Forschung und Dokumentation

Integriertes Ökosystemmonitoring
Freyunger Straße 2
D-94481 Grafenau
GERMANY
e-mail: angelika.koelbl@npv-bw.bayern.de

**Contact for site DE02:**
Nicole Wellbrock
Thünen Institute
Alfred-Möller-Straße 1,
Haus 41/42, 16225
Eberswalde,
GERMANY
e-mail: icp-neuglobsow@thuenen.de

**EE / Estonia**
NFP:
Heidi Koger
Ambient Air Department,
Ministry of Climate,
Suur-Ameerika 1,10122 Tallinn,
ESTONIA
e-mail: heidi.koger@kliimaministeerium.ee

Kairi Lõhmus
Estonian Environmental Research Centre
Marja 4d, 10617 Tallinn,

ESTONIA
e-mail: kairi.lohmus@klab.ee

**ES / Spain**
NFP:
Jesús Miguel Santamaría and
David Elustondo
Laboratorio Integrado de Calidad Ambiental,
LICA
Departamento de Química y Edafología
Universidad de Navarra
Irunlarrea 1, 31008 Pamplona
SPAIN
e-mail: chusmi@unav.es
delusto@unav.es

**FI / Finland**
Contact persons:
Martin Forsius and Jussi Vuorenmaa
Finnish Environment Institute, SYKE
Latokartanonkaari 11
FI-00790 Helsinki
FINLAND
e-mail: martin.forsius@syke.fi
jussi.vuorenmaa@syke.fi

**IE / Ireland**
NFP:
Thomas Cummins
University College Dublin
UCD School of Agriculture and
Food Science
Belfield, Dublin 4
IRELAND
e-mail: thomas.cummins@ucd.ie

**IT / Italy**
NFP:
Giancarlo Papitto
Comando Unità Tutela Forestale,
Ambientale e Agroalimentare Carabinieri
Ufficio Studi e Progetti
Via Giosuè Carducci 5
I-00187 Rome
ITALY
e-mail: giancarlo.papitto@carabinieri.it

**LT / Lithuania**
Contact for sites LT01, LT03:
Algirdas Augustaitis
Vytautas Magnus University
Agricultural Academy
Faculty of Forest Sciences and Ecology
Studentu 13
LT-53362 Kaunas dstr.
LITHUANIA
email: algirdas.augustaitis@vdu.lt

**NO / Norway**
NFP:
Heleen de Wit
Norwegian Institute for Water Research,
Gaustadalléen 21
NO-0349 Oslo
NORWAY
e-mail: heleen.de.wit@niva.no

**PL / Poland**
Contact for sites PL06, PL10:
Krzysztof Skotak
Institute of Environmental Protection
National Research Institute
ul. Kolektorska 4
01-692 Warsaw
POLAND
e-mail: krzysztof.skotak@ios.edu.pl

**RU / Russia**
NFP:
Anna Koukhta
Institute of Global Climate and Ecology
Glebovskaya str. 20 B
107258 Moscow
RUSSIA
e-mail: anna_koukhta@mail.ru

**SE / Sweden** NFP: Pernilla Rönnback
Swedish University of Agricultural Sciences,
SLU
Department of Aquatic Sciences and
Assessment
P.O. Box 7050 SE-75007 Uppsala
SWEDEN
e-mail: pernilla.ronnback@slu.se

# Report on the tree species development after disturbances at the Aneboda IM site (Sweden)

Andrea Törnqvist[1]

*[1]Student at the Swedish University of Agricultural Sciences /Biology and environmental science programme*

Aneboda was affected by storm Gudrun (2005) which led to 10-20% of the trees being felled. After Gudrun there was a severe bark beetle attack, which killed almost all spruce > 10 cm in diameter. Before the bark beetle attack the forest was mature and dominated by spruce, with quite a few small beech trees and some large ones. Thanks to the environmental monitoring on the site, the development of the forest after the disturbances could be followed, to see if it would return to being spruce dominated, or if there would be a shift to a mixed or broadleaved forest. This is a summary of a bachelor's thesis on the forest's recovery after disturbances (Törnqvist 2023). The consequences of the drastic decrease in mature spruce meant that there were fewer spruce trees which could distribute seeds, which is why a decreased establishment of spruce was expected. As a result of the open areas with exposed mineral soil after the storm it was expected that there would be an establishment of birch, since birch thrives in open areas and tends to spread quickly after disturbances. Fewer spruce also means less competition for sunlight, which could give an advantage to beech, which is why there was also expected to be an expansion of the small beech trees present in the forest before the disturbances, if the newly established birches do not inhibit the beech.

To examine the development of the forest after the disturbances, data from IM's tree indication plots (BI subprogramme) were used, where trees higher than 130 cm (the height for diameter at breast height measurements) are inventoried every fifth year. The focus lay on the number of trees < 5 cm in diameter from the period 1996-2022. Thicker trees do not tell us much about new establishment and have been excluded from this summary.

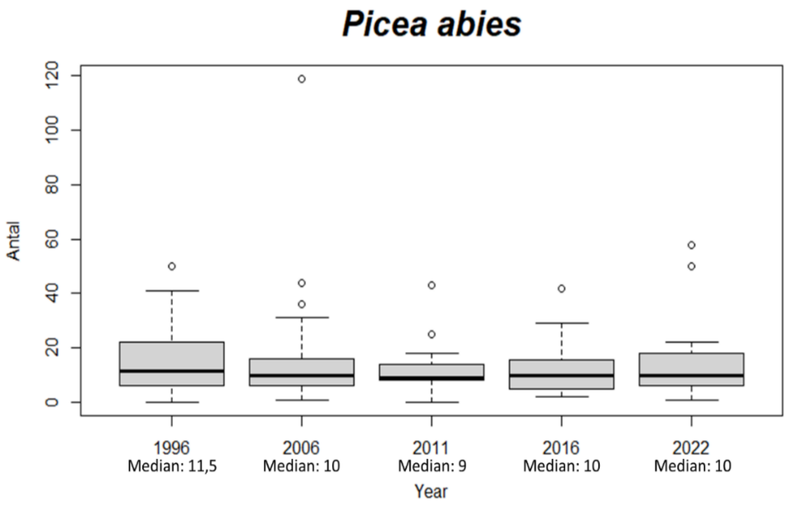

*Figure 1. Distribution of the number of spruce < 5 cm diameter at breast height in all available plots. The Y-axis shows the number of trees, and the x-axis shows the years where the inventories took place.*

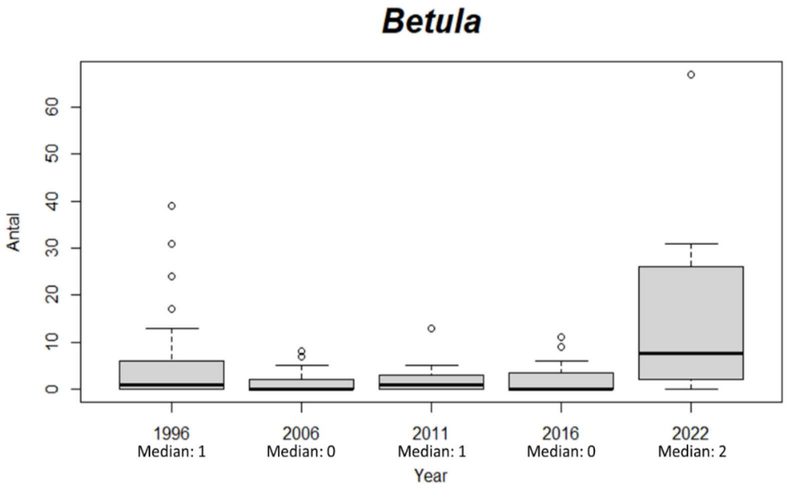

*Figure 2. Distribution of the number of birch < 5 cm diameter at breast height in all available plots. The Y-axis shows the number of trees, and the x-axis shows the years where the inventories took place.*

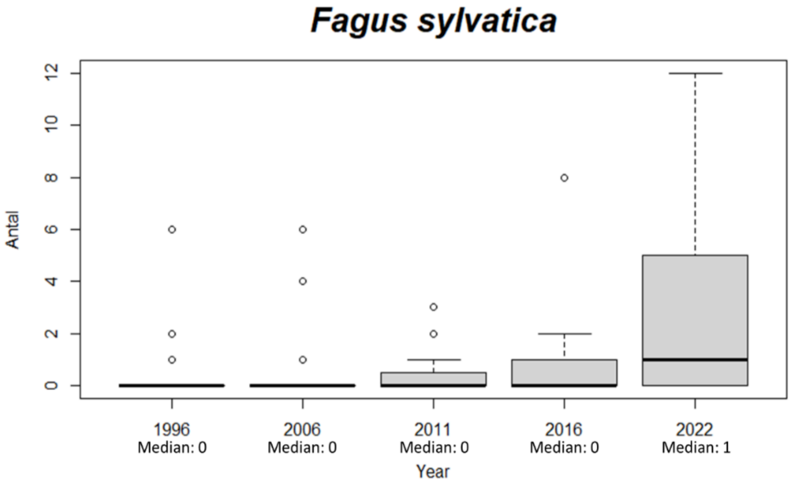

*Figure 3. Distribution of the number of beech < 5 cm diameter at breast height in all available plots. The Y-axis shows the number of trees, and the x-axis shows the years where the inventories took place.*

As expected, the results indicate that there has been no change in establishment of spruce (Fig. 1). The establishment of birch (Fig. 2) was not as high as expected, which could be due to the missing data from the areas with the highest potential for establishment of birch, since the disturbances made these plots inaccessible. Lastly, the results show that there has been an expansion of beech, which could indicate a regime shift from a spruce dominated forest to a beech dominated forest. It is, however, too early in the process to determine this.

## Reference

Törnqvist, A (2023). *Trädbeståndets utveckling i en naturskog efter storm och barkborreangrepp.* (Bachelor thesis) Swedish University of Agricultural Sciences. Department of Aquatic Sciences and Assessment/Biology and environmental science programme.

# IM ground vegetation indices over two decades

Ulf Grandin[1]

[1] *Swedish University of Agricultural Sciences (SLU), Department of Aquatic Sciences and Assessment, Box 7050, SE–750 07 Uppsala, Sweden*

## Introduction

At some ICP Integrated monitoring stations, the monitoring of ground vegetation has continued for more than 20 years. This provides an opportunity to investigate temporal trends that are more than annual or short-term fluctuations. However, vegetation generally shows a slow response to environmental changes as many species, especially in habitats where IM stations are located, are perennial. This is a shallow synoptic study utilising data reported to the ICP IM database, investigating whether there are any general trends in the vegetation communities at the IM sites when looking at the community as a whole. Given the changing levels of sulphur and nitrogen deposition over the last two decades (Forsius et al., 2021), a primary goal is to investigate if these changes are reflected in general plant diversity and in changes in community weighted Ellenberg indices for soil acidity (R). As the deposition of nitrogen shows a different temporal pattern than sulphur, the analyses also included Ellenberg index for soil nutrients (N). Finally, to see if there are any visible effects in the vegetation as a result of the warmer climate, Ellenberg index for temperature (T) was also included in the study.

## Methods

Data comes from the ICP Integrated Monitoring database, sub-programme VG. Monitoring sites with less than four years of data on species cover in the ground and field layers were excluded. In addition, data from Finland were also excluded as their vegetation monitoring covered only four years and ceased after 1998 when most other countries started their more long-term monitoring. Preliminary analyses showed that data from the Lithuanian sites LT01_100 and LT03_100 from 2015 deviated so much that also these were excluded from further analyses.

In accordance with the IM manual, each monitoring site within a monitoring station consists of a larger “intensive” monitoring plot, about 50 × 50 m. Within this plot cover for each species in the ground and field layers is assessed in smaller randomly placed replicates of about 50 × 50 cm. Size of both the larger plot and the smaller replicate plots vary slightly among countries. Also, the number of replicates vary.

For each of the smaller replicate plots in each year, Shannon diversity and cover-weighted mean Ellenberg values (Ellenberg et al., 1992) for soil acidity (R), soil nutrients (N) and temperature preference (T) were calculated, using the R packages “vegan” and “vegdata”. Temporal trends in these four variables were assessed by Mann Kendall tests, and significant trends are illustrated by linear regression lines in scatterplots.

## Results and discussion

There are only three countries that have reported detailed data on ground vegetation over the last two decades. Moreover, half of the monitoring sites fulfilling these criteria comes from Sweden, and the other from Norway and Lithuania. All of these sites have shown low to moderate exceedances of critical loads for both nitrogen and sulphur (Forsius et al., 2021). Given this biased selection, the results are probably not representative for the whole IM network. Among the sites that were selected, it was only the Swedish sites and one site from Lithuania that showed any significant temporal trends in diversity or in the included Ellenberg indices (Table 1, Figure 1).

Four out of six Swedish sites showed decreasing Ellenberg indices for soil acidity (R), indicating a more acidic situation. The Swedish site with no temporal trend for acidity is located on the west coast which received high amounts of sulphur during the acid rain era. The site that showed increasing Ellenberg R index is located in a pristine area in northern Sweden, with consistently low levels of all kinds of air pollution.

In Lithuania, one out of two monitoring sites at one IM station (LT01) showed temporal trends. This station is located in an area characterised by low levels of anthropogenic air pollution (Gulbinas & Samuila, 2002). At this site, the plant community indicated significant increases in Ellenberg indices for soil nutrients and temperature, and decreasing trends in diversity (Table 1, Figure 1). The other monitoring site at this station did not show any consistent temporal trends, even if there are clear variations among the different surveys of the site. The sites at other Lithuanian station (LT03) did not show any significant temporal trends.

***Table 1**. Direction of Theil-Sen's slope for significant (α = 0.05) Mann Kendall tests of temporal trends in field and ground layer vegetation at IM sites with vegetation monitoring over two decades.*

| IM Site | Ellenberg index | | | Shannon |
|---|---|---|---|---|
| | R | N | T | |
| LT01_100 | - | - | - | - |
| LT01_102 | - | ↑ | ↑ | ↓ |
| LT03_100 | - | - | - | - |
| NO01_1 | - | - | - | - |
| NO02_1 | - | - | - | - |
| SE04_2 | - | ↓ | - | ↑ |
| SE14_1 | ↓ | - | ↓ | ↑ |
| SE15_1 | ↓ | ↓ | - | ↑ |
| SE15_2 | ↓ | - | - | - |
| SE16_1 | ↑ | ↑ | - | - |
| SE16_2 | ↓ | - | - | - |

This study focussed on whole plant community responses over time. Bryophytes were not separated from vascular plants. Deeper studies should separate these species groups as bryophytes generally show a faster response to changes in deposition, than vascular plants (see e.g. Weldon et al., 2022). Moreover, a more thorough analysis should look at temporal trends for individual species. There can be both significant increases and decreases of individual species, that may be hidden when analysing the community as a whole (Jandt et al., 2011).

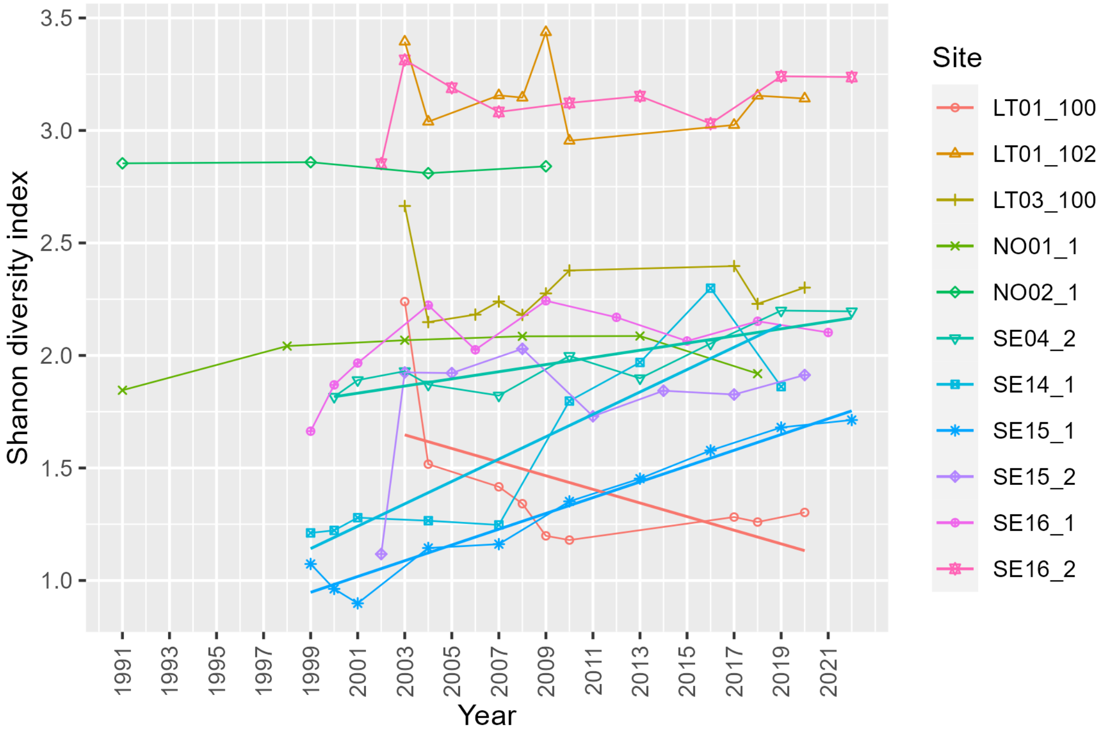

*Figure 1. Temporal patterns in Shannon diversity of ground vegetation at all IM monitoring sites with vegetation monitoring for at least two decades. Each point is the mean of all replicates within a site and year. Error bars not shown but are fairly constant within each site. Significant trends (Mann Kendall, p < 0.05) indicated by regression lines.*

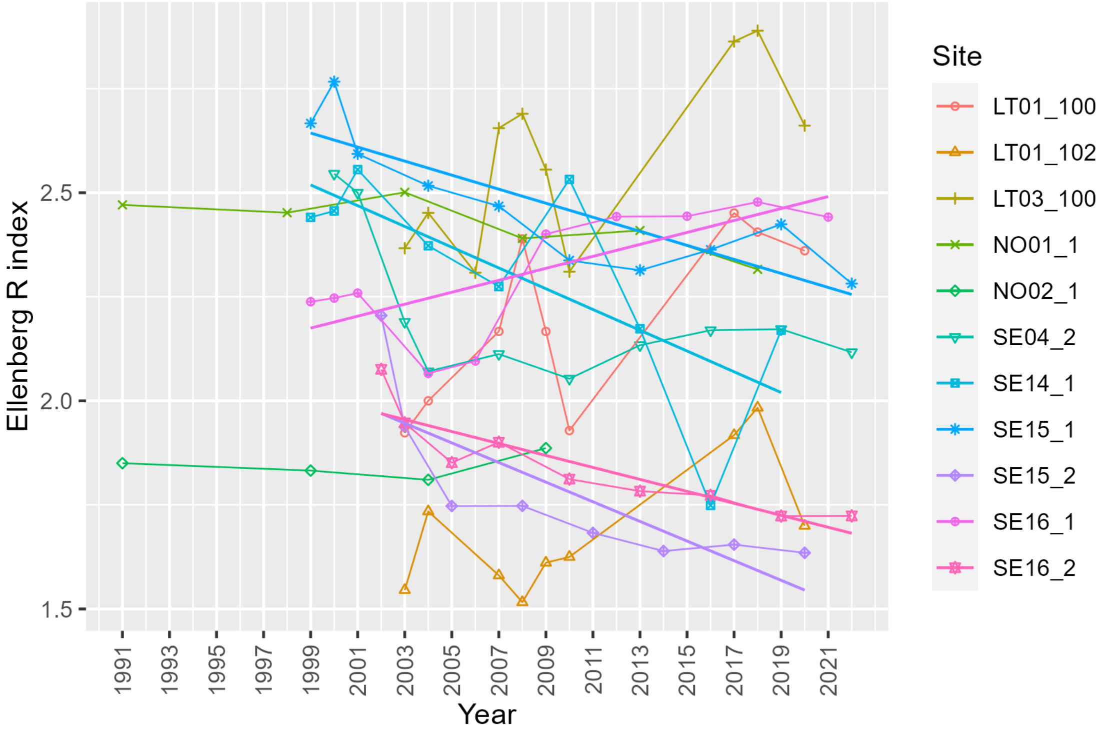

*Figure 2. Temporal patterns of Ellenberg index for soil acidity for ground vegetation at all IM monitoring sites with vegetation monitoring for at least two decades. Each point is the mean of all replicates within*

*a site and year. Error bars not shown but are fairly constant within each site. Significant trends (Mann Kendall, p < 0.05) indicated by regression lines.*

*Figure 3. Temporal patterns of Ellenberg index for nutrients for ground vegetation in all IM monitoring sites with vegetation monitoring for at least two decades. Each point is the mean of all replicates within a site and year. Error bars not shown but are fairly constant within each site. Significant trends (Mann Kendall, p < 0.05) indicated by regression lines.*

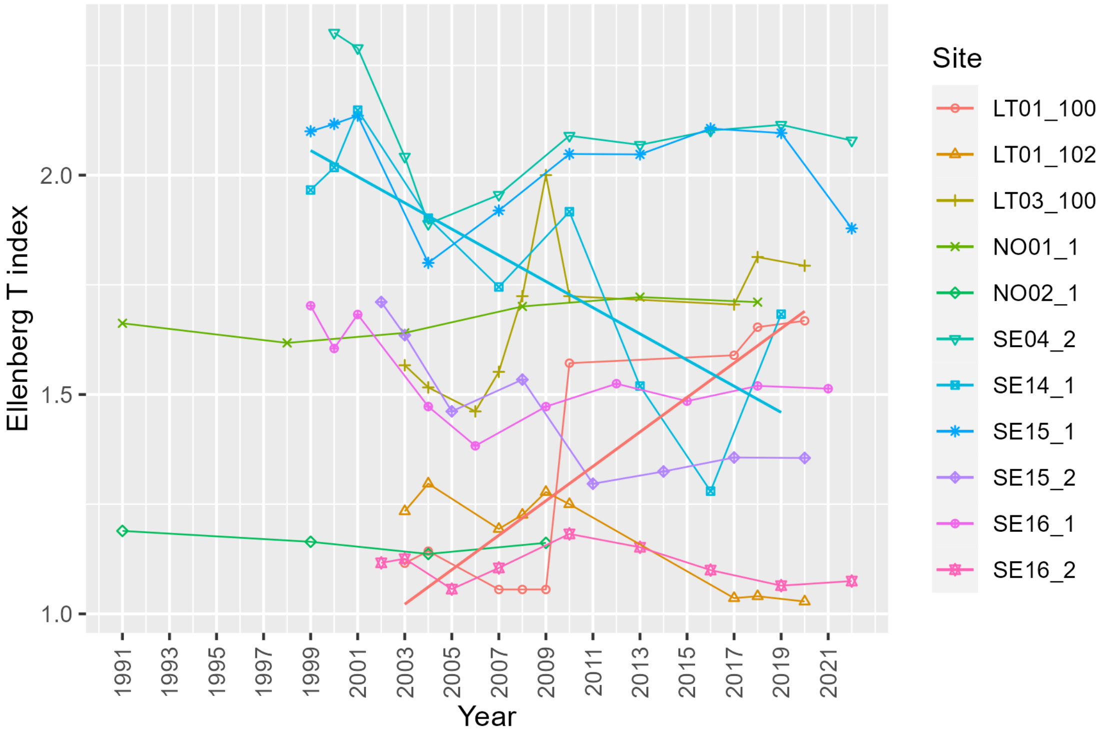

*Figure 4. Temporal patterns of Ellenberg index for temperature for ground vegetation in all IM monitoring sites with vegetation monitoring for at least two decades. Each point is the mean of all replicates within a site and year. Error bars not shown but are fairly constant within each site. Significant trends (Mann Kendall, $p < 0.05$) indicated by regression lines.*

## Conclusions

This synoptic summary of available vegetation data in the IM database showed that there is a bias in the vegetation monitoring, or at least the reporting. Countries are encouraged to initiate the "VG" sub-programme in the Integrated monitoring manual, with determination of cover of all species.

Due to the low number of sites with long term data on plant cover, it is hard to draw any general conclusions about general trends in the plant community at the IM sites.

## References

Ellenberg, H., Weber, H. E., Düll, R., Wirth, V., Werber, W., & Paulissen, D. (1992). Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, *18*.

Forsius, M., Posch, M., Holmberg, M., Vuorenmaa, J., Kleemola, S., Augustaitis, A., Beudert, B., Bochenek, W., Clarke, N., & de Wit, H. A. (2021). Assessing critical load exceedances and ecosystem impacts of anthropogenic nitrogen and sulphur deposition at unmanaged forested catchments in Europe. *Science of The Total Environment*, *753*, 141791.

Gulbinas, Z., & Samuila, M. (2002). Integrated monitoring in small, wooded catchments in Lithuania. *Geological Quarterly*, *46*(1), 81-97.

Jandt, U., von Wehrden, H., & Bruelheide, H. (2011). Exploring large vegetation databases to detect temporal trends in species occurrences. *Journal of Vegetation Science*, *22*(6), 957-972. https://doi.org/https://doi.org/10.1111/j.1654-1103.2011.01318.x

Weldon, J., Merder, J., Ferretti, M., & Grandin, U. (2022). Nitrogen deposition causes eutrophication in bryophyte communities in central and northern European forests. *Annals of forest science*, *79*(1), 24. https://doi.org/10.1186/s13595-022-01148-6

# Co-operation with eLTER

After many years of informal close co-operation between the eLTER (Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research) network and the WGE, a formal letter of co-operation was drafted, circulated, revised, and officially adopted at the Geneva meeting in September 2022. Approximately half of the ca 200 sites that will form the core of the eLTER Research Infrastructure are also part of one or more ICP Networks, so in many ways this was an obvious step to take. For more information see https://elter-ri.eu . The focus is on co-operation in the following areas:

1. Standardisation and harmonisation
2. Methodological development for both cost efficiency and data accuracy (eDNA, remote sensing, drones)
3. Scientific co-operation in data evaluation and analyses
4. Network development
5. Service Portfolio

One possibility came out of a gap identification exercise done on the eLTER network. The results are shown in the figure below and indicate four key geographic areas that are currently underrepresented. The participation of sites in the ICP networks located in these areas would be of great value and we would encourage them to consider joining the eLTER network.

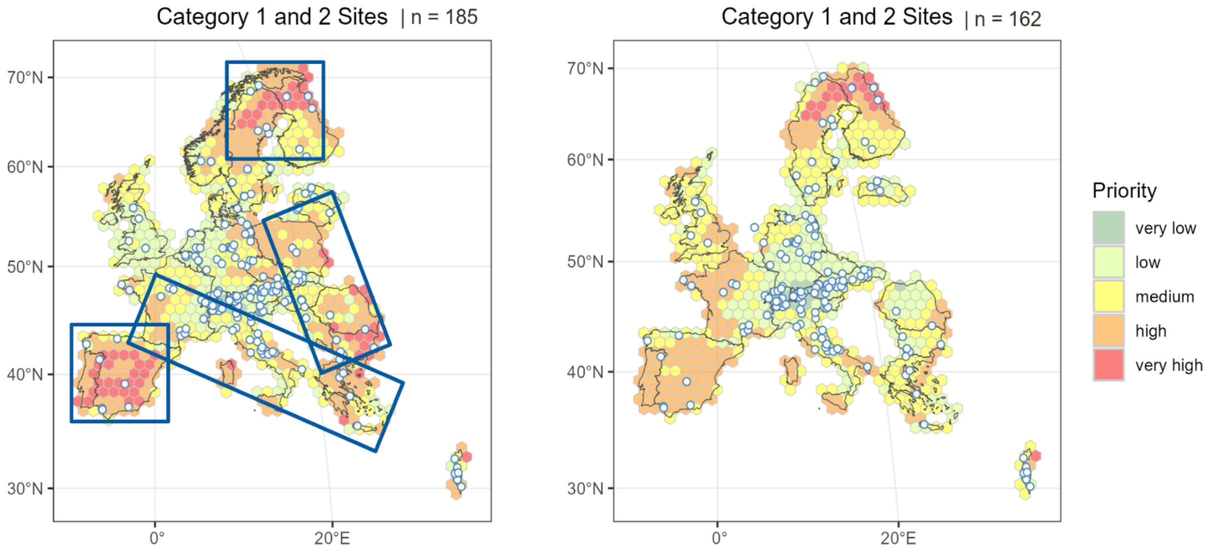

*Figure 5 : Gaps identified in the eLTER RI network coverage (left panel all likely participating countries, right panel only those currently confirmed), boxes indicate the four broad areas identified as having high priority (a high proportion of orange and red coloured areas) for adding further sites.*

An upcoming event that may be of interest is the eLTER Science Conference to be held in Tampere, Finland 23-27 June 2025 https://elter-ri.eu/science-conference

# New logo

After many years it is finally time to retire the old ICP IM logo and replace it with a fresh new one. We presented our proposal earlier this year and received useful feedback, which is now reflected in the final version as shown below. Please use it in your IM related publications!

**The old logo**

**The new logo**

# National activity reports

The following reports of national activities were received - many thanks to all those who contributed, and we look forward to a wider coverage of the network in the next issue, especially from those countries who have not sent an update for a while.

## Report on National ICP IM activities in Austria

Gisela Pröll, Johannes Kobler, Ika Djukic, Karl Knaebel, Sarah Venier & Thomas Dirnböck

*National Focal Point Austria Umweltbundesamt, Spittelauer Lände 5, 1090 Vienna, Austria*

The only ICP Integrated Monitoring station in Austria, Zöbelboden, was established in the year 1992 in the northern part of the National Park Kalkalpen at 550 to 956 m.a.s.l. Beside ICP IM, the site also hosts air pollution monitoring in the framework of EMEP and is part of the Austrian EU NEC directive sites network. Apart from reporting to the ICP Integrated Monitoring Programme, the data and metadata is publicly available at the DEIMS-SDR portal (https://deims.org/8eda49e9-1f4e-4f3e-b58e-e0bb25dc32a6). Since 2006, Zöbelboden is part of the Long-term Ecosystem Research Network (LTER Austria) and serves as a research station for several universities and research institutes within Austria and beyond. In the year 2023, besides running the standard ICP IM monitoring program, we pursued a number of research and monitoring activities: In a study by the Anton Bruckner Private University and the University of Salzburg, eco-acoustic measurements served as a tool for monitoring biodiversity and the human impact on soundscapes of the National Park Kalkalpen. Soil sampling for microplastics and PFAS analyses took place in cooperation with the provincial government of Upper Austria in 2022. Extreme weather events and soil greenhouse gas fluxes were investigated in the project EXAFOR funded by the Austrian Climate Research Programme (ACRP). Automated biodiversity monitoring continued in the framework of the global LifePlan project funded by the European Research Council (https://www2.helsinki.fi/en/projects/lifeplan). Within the EU Horizon2020 eLTER PLUS (2020-2026), we cooperated with the Soil Biodiversity Observation Network (SoilBON) to investigate the soil biodiversity at LTER Zöbelboden. The 5th inventory of epiphytic mosses was conducted to analyze abundance changes over 30 years.

Owing to its excellent instrumentation and long-term data, Zöbelboden was included in numerous national, European, and international research projects (e.g. FWF DICE, ÖAW C-Alps, ACRP CCN-Adapt, ACRP CentForCSink, ACRP WoodNClimate, EU Live+ EnvEurope, EU SEE Orientgate, EU ExpeER, EU eLTER, EU Horizon2020 EcoPotential, EU Horizon Benchmark). The diverse results were published in more than 70 scientific papers and several book contributions; they are continuously made available as TV, print and online media contributions. Currently, LTER Austria is pursuing an integration in the Europe-wide eLTER Research Infrastructure (https://elter-ri.eu/) in accordance with the Austrian strategy for research infrastructures.

*Acknowledgements*
Long-term monitoring at Zöbelboden is funded through the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology. The National Park Kalkalpen and the Federal State Forests provide technical support and co-funding.

# Report on National ICP IM activities in Estonia from 2022 to 2023 and trends in past 10 years

Lõhmus, K.[1].

[1]*Estonian Environmental Research Centre (EKUK), Marja 4d, 10617 Tallinn, Estonia, e-mail: kairi.lohmus@klab.ee*

## Introduction

The Estonian integrated monitoring programme is run on two sites (EE01 Vilsandi and EE02 Saarejärve). The monitoring programme was started in 1994, that will be 30 years in 2024. In Vilsandi the site has been managed by Estonian Environmental Research Centre (EKUK) since the beginning. In Saarejärve the site was managed by IM Saare from 1994 to 2015, in 2016 Estonian Environmental Research Centre took over.

Starting from 2019, the programme's intensity was changed. Site monitoring ended at the spruce area in Saarejärve, some subprogrammes were stopped all together. Currently the following programmes are conducted monthly with few exceptions: meteorology, air chemistry, precipitation chemistry, metal chemistry of mosses (in every 5 years), throughfall, stemflow, soil chemistry (in every 5 years), soil water chemistry, groundwater chemistry (in every 5 years only in EE02), runoff water chemistry (only in EE02), foliage chemistry, litterfall chemistry, vegetation (in every 5 years), trunk epiphytes (in every 5 years), microbial decomposition and toxicity assessment (in every 5 years only in EE02).

In 2016 the stream's weir's location was changed slightly in Saarejärve to get more accurate results. In October of 2021 the precipitation collector was moved to a more suitable place in Saarejärve. The old spot was overgrown with shrub and trees.

*Figure 6. A view to lake Saare at Saarejärve IM site.*

## Activities in 2022 and 2023

In 2022 besides yearly programme (meteorology, air chemistry, precipitation chemistry, throughfall, stemflow, soil water chemistry, runoff water chemistry at EE02, foliage chemistry, litterfall chemistry and microbial decomposition) vegetation at intensive plot at Saarejärve (EE02) was also done. There were few changes compared to last time which was in 2017 – some fallen trees and dry branches. Most dominant species in field layer are European blueberry (*Vaccinium myrtillus*) and cranberry (*Vaccinium vitis-idaea*). Glittering woodmoss (*Hylocomium splendens*) is most common in the bottom layer, but also species from genus *Dicranum*, red-stemmed feathermoss (*Pleurozium schreberi*), knights plume moss (*Ptilium crista-castrensis*), and big shaggy-moss (*Rhytidiadelphus triquetrus*) can be seen.

In 2023 only normal yearly programme was done. Some smaller maintenance work was conducted, and no major changes occurred.

## Major trends over the past ten years (2014-2023)

All the trends have been calculated with weighed yearly averages which take into account the amount of precipitation as well. In 2022 there was 555 mm of precipitation at Saarejärve (EE02) and 738 mm at Vilsandi (EE01). In 2023 Saarejärve had 583 mm of precipitation and Vilsandi had 772 mm. The long run average precipitation amount in Estonia is 661 mm. Since Vilsandi is on a small island at the west coast of Saaremaa (Estonia's biggest island), it is strongly affected by the Baltic Sea. Saarejärve on the other hand is inland only 24 kms away as the crow flies from Lake Peipus.

## Precipitation Chemistry (PC)

The concentrations of $NO_3$-N (from 0.16 mgN/l in 2014 to 0.12 mgN/l in 2023) have decreased over the past 10 years in precipitation at Saarejärve (EE02). The trends in $SO_4$-S concentrations still show decrease as well, but it is insignificant.

In Vilsandi (EE01) the trends show a decrease in the concentrations of total nitrogen (from 0.85 mg/l in 2014 to 0.53 mg/l in 2023) and Pb (from 0.31 µg/l in 2014 to 0.18 µg/l in 2023), however there has been an increase in the pH from 5.0 in 2014 to pH 5.2 in 2023 and in concentration of chlorides (1,1 mg/l in 2014 to 2,3 mg/l in 2023).

Figure 2 shows the change in the concentrations of nitrates in precipitation at EE02. According to Mann-Kendall analysis the significance level of this change was the highest for Saarejärve. Another significant change is shown on figure 3 that depicts the trends with pH, chloride, lead and total nitrogen concentrations at EE01.

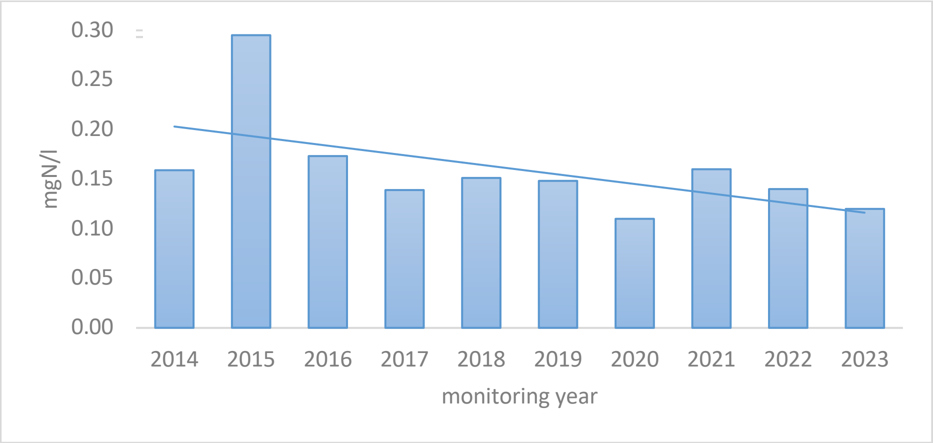

*Figure 7. The change in the concentrations of NO3-N (mgN/l) in precipitation at Saarejärve (EE02) from 2014 to 2023.*

*Figure 8. The change in pH and the concentrations of Cl, Pb and total nitrogen in precipitation at Vilsandi (EE01) from 2014 to 2023.*

## Throughfall (TF)

Over the past 10 years there have been a few major changes in throughfall (shown on figure 4). Like in precipitation, the concentration of nitrates has decreased in both Saarejärve (EE02) and Vilsandi (EE01) throughfall. At Saarejärve monitoring area there has also been a decrease in the concentrations of sulphates (0.58 mgS/l in 2014 to 0.21 mgS/l in 2023), calcium (from 1.6 mg/l to 0.85 mg/l), magnesium (from 0.35 mg/l to 0.19 mg/l), cadmium (from 0.05 µg/l in 2018 to 0.025 µg/l in 2023), copper (from 1.4 µg/l in 2018 to 0.72 µg/l in 2023), nickel (0.31 µg/l in 2018 to 0.17 µg/l in 2023) and conductivity (from 24 µS/cm to 17 µS7cm). As for Vilsandi there has been an increase in pH levels (pH 4.9 in 2014 to pH 5.2 in 2023) and decrease in the concentrations of magnesium (from 3.6 mg/l to 0.56 mg/l), potassium (from 4.0 mg/l to 2.3 mg/l), cadmium (from 0.1 µg/l to 0.058 µg/l), copper (from 4.3 µg/l to 1.1 µg/l), nickel (from 2.4 µg/l to 0.26 µg/l), lead (from 1.4 µg/l to 0.39 µg/l), total phosphorus (from 0.2 mg/l to 0.1 mg/l) and total nitrogen (from 2.3 mg/l to 1.3 mg/l).

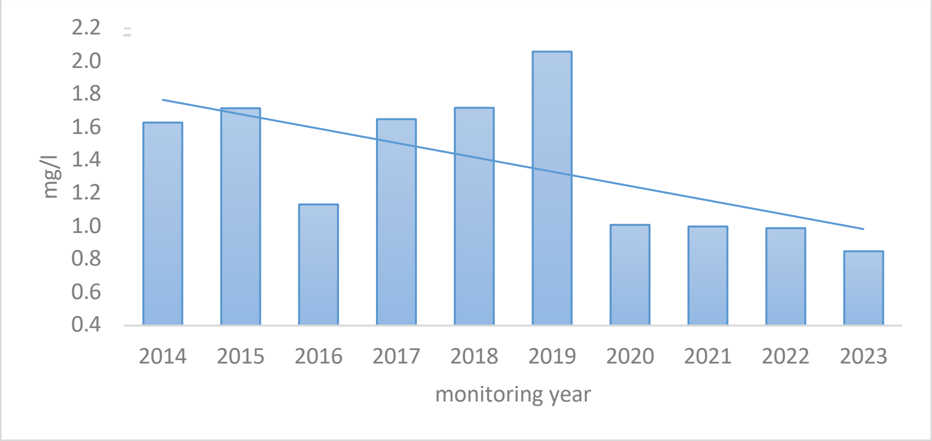

*Figure 9. Changes in calcium levels in throughfall at Saarejärve (EE02) from 2014 to 2023.*

## Stemflow (SF)

The trends in stemflow at Saarejärve (EE02) show significant increase with total nitrogen concentrations from 0.25 mg/l in 2014 up to 1.4 mg/l in 2023. In 2019 the total nitrogen was at its highest concentration of 1.5 mg/l. The changes of this trend are shown on figure 5.

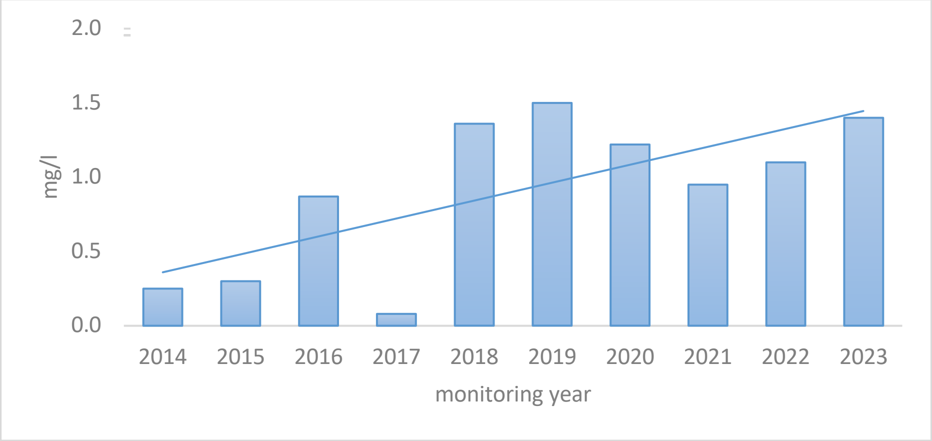

*Figure 10. The change in concentrations of total nitrogen (mg/l) at Saarejärve (EE02) stemflow from 2014 to 2023.*

Other trends were not as significant, however there has been a decrease in sulphates (from 1,3 mgS/l to 0.26 mgS/l), dissolved organic carbon (from 99 mg/l to 54 mg/l), lead (from 0.6 µg/l in 2018 to 0.4 µg/l in 2023) and copper (from 2.1 µg/l in 2018 to 1.6 µg/l in 2023) concentrations at EE02.

According to Mann-Kendall trend analysis concentrations in stemflow at Vilsandi (EE01) show decrease in sulphates from 2.4 mgS/l to 1.5 mgS/l, dissolved organic carbon from 131 mg/l to 74 mg/l and potassium from 9.1 mg/l to 9 mg/l with highs of 22 mg/l in 2017 over the past 10 years (2014-2023). There has also been a decrease in metal concentrations – nickel (from 5.5 µg/l to 0.81 µg/l) and significant decrease in aluminum concentrations (from 173 µg/l to 108 µg/l).

## Soil water chemistry (SF)

There have been few major trends in the soil water at both sites – Saarejärve (EE02) and Vilsandi (EE01). In the first depth level (10 cm) at EE02 the trends show decrease in $NH_4$-N and labile aluminum concentrations. In the second depth level (40 cm) at EE02 the soil water contains decreasing amounts of labile aluminum but increasing amounts of total phosphorus and $NH_4$-N. The changes in labile aluminum concentrations are shown on figure 6.

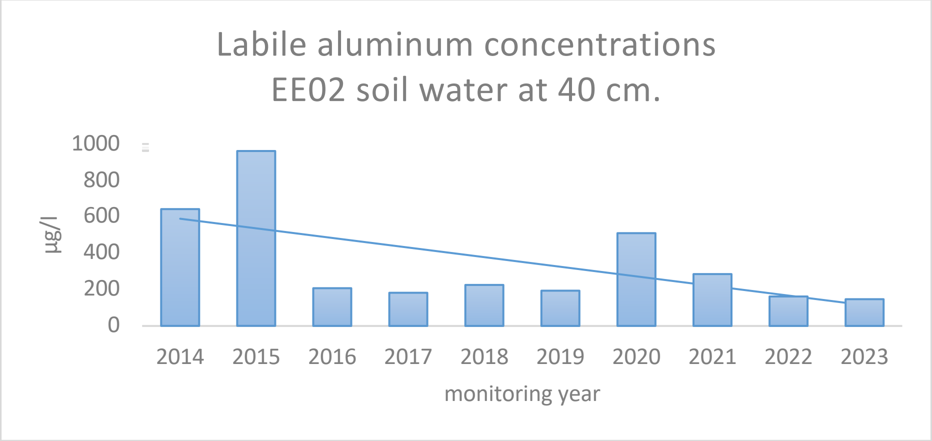

*Figure 11. Major trends in soil water at Saarejärve (EE02) from 2014 to 2023.*

At EE01 in the first depth level at 17 cm there has been a decrease in potassium concentrations and increase in calcium, magnesium and nickel concentrations and in conductivity. In the second depth level at 35 cm there has been an increase in magnesium and sodium levels and in conductivity. Some of these trends are depicted on figure 7.

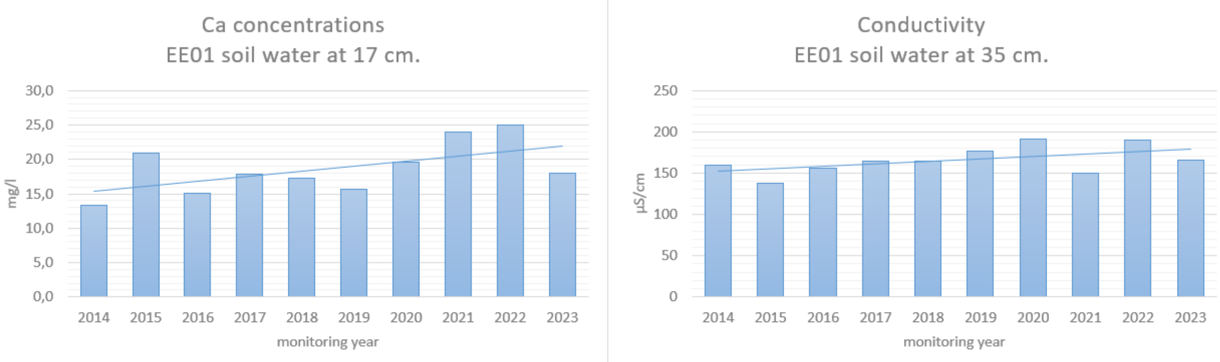

*Figure 12. Major trends in soil water at Vilsandi (EE01) from 2014 to 2023.*

## Runoff water chemistry (RW)

Samples for runoff chemistry are gathered only in Saarejärve (EE02) once a month. There have not been any major changes from 2016 to 2023. Earlier years have not been included in analysis due to the change in weir’s location and recalculations of the flow. Although potassium concentrations show a small decrease. Figure 8 shows the change in potassium levels.

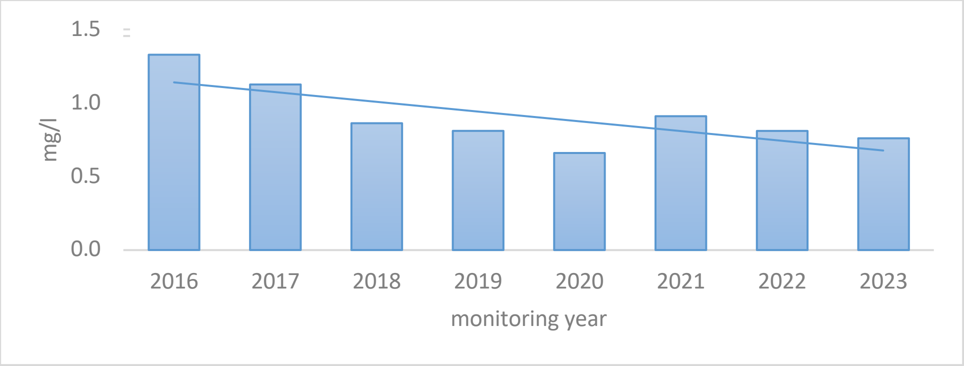

*Figure 13. The change in potassium levels at EE02 runoff from 2016 to 2023.*

## Conclusions

The concentrations of $SO_4$-S and $NO_3$-N show a steady decrease at both monitoring sites in Estonia. Usually, the waters contain higher concentrations of elements during the first half of the year and as well during dry periods at which the samples are more concentrated due to lower amount of precipitation.

# Current state of the network of Integrated Monitoring of the Natural Environment base stations in Poland

Andrzej Kostrzewski[1], Mikołaj Majewski[1]

[1] *Centre for Integrated Monitoring of the Natural Environment, Adam Mickiewicz University in Poznan, Poland*

The Integrated Monitoring of the Natural Environment (IMNE) is carried out as part of the nature monitoring subsystem of the State Environmental Monitoring in Poland coordinated by Chief Inspector for Environmental Protection (Kostrzewski et al. 1995). Currently, the IMNE programme is implemented on the basis of the Strategic State Environmental Monitoring Programme for 2020-2025. The purposes of the IMNE include providing the data on the state of representative Poland's geoecosystems, determining the mechanisms of their functioning and transformations at different spatial and temporal scales, determining the type and nature of environmental threats and their protection (Kostrzewski, Majewski 2018, 2021). There are 12 base stations in the IMNE network, 9 of which are part of the European ICP Integrated Monitoring network and 2 are in the process of being incorporated into the network.

The distribution of the IMNE base stations refers to the landscape structure of Poland, and the selected catchments are representative for individual geographical regions. The adopted assumptions for the distribution of the IMNE base stations in individual landscape zones allow the identification of transformations of the landscape structure of Poland in spatial and temporal scales.

In the Baltic Sea coastal zone the Wolin Station is located, in the young glacial zone of the Polish Lowlands there are 6 stations: Parsęta, Puszcza Borecka, Wigry, Pojezierze Chełmińskie, Poznań-Morasko. The first three of these catchments are slightly anthropogenically transformed, whereas the last two stations (Pojezierze Chełmińskie and Poznań-Morasko) are under strong anthropopressure (agricultural and urban, respectively). The old glacial landscape of central Poland is represented by the Kampinos Station. In turn, in the uplands and mountains zone there are 5 stations: Łysogóry, Roztocze, Pogórze Karpackie (outside the ICP IM network), Beskid Niski and Karkonosze. The distribution of base stations in Poland enables identification and determination of changes and variability in the functioning of monitored river and lake catchment geoecosystems on three meridional and three latitudinal transects.

Two new stations have been being added to the ICP IM network since 2023: Poznań-Morasko and Karkonosze. The geographical individuality of the studied catchment at the Poznań-Morasko station is its location within the boundaries of the Poznań agglomeration, which makes it possible to obtain data characterising the scale and dynamics of transformations of river catchments as a result of human activities. The natural environment of the catchment is characterised by significant transformations as a result of human activity. The most important environmental problems existing in the catchment area include the threat of surface and groundwater pollution due to disorderly water and sewage management. The Karkonosze station represents a mountain landscape. The catchment area contains a great variety of ecosystems, habitats and plant communities, characterised by an altitudinal zonation typical of mountainous areas. The lower forest zone is covered by forests with a habitat and species structure typical of the entire Sudety area. These include forest habitats such as acidic Sudeten beech and spruce-fir forest, which are currently being restored through the restoration of silver fir. Valuable meadow ecosystems are located here. The upper forest zone is overgrown by the Sudeten spruce forest, diversified with numerous slope transitional peat bogs. The catchment area combines mountain and boreal elements.

## References

Kostrzewski A., Majewski M. (red.), 2018: Stan i przemiany środowiska przyrodniczego geoekosystemów Polski w latach 1994-2015 w oparciu o realizację programu Zintegrowanego Monitoringu Środowiska Przyrodniczego, Główny Inspektorat Ochrony Środowiska, Biblioteka Monitoringu Środowiska, Warszawa.

Kostrzewski A., Majewski M. (red.), 2021: Zintegrowany Monitoring Środowiska Przyrodniczego. Organizacja, system pomiarowy, metody badań. Wytyczne do realizacji, Biblioteka Monitoringu Środowiska, Warszawa.

Kostrzewski A., Mazurek M., Stach A., 1995: Zintegrowany Monitoring Środowiska Przyrodniczego – Zasady organizacji, system pomiarowy, wybrane metody badań. Bibl. Monit. Środ., Warszawa.

## Report on National ICP IM activities in Sweden

Lundin, L.[1], Rönnback, P.[1], Bovin, K.[2], Eveborn, D[2]., Grandin, U.[1], Jutterström, S.[3], Kronnäs, V.[3], Pihl Karlsson, G.[3], Kurén Weldon, J.[1], Löfgren, S.[1], Moldan, F.[3], and Thunholm, B[2] 2024.

[1] *Swedish University of Agricultural Sciences (SLU), Department of Aquatic Sciences and Assessment, Box 7050, SE–750 07 Uppsala, Sweden, e-mail: pernilla.ronnback@slu.se*

[2] *Geological Survey of Sweden (SGU), Box 670, SE–751 28 Uppsala, Sweden.*

[3] *Swedish Environmental Research Institute (IVL), Box 47086, SE–402 58 Gothenburg, Sweden.*

*The programme is funded by the Swedish Environmental Protection Agency.*

### Introduction

The Swedish integrated monitoring programme is running on four sites distributed from south central Sweden (SE14 Aneboda), over the middle part (SE15 Kindla), to a northerly site (SE16 Gammtratten). The long-term monitoring site SE04 Gårdsjön F1 is complementary on the inland of the west coast and was influenced by long-term high deposition loads. The sites are well-defined catchments with mainly coniferous forest stands dominated by bilberry spruce forests on glacial till deposited above the highest coastline. Hence, there has been no water sorting of the soil material. Both climate and chemical deposition gradients coincide with the distribution of the sites from south to north (Table 1).

*Table 1. Geographic location and long-term climate and hydrology at the Swedish IM sites (long-term average values, 1:1961–1990 and 2: 1991-2020).*

| | SE04 | SE14 | SE15 | SE16 |
|---|---|---|---|---|
| Site name | Gårdsjön F1 | Aneboda | Kindla | Gammtratten |
| Latitude; Longitude | N 58° 03´;<br>E 12° 01´ | N 57° 05´;<br>E 14° 32´ | N 59° 45´;<br>E 14° 54´ | N 63° 51´;<br>E 18° 06´ |
| Altitude, m | 114–140 | 210–240 | 312–415 | 410–545 |
| Area, ha | 3.7 | 18.9 | 20.4 | 45 |
| Mean annual temperature (1), ºC<br>Mean annual temperature (2), ºC | +6.7<br>+7.2 | +5.8<br>+6.7 | +4.2<br>+5.3 | +1.2<br>+2.4 |
| Mean annual precipitation (1), mm<br>Mean annual precipitation (2), mm | 1000<br>1080 | 750<br>730 | 900<br>900 | 750<br>660 |
| Mean annual evapotranspiration, mm | 480 | 470 | 450 | 370 |
| Mean annual runoff, mm (1) | 520 | 280 | 450 | 380 |

The forest stands are mainly over 100 years old and at least three of them have about hundred years of natural continuity. Until the 1950's, the woodlands were lightly grazed in restricted areas. In early 2005, a heavy storm struck the IM site SE14 Aneboda. Compared with other forests in the region, however, this site managed rather well and roughly 20–30% of the trees in the area were storm-felled. In 1996, the total number of large woody debris in the form of logs was 317 in the surveyed plots, which decreased to 257 in 2001. In 2006, after the storm, the number of logs increased to 433, corresponding to 2711 logs in the whole catchment. In later years, 2007–2010, bark beetle (*Ips typographus*) infestation has almost totally erased the old spruce trees. In 2011, more than 80% of the trees with a diameter at breast height over 35 cm where dead (Löfgren et al. 2014) and currently almost all spruce trees with diameter of ≥20 cm are dead. Also, at SE04 Gårdsjön F1, considerable natural processes have influenced the forest stand conditions during later years, with increasing number of dead trees due to both storm felling and bark beetle infestation. Occasionally, access to the site is hampered due to fallen trees, creating a need for chain saw cleaning of footpaths. Also, in SE15 Kindla, an increasing number of fallen trees and logs exert perturbation, forming gaps in the forest.

In the following, presented results mainly relate to 2022 and include climate, hydrology and water chemistry as well as some ongoing work at the four Swedish IM sites (Weldon, 2023).

## Climate and Hydrology in 2022

### Air temperature

Based on long-term (1961-1990) mean values from the Swedish Meteorological and Hydrological Institute (SMHI), and measured data from climate monitoring at the IM sites, the 2022 annual mean temperatures were 0.9-2.0 °C higher for all four sites. Largest deviation occurred at the northern site SE16 Gammtratten. A new, 30 years long climate period (1991-2020) now exists with higher temperature values than 1961-1990 showing somewhat lower temperature deviations in 2022 with 0-0.7 °C as noticed from the previous period (Table 1). Compared with the on-site measured time series, 22 years at site SE16 Gammtratten and 26 years at the other sites, the temperatures in 2022 were higher at all sites with 0.5 °C at the two northern sites and 1.0-1.2 °C at the southern sites. The mean annual temperature was above zero degrees for all four sites, but all sites had mean monthly temperatures below zero in December. At the two northern sites, also the winter period showed degrees below zero.

Monthly average temperatures in the first month of the year were higher compared to long-term means of both reference periods (SMHI) at all stations. Larger deviations for the first period and smaller compared to the second period. December showed lower temperature at all stations and especially for the second period. In October-November higher temperatures were observed for all four stations while the rest of the months showed variations between lower and higher temperatures compared to both reference periods.

### Precipitation

Annual precipitation amounts in the two reference periods (SMHI) showed higher values for the second period and in 2022, precipitation was lower at all four sites with larger deviations when compared with the second period. Most months had lower precipitation while mainly February had higher values. The site SE16 Gammtratten had mainly small deviations except for October-November when larger deviations occurred, and this also noted for site SE14 Aneboda.

### Groundwater levels

High groundwater levels during winter and lower levels in summer and early autumn characterize the annual hydrological patterns of the southern catchments. At the northern locations, the general picture is low groundwater levels in winter when precipitation is stored as snow, raising levels at spring snowmelt followed by lower levels in summer due to evapotranspiration and groundwater outflow. However, depending on rainfall events in summer and/or autumn, the groundwater levels could occasionally be elevated also during these periods. Common are elevated levels in autumn. In 2022, only the site SE16 Gammtratten started the year on comparably low levels (2-3 m below ground surface) while all other sites had fairly high groundwater levels (0.2 m to c. 1 m). In SE16 Gammtratten, levels showed receding levels beginning of May (c. 3 m). From May to December, the levels were higher on c. 2 m. The site SE15 Kindla showed a more varying pattern throughout the year with levels mainly on 0.2-0.8 below ground surface and ending high in December.

### Discharge

Precipitation, evapotranspiration and groundwater levels affect the runoff patterns. The stream water discharge patterns (Fig. 1) reflect the groundwater levels. Generally, snow accumulates during winter at the two northern IM sites, resulting in low groundwater levels and low stream water discharge. However, warm winter periods with temperatures above 0 °C have during a number of years contributed to snowmelt and excess runoff also during this season. However, only the most northern site SE16 Gammtratten had low flows throughout the 2022 first months. At SE15 Kindla, runoff was low in January, but the flow started to increase already in February which didn't occur at the other sites with fairly low runoff in beginning of the year (Fig. 1).

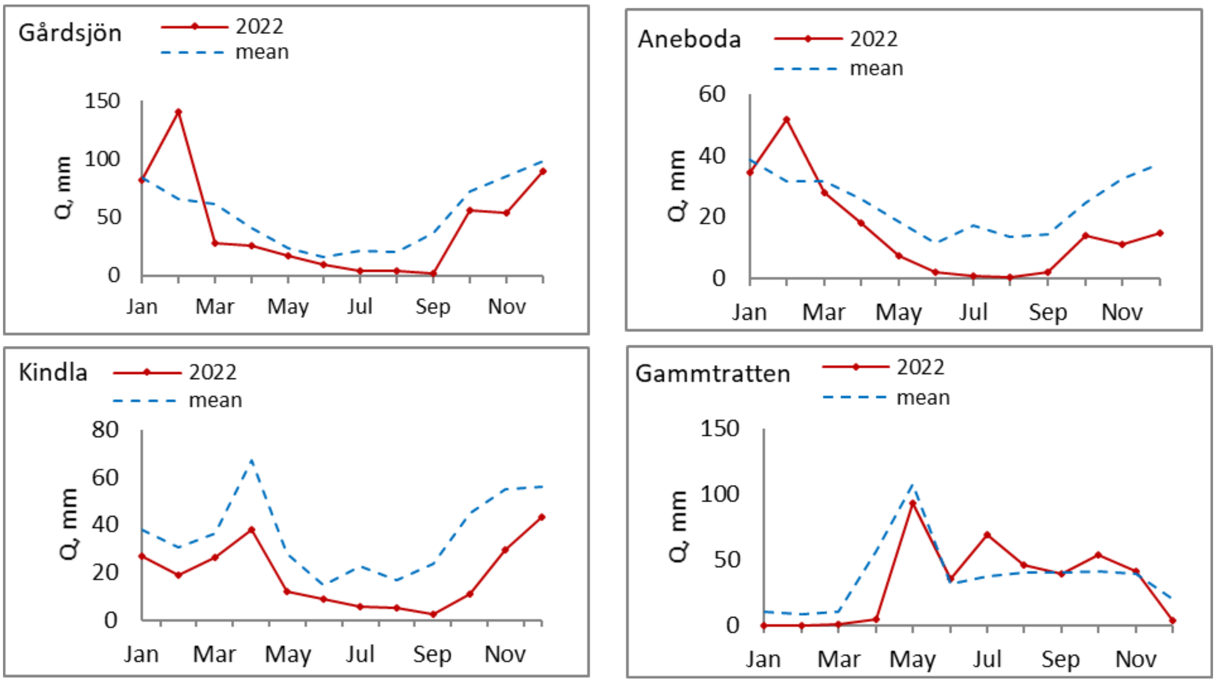

*Figure 1. Monthly discharges at the four Swedish IM sites in 2022 compared with the monthly averages for the period 1996–2022 (mean). Note the different scales at the Y-axis.*

At SE16 Gammtratten, this pattern was fairly typical with a slightly later snowmelt peak in May and low discharge also in April. There was a discharge peak in July not shown in the long-term mean. Later, in the end of the year, low temperatures caused snowfall and snow accumulation with low discharge in

December. At SE04 Gårdsjön 2022, the pattern mainly agreed with the long-term mean apart from the high discharge peak in February. However, March-November showed lower runoff compared with the long-term mean. Autumn discharge resembled the long-term mean, however somewhat low. The runoff at SE14 Aneboda in 2022 showed mainly similar pattern as the long-term mean but with lower discharge from March to December. There was also a deviating discharge peak in February. The lower runoff compared to long-term mean was partly also seen in 2021. (Fig. 1). At SE15 Kindla, the overall runoff throughout the year was lower compared to the long-term mean and quite low summer discharges. There was an ordinary discharge peak in April and increasing discharges in autumn, however lower compared to earlier. The common discharges peaks in summer and autumn were not seen.

The ordinary snowmelt peak in April 2022 agreed with the long-term mean but deviated from 2021 when the snowmelt peak was early in March. In 2022 the low summer runoff agreed with 2019 and 2020.

In 2022, the annual runoff made up 30–55% of the annual precipitation (Table 2), which is lower compared to the normal 40–60%, especially for SE14 Aneboda and SE15 Kindla where c. 50% would be normal. The other two sites were in normal range. The evapotranspiration was fairly normal but comparably low at SE14 Aneboda, probably due to the slightly poor forest cover due to bark beetle infestation. SE15 Kindla showed high evapotranspiration reflecting an unusually low runoff. Throughfall was high for all sites resulting in low interception indicating lower canopy closure, being a result from forest damage at SE14 Aneboda and most likely decreasing stands at SE04 Gårdsjön and SE15 Kindla. For SE16 Gammtratten the stands are more open providing larger possibility for throughfall.

Slightly deviating values concerned low precipitation at SE04 Gårdsjön resulting in somewhat low evapotranspiration. Also, SE14 Aneboda had fairly low precipitation and low runoff, anyhow resulting in low evapotranspiration. Throughfall was higher than bulk precipitation, which is out of range, but the poor forest stand conditions would contribute. SE15 Kindla had low precipitation and runoff which might be related to precipitation distribution over the months. SE16 Gammtratten showed reasonable distribution for the water balance.

*Table 2. Compilation of the 2022 water balances for the four Swedish IM sites.*

P – Precipitation, TF – Throughfall, I – Interception, R – Water runoff

| | Gårdsjön SE04 | | Aneboda SE14 | | Kindla SE15 | | Gammtratten SE16 | |
|---|---|---|---|---|---|---|---|---|
| | mm | % of P | mm | % of P | mm | % of P | mm | % of P |
| Bulk precipitation, P | 927 | 100 | 531 | 100 | 757 | 100 | 798 | 100 |
| Throughfall, TF | 742 | 80 | 546 | 103 | 580 | 77 | 633 | 79 |
| Interception, P–TF | 185 | 20 | -15 | -3 | 177 | 23 | 165 | 21 |
| Runoff, R | 512 | 55 | 184 | 35 | 228 | 30 | 387 | 48 |
| P–R | 415 | 45 | 347 | 65 | 529 | 70 | 411 | 52 |

## Water chemistry in 2022

Low ion concentrations in bulk deposition (electrolytical conductivity 0.7–2 mS m$^{-1}$) characterised all four Swedish IM sites. The concentrations of ions in throughfall that include dry deposition, were higher at the two southern sites. At the central and northern sites SE15 Kindla and SE16 Gammtratten, the conductivity in throughfall (c. 0.8 mS m$^{-1}$) was almost the same as in bulk deposition indicating very low sea salt deposition and uptake of ions by the trees. At the two southern sites, sea salt deposition provides tangibly higher ion concentrations, especially at the west coast SE04 Gårdsjön site, 4 mS m$^{-1}$ in throughfall and c. 2 mS m$^{-1}$ in bulk deposition. The groundwater pathways are short and shallow in the catchments, providing rapid soil solution flow paths from infiltration to surface water runoff. However, the conductivity in soil water was higher compared to throughfall showing influences from evapotranspiration and soil chemical processes.

The deposition acidity has during the last 10 years been rather similar at all sites with somewhat higher pH values at three sites (0.0–0.5 units) in throughfall compared with bulk deposition. SE16 Gammtratten had similar pH (c. 5.1) in both bulk deposition and throughfall. The sites SE04 Gårdsjön and SE14 Aneboda had 0.2 and 0.5 pH units, respectively higher pH in throughfall compared with in bulk deposition (Table 3).

*Table 3. Mean bulk deposition, pH throughfall and stream runoff values 2022 at the four Swedish IM sites. S and N in kg ha$^{-1}$ yr$^{-1}$.*

| | SE04 | SE14 | SE15 | SE16 |
|---|---|---|---|---|
| pH, bulk deposition | 5.1 | 5.0 | 5.2 | 5.1 |
| pH, throughfall | 5.3 | 5.5 | 5.5 | 5.1 |
| pH, streamwater | 4.5 | 4.6 | 4.8 | 5.6 |
| S, bulk deposition | 2.2 | 1.3 | 1.1 | 0.8 |
| S, runoff | 5,0 | 5,9 | 2,1 | 1,3 |
| N, bulk deposition | 5.9 | 3.8 | 3.2 | 2.4 |
| N, runoff | 2.2 | 0.7 | 0.5 | 0.9 |

The share of major anions in bulk deposition was similar for sulphate, chloride and nitrate at three of the sites, while chloride dominated at SE04 Gårdsjön due to the proximity to the sea. Sea salt showed clear influences on throughfall at SE04 Gårdsjön and at SE14 Aneboda indicating effects of dry deposition. In throughfall, organic anions contributed significantly at all four sites. The chemical composition changed along the flow paths through the catchment soils and e.g. the sulphate concentrations were higher in stream water compared with deposition, indicating desorption or mineralization of previously accumulated sulphur in the soils. At SE16 Gammtratten and SE15 Kindla runoff of chloride and sulphate were on similar levels. At SE04 Gårdsjön chloride dominated while, sulphur showed a higher value at SE14 Aneboda.

Nitrogen runoff was lower compared to input by bulk deposition indicating storage of N in the catchments. Highest input was found in SE04 Gårdsjön and lowest in SE16 Gammtratten (Table 3). Share of retained N varied from 63-84% with low values in SE04 Gårdsjön and SE16 Gammtratten but the two other sites had values somewhat above 80%.

Organic-N was the dominating nitrogen fraction in all stream waters, ranging from 0.09 to 1.5 kg $N_{org}$ $ha^{-1}$, $yr^{-1}$ Inorganic N runoff was low (≤0.7 kg $N_{inorg}$ $ha^{-1}$, $yr^{-1}$) at the sites. The higher inorganic flow at SE04 Gårdsjön and SE14 Aneboda were likely depended on deteriorated forest stands. SE15 Kindla and SE16 Gammtratten showed low flows.

In summary, the four Swedish IM sites show low ion concentrations and permanently acidic conditions in the aqueous media. In stream water, only the northern site SE16 Gammtratten had buffering capacity related to bicarbonate alkalinity. Organic matter has an impact on the water quality with respect to colour, metal complexation, and nutrient concentrations at all sites, but less at SE15 Kindla, where rapid soil water flow paths provide relatively low DOC concentrations but acidic waters. At SE14 Aneboda, the forest dieback provides a relatively high share of runoff as well as high nitrate concentrations compared with the other three sites. However, mainly low concentrations existed of inorganic nutrients ammonia, nitrate and phosphate. At SE04 Gårdsjön, deposition is strongly influenced by input from the sea.

## References

Löfgren, S., Grandin, U. and Stendera, S. 2014. Long-term effects on nitrogen and benthic fauna of extreme weather events: Examples from two Swedish headwater streams. Ambio 43, 58-76. Doi; 10.1007/s13280-014-0562-3

Weldon, J. (ed.) 2023. Integrerad övervakning av miljötillståndet i svensk skogsmark – IM. Årsrapport 2020. Integrated monitoring of environmental status in Swedish forest ecosystems – IM. Annual Report for 2022. Rapport 2023:12. SLU. Uppsala. p29 and p23 appendix. (In Swedish with English summary)