Forest Condition in Europe

The 2023 Assessment

ICP Forests Technical Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention)

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United Nations Economic Commission for Europe (UNECE)
Convention on Long-range Transboundary Air Pollution (Air Convention)
International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)

http://icp-forests.net

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Cover photo by Marco Natkhin | Thünen Institute of Forest Ecosystems

Recommended citation

Michel A, Kirchner T, Prescher A-K, Schwärzel K, editors (2023) Forest Condition in Europe: The 2023 Assessment. ICP Forests Technical Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention). Eberswalde: Thünen Institute. https://doi.org/10.3220/ICPTR1697801881000

ISSN 1020-3729 (print) ISSN 2702-5411 (online)
ISBN 978-3-86576-263-4 DOI 10.3220/ICPTR1697801881000

5 ATMOSPHERIC DEPOSITION IN EUROPEAN FORESTS IN 2021

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Introduction

The atmosphere contains a large number of substances of natural and anthropogenic origin. A large part of them can settle, be adsorbed to receptor surfaces, or be included in rain and snow and finally reach land surface as wet and dry deposition.

In the last century, human activities led to a dramatic increase in the deposition of nitrogen and sulphur compounds.

Sulphur deposition almost completely occurs in the form of sulphate (SO_4^{2-}), derived from marine aerosol and from sulphuric acid formed in the atmosphere by the interaction of gaseous sulphur dioxide (SO_2) with water.

SO_2 emissions derive mainly from coal combustion and also from vehicle fuel combustion, volcanoes, forest fires, and other sources, and have increased since the 1850s, causing an increase in sulphate deposition and deposition acidity, which can be partly buffered by the deposition of base cations, mainly calcium (Ca^{2+}) and magnesium (Mg^{2+}).

Natural sources of nitrogen (N) in the atmosphere are mainly restricted to the emission of N_2O and N_2 during denitrification and the conversion of molecular nitrogen gas (N_2) into NO_x during lightning. However, human activities cause high emissions of nitrogen oxides (NO_x) during combustion processes, and of ammonia (NH_3) deriving from agriculture and farming. They are found in atmospheric deposition in the form of nitrate (NO_3^-) and ammonium (NH_4^+).

Nitrogen compounds have significant effects on the ecosystem: they are important plant nutrients that - when in excess - may lead to ecosystem eutrophication, and they strongly influence plant metabolism (e.g., Silva et al. 2015), forest ecosystem processes (e.g. Meunier et al. 2016), and biodiversity (e.g., Bobbink et al. 2010). They can also act as acidifying compounds (Bobbink and Hettelingh 2011).

Emission and deposition of sulphur and to a lesser extent nitrogen have decreased in the last decades (Waldner et al. 2014, EEA 2016, Rogora et al. 2022)

Materials and methods

Atmospheric deposition is collected on the ICP Forests intensive monitoring plots under the tree canopy (throughfall samplers, Fig. 5-1, left) and with open-field samplers (Fig. 5-1, right) in a nearby clearance. Throughfall samples are used to estimate wet deposition, i.e. the amount of pollutants carried in by rain and snow, but they also include dry deposition from particulate matter and gases collected by the canopy. The total deposition to a forest, however, also includes nitrogen taken up by leaves and organic nitrogen compounds. It can be estimated by applying canopy exchange models.

It is important to note the different behaviour of individual ions when they interact with the canopy: in the case of sodium, chloride and sulphate, the interaction is almost negligible and it can be assumed that throughfall deposition includes the sum of wet and dry deposition. This is not the case for other ions, such as ammonium: tree canopies and their associated microbial communities strongly interact with them. For example, tree leaves can take up ammonium ions and release potassium ions and organic compounds, affecting the composition of throughfall deposition.

Sampling, analysis and quality control procedures are harmonized on the basis of the ICP Forests Manual (Clarke et al. 2022).

Quality control and assurance include laboratory ring-tests, the use of control charts, and performing conductivity and ion balance checks on all samples (König et al. 2010). In calculating the ion balance, the charge of organic compounds was considered proportional to the dissolved organic carbon (DOC) content following Mosello et al. (2005, 2008).

In this report, we present the results of the 2021 annual throughfall deposition sampling from 287 permanent plots, collected following the ICP Forests Manual. Sixteen plots were excluded because the duration of sampling covered less than 90% (329 days) of the year, and 106 other plots were marked as "not validated" because the conductivity check was passed for less than 30% of the analysis of the year, or the laboratory did not participate in the mandatory Working Ring Test, or did not pass the minimum requirement of the test. For further 4 sites, data for one specific variable (ammonium) were rejected because the laboratory did not pass the test for that variable.

As the deposition of marine aerosol represents an important contribution to the total deposition of sulphate, calcium and magnesium, a sea-salt correction was applied, subtracting from the deposition fluxes the marine contribution, calculated as a fraction of the chloride deposition according to the ICP Integrated Monitoring Manual (FEI 2013).

The color classes on the presented maps (low, medium, high) have been chosen to visualize the spatial distribution of deposition rates across Europe and do not necessarily correspond to the ecological impact of the deposition.

Results

The uneven distribution of emission sources and receptors and the complex orography of parts of Europe results in a marked spatial variability of atmospheric deposition. However, on a broader scale, regional patterns in deposition arise. As in the previous years, high values of nitrate deposition in 2021 were mainly found in Germany, Denmark, the most southern part of Sweden, Poland, and Lithuania. The number of plots with high ammonium deposition was, however, larger than for nitrate, particularly in Belgium, Germany, Switzerland, Austria, northern Italy, Slovenia, eastern England and the most southern part of Sweden (Figs. 5-2, 5-3).

It is generally assumed that negative effects of nitrogen deposition on forests become evident when the total deposition of inorganic nitrogen (i.e. the sum of nitrate and ammonium deposition) exceeds a specific threshold, known as the critical load. Critical loads can be evaluated for each site by modeling, but more generic critical loads (empirical critical loads) are also being evaluated, ranging between 3 and 17 kg N ha^{-1} yr^{-1} depending on the type of forest and ecosystem compartment (Bobbink et al. 2022). In 2021, throughfall inorganic nitrogen deposition higher than 10 kg ha^{-1} yr^{-1} was mainly measured in most of central Europe, including Germany, Poland, Austria, Switzerland, Slovenia, Croatia, but also in Belgium, Denmark, northern Italy and other countries (Fig. 5-4). Throughfall inorganic nitrogen deposition higher than 20 kg ha^{-1} yr^{-1} was recorded in Belgium, Germany, southern Sweden, and Austria. Because total nitrogen deposition on forests is higher than throughfall nitrogen deposition (Braun et al. 2022), the critical loads for nitrogen are likely still exceeded in large parts of Europe.

Sulphate deposition has very much decreased since the start of the monitoring and currently the highest throughfall deposition is still found close to large point sources. In the southern part of Europe, sulphate deposition is also influenced by volcanic emission and by the episodic deposition of Saharan dust. In 2021, throughfall deposition of sulphate (corrected for the marine contribution) higher than 3 kg S ha^{-1} yr^{-1} was found on a small number of sites in Croatia, Serbia, Bulgaria, Germany, Poland, Czechia, Slovakia, and Austria, and at a site in southern Italy influenced by volcanic emission (Fig. 5-5). Throughfall sulphate deposition higher than 6 kg ha^{-1} yr^{-1} was recorded in Croatia, Serbia, Bulgaria and near the borders of Czechia with Germany and Poland.

Calcium and magnesium are also analyzed in the ICP Forests deposition monitoring network, as their deposition can buffer the acidifying effect of atmospheric deposition, protecting soil from acidification. High values of (sea-salt corrected) calcium throughfall deposition were mostly found in a large area in central, eastern and southern Europe, mainly related to the deposition of Saharan dust (Fig. 5-6). High magnesium deposition was found primarily in southeastern Europe (Fig. 5-7).

Figure 5-1: Throughfall samplers on a Level II plot (left) and open-field samplers on a neighboring meadow (right) in Schorfheide, Germany (Images: Berit Michler)

Conclusions

Sulphate throughfall deposition has very much decreased since the start of the monitoring and currently high sulphate deposition is restricted to areas close to large point sources, mainly in eastern and southern Europe. High throughfall deposition of inorganic nitrogen is still observed throughout central Europe, with high ammonium depositions being found in a wider area than high nitrate deposition.

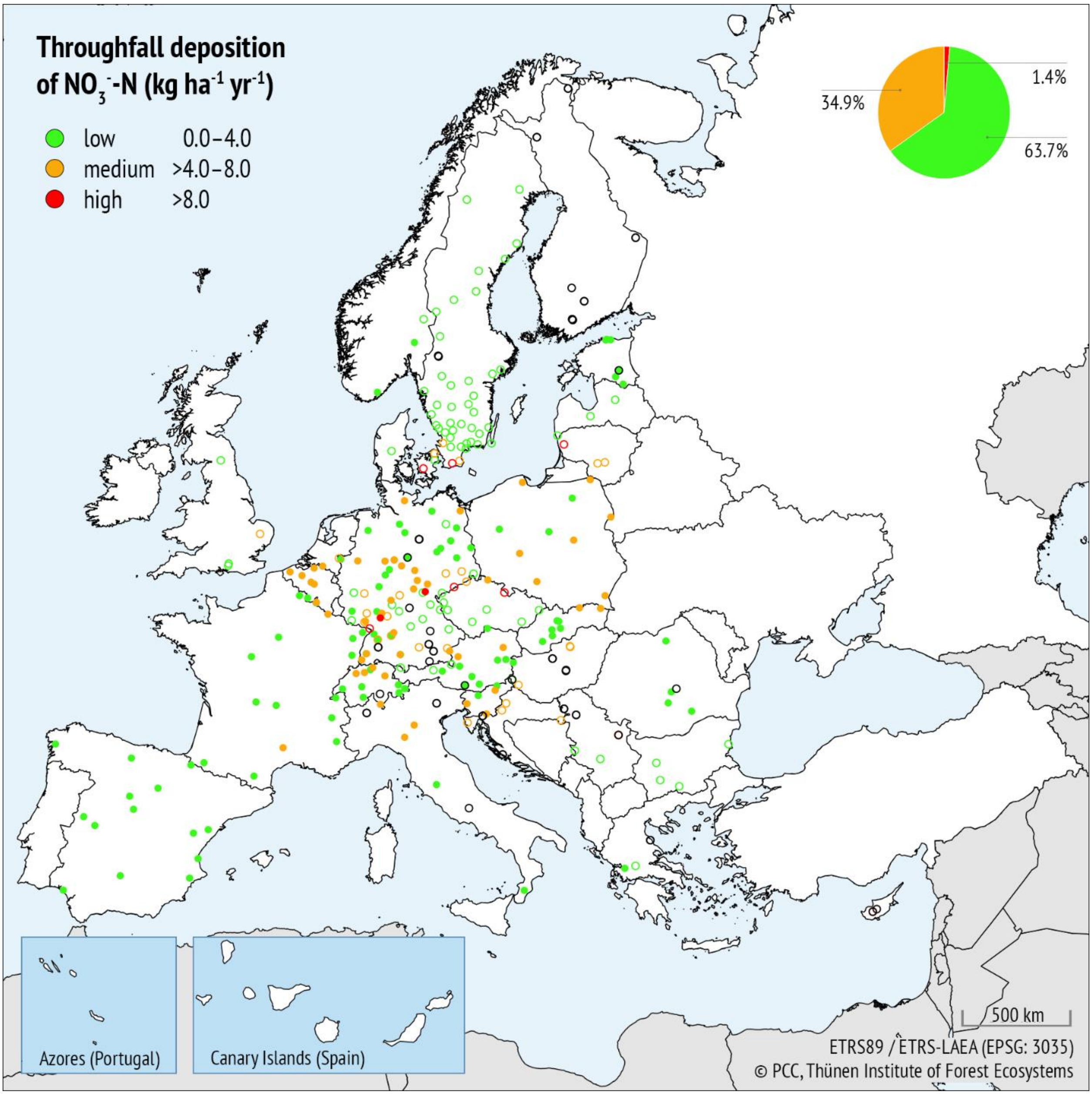

Figure 5-2: Throughfall deposition of nitrate-nitrogen (kg NO_3^--N ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

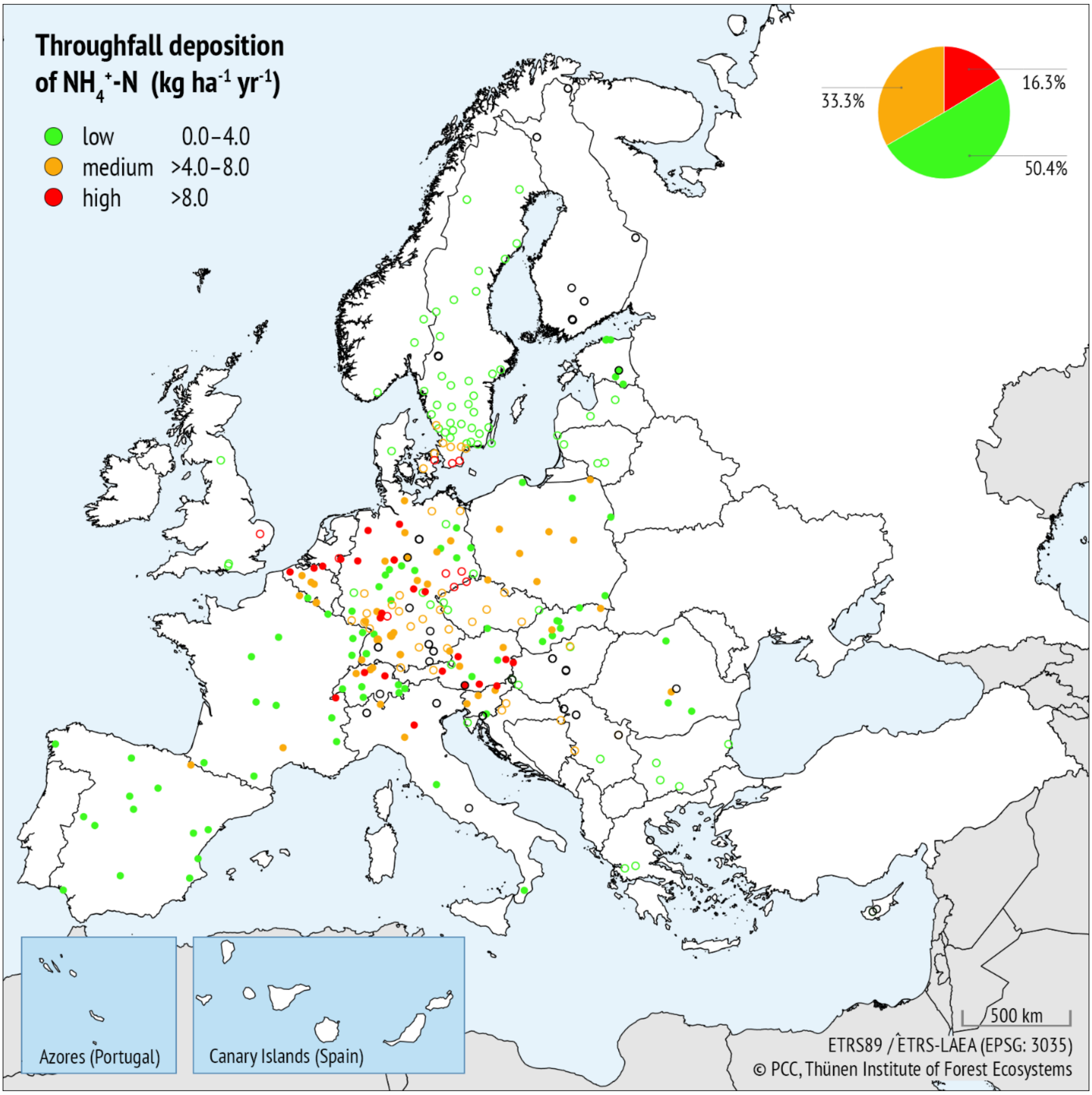

Figure 5-3: Throughfall deposition of ammonium-nitrogen (kg NH_4^+-N ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

EVALUATIONS

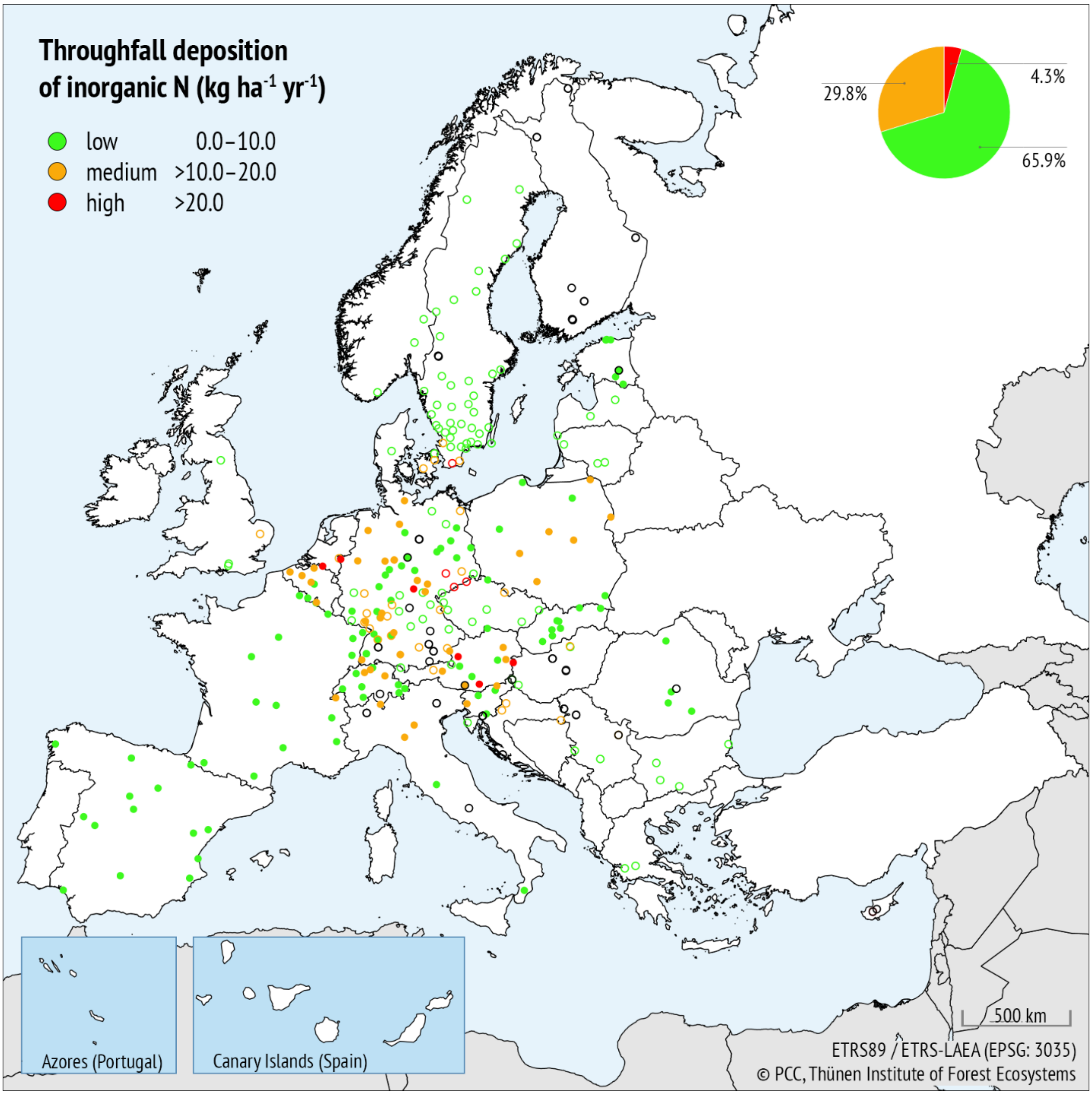

Figure 5-4: Throughfall deposition of inorganic nitrogen (kg NO_3^--N + NH_4^+-N ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

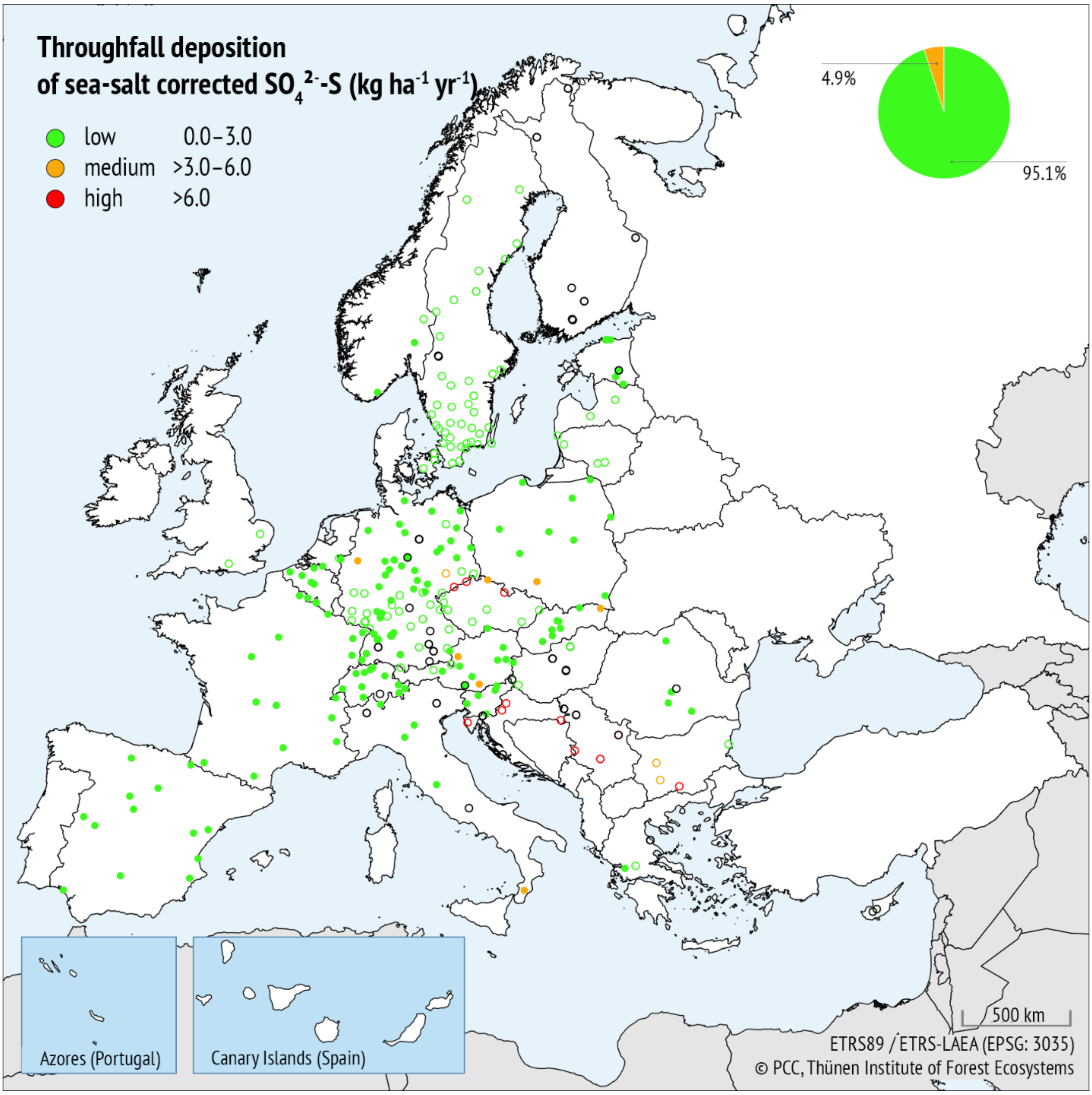

Figure 5-5: Throughfall deposition of sea-salt corrected sulphate-sulphur (kg SO_4^{2-}-S ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

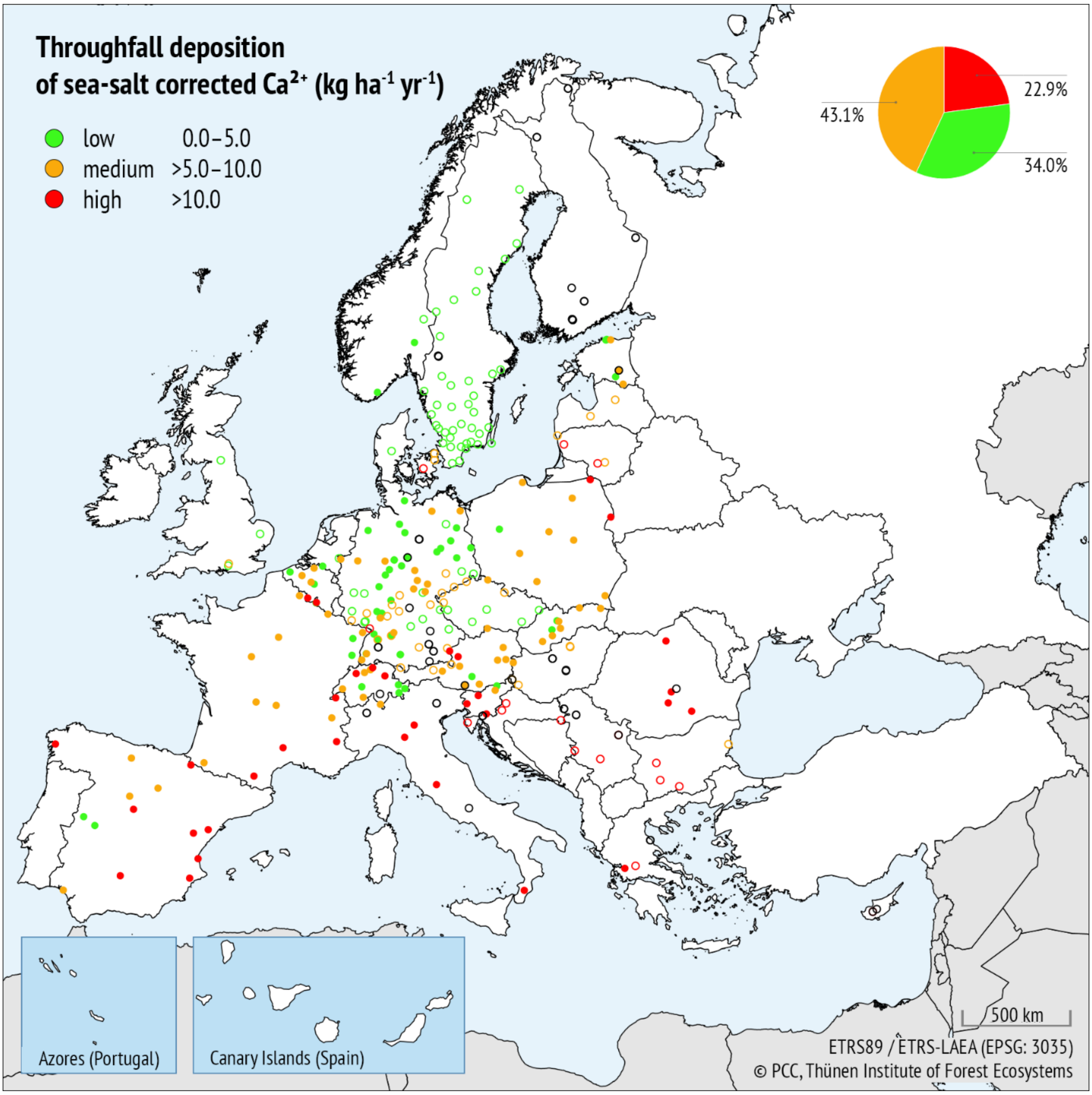

Figure 5-6: Throughfall deposition of sea-salt corrected calcium (kg Ca^{2+} ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

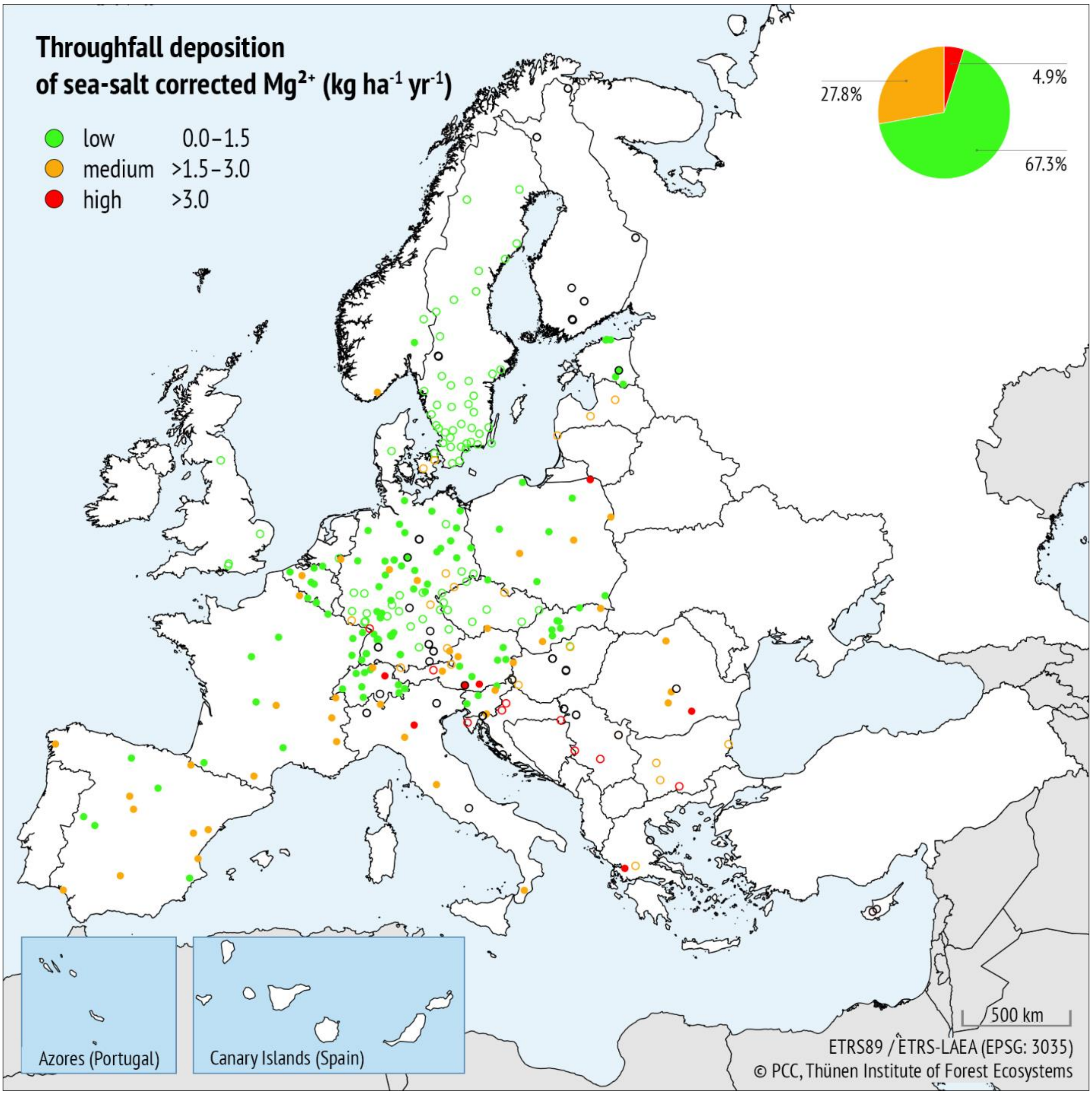

Figure 5-7: Throughfall deposition of sea-salt corrected magnesium (kg Mg^{2+} ha^{-1} yr^{-1}) measured in 2021 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

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