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Working Group on Effects

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Progress in activities and workplan for 2024–2025 of effects-oriented activities: Air pollution effects on materials, the environment and crops: Air pollution effects on forests

Effects of air pollution on forests

Progress report by the Programme Coordinating Centre of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

Summary

The present report by the Programme Coordinating Centre of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) describes the outcomes of activities carried out since the previous report (ECE/EB.AIR/GE.1/2023/INF.7–ECE/EB.AIR/WG.1/2023/INF.7) and presents the outcomes of the fortieth meeting of the ICP Forests Task Force (which took place from June 13 to 14, 2024 in Prague/Czech Republic). The activities were carried out and the report prepared in accordance with the 2024–2025 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/154/Add.1) and in accordance with the revised mandate for the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Executive Body decision 2019/16).[1]

Forests are increasingly threatened by climate change-related factors, and the knowledge and understanding of forest dynamics is necessary to identify management solutions for forest resilience while maintaining biodiversity and provision of ecosystem services. Continued monitoring is essential to document progress to reduce air pollution impacts on forests, an important factor affecting the health and sustainability of forest ecosystems around the world, especially under the concurrent pressure exerted by annual meteorological fluctuations and long-term climate change. The data generated by the

[1] Available at www.unece.org/env/lrtap/executivebody/eb_decision.html.

monitoring networks installed under ICP Forests demonstrates its high relevance at scientific and political levels. The ecosystem-oriented approach includes the main biotic and abiotic stressors that may impact our forests, and therefore enables identification of the role of air pollution. Yet, it is important to contextualize ICP Forests results within the larger picture offered by studies originating from other research and monitoring initiatives.

Climate change is dramatically affecting our forests, together with lasting effects of air pollution and acidification. On one side, there are reports of widespread increased tree mortality and reduced growth, although with some regional differences. On the other side, the complex dynamics of air pollution across forest ecosystems, and the complexity of related measurements, have been pointed out. Canopy processes, phenology, and leaf traits can have an important role for the measured deposition levels, e.g., on N-related species and other nutrients, and on the onset of ozone visible symptoms. Despite some stagnation of the temporal trend in ozone concentration, ozone is still causing visible symptoms on a variety of broadleaved species. Forest health and growth were extensively affected, mostly by climate-change related factors but also in combination with atmospheric deposition of N and foliar nutrition, although with yet unclear patterns. In parts of Europe, soil has not yet recovered from previous high acidification loads. Soil type and tree species have been confirmed as strong drivers of soil carbon stocks across Europe, and dynamics observed in soil carbon differed between topsoil and subsoil. In addition, soil microbiota is emerging more and more as an important driver of forest growth – and likely of forest health.

As in the previous years, high throughfall deposition of nitrate and ammonium in 2022 was mainly found in central Europe, but single plots with high deposition values were also reported from other parts of Europe. The number of plots with high ammonium deposition was, however, larger than for nitrate. Sulphate deposition has decreased very much since the start of the monitoring and currently the highest throughfall deposition is still found close to large point sources, mainly in eastern and southern Europe.

In 2023, the overall mean defoliation for all species was 24.0%. There was a very slight increase of 0.1 percentage points (%p) in mean defoliation as compared to 2022, mainly due to an increase of 0.3%p for conifers, while defoliation of broadleaves remained unchanged. The strongest increase in defoliation occurred in deciduous temperate oaks (+1.7%p) and in Mediterranean lowland pines (+1.3%p), while the strongest decrease was recorded in evergreen oaks (-0.8%p) and common beech (0.5%p).

I. Introduction

1. The present report of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) is submitted for consideration by the Working Group on Effects in accordance with the 2024-2025 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/148/Add.1) and in accordance with the revised mandate for the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Executive Body decision 2019/16).

2. Germany is the lead country of ICP Forests, the Programme Coordinating Centre of which is hosted by the Johann Heinrich von Thünen Institute (Federal Research Institute for Rural Areas, Forestry and Fisheries) under the Federal Ministry of Food and Agriculture. Since 2017, the Chairman of the ICP Forests' Task Force is hosted by the Swiss Federal Institute for Forest Snow and Landscape Research (WSL). A total of 42 Parties to the Convention participate in ICP Forests activities.

3. Both meetings, the 11th ICP Forests Scientific Conference FORECOMON and the 40th ICP Forests Task Force Meeting were held in Prague/Czech Republic, 11–14 June 2024, with 79 participants from 28 countries.

II. Outcomes and deliverables during the reporting period

4. During the reporting period, ICP Forests produced or contributed to the following publications and reports:

(a) The 2024 joint progress report on policy-relevant scientific findings of the Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) and the Working Group on Effects (ECE/EB.AIR/GE.1/2024/3−ECE/EB.AIR/WG.1/2024/3). The report contains information on the data gathered and recorded by ICP Forests in 13 domains covering the most relevant aspects of forest ecosystems in Europe;

(b) The 2024 progress report of the Programme Coordinating Centre of ICP Forests to the EMEP Steering Body and the Working Group on Effects (ECE/EB.AIR/GE.1−WG.1/2024/INF. 7);

(c) The 2024 Technical Report of ICP Forests[2], which presents results from 30 of the 42 countries participating in ICP Forests., including thematic papers on:

(i) Atmospheric throughfall deposition in European forests in 2022;

(ii) Meteorological conditions in European forests in 2022;

(ii) Tree crown condition in 2023;

5. A total of 49 scientific papers based on ICP Forests data and with significant use of plots and methods were published in international peer-reviewed journals in 2023.

6. The data unit at the Programme Co-ordinating Centre (PCC) of ICP Forests is constantly improving the data management, data availability and usability, and information flow within the programme and to the scientific community and the public. The following developments of the data unit were recently accomplished:

(i) Based on the unification of data structures over time, which took place over the last few years, many data series could be harmonized, in cooperation with the corresponding Expert Panels and national partners;

(ii) A review of the litterfall database structure has started.

[2] Michel A, Haggenmüller K, Kirchner T, Prescher A-K, Schwärzel K, editors (2024) Forest Condition in Europe: The 2024 Assessment. ICP Forests Technical Report under the UNECE Convention on Long-range transboundary Air Pollution (Air Convention). Eberswalde: Thünen Institute. Forthcoming.

7. The results from the Working Group on Quality in Laboratories of ICP Forests on the 26th Needle/leaf Interlaboratory Comparison Test 2023/2024 with 41 laboratories from 22 countries, and the 13th Deposition and Soil Solution Working Ring test 2023/2024 with 35 labs from 23 countries were published. These reports can be downloaded from the ICP Forests website[3,4].

III. Expected outcomes and deliverables for the next reporting period and in the longer term

8. In the second half of 2024 and in 2025, ICP Forests will carry out the following activities, in accordance with the 2024-2025 work plan for the Convention and with the decisions taken at the fortieth meeting of the Task Force:

(a) Further acquisition of data on the condition and development of forest ecosystems and efforts to improve data quality and the data management system;

(b) Contribution to the 2025 joint progress report on policy-relevant scientific findings of the Steering Body to the EMEP and the Working Group on Effects (ECE/EB.AIR/GE.1/2025/3–ECE/EB.AIR/WG.1/2025/3);

(c) Finalization of the draft 2024 Technical Report of ICP Forests.

IV. Cooperation with other groups, task forces and subsidiary bodies, including with regard to synergies and possible joint activities

9. The collaboration between ICP Forests and EMEP agreed in 2023 was continued. ICP Forests uses EMEPs nitrogen and sulphur deposition data to fill data gaps. EMEP uses atmospheric deposition data collected by ICP Forests in the forest to calibrate EMEP models.

V. Strengthening the involvement of countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia

10. Most of the countries of South-Eastern Europe and Turkey are included in the extensive ICP Forests Level I monitoring of forest ecosystems. The more complex and intensive Level II monitoring is carried out at only a few sites in South-Eastern Europe. None of the countries of the Caucasus or Central Asia is active in ICP Forests monitoring activities. We take every opportunity – e.g., at our scientific conferences – to contact these countries.

11. ICP Forests participated in the International Scientific Conference "Forest Science for People and Societal Challenges" on the occasion of the 90th anniversary of the Romanian National Institute for Research and Development in Forestry "Marin Drăcea". The meeting took place from October 2 to 5, 2023 in Bucharest.

VI. Scientific and technical cooperation with relevant international bodies

12. ICP Forests chaired a session at the 26th IUFRO World Congress. The title of the session was ‘Nitrogen Depositions in Forests in a changing climate: Trends and Implications on Forest Ecosystem Services. There were eight oral and nine poster presentations from all over the world. The conference was held in Stockholm/Sweden in June 2024.

[3] http://icp-forests.net/page/working-group-on-quality
[4] http://icp-forests.net/page/icp-forests-other-publications

13. Following up the decision made at the 39th Task Force meeting, there is an ongoing process to establish a cooperation agreement with the Joint Research Centre (JRC) of the European Commission. The agreement intends to (i) promote joint research and joint publications, (ii) facilitate potential and reciprocal exchange of scientific personnel and (iii) facilitate mutual access to data, provided that data protection and relevant results are protected for both parties. Currently, the amendments to the cooperation agreement proposed by ICP Forests are being reviewed by the JRC.

14. ICP Forests also participated in the task force meetings of ICP Integrated Monitoring, ICP Modelling and Mapping as well as of ICP Waters and presented the progress of work.

VII. Highlights of the scientific findings: policy-relevant issues

15. The ICP Forests' 2024 Technical Report presents research highlights that are priority themes of the UNECE Air Convention such as nitrogen deposition, ozone (O3), heavy metals, biodiversity, and interactions between air pollution and climate change. These presented research highlights are articles based on ICP Forests data and infrastructure, but also include work that originated outside the ICP Forests community but is significant to the Air Convention. Examples of the research highlights are included below.

16. One of ICP Forests' monitoring objectives is to obtain accurate deposition data from forests. This data is not only needed to assess the impact of air pollution on forest health, but is also required for reporting under the NEC Directive and desired for calibrating and validating EMEP's models. Verstraeten[5] et al. (2023) compared the deposition fluxes in spring in homogeneous beech, oak, spruce and pine stands with the pollen concentrations of the predominant tree species in the air measured at aerobiological stations near cities. The authors found that the estimation of throughfall fluxes is significantly altered by tree pollen. Particularly for beech they found a positive relationship between the airborne pollen concentrations and throughfall fluxes of potassium, ammonium, organic nitrogen, and carbon. On the other hand, the results indicated that pollen is acting as a sink for nitrogen and as a source for ammonium. From this can be concluded that pollen appears to play a complex role in forest nutrient cycling also with regard to inorganic N. Guerrieri[6] et al. (2024) examined the extent to which microbes transform atmospheric nitrogen in forest canopies, and how microbes contribute to nitrate fluxes reaching the soil surface via throughfall. To this end, they combined isotopic and genetic analyses to estimate canopy nitrification at ten ICP Forests sites, to identify microorganism involved in this process, and to quantify the contribution of gross canopy nitrification to nitrogen fluxes. Through isotope fingerprinting microbial canopy nitrification was identified as a key process in nitrogen cycling. Guerrieri et al. showed that nitrate in throughfall originates from a mixture of atmospheric and biological sources. Up to 80% of the nitrate reaching the soil via throughfall was derived from canopy nitrification, equivalent to a flux of up to 5.76 kg N ha^{-1} yr^{-1}. It has also been shown that biological nitrification in the tree canopy consumes ammonium deposited on leaf and needle surfaces, thereby increasing nitrate inputs to the soil.

17. Two studies conducted in Greek forests focused on the cycling and status of boron and cobalt respectively (Michopoulos[7,8] et al. 2023a, 2023b). They are remarkable because these elements are not included in the standard list of parameters commonly assessed in the ICP Forests deposition survey, but both are essential plant micronutrients. Evidence was

5 Verstraeten A, Bruffaerts N, Cristofolini F, et al. (2023) Effects of tree pollen on throughfall element fluxes in European forests. Biogeochemistry 165, 311–325. https://doi.org/10.1007/s10533-023-01082-3

6 Guerrieri R, Cáliz J, Mattana S, et al. (2024) Substantial contribution of tree canopy nitrifiers to nitrogen fluxes in European forests. Nature Geoscience 17, 130–136. https://doi.org/10.1038/s41561-023-01364-3

7 Michopoulos P, Kostakis M, Koulelis P, et al. (2023a) Cycling and status of boron in two forest types in Greece. Ann. For. Res. 66, 113–122. https://doi.org/10.15287/afr.2023.2940

8 Michopoulos P, Kostakis M, Kaoukis K, et al. (2023b) Cycling and status of cobalt in some forest types. Folia Oecologia 50, 72–79. https://doi.org/10.2478/foecol-2023-0006

found that small amounts of boron and cobalt undergo long-range transport through the atmosphere and reach the forest canopy mainly through dry deposition.

18. Taking meteorological changes such as air temperature, atmospheric humidity, and wind as well as changes in air pollutants like nitrogen oxides into account, statistical downscaling projects a decrease in ground-level ozone concentrations in Europe under the moderate SSP2-4.5 scenario, but an increase in concentrations under the pessimistic SSP3-7.0 scenario (Hertig[9] et al. 2023). In line with this, Ferretti[10] et al. (2024) showed that high summer ozone concentrations and foliar symptoms slightly decreased in European forests over the period 2005–2018. Ozone concentrations were higher in the Mediterranean and the Alpine biogeographic regions. Ozone has a significant effect on symptoms in the most sensitive species. Also, it was shown that symptoms tend to be driven by functional leaf traits.

19. Saenger[11] et al. (2024) found that recovery after soil acidification depends on the initial base saturation status. On acidic sites, increasing soil acidification was observed across the entire profile, while pools of exchangeable base cations increased. On the other hand, the global buffering capacity of less acidic soils improved. Karlsson[12] et al. (2024) found that the reduced deposition load in Sweden has improved the acidification status of the soil solution. However, forest ecosystems are far from fully recovered. Sulphur concentrations in the soil solution have decreased, and at many of the most acidified sites the Anion Neutralising Capacity (ANC) has increased significantly, but is still below zero. On several less acidified sites, pH values in the soil solution have increased, but there are also some sites with decreased pH values. The forest ecosystems in southwest Sweden are often close to nitrogen saturation, with frequent leakage of nitrate from the root zone, which does not appear to have changed over the last 35 years. From this it is concluded that continued monitoring of soil water chemistry is important to follow the forest soil recovery progress in a changing climate.

20. It becomes more and more evident that the forest soil microbiome, i.e., bacteria, archaea, and fungi, plays an essential role in response to eutrophication caused by nitrogen deposition. Baldrian[13] et al. (2023) found that nitrogen deposition substantially affects the forest soil microbial processes, especially in the temperate zone. The soil microbiome drives multiple crucial steps in the biogeochemical cycles (Meena[14] et al. 2023). Several studies highlight the relative importance of the fungal communities. Based on DNA sequencing of soil samples from 238 ICP Forests Level II plots across a northeast–southwest gradient in Europe, Anthony[15] et al. (2024) demonstrated that fungal, but not bacterial, composition and richness are correlated with tree growth rates and tree biomass carbon stocks.

21. Recurrent climate-induced disturbances affect the health of European forests, which respond with increased crown defoliation, dieback and mortality. Against this background,

[9] Hertig E, Jahn S, Kaspar-Ott I (2023) Future local ground-level ozone in the European area from statistical downscaling projections considering climate and emission changes. Earth's Future 11, e2022EF003317. https://doi.org/10.1029/2022EF003317.

[10] Ferretti M, Cailleret M, Haeni M, et al. (2024) The fingerprint of tropospheric ozone on broadleaved forest vegetation in Europe. Ecol. Indic. 158, 111486. https://doi.org/https://doi.org/10.1016/j.ecolind.2023.111486.

[11] Saenger, A.0, André, F., Jonard, M., Nicolas, M. and Ponette, Q. (2024) Carbon sequestration and nitrogen loss drive the evolution of French forest soils. Front. For. Glob. Change 7:1338239. https://doi.org/10.3389/ffgc.2024.1338239.

[12] Karlsson GP, Akselsson C, Hellsten S, Karlsson PE (2024) Atmospheric deposition and soil water chemistry in Swedish forests since 1985 – Effects of reduced emissions of sulphur and nitrogen. Science of The Total Environment 913:169734. https://doi.org/10.1016/j.scitotenv.2023.169734.

[13] Baldrian P, López-Mondéjar R, Kohout P (2023) Forest microbiome and global change. Nat Rev Microbiol 21:487–501. https://doi.org/10.1038/s41579-023-00876-4.

[14] Meena M, Yadav G, Sonigra P, et al. (2023) Multifarious responses of forest soil microbial community toward climate change. Microb Ecol 86:49–74. https://doi.org/10.1007/s00248-022-02051-3.

[15] Anthony MA, Tedersoo L, De Vos B., et al. (2024) Fungal community composition predicts forest carbon storage at a continental scale. Nat Commun 15, 2385. https://doi.org/10.1038/s41467-024-46792-w.

Rukh[16] et al. (2023) investigated the resilience of European beech to climate change by comparing the effects of recent major droughts (2003 and 2018/2019) in Central Europe. The results suggest that increased drought exposure of beech trees could push them beyond their hydraulic safety margins, with synergistic effects of drought-related impacts potentially leading to reduced recovery and later tree death. To better predict the future vitality of beech in Central Europe, the authors recommend investigating both the short- and long-term effects of defoliation and its influence on growth after drought periods.

22. In recent years, forests across Europe have experienced increasing mortality and overall declining growth (Rybar[17] et al. 2023). This trend, which is caused by more frequent and more intense droughts, is altered by nitrogen deposition, as reported in a study by Dietrich[18] et al. (2024). Several tree species in Central Europe change their response to climate with high nitrogen deposition, albeit in both directions. Similar results were obtained in a study by Cuciurean[19] et al. (2024), who investigated the influence of air pollution on forests. They found that the pollutants impaired the growth of the trees and that the trees accumulated heavy metals in the wood, the concentrations of which decreased over time as pollution decreased.

23. The 2024 Technical Report presents results from 31 of the 42 countries participating in ICP Forests. Highlights of these results are briefly discussed in the following paragraphs.

24. In 2022, acidifying, buffering, and eutrophying compounds of open field bulk and below canopy throughfall deposition were analyzed from 281 permanent plots and following the ICP Forests Manual, in both the European ICP Forests network and the Swedish Throughfall Monitoring Network. Fourteen plots were excluded because the duration of sampling covered less than 90% (329 days) of the year, and 86 other plots were marked as ”not validated” because the conductivity check was passed for less than 30% of the analyses 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. The main findings were:

(i) The uneven distribution of emission sources and receivers and the complex orography in parts of Europe lead to a pronounced spatial variability of atmospheric deposition. On a broader scale, however, there are regional patterns in deposition. As in previous years, high (>8.0 kg ha^{-1} y^{-1}) and moderate (>4.0 to 8.0 kg ha^{-1} y^{-1}) depositions of nitrate and ammonium were found mainly in Central Europe, from Belgium to Germany to Poland and further south to Switzerland, Austria, Italy and Slovenia. Two thirds of the plots have low (<4.0 kg ha^{-1} y^{-1}) nitrate levels, but only 50 per cent of the plots have low (<4.0 kg ha^{-1} y^{-1}) ammonium levels. The latter means that atmospheric nitrogen deposition is increasingly dominated by ammonium.

(ii) It is generally assumed that negative effects of nitrogen (N) 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} y^{-1} depending on the type of forest and ecosystem compartment (Bobbink[20] et al. 2022). In 2022, throughfall inorganic nitrogen deposition more than 10 kg $ha^{-1}y^{-1}$ was mainly measured in most of central Europe,

[16] Rukh S, Sanders TG, Krüger I, et al. (2023) Distinct responses of European beech (Fagus sylvatica L.) to drought intensity and length—a review of the impacts of the 2003 and 2018–2019 drought events in Central Europe. Forests, 14(2), 248.

[17] Rybar J, Sitková Z, Marcis P, et al. (2023) Declining radial growth in major western Carpathian tree species: insights from three decades of temperate forest monitoring. Plants 12(24), 4081.

[18] Dietrich V, Lauritz M, Roggenhofer MM, et al. (2024) Drought effects on growth and density of temperate tree regeneration under different levels of nitrogen deposition. Forest Ecology and Management 559, 121825.

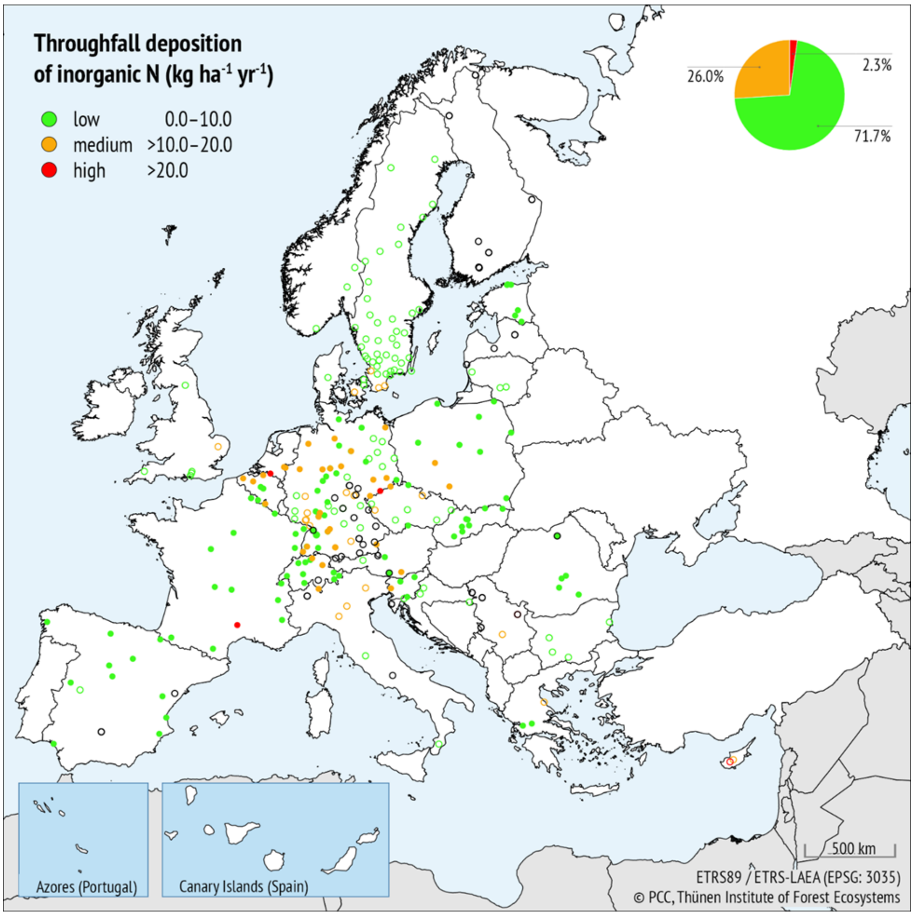
[19] Cuciurean CI, Sidor CG, Camarero JJ, et al. (2024) Detecting changes in industrial pollution by analyzing heavy metal concentrations in tree-ring wood from Romanian conifer forests. Environmental Research, 118884.

[20] Bobbink R, Loran C, Tomassen H, eds (2022) Review and revision of empirical critical loads of nitrogen for Europe. Dessau-Rosslau: German Environment Agency.

including Belgium, Germany, Poland, Czechia, Austria, Switzerland, Slovenia and northern Italy, but high deposition was also found in other countries, including France, the United Kingdom of Great Britain and Northern Ireland, Denmark, Sweden, Serbia, Greece, and Cyprus. (Figure I). Nitrogen deposition of more than 10 kg $ha^{-1}y^{-1}$ was measured on 30 % of the plots (Figure I). Throughfall inorganic nitrogen deposition higher than 20 kg $ha^{-1}y^{-1}$ was recorded in Belgium, Germany, and France. Because total nitrogen deposition on forests is higher than throughfall nitrogen deposition (Braun[Error! Bookmark not defined.] et al. 2022), the critical loads for nitrogen are likely still e xceeded in large parts of Europe.

Figure I

Throughfall deposition of inorganic nitrogen (NO_3^--N + NH_4^+-N) (kg N ha^{-1} yr^{-1}) measured in 2022 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network.



Notes: Coloured dots: validated data. Coloured circles: not validated data. Black circles: monitoring period shorter than 330 days.

(ii) Sulphate deposition has substantially decreased since the start of the monitoring in some countries as early as in 1985 but high throughfall sulphate deposition is still found close to large point sources. In southern Europe, sulphate deposition is also influenced by volcanic emission and by the episodic deposition of Saharan dust. In 2022, high (>6.0 kg ha^{-1} y^{-1}) and moderate (>3.0 to 6.0 kg ha^{-1} y^{-1}) throughfall deposition of sulphate (corrected for the marine contribution) was found mainly in central and south-eastern Europe with a small number of sites in Germany, Poland, Czechia, Slovakia, Croatia, Serbia, Bulgaria, Greece, and Cyprus. However, sulphate deposition of more than 3 kg ha^{-1} y^{-1} was only measured on 5.4 % of the plots.

(iii) Atmospheric deposition of nitrogen and sulphur compounds markedly decreased in the last years, yet at different rates. Considering 133 plots for which deposition values were validated for the whole period 2017–2022, throughfall deposition of oxidized nitrogen, reduced nitrogen and non-marine sulphur in 2020–2022 was lower than in 2017–2019 by 24%, 12% and 31%, respectively (Fig. 6-8, left panel), while the differences in the amount of precipitation between the two periods were negligible.

25. Tree crown defoliation and occurrences of biotic and abiotic damage are important indicators of forest condition. As such, they are considered within criterion 2 “Forest health and vitality”, one of the six criteria adopted by Forest Europe (formerly the Ministerial Conference on the Protection of Forests in Europe) to provide information for sustainable forest management in Europe.[21] Defoliation surveys are conducted in combination with detailed assessments of biotic and abiotic damage causes. Unlike assessments of tree damage, which can in some instances trace the tree damage to a single cause, defoliation is an unspecific parameter of tree vitality, which can be affected by a number of anthropogenic and natural factors. The most important results are as follows:

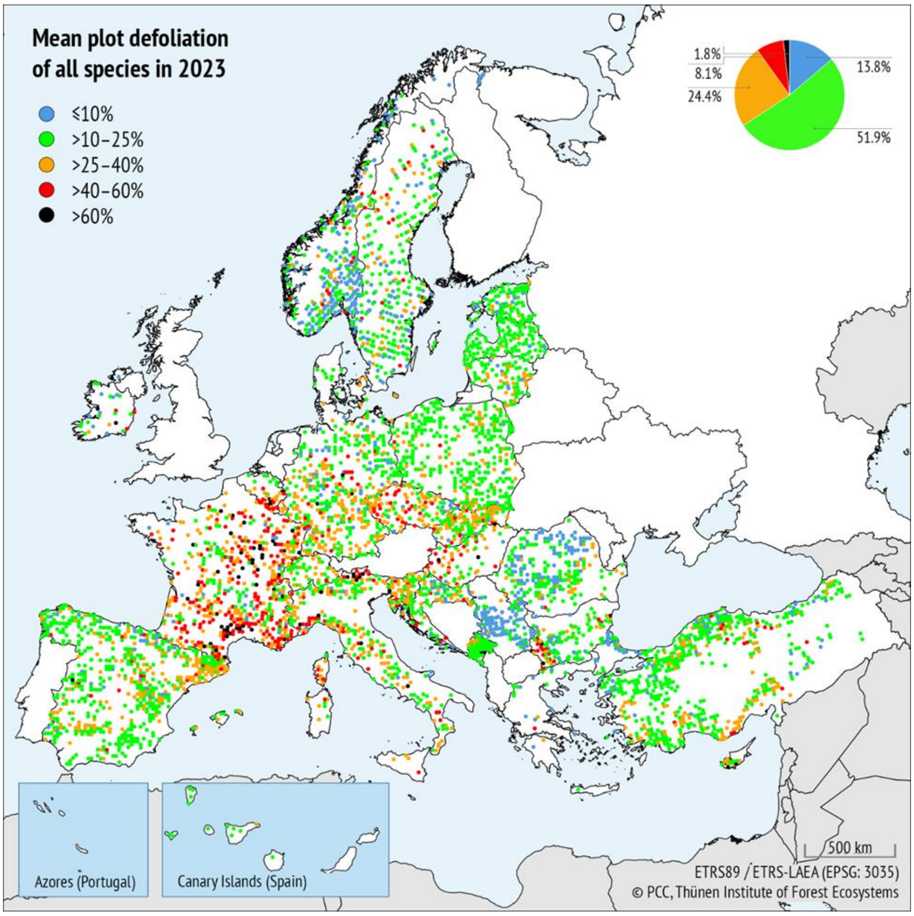
(i) The transnational crown condition survey in 2023 was conducted on 107 818 trees on 5 598 plots in 27 countries. Out of those, 101 912 trees were assessed in the field for defoliation. The overall mean defoliation for all species was 24.0% in 2023; based on a slight increase in defoliation of 0.3% for conifers and no change for broadleaves in comparison with 2022. Broadleaved trees showed a higher mean defoliation than coniferous trees (24.6% vs. 23.3%), as in previous years. Correspondingly, conifers had a higher frequency of trees in the defoliation classes ‘none’ and ‘slight’ (70.5% combined) than broadleaves (66.8%) and a lower frequency of trees with more than 60% defoliation (3.1% vs. 5.3%). Norway spruce had the highest share of standing dead trees (1.2%), and common beech the lowest (0.4%).

(ii) Among the main tree species and tree species groups, deciduous temperate oaks and evergreen oaks displayed the highest mean defoliation (29.3% and 27.8%, respectively). Common beech had the lowest mean defoliation (21.9%). The strongest increase in defoliation compared to 2022 occurred in deciduous temperate oaks (+1.7%p) and in Mediterranean lowland pines (+1.3%p), the strongest decrease in evergreen oaks (-0.8%p) and common beech (-0.5%p), while there were only minor changes for the other species and species groups.

(iii) Mean defoliation of all species at plot level in 2023 is shown in Figure II. Two thirds (65.7%) of all plots had a mean defoliation up to 25%, and only 1.8% of the plots showed severe defoliation (more than 60%). While plots with defoliation up to 10% were located mainly in Norway, Serbia, Romania, and Türkiye, plots with slight mean defoliation (11-25%) were found across Europe. Clusters of plots with moderate to severe mean defoliation were found from the Pyrenees through southeast (Mediterranean) France to northern Italy, but also from central and northern France through Germany and into Czechia, Slovakia, and Hungary, as well as in western Bulgaria and central parts of Norway and Sweden.

[21] See www.foresteurope.org/docs/MC/MC_lisbon_resolution_annex1.pdf.

Figure II
Mean plot defoliation of all species in 2022



Notes: The legend (top left) shows defoliation classes ranging from none (blue), slight (green), moderate (orange and red), to severe (black). The percentages refer to the needle/leaf loss in the crown compared to a reference tree. The pie chart (top right) shows the percentage of plots per defoliation class. Dead trees are not included.

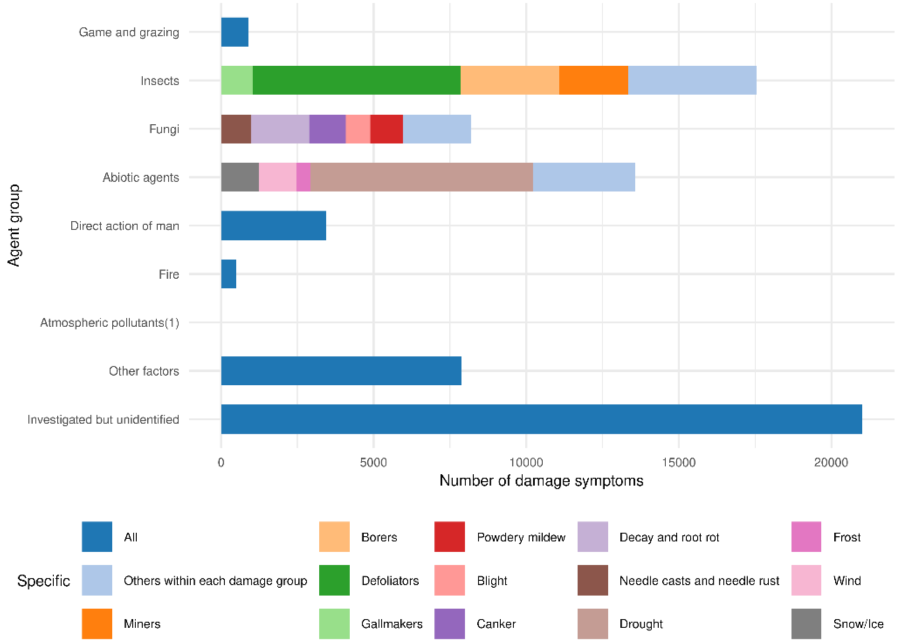
26. Combining the assessment of damage symptoms and their biotic and abiotic causes with observations of defoliation allows for a better insight into the condition of trees, and the interpretation of the state of European forests and its trends in time and space is made easier:

(i) In 2023, damage cause assessments were carried out on 101 727 trees on 5 497 plots and in 26 countries. On 49 992 trees (49.0%) at least one symptom of damage was found, which is the same level as in 2022. In total, 73 031 observations of damage were recorded (multiple damage symptoms per tree were possible). Both fresh and old damage was reported.

(ii) Insects were the predominant cause of damage and responsible for 24.0% of all recorded damage symptoms (Figure III). Within the group of insects, 38.9% of damage symptoms were caused by defoliators. Wood borers were responsible for 18.4%, leaf miners for 12.9%, sucking insects for 9.9%, and gallmakers for 5.5% of the damage caused by insects. Abiotic factors were the second major causal agent group responsible for 18.6% of all damage symptoms. Within this agent group, more than half of the symptoms (53.7%) were attributed to drought, while snow/ice and hail caused 11.8%, wind 9.2%, heat/sun scald 3.4% and frost 3.3% of the symptoms. The third major identified cause of tree damage were fungi with 11.2% of all damage symptoms. The agent group ‘Atmospheric pollutants’ refers here only to damage caused by direct atmospheric pollution impact. Visible symptoms of direct atmospheric pollution impact, however, were very rare (0.03% of all damage symptoms).

Figure III

Number of damage symptoms according to agent groups and specific agents/factors



Notes: Multiple damage symptoms per tree were possible, and dead trees are included (n=68 593). (1) Visible symptoms of direct atmospheric pollution impact only.

(iii) There were 1.164 new dead trees in the damage assessment 2023 (703 broadleaves and 461 conifers). This results in a mortality rate of 1.1%, which represents an increase compared to 2022 (0.9%). The highest numbers of dead trees among the main tree species and species groups were found for Scots pine (171 trees, corresponding to a mortality rate of 1%), Norway spruce (156 trees, corresponding to 1.5%), deciduous temperate oaks (112 trees, corresponding to 1.3%), and deciduous (sub-) Mediterranean oaks (78 trees, corresponding to 1%). Mortality rates for the other main species and species groups were below 1%. Among other broadleaves, particularly high numbers of dead trees were found for downy birch (Betula pubescens, 124 trees, corresponding to a mortality rate of 4.5%), and European ash (Fraxinus excelsior, 71 trees, corresponding to 7.9%). Most dead trees were reported from Norway (215, mostly broadleaves and mainly downy birch), France (165, mainly oak species), Spain (125, mainly Quercus ilex and Pinus nigra), Bulgaria (77, mainly Scots pine), and Germany (72, also mainly Scots pine). The main cause of mortality to broadleaved trees on Level I plots was abiotic factors, followed by fire, fungi, and insects. Fire was causing the death of most coniferous trees, followed by abiotic agents, insects, and fungi. The determination of the cause of tree death is often very difficult; it could not be identified for more than 60% of the dead trees in 2023.

VIII. Publications

27. For a full list of all 49 ICP Forests publications using ICP Forests data or the ICP Forests infrastructure in peer-reviewed journals and references for the present report, please refer to the 2024 ICP Forests Technical Report or visit the ICP Forests website.[22]

[22] See http://icp-forests.net/page/publications.