United Nations ECE/EB.AIR/GE.1/2023/INF.7 –ECE/EB.AIR/WG.1/2023/INF.7

25 July 2023

English only

Economic Commission for Europe

Executive Body for the Convention on Long-range Transboundary Air Pollution

Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe

Working Group on Effects

Ninth joint session
Geneva, 11–15 September 2023
Item 9 (b) (iii) of the provisional agenda
Progress in activities and workplan for 2024–2025 of effects-oriented activities

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.1/2022/11–ECE/EB.AIR/WG.1/2022/4) and presents the outcomes of the thirty-ninth meeting of the ICP Forests Task Force (online meeting, 7 and 8 June 2023). The activities were carried out and the report prepared in accordance with the 2022–2023 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).[1]

While air pollution to forests has considerably changed since the 1980s, it may still have significant effects on forest ecosystems, also in combination with increasing pressure from climate change. Reduced growth and increased susceptibility to drought damage, pests and pathogens were frequently reported in articles published in 2022 based on ICP Forest's data or infrastructure. Air pollution, especially N deposition and tropospheric ozone, continues to affect forest ecosystems. N deposition levels remain high in several European regions and have been found to affect tree growth, lead to imbalances in tree nutrition and to soil acidification, and affect the composition of understory communities of plants, mosses, and lichens. Ozone has been reported to affect tree growth, fruiting, and foliar condition, although its effect is modulated by a number of site and plant traits.

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

As in the previous years, high throughfall deposition of nitrate and ammonium in 2021 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 the southern part of Europe, sulphate deposition is also influenced by volcanic emission and by the episodic deposition of Saharan dust.

Meteorological measurements at ICP Forests Level II plots show that the year 2021 was warmer in southern, south-eastern, and east-central Europe and cooler in western, central, and northern Europe compared to the long-term mean (1990 to 2020). In contrast to the year as a whole, it was significantly warmer than normal during the vegetation period in most of Europe (often by up to +2 °C). The deviation of total precipitation in 2021 from the long-term average (1990–2020) is less than 25% in either direction on the majority of ICP Forests Level II plots and seldom reaches higher values. Towards the Mediterranean Sea, especially in south-central Europe and Northern Italy, as well as in south-eastern Europe, Poland and Spain higher negative deviations were found. In general, the year 2021 was slightly drier than normal all across Europe.

In 2022, we witnessed a slight increase in mean defoliation as compared to 2021, with a smaller change for conifers (0.6%) than for broadleaves (1.4%). While no change in mean defoliation was recorded for Scots pine and a very small increase for Norway spruce (0.2%) and deciduous temperate oaks (0.3%), larger increases were recorded for other main species and species groups, especially for Austrian pine (1.9%) and evergreen oaks (2.0%). This year a 2.6% rise in the number of trees with damage symptoms was recorded, and the overall number of recorded damage symptoms was also higher than in 2021.

As part of the review of the current ICP Forests strategy, a questionnaire was developed and sent to ICP Forests member countries to find out how member countries view the ICP Forests strategy and what suggestions they have for the new ICP Forests strategy. The survey results show that the current strategy is still relevant and timely. The strategy has helped in many member states to (i) strengthen monitoring activities and (ii) secure financial resources for monitoring infrastructure and staff. However, financial resources for monitoring infrastructure and personnel are always an issue; more activities to secure the program are highly desirable. Activities to expand the program are actually already mentioned in the current strategy and are already included in the ICP Forests work plan.

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 2022-2023 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 10th ICP Forests Scientific Conference FORECOMON and the 39th ICP Forests Task Force Meeting were held online, 6–8 June 2023, with 77 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 2023 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.1/2023/3−ECE/EB.AIR/WG.1/2023/3). 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 2023 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.1/2023/INF.7 −ECE/EB.AIR/WG.1/2023/INF. 7);

(c) The 2023 Technical Report of ICP Forests[2], which presents results from 31 of the 42 countries participating in ICP Forests., including thematic papers on:

(i) Atmospheric throughfall deposition in European forests in 2021;

(ii) Meteorological conditions in European forests in 2021;

(ii) Tree crown condition in 2022;

(iii) Results of the survey among ICP Forests member countries on the currently valid ICP Forests strategy and future activities.

5. A total of 65 scientific papers based on ICP Forests data and with significant use of plots and methods were published in international peer-reviewed journals in 2022.

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) Two new surveys (Soil Level I & Assessment of Epiphytic Lichen Diversity) were implemented in the database;

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[2] 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. Forthcoming.

(ii) 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;
(iii) For several surveys, gap-filling, aggregation and reporting scripts were developed and implemented at the PCC.

7. The results from the Working Group on Quality Assurance and Quality Control of ICP Forests on the 24th Needle/leaf Interlaboratory Comparison Test 2021/2022 with 47 laboratories from 25 countries, the 11th Deposition and Soil Solution Working Ringtest 2021/2022 with 39 labs from 23 countries, and the 10th Soil Ringest 2021 with 32 labs from 21 countries were published. These reports can be downloaded from the ICP Forests website[3,4].

8. ICP Forests contributed to the report on "Review and revision of empirical critical loads of nitrogen for Europe" by the Coordination Centre for Effects (CCE) of the ICP Modelling and Mapping. It features a chapter on "Effects of nitrogen deposition on forests and other wooded land" and provides updated numbers for empirical critical loads for different forests.

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

9. In the second half of 2023 and in 2024, ICP Forests will carry out the following activities, in accordance with both the 2022–2023 and the 2024-2025 work plan for the Convention and with the decisions taken at the thirty-ninth 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 2024 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.1/2024/3–ECE/EB.AIR/WG.1/2024/3);

(c) Finalization of the draft 2023 Technical Report of ICP Forests.

(d) Development of ICP Forests Brief No. 6.

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

10. The Programme Co-ordinating Centre (PCC) of ICP Forests organized a meeting of scientists from ICP Forests and EMEP to deepen collaboration between the two bodies. During the meeting, objectives and actions for closer collaboration between ICP Forests and EMEP were identified and discussed. Some of these identified measures, such as data sharing, have already been partially initiated.

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

11. 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

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

[4] http://icp-forests.net/page/icp-forests-other-publications

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.

VI. Scientific and technical cooperation with relevant international bodies

12. ICP Forests participated in the scientific and technical symposium 'Assessing Forest Damage and Disturbance', jointly organized by the United Nations Economic Commission for Europe (UNECE), the Food and Agriculture Organization of the United Nations (FAO) and the Austrian Federal Ministry of Agriculture, Forestry, Spatial Planning and Water Management. The meeting was held in Vienna/Austria from 29-30 September 2022. The objective of the symposium was to contribute to a harmonized assessment of forest damage and disturbance in the UNECE region and to identify innovative monitoring and reporting techniques for application at the international and national levels.

13. ICP Forests participated in the workshop ‘Towards harmonized forest observation, reporting and data collection framework’, held in Kutná Hora/Czech Republic from 14 to 16 September 2022. During the workshop, participants discussed the current state of forest monitoring in EU Member States and its readiness for the establishment of a common harmonised framework for forest observation, reporting and data collection, as outlined in the New EU Forest Strategy. ICP Forests also participated in the workshop in Uppsala/Sweden in February 2023 building on the results in Kutna Hora.

14. ICP Forests participated in the conference "Acid Rain - The Future Environment and Role of Multiple Air Pollutants" with some presentations. The conference was held in Niigata/ Japan in April 2023.

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

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

16. The ICP Forests' 2023 Technical Report presents research highlights that are priority themes of the UNECE Air Convention such as nitrogen deposition, ozone (O3), heavy metals, 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.

17. Atmospheric acid deposition has decreased considerably since the 1980s following clean-air policies. Numerous studies have shown soil acidification though recent studies indicate the recovery from this human-induced soil acidification. In Lower-Saxony, Germany, Ahrends[5] et al. (2022a) could show a trend reversal or a stagnation of the acid-base status at a strong acidification level. The recovery was faster under deciduous trees compared to coniferous stands. In the UK (Vanguelova[6] et al. 2022) and in Germany (Ahrends[7] et al. 2022b), the authors found diverse patterns for individual nutrient balances due to the combined effects of changing deposition, climate and forest harvesting.

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[5] Ahrends B, Fortmann H, Meesenburg H (2022a) The influence of tree species on the recovery of forest soils from acidification in Lower Saxony, Germany. Soil Systems 6:40. https://doi.org/10.3390/soilsystems6020040

[6] Vanguelova E, Benham S, Nisbet T (2022) Long term trends of base cation budgets of forests in the UK to inform sustainable harvesting practices. Applied Sciences 12:2411. https://doi.org/10.3390/app12052411

[7] Ahrends B, von Wilpert K, Weis W, et al (2022b) Merits and limitations of element balances as a forest planning tool for harvest intensities and sustainable nutrient management—a case study from Germany. Soil Systems 6:41. https://doi.org/10.3390/soilsystems6020041

18. Braun et al. (2022)[8] developed a statistical model for calculating total N deposition as a function of throughfall N deposition. The model is based on data from studies in selected European countries with measured throughfall N deposition and simultaneous estimates of total N deposition derived from combinations of measurements and detailed modelling. The model may provide an alternative to more complex canopy budget models and has the advantage that no information on bulk or wet deposition is required, making it more widely applicable. The model can be used within a range of 0-20 kg ha 1 yr-1 throughfall N deposition.

19. ICP Forests growth data was used for an innovative study on the role of ectomycorrhizal fungi composition. While these results cannot provide a clear causality or directionality, the study provides clear evidence that slow and fast growth of broadleaves and coniferous trees is linked to the ectomycorrhizal fungi composition (Anthony[9] et al. 2022). At this point, it should be recalled that an earlier ICP Forests publication showed that there is a correlation between the composition of ectomycorrhizal fungi and the level of N deposition (van der Linde[10] et al. 2018).

20. A study in western Germany (Rhineland-Palatinate), investigated the relationships between surface O_3 (expressed as concentration- and flux-based metrics), water stress on tree growth from 1998 to 2019, basal area increment (BAI), and fructification of European beech (Fagus sylvatica L.) and Norway spruce (Picea abies L. H. Karst.) (Eghdami[11] et al. 2022). A random forest analysis showed that soil water content and daytime O_3 mean concentrations were the best predictors of BAI at all sites. The highest mean score of fructification was observed during dry years, while low or no fructification was observed in most humid years. Combined effects of drought and O_3 pollution influenced tree growth decline in European beech and Norway spruce the most.

21. Wohlgemuth[12] et al. (2022) investigated controls on foliar stomatal Hg(0) uptake by combining Hg measurements of 3569 foliage samples across Europe with data on tree species traits and environmental conditions. The most relevant parameter impacting daily foliar stomatal Hg(0) uptake was tree functional group (deciduous versus coniferous trees). On average, they measured 3.2 times higher daily foliar stomatal Hg(0) uptake rates in deciduous leaves than in coniferous needles.

22. Gazol and Camarero[13] (2022) based their analysis on two independent data sources, including the ICP Forests Level I dataset, identifying hotspots of forest mortality and showing that their occurrence is partially explained by the simultaneous occurrence of extreme droughts and heat waves. These results are mirrored by George[14] et al. (2022) who found that European forests show consistent signs of drought-induced dieback, which can be partly explained by anomalies in soil moisture and the occurrence of droughts during the last 25 years.

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[8] Braun S, Ahrends B, Alonso R, et al (2022) Nitrogen deposition in forests: Statistical modeling of total deposition from throughfall loads. Front For Glob Change 5:1062223. https://doi.org/10.3389/ffgc.2022.1062223.

[9] Anthony MA, Crowther TW, van der Linde S, et al (2022) Forest tree growth is linked to mycorrhizal fungal composition and function across Europe. ISME J 16:1327–1336. https://doi.org/10.1038/s41396-021-01159-7

[10] Van der Linde S, Suz LM, Orme CDL, et al (2018) Environment and host as large-scale controls of ectomycorrhizal fungi. Nature 558:243–248. doi: 10.1038/s41586-018-0189-9

[11] Eghdami H, Werner W, De Marco A, Sicard P (2022) Influence of ozone and drought on tree growth under field conditions in a 22-year time series. Forests 13:1215. https://doi.org/10.3390/f13081215

[12] Wohlgemuth L, Rautio P, Ahrends B, et al (2022) Physiological and climate controls on foliar mercury uptake by European tree species. Biogeosciences 19:1335–1353. https://doi.org/10.5194/bg-19-1335-2022

[13] Gazol A, Camarero JJ (2022) Compound climate events increase tree drought mortality across European forests. Science of The Total Environment 816:151604. https://doi.org/10.1016/j.scitotenv.2021.151604

[14] George J-P, Sanders TGM, Timmermann V, et al (2022) European-wide forest monitoring substantiate the neccessity for a joint conservation strategy to rescue European ash species (Fraxinus spp.). Sci Rep 12:4764. https://doi.org/10.1038/s41598-022-08825-6

23. Abiotic, environmental stressors (such as drought) not only cause damage to trees by disturbing physiological processes such as water transport and uptake of nutrients, but also make forest trees more susceptible to damage from biotic agents such as fungi or insects. In European coniferous forests, recent heat wave-associated droughts have regionally increased the mortality rates associated with bark beetle infestations. This trend is likely to continue under more frequent extreme events of drought and heat in the coming decades. Analysing resistance of five host tree species to bark beetle attack and beetle-induced mortality based on ICP Forests Level I data, Jaime[15] et al. (2022) suggested that the joint influence of drought events and bark beetle disturbance threatens the persistence of coniferous forests, highlighting the importance of studying disturbance interactions for the health of European forests.

24. Bryophytes were studied in relation to nitrogen deposition by Weldon[16] et al. (2020). They included 187 plots within the ICP Forests and ICP IM programmes at the European scale, covering the period 1994–2016. Coniferous forests showed lower functional diversity and Pielou evenness than broadleaf-dominated forests. Throughfall nitrogen deposition was significantly associated with increased bryophyte community nitrogen preference (especially in younger forests) and a decrease in species evenness. The authors concluded that nitrogen deposition is likely to adversely affect forest bryophyte communities, having negative impacts in terms of increased dominance of nitrophilic species at the expense of N-sensitive species and a decrease in species evenness.

25. The 2023 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.

26. In 2021, acidifying, buffering, and eutrophying compounds of open field bulk and below canopy throughfall deposition were analyzed from 287 permanent plots and following the ICP Forests Manual, in both the European ICP Forests network and the Swedish Throughfall Monitoring Network:

(i) 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 (>8 kg ha^{-1} y^{-1}) 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 (>8 kg ha^{-1} y^{-1}) was, however, larger than for nitrate, particularly in Belgium, Germany, Switzerland, Austria, northern Italy, Slovenia, eastern England and the most southern part of Sweden. It can be concluded that N deposition is becoming more ammonium-dominated;

(ii) 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 y-1 depending on the type of forest and ecosystem compartment (Bobbink[17] et al. 2022). In 2021, throughfall inorganic nitrogen deposition higher than 10 kg ha-1 y-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 (Figure I). Throughfall inorganic nitrogen deposition higher than 20 kg ha-1 y-1 was recorded in Belgium, Germany, southern Sweden, and Austria. Because total nitrogen deposition on forests is higher than throughfall nitrogen

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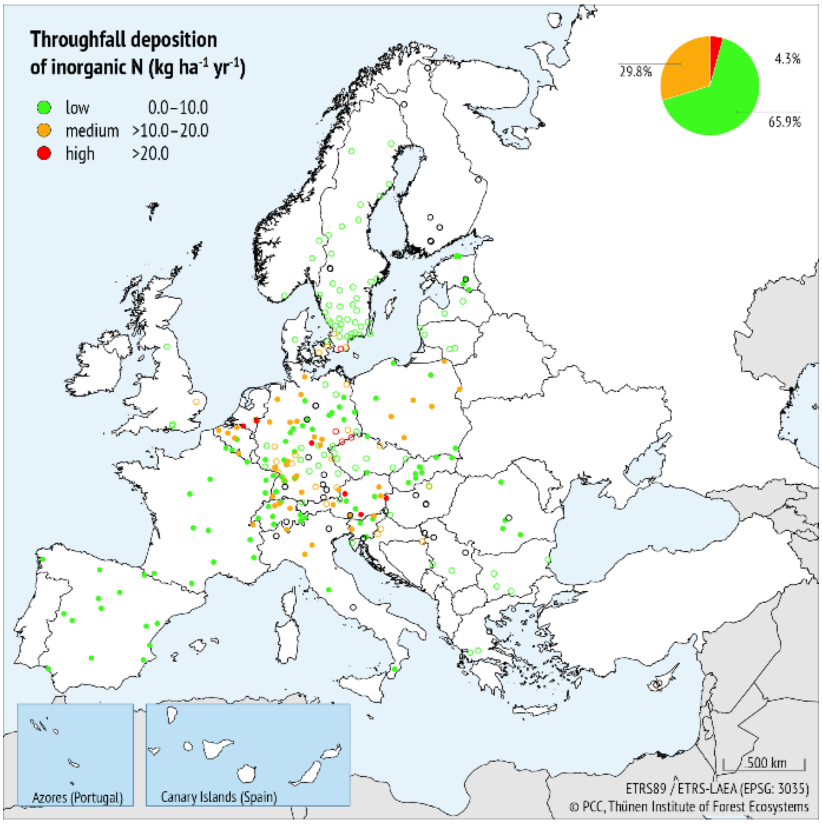
[15] Jaime L, Batllori E, Ferretti M, Lloret F (2022) Climatic and stand drivers of forest resistance to recent bark beetle disturbance in European coniferous forests. Global Change Biology 28:2830–2841. https://doi.org/10.1111/gcb.16106

[16] 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. https://doi.org/10.1186/s13595-022-01148-6

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

deposition (Braun[8] et al. 2022), the critical loads for nitrogen are likely still exceeded in large parts of Europe.

Figure I
Throughfall deposition of inorganic nitrogen (NO3--N + NH4+-N) (kg N ha-1 yr-1) measured in 2021 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.

(iii) 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 emissions 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 y-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. Throughfall sulphate deposition higher than 6 kg ha-1 y-1 was recorded in Croatia, Serbia, Bulgaria and near the borders of Czechia with Germany and Poland.

27. Observing weather conditions and their seasonal variations on forest monitoring plots is essential not only for identifying and interpreting trends in forest condition, but also for better understanding how climate interacts with other stressors such as air pollution, disease, or pests, and how these interactions affect forest conditions. Against this background, the ICP Forests Level II plots were equipped with meteorological measurement devices as early as the 1990s. The resulting Europe-wide network of forest meteorological stations provides site-specific forest meteorological data including air temperature, relative humidity, precipitation, wind speed and direction, global radiation, soil moisture and temperature. Temperature and precipitation patterns play a key role in climate change impacts on forests

(Kirilenko and Sedjo[18] 2007). The 2023 Technical Report of ICP Forests, therefore, focuses first on presenting and interpreting air temperature and precipitation data from 2021 in comparison with long-term mean values for different climatic regions in Europe. In 2021, rainfall and air temperature data from a number of plots were analysed:

(i) The year 2021 was warmer than normal in southern, southeast- and east-central Europe and cooler in west-central and northern Europe. In contrast to the year as a whole, it was significantly warmer than normal during the vegetation period in most of Europe (often by up to +2 °C). In 2021, maximum temperatures above 40 °C during the vegetation period occurred at Level II plots in western and southern Spain as well as in south-eastern Europe, but also on one Level II plot in Poland. The majority of Level II plots in central Europe showed maximum temperatures during the vegetation period between 26 °C and 36 °C. The number of hot days and late frost events and their deviation from the long-term average depended on the climatic region.

(ii) The distribution of total annual precipitation in 2021 shows a more or less normal pattern. The highest annual precipitation was found in the Alps and mountain stations in Greece and the lowest in Spain and east-central and south-eastern Europe. The deviation of total precipitation in 2021 from the long-term average (1990–2020) is less than 25% in either direction on the majority of plots and seldom reaches higher values. In general, 2021 was slightly drier than normal all across Europe.

28. 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:[19]

(i) The transnational crown condition survey in 2020 was conducted on 105 696 trees on 5 453 plots in 27 countries. Out of those, 101 190 trees were assessed in the field for defoliation. The overall mean defoliation for all species was 23.8% in 2022; an increase in defoliation of 0.6% for conifers and 1.4% for broadleaves in comparison with 2021. Broadleaved trees showed a higher mean defoliation than coniferous trees (24.7% vs. 23.0%), as in previous years. Correspondingly, conifers had a higher frequency of trees in the defoliation classes ‘none’ and ‘slight’ (71.3% combined) than broadleaves (67%) and a lower frequency of trees with more than 60% defoliation (3.0% vs. 5.0%). Norway spruce had the highest share of standing dead trees (1.6%), common beech, Austrian pine and deciduous (sub-) Mediterranean oaks the lowest (0.2% each);

(ii) Among the main tree species and tree species groups, deciduous temperate oaks and evergreen oaks displayed the highest mean defoliation (27.7% and 28.6%, respectively). Common beech had the lowest mean defoliation (22.4%). The strongest increase in defoliation compared to 2021 occurred in evegreen oaks (+2%) and in Austrian pine (+1.9%), while there was no increase in Scots pine and only a small increase in Norway spruce (0.2%) and deciduous temperate oaks (+0.3). Defoliation increased in all species and species groups compared to 2021, except in Scots pine;

(iii) Mean defoliation of all species at plot level in 2021 is shown in figure II below. Two thirds (65.9%) of all plots had a mean defoliation up to 25%, and only 1.4% 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 south-east (Mediterranean) France to west 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.

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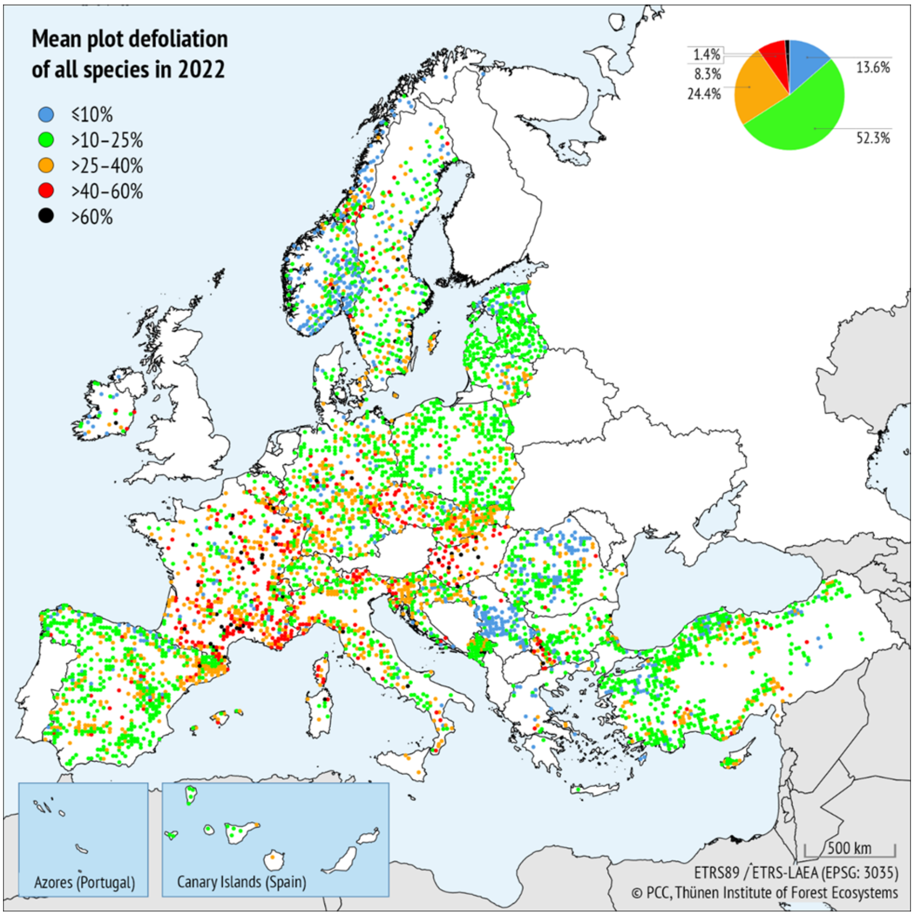
[18] Kirilenko AP, Sedjo RA (2007) Climate change impacts on forestry. PNAS 104(50):19697-19702. https://www.pnas.org/doi/full/10.1073/pnas.0701424104

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

(iv) Trends show a considerable increase in defoliation of evergreen oaks over the past 20 years (7.3%). On the other hand, the increase in defoliation for deciduous temperate oaks (3.2%) and common beech (3.9%) has been relatively low, while the increase of defoliation for Scots pine, Mediterranean lowland pines and Norway spruce was moderate. Trends were not significant for deciduous (sub-) Mediterranean oaks and Austrian pine.

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.

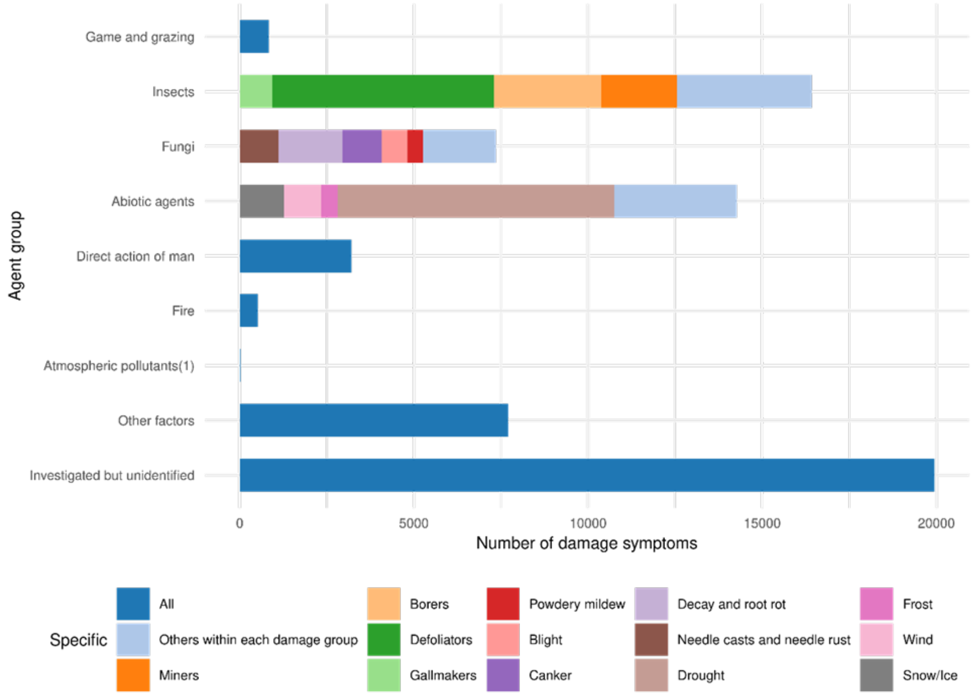
29. Combining the assessment of damage symptoms and their biotic and abiotic causes with observations of defoliation allows for a better insight into the condition of trees, and the interpretation of the state of European forests and its trends in time and space is made easier:

(i) In 2022, damage cause assessments were carried out on 99 920 trees on 5 339 plots and in 26 countries. On 49 004 trees (49%) at least one symptom of damage was found, which is 2.6% higher than in 2021 (46.4%). In total, 70 300 observations of damage were recorded (multiple damage symptoms per tree were possible). Both fresh and old damage was reported. Most of the reported damage symptoms were observed on the leaves of broadleaved trees (29.6%), followed by twigs and branches (27.1%), and stems (21.3%). Needles were also often affected (15.1%), while roots, collar, shoots, buds, and fruits of both broadleaves and conifers were less frequently affected. More than half (54.9%) of all recorded damage symptoms had an extent of up to 10%, 35.6% had an extent between 10% and 40%, and 9.6% of the symptoms covered more than 40% of the affected part of a tree;

(ii) Insects were the predominant cause of damage and responsible for 23.4% of all recorded damage symptoms (Figure III). Within the group of insects, 38.7% of damage symptoms were caused by defoliators. Wood borers were responsible for 18.8%, leaf miners for 13.2%, sucking insects for 11.7%, and gallmakers for 5.7% of the damage caused by insects. Abiotic factors were the second major causal agent group responsible for 20.3% of all damage symptoms. Within this agent group, more than half of the symptoms (55.6%) were attributed to drought, while snow/ice and hail caused 11.2%, wind 7.5%, heat/sun scald 3.5% and frost 3.4% of the symptoms. The third major identified cause of tree damage were fungi with 10.5% 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) This year a 2.6% rise in the number of trees with damage symptoms was recorded, and the overall number of recorded damage symptoms was also higher than in 2021. As in previous years, the number of damage symptoms per assessed tree was substantially higher for broadleaves than for conifers (0.84 vs. 0.56%, respectively). Insects, abiotic causes, and fungi were the most common damage agent groups for all species, comprising altogether more than half of all damage records. Tree mortality in 2022 was 0,9% (873 trees). Mortality rates for the main species and species groups ranged from 0.3 to 0.7% (except for Norway spruce with 1.9%), and the main causes of mortality were abiotic factors, followed by insects, fungi and fire.

30. The current ICP Forest Strategy was adopted at the 32nd Task Force meeting in 2016, and expires at the end of 2023. Therefore, at the meeting of the Programme Coordinating Group (PCG) in November 2022, a working group was formed to develop a new strategy for the period 2024 to 2030. At this meeting, it was decided to ask the member states' views on the strategy by means of a questionnaire. The aim was, on the one hand, to get to know the views of the ICP Forests member states on the strategy currently in force and, on the other hand, to take account of the partners' ideas in the development of the new strategy. The questionnaire consists of 24 questions, divided into questions on the relevance and validity

of the current strategy, on the priorities of the member countries in relation to forest environmental monitoring, and on the countries' views on the future of program-related monitoring activities:

(i) 22 out of 31 active member states of ICP Forests have completed the questionnaire and two other countries have partially answered it. 88% of the member states participating in the survey are familiar with the current strategy, and all countries that participated in the survey agree or strongly agree with the objectives listed in the current ICP Forestry Strategy;

(ii) 81% of the member states participating in the survey did not think that goals or actions were missing in the current ICP Forests Strategy. However, it was noted that the strategy highlights air pollution, but changes in climate and biodiversity should play a more visible role. Other comments were that ICP Forests should increase the visibility of ICP Forests methods and data to encourage collaboration with other networks, or that linking remote sensing technologies and ICP Forests data would be desirable;

(iii) For 88% of the countries participating in the survey, the expansion of the ICP Forests strategy through topics such as ‘Interaction with climate change and extremes’ or ‘Impact on carbon sequestration’ from high to essential priority. For about half of the countries participating in the survey, topics such as 'Water purification' or 'Heavy metals as additional pollutants' are of high to essential priority for the new strategy. Other topics such as ‘Pesticides/Insecticides’, ‘Microplastics’, or ‘Per- & polyfluoroalkyl substances’ were considered as less relevant for ICP Forests. Activities to expand the program were included in the new ICP Forests Strategy;

(iv) The survey results show that the strategy has helped in many member states to strengthen monitoring activities and secure financial resources for monitoring infrastructure and staff. However, financial resources for monitoring infrastructure and personnel are always an issue; more activities to secure the program are highly desirable.

VIII. Publications

31. For a full list of all 65 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 2023 ICP Forests Technical Report or visit the ICP Forests website.[20]

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