United Nations ECE/EB.AIR/GE.1/2021/11–ECE/EB.AIR/WG.1/2021/4

Economic and Social Council

Distr.: General
10 August 2021

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

Seventh joint session
Geneva, 13–16 September 2021
Item 10 (c) (ii) of the provisional agenda
Progress in activities in 2021 and further development 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.1/2020/11–ECE/EB.AIR/WG.1/2020/4) and presents the outcomes of the thirty-seventh meeting of the ICP Forests Task Force (Birmensdorf, Switzerland (hybrid), 10 and 11 June 2021). The activities were carried out and the report prepared in accordance with the 2020–2021 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/144/Add.2, table 1, item 1.1.1.11) 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).[a]

Based on the analysis of 290 ICP Forests level II and Swedish Throughfall Monitoring Network plots across Europe in 2019, regional patterns in throughfall deposition were identified. High values of nitrate deposition were mainly found in Central and Western Europe (eastern Austria, Belgium, Czechia, Denmark, Germany and Switzerland), while for ammonium they were also found in northern Italy and Poland. It is generally considered that negative effects of nitrogen deposition (i.e. the sum of nitrate and ammonium deposition) on forests become evident when inorganic nitrogen deposition is higher than a specific threshold, known as the critical load. The critical load[b] for deciduous forests is 10 – 20 kg N ha^{-1} y^{-1} and 5 - 15 kg N ha^{-1} y^{-1} for coniferous forests. The 2019 throughfall inorganic nitrogen (N) deposition measurements indicate that critical loads are currently exceeded at many forest sites in Europe; N deposition higher than 10 kg ha-1 y-1 were mainly measured in

Central and Western Europe including Austria, Belgium, Czechia, Germany, northern Italy and Switzerland.

The 2020 transnational crown condition survey was conducted on 107,520 trees on 5,663 plots in 27 countries. The overall mean defoliation for all species was 23.3 per cent: there was no change for conifers and a very slight increase in defoliation for broadleaved trees in comparison with 2019. Broadleaved trees showed a higher mean defoliation than coniferous trees (23.3 per cent versus 22.2 per cent, respectively). The damage assessment revealed that insects were again the predominant cause of damage, being responsible for 24.8 per cent of all recorded damage symptoms, while abiotic agents were the second major causal agent group, being responsible for 17.3 per cent of all damage symptoms.

The combined Forest Soil Condition Database stores heavy metal data for about 1,000–1,500 plots from the first inventory (1985–1996, mainly forest floor) and 3,000–3,500 plots from the second inventory (2006–2008, mainly forest floor and mineral topsoil). Natural background concentrations differ between countries and biogeographical regions, where the boreal zone shows the lowest concentration levels for most heavy metals. Overall, concentrations of the heavy metals between both surveys for most plots, countries and biogeographical regions decreased, with larger changes in the forest floor compared to the mineral topsoil.

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

[b] Roland Bobbink and Jean-Paul Hettelingh, eds., *Review and revision of empirical critical loads and dose-response relationships: Proceedings of an expert workshop, Noordwijkerhout (Netherlands), 23–25 June 2010* (Coordination Centre for Effects/National Institute for Public Health and the Environment of the Netherlands, 2011).

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 2020–2021 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/144/Add.2, table 1, item 1.1.1.11) and in accordance with the revised mandate of ICP Forests (Executive Body decision 2019/16).[1]

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. A total of 42 Parties to the Convention participate in ICP Forests activities.

3. The ninth ICP Forests scientific conference "Forest Monitoring to assess Forest Functioning under Air Pollution and Climate Change" and the thirty-seventh ICP Forests Task Force Meeting were successfully held in a hybrid format (Birmensdorf, Switzerland, June 7–11, 2021).

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 2020 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.1/2020/3–ECE/EB.AIR/WG.1/2020/3). 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 2020 progress report by the Programme Coordinating Centre of ICP Forests to the EMEP Steering Body and the Working Group on Effects (ECE/EB.AIR/GE.1/2020/11–ECE/EB.AIR/WG.1/2020/4);

(c) The 2021 Technical Report of ICP Forests,[2] which presents results from 32 of the 42 countries participating in ICP Forests, including thematic papers on:

(i) Atmospheric throughfall deposition in European forests in 2019;

(ii) Tree crown condition in 2020;

(iii) Heavy metals in forest floor and topsoil of ICP Forests Level I plots.

5. A total of 81 scientific papers based on ICP Forests data and with significant use of plots and methods were published in international peer-reviewed journals in 2020. These publications cover the following fields: atmospheric deposition, ozone concentrations and heavy metals (10 articles); climate effects (19 articles); forest biodiversity and deadwood (10 articles); forest soils and soil carbon (10 articles); nutrient cycling, tree physiology and phenology (20 articles); tree condition and damage causes (12 articles).

6. The report "Heavy metals in forest floors and topsoils of ICP Forests Level I plots: Based on the combined Forest Soil Condition Database - Level I (FSCDB.LI)"[3] investigates total heavy metal (HM) concentrations in European forest soils. The objectives are to: (a) explore the spatial variation (patterns and hotspots) of heavy metal concentrations and stocks

---

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

[2] Alexa Michel, Anne-Katrin Prescher and Kai Schwärzel, eds., "Forest Condition in Europe: 2021 Technical Report of ICP Forests. Report under the UNECE Convention on Long-range Transboundary Air Pollution" (forthcoming).

[3] Tine Bommarez, Nathalie Cools and Bruno De Vos, Report of the Research Institute for Nature and Forest 2021 (5) (Geraardsbergen, Belgium, Forest Soil Coordinating Centre of ICP Forests/Research Institute for Nature and Forest, Brussels, 2021).

in forest floors and topsoils throughout Europe; (b) investigate whether there is a significant temporal change between the data observed during the first (S1) and second (S2) soil surveys; (c) evaluate whether the HM concentrations and stocks exceed contamination or pollution levels; and (d) compare the observed forest soil concentration levels with reference databases and maps of HM in soils or in mosses at the European scale.

7. ICP Forests Brief No. 4 "Increased evidence of nutrient imbalances in forest trees across Europe"[4] was published.

8. A contribution was made to criterion 2 "Forest health and vitality" in the State of Europe's Forests 2020 Report.[5]

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

9. In the second half of 2021 and in 2022, ICP Forests will carry out the following activities, in accordance with both the 2020–2021 and the 2022–2023 (forthcoming) workplans for the Convention and with the decisions taken at the thirty-seventh 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 2021 joint progress report on contribution to the review of the Gothenburg Protocol (ECE/EB.AIR/GE.1/2021/3–ECE/EB.AIR/WG.1/2021/3);

(c) Finalization of the draft 2021 Technical Report of ICP Forests;

(d) Publication of ICP Forests Brief No. 5: Long-term defoliation trends (forthcoming);

(e) 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. ICP Forests participated in the kick-off meeting for the "Review and revision of empirical critical loads for nitrogen (CLempN)". The meeting was organized by the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP Modelling and Mapping) (online, 15 and 16 June 2020). ICP Forests contributed to the review and revision of the empirical critical load for nitrogen (CLempN) as author and reviewer of the book chapters.

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, as well as 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. ICP Forests takes every opportunity – for example, at ICP Forests scientific conferences – to contact these countries.

---

[4] Inken Krüger and others (Eberswalde, Germany, Thünen Institute of Forest Ecosystems, 2020).

[5] Ministerial Conference on the Protection of Forests in Europe - Forest Europe (2020), available at https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf.

VI. Scientific and technical cooperation with relevant international bodies

12. ICP Forests participated in the National Emissions Ceiling Ecosystems Expert Group meeting (online, 4 and 5 June 2020), organized by the Clean Air Unit (Directorate General of the Environment) of the European Commission.

13. ICP Forests participates regularly in the National Reference Centres/European Environment Information and Observation Network Forests webinars organized by the European Environment Agency. These webinars present and discuss items related to the development of the Forest Information System for Europe to support policies aimed at the protection and sustainable and multifunctional use of forests in Europe.

14. In 2020, ICP Forests participated in the task force meetings of the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP Integrated Monitoring), ICP Modelling and Mapping, the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) as well as of the International Cooperative Programme for Assessment and Monitoring of the Effects of Air Pollution on Rivers and Lakes (ICP Waters) and presented the progress of its work. All the task force meetings were held online due to the coronavirus disease (COVID-19) pandemic.

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

15. Examples of the highlights of 81 publications using ICP Forests data or the ICP Forests infrastructure in peer-reviewed journals in 2020 include the following results and conclusions:

(a) The ICP Forests data show that temporal trends of ground-level ozone concentrations are variable and site-dependent. For instance, at Czech sites, a steady increase from 2014 to the current time has been reported,[6] while, in the western part of Germany, ozone concentrations did not show any significant trends during the 22-year study period 1998–2019; in the latter case, periods of elevated ozone were often observed in parallel with increased plant water stress. In a study conducted in Switzerland, a negative correlation was observed between phosphorus concentration in foliage and tropospheric ozone flux (phototoxic ozone dose - POD1).[7] Regarding the severity of ozone-induced visible leaf damage, it should be noted that it may be the result of a combination of several factors such as soil water content, air temperature, relative humidity, solar radiation and ozone concentration through their influence on stomatal conductivity or ozone uptake. Hence, Critical Levels based on flux-response functions to protect forests against adverse ozone effects are proposed;[8]

(b) Several studies yielded further insights into the effects of nitrogen (N) deposition and ground-level ozone on forest ecosystem functioning. In a national study, strong evidence was found that decreasing phosphorus and potassium concentrations in leaves of European beech are partly explained by excessive N deposition.**Error! Bookmark not defined.** At the European level, one study demonstrated that N deposition is a factor at least as important as climate to modulate forest growth at the European scale, with a tipping point for growth where deposition exceeds 30 kg of N per hectare per year (ha^{-1} yr^{-1}), higher N inputs

---

[6] Iva Hůnová, Marek Brabec and Marek Malý, "Trends in ambient O_3 concentrations at twelve sites in the Czech Republic over the past three decades: Close inspection of development", *Science of the Total Environment*, vol. 746 (December 2020).

[7] Sabine Braun, Christian Schindler and Beat Rihm, "Foliar nutrient concentrations of European beech in Switzerland: Relations with nitrogen deposition, ozone, climate and soil chemistry", *Frontiers in Forests and Global Change* (2020).

[8] Pierre Sicard and others, "Epidemiological derivation of flux-based critical levels for visible ozone injury in European forests", *Journal of Forestry Research*, vol. 31, pp. 1509–1519 (2020).

leads to reduced growth.[9] In the same study, no significant effect of ozone on forest growth was detected. Lastly, throughfall deposition of dissolved organic N is a good predictor of the tissue total N content of three moss species in boreal forests.[10] The accumulation of free ammonium in tissues collected at southern plots suggested that mosses are near the N saturation state already at a deposition rate of 3–5 kg N ha^{-1} yr^{-1};

(c) ICP Forests data were used to study the nutritional status of forests potentially being affected by increased carbon dioxide, N and sulfur deposition, and climate change. It was found that foliar concentrations of N, phosphorus, potassium, sulfur and magnesium decreased during the past three decades with increasing carbon dioxide;[11]

(d) Twenty years of soil solution monitoring in Switzerland revealed an ongoing, but site-specific soil acidification. In strongly acidified soils, acidification indicators changed only slowly, possibly due to high buffering capacity of aluminium. In contrast, in less acidified sites, an increasing acidification rate over time was observed, reflected by the continued decrease in the ratio of base cations to aluminium ratio (BC/Al ratio).[Error! Bookmark not defined.] The same study demonstrated that the main driver of soil acidification is the high N deposition rate, causing cation losses and hampering sustainable nutrient balances for tree nutrition. Both N deposition and nitrate leaching have decreased since 2000, though the latter trend may be partly explained by increased drought in recent years. Nonetheless, those high N depositions are still affecting the majority of the forest sites. The interactions between N deposition and soil chemistry suggest an impaired uptake of potassium and phosphorus of beech stands in Switzerland at higher N loads.[12]

16. The ICP Forests Technical Report 2021 (see footnote 2.) presents results from 32 of the 42 countries participating in ICP Forests. Highlights of these results will be briefly discussed in the following subparagraphs:

(a) In 2019, acidifying, buffering and eutrophying compounds of open field bulk and below canopy throughfall deposition were analysed from 290 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. In the case of nitrate, high (>8 kg ha^{-1} y^{-1}) and moderate (4–8 kg ha^{-1} y^{-1}) throughfall deposition was mainly found in Central and Western Europe, including Austria, Belgium, Czechia, Germany, Italy, Poland and Slovenia, but single plots with high deposition values are also reported in other countries. The Central and Western European area of high (>8 kg ha^{-1} y^{-1}) and moderate (4–8 kg ha^{-1} y^{-1}) ammonium throughfall deposition is larger than for nitrate, with higher throughfall deposition values particularly in Germany, Belgium, and northern Italy, western Slovakia and Poland;
>
> (ii) It is generally considered that negative effects of N deposition on forests become evident when inorganic N deposition (i.e. the sum of nitrate and ammonium deposition) is higher than a specific threshold, known as the critical load. Critical loads can be evaluated for each site by modelling, but more generic critical loads (empirical critical loads) are also being evaluated,[13] ranging from 10 to 25 kg ha^{-1} y^{-1}.

---

[9] Sophia Etzold and others, “Nitrogen deposition is the most important environmental driver of growth of pure, even-aged and managed European forests”, *Forest Ecology and Management*, vol. 458 (February 2020).

[10] Maija Salemaa and others, “Forest mosses sensitively indicate nitrogen deposition in boreal background areas”, *Environmental Pollution*, vol. 261 (June 2020).

[11] Josep Penuelas and others, “Increasing atmospheric CO_2 concentrations correlate with declining nutritional status of European forests”, *Communications Biology*, vol. 3, art. No. 125 (2020).

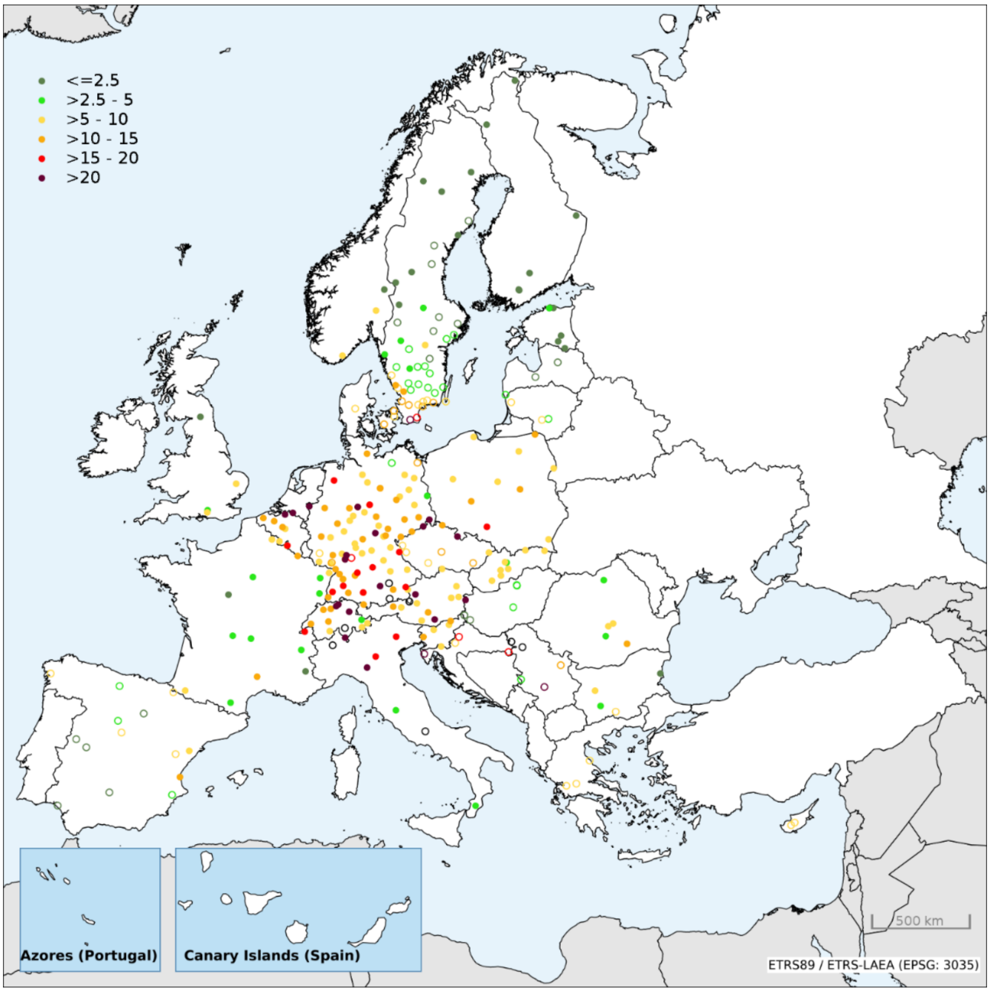
[12] Sabine Braun, Simon Tresch and Sabine Augustin, “Soil solution in Swiss forest stands: A 20 years’ time series”, *PLOS ONE*, vol. 15, No. 7 (2020).

[13] Roland Bobbink and Jean-Paul Hettelingh, eds., *Review and revision of empirical critical loads and dose-response relationships: Proceedings of an expert workshop, Noordwijkerhout (Netherlands),*

In 2019, throughfall inorganic N deposition higher than 10 kg ha^{-1} y^{-1} was mainly measured in Central and Western Europe, including Germany, Belgium, northern Italy, Switzerland, Austria, and Czechia (see figure I below). Total deposition of N is typically a factor 1 to 2 higher than (below canopy) throughfall deposition, due to N being taken up by tree leaves in the canopy.

Figure I

Throughfall deposition of inorganic nitrogen (NO3--N + NH4+-N) (kg N ha-1 yr-1) measured in 2019 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network.



Notes: Coloured dots, validated data; Coloured circles, unvalidated data; Black circles, monitoring period shorter than 330 days.

(b) 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:[14]

(i) The transnational crown condition survey in 2020[15] was conducted on 107,520 trees on 5,663 plots in 27 countries. Out of those, 102,534 trees were assessed in the

---

23–25 June 2010 (Coordination Centre for Effects/National Institute for Public Health and the Environment of the Netherlands, 2011).

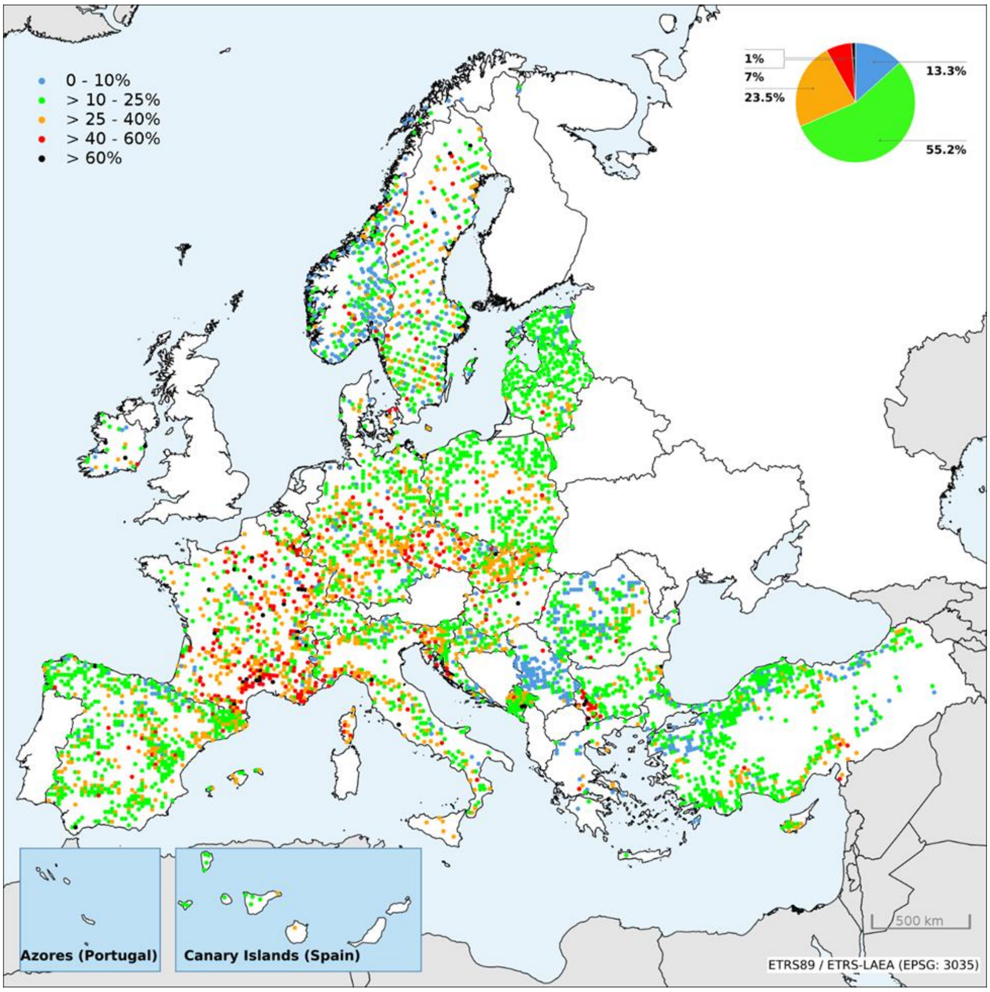
[14] See www.foresteurope.org/docs/MC/MC_lisbon_resolution_annex1.pdf.

[15] Volkmar Timmermann and others, “Tree crown condition in 2020” in Alexa Michel, Anne-Katrin Prescher and Kai Schwärzel, eds., “Forest Condition in Europe: 2021 Technical Report of ICP Forests. Report under the UNECE Convention on Long-range Transboundary Air Pollution” (forthcoming).

field for defoliation. The overall mean defoliation for all species was 23.3 per cent in 2020; there was no change for conifers and a very slight increase in defoliation for broadleaves in comparison with 2019. Broadleaved trees showed a higher mean defoliation than coniferous trees (23.3 versus 22.2 per cent, respectively). Correspondingly, conifers had a higher frequency of trees in the “none” and “slight” defoliation classes (73.4 per cent combined) than broadleaves (69.9 per cent) and a lower frequency of trees with more than 60 per cent defoliation (2.7 versus 3.8 per cent);

(ii) Mean defoliation of all species at plot level in 2020 is shown in figure II below. More than two thirds (68.5 per cent) of all plots had a mean defoliation up to 25 per cent, and only 1 per cent of the plots showed severe defoliation (more than 60 per cent). While plots with defoliation up to 10 per cent were located mainly in Norway, Serbia, Romania and Turkey, plots with slight mean defoliation (11–25 per cent) were found across Europe. Clusters of plots with moderate to severe mean defoliation were found from the Pyrenees through southeast (Mediterranean) France to western Italy, but also from central and northern France through Germany and into Czechia, Slovakia and Hungary, as well as in western Bulgaria and coastal Croatia.

Figure II
Mean plot defoliation of all species in 2019



Notes: The legend (top left) shows defoliation classes ranging from none (blue), to slight (green), to 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.

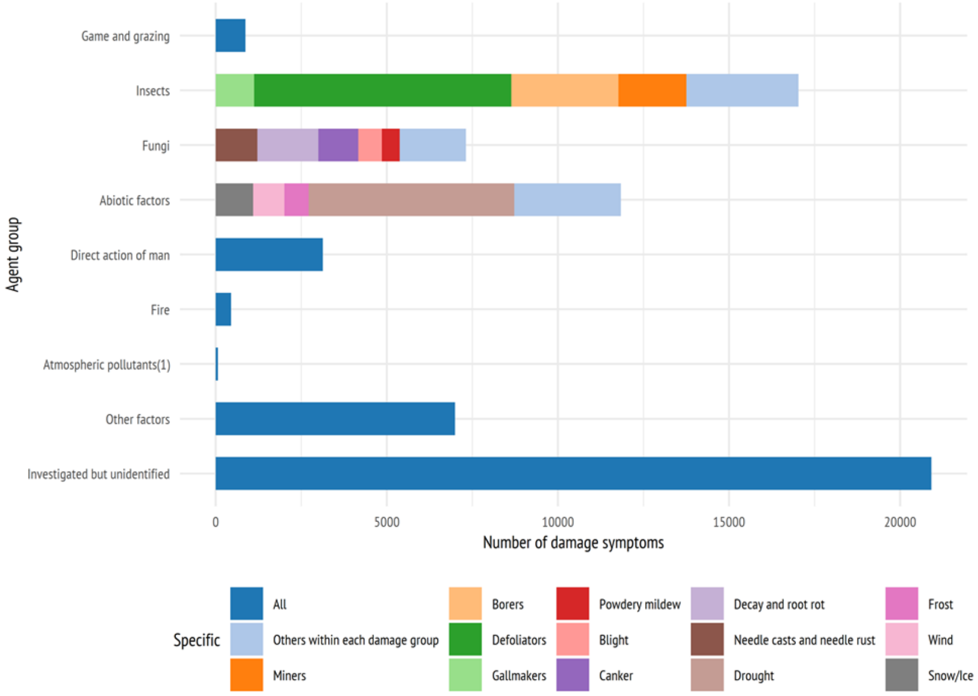
(c) Combining the assessment of damage symptoms and their biotic and abiotic causes with observations of defoliation allows for a better insight into the condition of trees, and the interpretation of the state of European forests and its trends in time and space is made easier:

(i) In 2020, investigation of causes of damage were carried out on 101,773 trees on 5,547 plots and in 26 countries. On 48,009 trees (47.2 per cent), at least one symptom of damage was found, which is 1.6 per cent less than in 2019 (48.8 per cent). In total, 68,593 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 (28.9 per cent), followed by twigs and branches (27.2 per cent) and stems (21.2 per cent). Needles were also often affected (15.4 per cent), while roots, collar, shoots, buds and fruits of both broadleaves and conifers were less frequently affected. More than half (52.3 per cent) of all recorded damage symptoms had an extent of up to 10 per cent, 38 per cent had an extent between 10 per cent and 40 per cent, and 9.7 per cent of the symptoms covered more than 40 per cent of the affected part of a tree;

(ii) Figure III below shows that insects were the predominant cause of damage and responsible for 24.6 per cent of all recorded damage symptoms on level I plots across Europe. Abiotic agents were the second major causal agent group responsible for 17.3 per cent of all damage symptoms. Within this agent group, roughly half of the symptoms (50.7 per cent) were attributed to drought, while snow and ice caused 9.2 per cent, wind 7.7 per cent, and frost 4.3 per cent of the symptoms. Fungi were the third major causal agent group, with 10.6 per cent 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.

(d) The combined Level I Forest Soil Condition Database comprises heavy metal data for about 1,000–1,500 plots from the first inventory (1985–1996) and 3,000–3,500 plots from the second inventory (2006–2008); predominantly, data of forest floor and topsoil (0–20 cm) compartments:

(i) Natural background concentrations differ between countries and biogeographical regions, where the boreal zone shows the lowest concentration levels for most heavy metals;

(ii) Overall, a decrease in heavy metal concentrations was observed between the two surveys for most plots, countries and biogeographic regions, with greater changes in forest soil compared to mineral topsoil;

(iii) Regional hotspots of elevated HM concentrations are clearly visible on maps and can be linked to local pollution sources and well-known contaminated areas;

(iv) Large-scale differences in HM concentrations can be partly explained by soil group and humus form;

(v) The observed spatial distribution patterns across Europe are comparable with those of the moss survey of ICP Vegetation and the EMEP deposition data for cadmium, lead and mercury.

VIII. Publications

17. For a full list of all 81 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 ICP Forests Technical Report 2021, or visit the ICP Forests website.[16]

---

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