ICP FORESTS

Forest Condition in Europe

The 2022 Assessment

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

Alexa Michel, Till Kirchner, Anne-Katrin Prescher, and Kai Schwärzel (editors)

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

http://icp-forests.net

Contact

Programme Co-ordinating Centre of ICP Forests
Kai Schwärzel, Head
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, Germany
Email: pcc-icpforests@thuenen.de

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SUMMARY

The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) is one of the most comprehensive programs within the Working Group on Effects (WGE) under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention). To provide a regular overview of the program's activities, the ICP Forests Programme Co-ordinating Centre (PCC) yearly publishes an ICP Forests Technical Report which summarizes research highlights and provides an opportunity for all participating countries to report on their national ICP Forests activities. The PCC also invites all ICP Forests Expert Panels (EP), Working Groups, and Committees to publish a comprehensive chapter on their most recent results from regular data evaluations.

This 2022 Technical Report presents results from 32 of the 42 countries participating in ICP Forests. Part A presents research highlights from the January–December 2021 reporting period, including:

- a concise overview by the EP Chairs of the most relevant key findings in the scientific literature in the forest-relevant, priority themes for the WGE strategic planning: N deposition, ozone, heavy metals, air pollution/climate change interactions;
- a list of 70 scientific publications for which ICP Forests data and/or the ICP Forests infrastructure were used;
- a list of all 21 official requests for ICP Forests data between January and December 2021;
- a review of the 9th ICP Forests Scientific Conference FORECOMON 2021.

Part B focuses on regular evaluations from within the programme. This year the Technical Report includes the following chapters:

- Atmospheric throughfall deposition in European forests in 2020;
- Tree crown condition in 2021;
- History and progress of the ICP Forests ringtest programme and the Working Group QA/QC in Laboratories.

Part C includes national reports on ICP Forests activities from the participating countries.

Online supplementary material complementing Part B is available online[1].

For contact information of all authors and persons responsible in this programme, please refer to the Annex at the end of this document. For more information on the ICP Forests programme, we kindly invite you to visit the ICP Forests website[2].

Following is a summary of the presented results from regular evaluations in ICP Forests (Part B).

Atmospheric deposition is an important pathway for atmospheric pollutants reaching remote areas, such as forest ecosystems. Pollutants are produced by industry, traffic, agriculture, and other human activities, and they are emitted into the atmosphere. They can be transported towards other areas, where they are deposited mainly through wet deposition of compounds dissolved in rain, snow, sleet, or similar, and dry deposition of particulate matter and gases, for example, through gravity or adsorption on the forest canopy. The amount of pollutants deposited can be modelled, but *in-situ* measurements are needed because of their relatively high local variability, related to the distribution of pollutant sources and local topography.

Chapter 6 of this report focuses on atmospheric throughfall deposition of acidifying, acid-buffering, and eutrophying compounds in European forests in 2020.

As in previous years, high values of nitrate deposition were mainly found in central Europe (Germany, Denmark, and Austria), while for ammonium they were also found in Belgium, northern Italy, Slovenia, and Switzerland. While most of central Europe receives a moderate amount of sulphate deposition, high values are mainly found close to the largest point sources. In the southern part of Europe, sulphate deposition is also influenced by volcanic activity and by the episodic deposition of Saharan dust.

Calcium, potassium, and magnesium deposition can buffer the acidifying effect of atmospheric deposition. High values of calcium deposition are reported in southern Europe, mainly related to the deposition of Saharan dust, and in eastern Europe.

During 2020, most of Europe experienced a prolonged lockdown due to the COVID-19 pandemic. Fortunately, the deposition monitoring operations of ICP Forests partners were only marginally affected. However, it seems likely that the environmental effect of the limitation of traffic and industrial activities caused a decrease in the emission of sulphur and nitrogen oxides, which in turn led to a significant reduction in nitrate and (to a lesser extent) in sulphate deposition.

Tree crown defoliation and occurrence of biotic and abiotic damage are important indicators of forest condition. Unlike assessments of tree damage, which can in some instances trace tree damage to a single cause, defoliation is an unspecific parameter of tree vitality, which can be affected by a number of

[1] http://icp-forests.net/page/icp-forests-technical-report

[2] http://icp-forests.net

anthropogenic and natural factors. Combining the assessment of damage symptoms and their causes with observations of defoliation allows for a better insight into the condition of trees. Chapter 7 on tree crown condition in 2021 presents results from crown condition assessments on the large-scale, representative, transnational monitoring network (Level I) of ICP Forests carried out in 2021, as well as long-term trends for the main tree species and species groups.

The transnational crown condition survey in 2021 was conducted on 106 451 trees on 5 565 plots in 27 countries. Out of those, 101 663 trees were assessed in the field for defoliation. The overall mean defoliation for all species was 23.5% in 2021, there was no change for broadleaves and a very slight increase in defoliation for conifers in comparison with 2020. Broadleaved trees showed a higher mean defoliation than coniferous trees (23.3% vs. 22.4%). Among the main tree species and tree species groups, deciduous temperate oaks and evergreen oaks displayed the highest mean defoliation (27.3% and 26.7%, respectively). Common beech had the lowest mean defoliation (20.9%) followed by deciduous (sub-) Mediterranean oaks and Mediterranean lowland pines with 22.0% each. Mediterranean lowland pines had the highest percentage (76.8%) of trees with ≤25% defoliation, while deciduous temperate oaks had the lowest (59.0%).

In 2021, damage cause assessments were carried out on 100 732 trees on 5 459 plots and in 26 countries. On 46 790 trees (46.4%) at least one symptom of damage was found, which is 0.8 percentage points less than in 2020 (47.2%).

Insects were the predominant cause of damage and responsible for 24.6% of all recorded damage symptoms. Within the group of insects, 41.4% of damage symptoms were caused by defoliators.

Abiotic agents were the second major causal agent group responsible for 16.2% of all damage symptoms. Within this agent group, almost half of the symptoms (46.2%) were attributed to drought, while snow and ice caused 10.8%, wind 9.0%, and frost 4.7% of the symptoms.

An important - and mostly little considered - factor in long-term environmental monitoring is consistently good data quality in the laboratory. After all, only actual changes or small trends in nature should be detected - not fluctuations in the quality of laboratory data. This was taken into account at a very early stage in the ICP Forests Level I and Level II surveys.

In the early 1990s, before the Europe-wide soil and foliage surveys on Level I started, the Expert Panels Soil and Foliar decided to carry out laboratory comparison tests (ringtests) prior to and in parallel with their surveys. In 2007, the Working Group QA/QC in Laboratories was established with the aim to co-ordinate the knowledge exchange between the different ringtests for foliage, soil, and water (deposition and soil solution) in which nearly 100 laboratories participate. Chapter 8 provides an overview on the history and progress of the ICP Forests ringtest programme and the Working Group QA/QC in Laboratories.

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ONLINE SUPPLEMENTARY MATERIAL

Online supplementary material complementing Chapter 7 is available at
http://icp-forests.net/page/icp-forests-technical-report

FOREWORD

I am pleased to introduce the 2022 Technical Report of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests).

In 2021, Switzerland hosted the 37th Task Force Meeting of the ICP Forests and the 9th Scientific Conference in Birmensdorf. This was the second Task Force meeting in Switzerland, after the one 31 years ago in 1990 in Interlaken. Switzerland is still an active member to the Air Convention and the ICP Forests.

The Swiss forest covers nearly 1/3 of the country. Preventing natural hazards is the most important function for 50% of the forests. Swiss forests are managed with the concept of close-to-nature silviculture since decades. However, also natural forests receive deposition of air pollutants, leading to subtle changes in forests.

Forest monitoring provides us with information on the status and trends of the forest condition. Together with data on deposition and on changes in the climate, we gain insights in dose-response relations and we can determine the sustainability boundaries of forests. This is essential for the national and international air pollution abatement policy and for regulatory measures aiming at reducing negative impacts on forest ecosystems. Whereas the sulfur emissions were successful reduced in the last decades, the high nitrogen emissions are still a matter of concern.

The climate change is another challenge affecting the Swiss forests. Measures to strengthen forests against climate change are already addressed in the Swiss forest law. Now the Federal Council is implementing the action plan 2020-25 of the overall strategy for adaptation to climate change in Switzerland.

Forest Monitoring data becomes more important and valuable with every year. The temporal development of forest conditions and growth reveal their interlinkages with deposition, climate and site conditions. After decades of monitoring, we have now a precious treasure of robust data.

I would like to thank the ICP Forests community for their efforts and wish the programme all the best and success for the future.

Dr. Paul Steffen
Deputy Director General, Federal Office for the Environment FOEN

FORECOMON 2021 Excursion to the Swiss Alps

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DEAR READER,

It is my great pleasure and honor to introduce the ICP Forests Technical Report "Forest Condition in Europe. The 2022 Assessment".

The report includes three main parts with highlights related to our monitoring activity (Part A: publications, data requests, 9th Scientific Conference, and condensed overview about the main findings in relation to air pollution and forests that appeared in selected scientific papers in 2021-2022), recent results and development (Part B: atmospheric deposition, tree crown condition, and ring-tests among laboratories), and the traditional reports from countries (Part C).

All the parts of this report help very much to understand the wealth of activity carried out within the ICP Forests (i) at pan-European scale, (ii) in the long-term, and (iii) with a concept that connects a large-scale survey for status and change detection (our Level I) to highly equipped sites for drivers-response relationships (our Level II). Thanks to its inclusive nature and multimedia and multilevel concept, a program that was initially conceived to monitor the effects of air pollution on forests, proves now to be useful also to monitor the effects related to climate change. In this respect, it is rewarding that our monitoring concepts, methods, and governance are now considered exemplary by many.

It is always important to consider that ICP Forests is part of the UN ECE Air Convention, the oldest multi-national and multi-lateral environmental agreement in the world, and that the values of our data series grow every year as data series get longer – see the amount of data requests and the increasing number (and quality!) of publications using our data. Here, my gratitude goes to the Air Convention bodies, the Lead Country, all the participating Countries, the Programme Co-ordinating Center, Groups, Panels, and Committees of the ICP Forests for their enduring support, passion, and commitment.

We have plans for the future. We want to further expand our monitoring in terms of portfolio of attributes to be measured and measurement methods, and in terms of geographical scope. We are also planning to make our annual Technical Report more complete, and in future there will be an augmented contribution from our Expert Panels.

For the time being, however, I wish you an informative and stimulating, still enjoyable, reading.

Marco Ferretti
Chairman of the ICP Forests
Swiss Federal Research Institute WSL

1 INTRODUCTION

The UNECE Convention on Long-range Transboundary Air Pollution (Air Convention[1]) was the first international treaty to limit, reduce and prevent air pollution and to provide information on its effects on a wide range of ecosystems, human health, crops, and materials. Since its establishment in 1979, it has been extended by eight protocols, advancing the abatement of the emission of sulphur (S), nitrogen oxides (NO_x), ground-level ozone (O_3), volatile organic compounds (VOC), persistent organic pollutants (POP), heavy metals (HM), and particulate matter (PM), including black carbon. The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) is one of seven subsidiary groups (six ICPs and a joint Task Force with WHO) that report to the Working Group on Effects (WGE) under the Air Convention. It is led by Germany; its Programme Co-ordinating Centre is based at the Thünen Institute of Forest Ecosystems in Eberswalde, while its Chairperson is based at the Swiss Federal Research Institute WSL.

ICP Forests is an extensive long-term forest monitoring network covering Europe and beyond. It was established in 1985 with the aim to collect, compile, and evaluate data on forest ecosystems across the UNECE region and monitor forest condition and performance over time.

ICP Forests provides scientific knowledge on the effects of air pollution, climate change, and other stressors on forest ecosystems. It monitors forest condition at two intensity levels:

- The Level I monitoring is based on 5624 observation plots (as at 2021) on a systematic transnational grid of 16 x 16 km throughout Europe and beyond to gain insight into the geographic and temporal variations in forest condition.
- The Level II intensive monitoring comprises 561 plots (as at 2020, Table 1-1) in selected forest ecosystems with the aim to clarify cause-effect relationships between environmental drivers and forest ecosystem responses.

Quality assurance and quality control procedures are coordinated by committees within the programme, and the ICP Forests Manual[2] ensures a standard approach for data collection in forest monitoring among the 42 participating countries. ICP Forests data is available upon request[3]; an open ICP Forests dataset providing an overview of the data, including general plot descriptions and information on data availability per plot over time, can be directly downloaded from the ICP Forests website[4].

Transnational long-term forest monitoring under ICP Forests has been a pioneering initiative that has proven to be successful in detecting, understanding, and modelling changes in forest ecosystems over the past 35 years. Under recent climatic changes, it is even more relevant than ever.

The yearly published ICP Forests Technical Report series summarizes the program's annual results and has become a valuable source of information on European forest ecosystem changes with time. This 2022 Technical Report of ICP Forests, its online supplementary material, and other information on the programme can be downloaded from the ICP Forests website[5].

Programme highlights in 2021

People

- We are extremely grateful to our colleague Peter Roskams for his dedication to ICP Forests, his expertise and friendship shared with us over the last 34 years. Peter left the Programme after being involved since 1987 and taking on various positions, e.g. as Chair of the EP Crown Condition and Damage Causes, member of the Programme Co-ordinating Group, and NFC representative for Belgium-Flanders.
- The lead country Germany has appointed a new representative after the retirement of Sigrid Strich. Juliane Henry from the Federal Ministry of Food and Agriculture has been warmly welcomed to the Programme.
- Michael Tatzber from the Austrian Research Centre for Forests BFW in Vienna has taken over the position as Chair of the Forest Foliar Co-ordination Centre (FFCC) from Alfred Fürst. Alfred will stay with us as Chair of the WG QA/QC in Laboratories.

Data Unit

- 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:
    - All structural problems and Manual changes known before last year's submission period were implemented successfully.
    - All data available in the database is now tested every night according to the latest checkroutines. The results, which provide an overview of any problems detected, are provided along with the data.

[1] https://unece.org/environment-policy/air
[2] http://icp-forests.net/page/icp-forests-manual
[3] http://icp-forests.net/page/data-requests
[4] http://icp-forests.org/open_data/
[5] http://icp-forests.net/page/icp-forests-technical-report

- Finally, a unique data structure was defined for all surveys, which considerably facilitates the submission of longer time series and improves the usability of the monitoring data.

Outreach and reporting

- Serious effects of the COVID-19 pandemic on the data collection, evaluation, and reporting of the forest monitoring under ICP Forests were reported from only a few countries; we thank all programme participants for their continuous effort and support in these difficult times.
- The new ICP Forests Brief No. 5[1] titled Tree health is deteriorating in the European forests reported that the proportion of fully foliated trees has declined over the past 30 years, while mean defoliation has increased, particularly since 2010. Insects and drought are the most frequently reported causes for tree damage.
- The results from the Working Group on Quality Assurance and Quality Control 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[2].
- A report on 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) was published in 2021 by Tine Bommarez, Nathalie Cools, and Bruno De Vos from the Research Institute for Nature and Forest (INBO) and ICP Forests Soil Co-ordinating Centre (FSCC) in Belgium. It can be downloaded from the ICP Forests website[3].
- The number of reported international, peer-reviewed publications using data that had either originated from the ICP Forests database or from ICP Forests plots remains high at 70 in 2021[4], thereby proving the relevance and use of the ICP Forests data and infrastructure in various research areas such as atmospheric deposition (esp. of nitrogen and sulfur), ozone concentrations, heavy metals, climate effects, tree condition and damage causes, forest biodiversity and deadwood, nutrient cycling, tree physiology, phenology, forest soils, and soil carbon.

Programme meetings

- The EMEP Steering Body and Working Group on Effects under the UNECE Air Convention met online 1–4 March 2021 and 13–16 September 2021[5], to discuss the progress in activities and further development of effects-oriented activities, e.g. with regard to the 2020-2021 workplan for the implementation of the Convention, the update of the WGE/EMEP scientific strategy, and the review of the Gothenburg protocol.
- At the Joint Expert Panel Meeting (8–12 March 2021), 233 registered participants joined online from 29 European countries and discussed current issues and developments in nine Expert Panels and Working Groups.
- The 37th ICP Forests Task Force Meeting was organized by the Swiss Federal Research Institute WSL and held as a hybrid meeting, 10–11 June 2020, with 58 participants from 27 countries.
- The 9th ICP Forests Scientific Conference FORECOMON on *Forest monitoring to assess forest functioning under air pollution and climate change* took place as a hybrid meeting at th Swiss Federal Research Institute WSL, 7–9 June 2021, with 23 oral and 61 poster presentations with authors and co-authors from 36 countries.
- The Programme Co-ordinating Group (PCG), Quality Assurance Committee, and Scientific Committee met in Berlin, 9–10 November 2021, to discuss current issues and the ICP Forests' further progress.

Acknowledgements

We wish to thank the Federal Ministry of Food and Agriculture (BMEL) and all participating countries for the continued implementation and financial support of the ICP Forests. We also thank the United Nations Economic Commission for Europe (UNECE) and the Thünen Institute for the partial funding of the ICP Forests Programme Co-ordinating Centre, and the Swiss Federal Research Institute WSL for supporting the Chairman.

Our sincere gratitude goes to Peter Waldner (NFC Switzerland) and his colleagues from the Swiss Federal Research Institute WSL and Sabine Augustin (Ministry Switzerland) and the Federal Office for the Environment (FOEN) for the organization and support of a smooth hybrid 37th Task Force Meeting of ICP Forests and FORECOMON 2021, 7–11 June 2021.

For more than 35 years the success of ICP Forests depends on the continuous support from 42 participating countries and the expertise of many dedicated individuals. We would like to hereby express again our sincere gratitude to everyone involved in the ICP Forests and especially to the participating countries for their ongoing commitment and co-operation in forest ecosystem monitoring across the UNECE region.

For a complete list of all countries that are participating in ICP Forests with their responsible Ministries and National Focal Centres (NFC), please refer to the Annex.

[1] http://icp-forests.net/page/icp-forests-briefs
[2] http://icp-forests.net/page/working-group-on-quality
http://icp-forests.net/page/icp-forests-other-publications
[3] http://icp-forests.net/page/icp-forests-other-publications
[4] http://icp-forests.net/page/publications
[5] https://unece.org/environment-policy/air

Table 1-1: Overview of the number of Level II plots per survey and country for which 2020 data were submitted to the ICP Forests Database by 27 June 2022

	Air quality	Crown condition	Deposition	Foliage	Ground vegetation	Ground vegetation biomass	Growth and yield	Leaf area index	Litterfall	Meteorology	Ozone injury	Phenology	Soil	Soil solution
Austria			15	16										
Belgium	5	13	9				5	5	5	9		5		9
Bulgaria		4	4		4				3					
Croatia	1	7	4	7					4		2	5		3
Cyprus	1	4	2							2			4	2
Czechia		15	7				15		7	11				7
Denmark		4	4				3		4	4		3		4
Estonia		6	6						1	1				5
Finland		6	7				6			8				8
France			27							13				14
Germany	38	46	78	41	33	13	40	22	49	69	17	60		58
Greece		4	3						4	4	4	3		3
Hungary		7	9				7	7		8	6			
Italy	6	28	7		8					7	6			3
Latvia	1	3	3						3					3
Lithuania	3	9	3								9			3
Norway		3	3		1									3
Poland	12	133	12											12
Romania			5				12	3		4		3		5
Serbia		5	5	3	5		4		5	5	5	5	1	3
Slovakia	3	9	7							6	4			4
Slovenia		10	4		5									
Spain	14	14	14				14	14	14	14	14	14		5
Sweden			50											
Switzerland	7	17	14							18	8			9
Turkey		52												
UK			5				3		4	5				5
Total	**91**	**399**	**307**	**67**	**56**	**13**	**109**	**51**	**103**	**188**	**75**	**98**	**5**	**168**

PART A

ICP Forests-related research highlights

2

FOREST CONDITION AND ENVIRONMENTAL DRIVERS IN EUROPE – RECENT EVIDENCE FROM SELECTED STUDIES

Marco Ferretti, Lars Vesterdal, Roberto Canullo, Nathalie Cools, Bruno De Vos, Stefan Fleck, Elena Gottardini, Leena Hamberg, Tom Levanič, Aldo Marchetto, Tiina M. Nieminen, Diana Pitar, Nenad Potočić, Pasi Rautio, Tanja Sanders, Volkmar Timmermann, Liisa Ukonmaanaho, Arne Verstraeten, Peter Waldner, Daniel Žlindra

Introduction

Marco Ferretti, Lars Vesterdal

ICP Forests reporting of activities to stakeholders (e.g. Air Convention bodies, Participating countries) is largely based on data and results produced by the Programme but should be also viewed in the perspective of other scientific sources.

Here we present a brief overview prepared by all the ICP Forests Expert Panels (EPs) and reviewed by the Scientific Committee. EPs were asked to provide an overview of main evidence and key findings in their subject areas over the past year and as prioritized within the Working Group on Effects (WGE) strategic planning under the UNECE Air Convention: nitrogen (N) deposition, ozone, heavy metals, air pollution/climate change interactions.

EPs based their input on approximately five arbitrarily selected recent papers that did not necessarily originate from the ICP Forests network. As agreed at the Programme Co-ordinating Group Meeting in 2021, scientific publications were selected if (1) peer-reviewed; (2) from the reporting year or the year before, if not yet included; (4) covering emerging issues; and (5) relevant to the UNECE Air Convention. A further requirement that studies should include data from more than one country, was not always considered, as many valuable studies were carried out at national level. In the future, the selection procedure will be further refined.

In the following, we summarize the main evidence according to three main ecosystem compartments: atmosphere, forest vegetation, and forest soil. Given the interrelationships and the continuous flux of energy and matter across the three compartments, some overlap will of course exist among the different chapters. Connection and interrelationships are particularly important in view of the interactions between the abiotic and biotic environment, and specifically air pollution, deposition, climate change and extreme events.

Recent evidence from selected studies

1 Atmosphere

1.1 Atmospheric deposition

Arne Verstraeten, Peter Waldner, Daniel Žlindra, Aldo Marchetto

Recent work focused on shifts in N and sulfur (S) deposition, the refining of methods for deposition monitoring and critical loads for sensitive lichens in relation to climate change.

Marchetto et al. (2021) conducted a study aiming to further improve both measurements and model-based estimates of S and N deposition in Europe. Measured N and S depositions from EMEP and ICP Forests, two largely independent networks covering most of Europe, were compared to depositions calculated with the EMEP MSC-W model. A generally good agreement (bias <25%) was found for S and nitrate deposition in the open field. For ammonium, however, differences were larger at some sites due to local ammonia sources, which could not be accounted for by the current model.

Chang et al. (2021) evaluated long-term changes in precipitation acidity and the composition of acidifying compounds using data from three different networks across North America, Europe, and East Asia. They found a general tendency towards increasing pH in North America and Europe owing to the reduction of SO_2 emissions. With regard to N, deposition evolved from nitrate- to ammonium-dominated.

Long-term trends of total (dry + wet) inorganic N deposition in Swedish forests were evaluated by Karlsson et al. (2021), showing somewhat larger decreases than expected from the decrease in the reported emissions in Europe. They emphasized the need to include estimates of dry deposition in the assessment of N deposition in forests.

Geiser et al. (2021) reassessed critical loads for epiphytic macrolichens in US forests and studied the interaction between effects of N deposition, relative humidity, temperature and precipitation on lichen communities. Critical loads were estimated to be 1.5 kg ha^{-1} y^{-1} N deposition and 2.7 kg ha^{-1} y^{-1} S deposition, which is extremely low, confirming the high sensitivity to air pollution of this group of organisms.

Interestingly, the study suggested that a reduction in N depositions could mitigate the expected negative effects of climate change on forest lichen communities.

1.2 Tropospheric ozone

Diana Pitar, Elena Gottardini

There is a general agreement about the need to adopt a flux-based risk assessment for the protection of European forests to tropospheric ozone (O_3). A study on the stomatal ozone fluxes carried out at low-elevation forest sites in Western Germany over the period 1998–2019 pointed out the importance to account for both O_3- and drought-induced effects on forest physiology and health: During growing seasons with sufficient water supply – and often lower O_3 levels – forests are at higher O_3 risk than during hot and dry periods (Eghdami et al. 2022).

As for the impact of O_3 on vegetation, the integrated effect of climate and O_3 fluxes on intra-annual tree ring increments of *Picea abies*, *Pinus sylvestris*, *Betula pendula*, and *Betula pubescens* was studied in the north-eastern part of Lithuania during the 2016–2018 period. Surface O_3 fluxes stimulated shrinking and inhibited the swelling of the tree stem, which resulted in a reduction of tree ring width in all tree species (Augustaitis 2021). Applying the ICP Forests protocol for assessment of leaf O_3 injury, Sicard et al. (2021) found a significant correlation between the percentage of symptomatic plant species within the light exposed sampling site (LESS) and POD1, based on observations carried out at nine Level II Italian forest monitoring sites over 2017–2019. The results confirm the suitability of this plant-response indicator for the assessment of phytotoxic O_3 levels in forests. In addition, a critical level of 11 mmol m^{-2} POD1 was recommended for forest protection against O_3 injury. The appearance of visible symptoms on hybrid poplar leaves was preceded by microscopic necrosis that developed weeks before and at half the phytotoxic O_3 dose (Turc et al. 2021). Notwithstanding the initial visible injury to foliage, the treated poplars had still not shown any growth or biomass reduction.

During the 21st century, simulations suggest a decrease of O_3 due to air pollution control; this decrease, combined with the indirect effects of rising atmospheric CO_2 concentration, which reduces stomatal uptake of O_3 and increases water use efficiency, should lead to the decline of O_3-induced reductions in northern hemispheric gross primary production (GPP) and carbon uptake. However, in hot spot regions such as East Asia, the model simulations suggest a sustained decrease in GPP by more than 8% throughout the 21st century (Franz and Zaehle 2021). Thus, it is important to continue the monitoring of O_3 and the assessment of effects considering the possible role of other environmental factors.

2 Forest vegetation

2.1 Forest growth

Tanja Sanders, Tom Levanič

After the drought years of 2018 and 2019, insights into tree responses emerged. Changes in tree growth in response to various environmental factors have therefore become increasingly important. Several studies investigated the response of beech (*Fagus sylvatica* L.) to drought and reported increased decline and mortality. It was found that basal area increment in 2018 was significantly lower than the average annual increment in previous years (Rohner et al. 2021).

Salomón et al. (2022) used near real-time dendrometer data to show that there appeared to be no impact on growth during the drought period, only on stem hydration; thus, the question is whether we can capture the current processes.

Detailed analyses of the effects of ozone (Jakovljević et al. 2021) or the composition of ectomycorrhizal fungi (Anthony et al. 2022) further increase the complexity of factors affecting growth, highlighting the need for multifactor studies.

2.2 Forest health

Nenad Potočić, Volkmar Timmermann, Tom Levanič

Tree growth and defoliation are widely used as indicators of tree vitality and forest health, despite being non-specific in terms of causes. Approaches to investigate defoliation as an indicator of forest health (mean values, defoliation classes, detrended values) are related to different research approaches and research goals, or simply to the fact that many climatic and non-climatic (structural, abiotic/biotic, etc.) factors influence defoliation as an overarching, general indicator of tree health and vitality. Regarding tree growth as an indicator of tree/forest health, various measures of growth are commonly used (annual/periodical basal area increment, radial increment, etc.), which is dictated both by the diversity of available data and the research design and needs.

Recent papers dealing with the association of tree defoliation and growth are building on the pool of knowledge accrued from the early 1990s onwards and are now aiming at a fresh perspective. For instance, Ferretti et al. (2021a) used the mean periodical defoliation (averaged over ten years) and the 10-year cumulated growth to determine possible negative effects of defoliation on tree growth across 91 Level II plots in France. They found that basal area increment (BAI) is consistently negatively and significantly related to mean defoliation, across functional groups and for most of the individual tree species considered, at a rate of 0.9% per unit increase of defoliation. The difference in BAI becomes significant at 15% (overall) and 15–30% (individual species) defoliation levels, thus providing evidence that the 25%-defoliation threshold adopted by international monitoring

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programs can be a reasonable approximation for tree health classification.

Tallieu et al. (2020), on the other hand, aimed to identify defoliation and radial increment signals in beech (*Fagus sylvatica* L.) in relation to climate, and opted to keep only high-frequency inter-annual signals. This led to the conclusion that several climatic drivers have an effect on both radial growth and crown condition, where previous-year climatic variables tend to control defoliation, while radial growth is more sensitive to current-year climate. In terms of sensitivity of tree health indicators, radial growth presented a strong common signal among trees, while the response of defoliation was more distinct at the individual tree level, resulting in defoliation capturing fewer pointer years than radial growth.

Regarding the applicability of defoliation as an indicator of tree vitality, Ferretti et al. (2021b) found that the relationship between defoliation and growth changes in relation to the time scale considered, becoming stronger when data are aggregated over longer time scales. This effect is likely due to the mechanisms behind the defoliation-growth relationship and is modified according to the factors causing damage. Nevertheless, in the view of the significant negative relation of radial growth to defoliation the study supports the use of defoliation as a rapid indicator of forest health and vitality.

Regardless of the research approaches used, or the results of these studies, the number of recent papers that discuss the relation of growth and defoliation, coupled with some ongoing research projects on similar topics, underline the importance of long-term monitoring of crown condition and growth as main tree health indicators, as well as the need for continuous supply of pan-European, harmonized forest monitoring data in the years to come.

2.3 Forest nutrition

Pasi Rautio, Liisa Ukonmaanaho

The highligted studies from the last year focused on characterization of plant-available soil nutrients and variation in foliar N and phosphorus (P) contents as affected by fruit production and prescribed burning.

Bel et al. (2020) found that for 81%, 87% and 90% of the soil samples (respectively for calcium, magnesium and potassium (K), the plant-available pools measured by isotopic dilution were greater than the conventional exchangeable pool of the same nutrients.

Nussbaumer et al. (2021) reported that leaf N and P contents decreased with increasing fruit production in *Fagus sylvatica* and *Quercus* species, as did leaf carbon (C) content in *Fagus sylvatica*. Overall, their findings suggest different resource dynamics strategies in *Fagus sylvatica* and *Quercus* species, which might in turn lead to differences in their adaptive capacity to a changing climate.

Espinosa et al. (2020) observed an increasing trend in N, P, and K concentrations in needles after prescribed burning treatment in a mixed stand of *Pinus nigra* and *Pinus pinaster* at the El Pozuelo site, as well as in a pure stand of *Pinus nigra* at the Beteta site in the Cuenca Mountains.

Finally, Prescott and Vesterdal (2021) reviewed recent key developments and the current understanding of litter decomposition and transformation processes as well as pathways for organic matter incorporation in forest soils. They highlighted e.g. the following issues: (i) The labile component of litter is a principle source of soil organic matter (SOM). (ii) The 'maximum decomposition limit' represents the proportion of litter material that has been transformed into persistent by-products rather than the amount that has not been decomposed. (iii) Decomposition and soil incorporation of organic matter can follow several pathways, depending on the site conditions (climate, parent material, soil characteristics), soil biota and vegetation.

2.4 Forest tree phenology

Stefan Fleck

There is consensus that human influence has warmed the atmosphere, ocean and land, and each of the last four decades has been successively warmer than any decade that preceded it since 1850 (IPCC 2021). These climate changes substantially alter the phenology of forest trees. In the years 2020 and 2021, significant advances were achieved in phenological modelling of canopy foliage status. Nölte et al. (2020) improved the phenological submodels for budburst and leaf senescence of oak in the 3-PG model using extensive datasets from Germany and France. While budburst was modelled based on a regression of its anomaly to mean spring temperature, the anomaly of leaf senescence was modelled as a regression to mean temperature of October.

Gárate-Escamilla et al. (2020) developed a new leaf senescence model for beech based on mean temperature in September, October, and November in the population area of the beech provenance and of the same temperature variable at the actual location of the beech stand. In their linear mixed model, they found that early dates of budburst are correlated with early dates of leaf senescence when populations originate from warmer regions in Europe, while the combination of early budburst with late leaf senescence is typical for colder origins e.g. in the northern countries in Europe.

The climatic adaptation of trees also plays a role in budburst models: Liang and Wang (2021) showed that a basic degree day budburst model, applied to data of 14 tree species in the USA National Phenology Network, is improved when climatic adaptation is considered in an empirical way in the model. The multivariate linear model of Marchand et al. (2020) models the inter-individual variability of budburst of oak, beech, and silver birch based on previous year's onset of leaf senescence and tree size and could explain 66% of the budburst variability. A model comparison for budburst models of birch, larch, spruce, ash and hazel was made by Asse et al. (2020) based on eight years of data from the French Alps, with the conclusion that process-based models are more robust under climate change conditions than purely correlative models.

The influence of photoperiod on budburst of beech, oak, ash, alder, birch, and horse chestnut was modelled by Meng et al. (2021) based on 36 years of observations from the Pan European Phenological Network in the Northern Alps. They propose two alternative model formulations to consider photoperiod. Journé et al. (2021) modelled fruit production of beech and oak and discovered an effect of current year canopy duration on top of the well-known effect of previous summer temperature.

2.4 Forest biodiversity and ground vegetation

Leena Hamberg, Roberto Canullo

Richard et al. (2021) investigated the temporal dynamics of understory vegetation responses to climate change. They found a time lag in the response of temperate forest understory vegetation to warming climate: the velocity at which atmospheric air temperatures are rising is twice as fast as the velocity at which understory plant communities are responding. The lag in the response of herbaceous plant communities to climate warming increased linearly over time. Greater lags were observed in plots with warmer baseline temperature conditions, and in denser and older forests. No clear differences were found between coniferous and deciduous forests nor between inside and outside of the fenced forested sample plot area (effect of herbivores). However, forest disturbances and anthropogenic disturbances had a negative effect on the lag.

In a study by Kermavnar et al. (2021), local stand characteristics and soil properties were the main controlling factors for both species and trait diversity in herb-layer communities across Slovenia whereas climatic parameters had a minor role.

Kaarlejärvi et al. (2021) investigated temporal turnover of the boreal forest understory in Finland in response to anthropogenic disturbance, especially forest management, along a soil fertility gradient. They found that changes in vascular plant communities in boreal forests were driven jointly by time since disturbance and fertility. The greatest change was observed in the most fertile forest stands during the first decade after a major disturbance, such as clear-cutting, but fertility was not a driver of community change in the oldest forests.

Frey et al. (2021) investigated the vertical distribution of the soil microbiome to a depth of 2 m in Swiss drought-exposed forests. With increasing soil depth fungal biomass and microbial diversity in soils decreased. However, bacterial abundance increased with soil depth. Bacterial and fungal communities varied significantly across the soil layers, especially among bacteria. Changes in microbial communities were associated with decreasing organic carbon, nitrogen, and clay content when soil depth increased. Both bacteria and fungi were also affected by tree species and substrate. In deep soil layers, poorly known bacterial, archaeal and fungal taxa were found.

3 Forest soil

Bruno De Vos, Nathalie Cools, Tiina Nieminen

3.1 Soil solid phase

Long-term ecosystem research continues to support that the N cycle interacts in a complex way with climate change and with all ecosystem compartments, among others soil, plants and micro-organisms. Anthony et al. (2022) showed that fast tree growth could be associated with ectomycorrhizal fungi that are more affiliated to inorganic and less to organic nitrogen acquisition. When including climate change scenarios in future projections of carbon and nitrogen cycles, Schlutow et al. (2021) expects for German forest soils that the litter decomposition rates will increase. However, Kwon et al. (2021) suggested that the projected increases in N deposition may have the capacity to dampen the climate-driven increases in litter decomposition, depending on the biome and decomposition stage of substrate. In Andalusia, forest health studies revealed the relevance of spatio-temporal changes in environmental factors including soil properties such as organic matter content, soil moisture and nutrient availability (Sánchez-Cuesta et al. 2021).

3.2 Soil solution

The decreasing trend in deposition since the 1990s seems to cause several changes in the nutrient balances in the forests. Soil solution chemistry continues to show decreasing S-SO_4 concentrations but on the other hand an increasing trend in dissolved organic carbon (Bardule et al. 2021, Sawicka et. 2021). In Germany, Brumme et al. (2021) showed in seven beech stands that most of the deposited nitrogen is retained in the trees, especially in the stands on less acidic soils, and that 28% is retained in the soil with high N/P and C/P ratios. P limitation in European forest soils is observed in more and more studies (Du et al. 2021; He et al. 2021), especially in combination with seasonal drought (Asensio et al. 2021).

Conclusions

Marco Ferretti, Lars Vesterdal

There was important evidence that emerges from the overview, and that shows in which scientific advancements ICP Forests data can play an important role.

(i) Air pollution continues to affect forest ecosystems. Still today, several forest ecosystem compartments (from trees to ground vegetation, mosses and lichens, including their diversity, composition of soil and soil solution) and processes (tree nutrition, tree growth, soil acidification, N and P cycling) are

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affected by air pollution, namely by N deposition, ground-level ozone, and heavy metals. While the acidity of precipitation is decreasing due to successful reduction of anthropogenic S emissions, N deposition is becoming more ammonium-dominated, and effects of local ammonia-emitting sources remain a challenge to modelling and mapping. The need for continuous monitoring remains in order to document and mitigate these effects on forest ecosystems.

(ii) Air pollution changes, and its effects on forests are diversified. Increased pH in precipitation in North America and Europe, a shift from nitrate to ammonium dominated N deposition, and possible future reduction of tropospheric ozone were reported. On the other side, the N deposition level remains high in several European regions and has been found to affect tree growth, lead to imbalances in tree nutrition, promote soil acidification, and affect the composition of understory communities of plants, mosses, and lichens. Ozone has been reported as a potential threat to biodiversity, tree growth and health, although effects are not always unidirectional. The multi-level, multi-media monitoring concept of ICP Forests proves to be essential to assess and model the condition of forest ecosystems, and to favor comparisons between models and measurements. It should be reinforced with e.g. a remote sensing component.

(iii) New insights to explain ecosystem responses. Novel methods and approaches provide new opportunities to unravel the mechanisms, processes and organism interactions by which ecosystems respond to air pollution and climate change. An example is the study of ectomycorrhizal community composition at ICP Forests Level II plots, which revealed an association between high rates of tree growth and ectomycorrhizal communities adapted to inorganic rather than organic N acquisition, a characteristic of forests with high N deposition. The role of the soil microbiome and its diversity for vitality and growth of forest trees under increasing stress from air pollution and climate change is a promising topic for integration in long-term forest monitoring and research, as shown also by other studies.

(iv) Climate change – a key driver and modifier of air pollution effects. Recent drought episodes coupled with high air temperatures in different parts of Europe have been shown to affect tree vitality, growth, nutrition and phenology at different scales. Alongside, windstorms hit several regions across Europe, causing devastating windthrow damage. Both disturbance factors (drought and windstorms) caused subsequent bark beetle infestations. It is likely that extreme events related to climate change will increase in frequency, and this will cause additional pressure on European forests. When considering the enduring pressure caused by air pollution in different forms and the projected increasing frequency of climate change-related events, there is an urgent need to better understand their interactions. An example mentioned by several authors is the observed interaction between N deposition, ozone and drought that can result in very diversified effects. While a considerable body of knowledge exists in terms of experimental studies under controlled conditions, evidence from observational studies of European forest ecosystems is still limited. Among others, this is an area of clear concern for the Air Convention, and where progress in scientific understanding and assessment remains necessary.

References

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. (in press). https://doi.org/10.1038/s41396-021-01159-7

Asensio D, Zuccarini P, Ogaya R, et al (2021) **Simulated climate change and seasonal drought increase carbon and phosphorus demand in Mediterranean forest soils.** Soil Biol Biochem 163:108424. https://doi.org/10.1016/j.soilbio.2021.108424

Asse D, Randin CF, Bonhomme M, et al (2020) **Process-based models outcompete correlative models in projecting spring phenology of trees in a future warmer climate.** Agr For Met 285-286:107931. https://doi.org/10.1016/j.agrformet.2020.107931

Augustaitis A (2021) **Intra-annual variation of stem circumference of tree species prevailing in hemi-boreal forest on hourly scale in relation to meteorology, solar radiation and surface ozone fluxes.** Atmosphere 12:1017. https://doi.org/10.3390/atmos12081017

Bārdule A, Bārdulis A, Polmanis K, et al (2021) **Trends of Scots pine forest health and element flow changes in the ICP Forests monitoring sites in Latvia.** Balt For 27. https://doi.org/10.46490/BF536

Bel J, Legout A, Saint-André L, et al (2020) **Conventional analysis methods underestimate the plant-available pools of calcium, magnesium and potassium in forest soils.** Scientific Reports 10:15703. https://doi.org/10.1038/s41598-020-72741-w

Brumme R, Ahrends B, Block J, et al (2021) **Cycling and retention of nitrogen in European beech (*Fagus sylvatica* L.) ecosystems under elevated fructification frequency.** Biogeosciences 18:3763–3779. https://doi.org/10.5194/bg-18-3763-2021

Chang C-T, Yang C-J, Huang K-H, et al (2021) **Changes of precipitation acidity related to sulfur and nitrogen deposition in forests across three continents in north hemisphere over last two decades.** Sci Total Environ 806:150552. https://doi.org/10.1016/j.scitotenv.2021.150552

Du E, Doorn M, de Vries W (2021) **Spatially divergent trends of nitrogen versus phosphorus limitation across European forests.** Sci Total Environ 771:145391. https://doi.org/10.1016/j.scitotenv.2021.145391

Eghdami H, Werner W, Bueker P, et al (2022) **Assessment of ozone risk to Central European forests: Time series indicates perennial exceedance of ozone critical levels.** Environ Res 203:111798. https://doi.org/10.1016/j.envres.2021.111798

Espinosa J, Madrigal J, Pando V, et al (2020) **The effect of low-intensity prescribed burns in two seasons on litterfall biomass and nutrient content.** Int J Wildland Fire 29:1029-1041. https://doi.org/10.1071/WF19132

Ferretti M, Bacaro G, Brunialti G, et al (2021a) **Tree canopy defoliation can reveal growth decline in mid-latitude temperate forests.** Ecol Indic 127:107749. https://doi.org/10.1016/j.ecolind.2021.107749

Ferretti M, Ghosh S, Gottardini E (2021b) **Stem radial growth is negatively related to tree defoliation and damage in conifers, Northern Italy.** Front For Glob Change 4:775600. https://doi.org/10.3389/ffgc.2021.775600

Franz M, Zaehle S (2021) **Competing effects of nitrogen deposition and ozone exposure on northern hemispheric terrestrial carbon uptake and storage, 1850-2099.** Biogeosciences 18:3219–3241 https://doi.org/10.5194/bg-18-3219-2021

Frey B, Walthert L, Perez-Mon C, et al (2021) **Deep soil layers of drought-exposed forests harbor poorly known bacterial and fungal communities.** Front Microbiol 12. https://doi.org/10.3389/fmicb.2021.674160

Gárate-Excamilla H, Brelsford CC, Hampe A, et al (2020) **Greater capacity to exploit warming temperatures in northern populations of European beech is partly driven by delayed leaf senescence.** Agr For Met 284:107908. https://doi.org/10.1016/j.agrformet.2020.107908

Geiser LH, Root H, Smith RJ, et al (2021) **Lichen-based critical loads for deposition of nitrogen and sulfur in US forests.** Environ Pollut 291: 118187. https://doi.org/10.1016/j.envpol.2021.118187

He H, Jansson P-E, Gärdenäs AI (2021) **CoupModel (v6.0): an ecosystem model for coupled phosphorus, nitrogen, and carbon dynamics – evaluated against empirical data from a climatic and fertility gradient in Sweden.** Geosci Model Dev 14, 735–761. https://doi.org/10.5194/gmd-14-735-2021

IPCC (2021). **Climate Change 2021: The Physical Science Basis.** Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte V, P Zhai, A Pirani, et al (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

Jakovljević T, Lovreškov L, Jelić G, et al (2021) **Impact of ground-level ozone on Mediterranean forest eco-systems health.** Sci Total Environ 783:147063. https://doi.org/10.1016/j.scitotenv.2021.147063

Journé V, Caignard T, Hacket-Pain A, et al (2021) **Leaf phenology correlates with fruit production in European beech (*Fagus sylvatica*) and in temperate oaks (*Quercus robur* and *Quercus petraea*).** Eur J For Res 140:733-744. https://doi.org/10.1007/s10342-021-01363-2

Kaarlejärvi E, Salemaa M, Tonteri T, et al (2021) **Temporal biodiversity change following disturbance varies along an environmental gradient.** Glob Ecol Biogeogr 30:476–489. https://doi.org/10.1111/geb.13233

Karlsson P E, Akselsson C, Hellsten S, et al (2021) **Twenty years of nitrogen deposition to Norway spruce forests in Sweden.** Sci Total Environ 809:152192. http://doi.org/10.1016/j.scitotenv.2021.152192

Kermavnar J, Kutnar L, Marinšek A (2021) **Disentangling the ecological determinants of species and functional trait diversity in herb-layer plant communities in European temperate forests.** Forests 12:552. https://doi.org/10.3390/f12050552

Kwon T, Shibata H, Kepfer-Rojas S, et al (2021) **Effects of climate and atmospheric nitrogen deposition on early to mid-term stage litter decomposition across biomes.** Front For Glob Change 4:678480. https://doi.org/10.3389/ffgc.2021.678480

Liang L, Wu J (2021) **An empirical method to account for climatic adaptation in plant phenology models.** Int J Biometeorol 65:1953-1966. https://doi.org/10.1007/s00484-021-02152-7

Marchand LJ, Dox I, Gricar J. et al (2020) **Inter-individual variability in spring phenology of temperate deciduous trees depends on species, tree size and previous year autumn phenology.** Agr For Met 290:108031. https://doi.org/10.1016/j.agrformet.2020.108031

Marchetto A, Simpson D, Aas W, et al (2021) **Good agreement between modeled and measured sulfur and nitrogen deposition in Europe, in spite of marked differences in some sites.** Front Environ Sci 9:734556. https://doi.org/10.3389/fenvs.2021.734556

Meng L, Zou Y, Gu L, et al (2021) **Photoperiod decelerates the advance of spring phenology of six deciduous tree species under climate warming.** Glob Change Biol 27:2914-2927. https://doi.org/10.1111/gcb.15575

Nölte A, Yousefpour R Hanewinkel M (2020) **Changes in sessile oak (*Quercus petraea*) productivity under climate change by improved leaf phenology in the 3-PG model.** Ecol Model 438:109285. https://doi.org/10.1016/j.ecolmodel.2020.109285

Nussbaumer A, Gessler A, Benham S, et al (2021) **Contrasting resource dynamics in mast years for European beech and oak – A continental scale analysis.** Front For Glob Change 4:689836. https://doi.org/10.3389/ffgc.2021.689836

Prescott CE, Vesterdal L (2021) **Tamm reviews: Decomposition and transformations along the continuum from litter to soil organic matter in forest soils.** Forest Ecol Manag 49:119522. https://doi.org/10.1016/j.foreco.2021.119522

Richard B, Dupouey J, Corcket E, et al (2021) **The climatic debt is growing in the understorey of temperate forests: Stand characteristics matter.** Glob Ecol Biogeogr 30:1474–1487. https://doi.org/10.1111/geb.13312

Rohner B, Kumar S, Liechti K, et al (2021) **Tree vitality indicators revealed a rapid response of beech forests to the 2018 drought.** Ecol Indic 120:106903. https://doi.org/10.1016/j.ecolind.2020.106903

Salomón RL, Peters RL, Zweifel R, et al (2022) **The 2018 European heatwave led to stem dehydration but not to consistent growth reductions in forests.** Nat Commun 13:1-11. https://doi.org/10.1038/s41467-021-27579-9

Sánchez-Cuesta R, Ruiz-Gómez FJ, Duque-Lazo J, et al (2021) **The environmental drivers influencing spatio-temporal dynamics of oak defoliation and mortality in dehesas of Southern Spain.** For Ecol Manag 485:118946. https://doi.org/10.1016/j.foreco.2021.118946

Sawicka K, Clark JM, Vanguelova E, et al (2021) **Spatial properties affecting the sensitivity of soil water dissolved organic carbon long-term median concentrations and trends.** Sci Total Environ 780:146670. https://doi.org/10.1016/j.scitotenv.2021.146670

Schlutow A, Schröder W, Jenssen M, et al (2021) **Modelling of soil characteristics as basis for projections of potential future forest ecosystem development under climate change and atmospheric nitrogen deposition.** Environ Sci Eur 33:87. https://doi.org/10.1186/s12302-021-00526-7

Sicard P, Hoshika Y, Carrari E (2021) **Testing visible ozone injury within a Light Exposed Sampling Site as a proxy for ozone risk assessment for European forests.** J For Res32:1351–1359 https://doi.org/10.1007/s11676-021-01327-7

Tallieu C, Badeau V, Allard D, et al (2020) **Year-to-year crown condition poorly contributes to ring width variations of beech trees in French ICP Level I network.** For Ecol Manag 465:118071. https://doi.org/10.1016/j.foreco.2020.118071

Turc B, Vollenweider P, Le Thiec D, et al (2021) **Dynamics of foliar responses to O_3 stress as a function of phytotoxic O_3 dose in hybrid poplar.** Front Plant Sci 12:679852. https://doi.org/10.3389/fpls.2021.679852

3 OVERVIEW OF ICP FORESTS-RELATED PUBLICATIONS (JANUARY – DECEMBER 2021)

Between January and December 2021, data that had either originated from the ICP Forests database or from ICP Forests plots were part of several international, peer-reviewed publications in various research areas, thereby expanding the scope of scientific findings beyond air pollution effects. These are compiled in the following list.

In addition, many publications – not reported here – cite the ICP Forests Manual[1], which reflects the high value and appreciation of standardized methods in forest ecosystem research.

The following overview includes 70 English online and in print publications from 2021 that have been reported to the ICP Forests Programme Co-ordinating Centre by the publication date of this report and added to the list of ICP Forests publications on the program's website[2].

Achilles F, Tischer A, Bernhardt-Römermann M, et al (2021) **Effects of moderate nitrate and low sulphate depositions on the status of soil base cation pools and recent mineral soil acidification at forest conversion sites with European beech ("Green Eyes") embedded in Norway spruce and Scots pine stands.** Forests 12:573. https://doi.org/10.3390/f12050573

Akselsson C, Kronnäs V, Stadlinger N, et al (2021) **A Combined Measurement and Modelling Approach to Assess the Sustainability of Whole-Tree Harvesting—A Swedish Case Study.** Sustainability, 13, 2395. https://doi.org/10.3390/su13042395

Alekseev A, Chernikhovskii D (2021) **Assessment of the health status of tree stands based on Sentinel - 2B remote sensing materials and the short-wave vegetation index SWVI.** IOP Conf Ser Earth Environ Sci 876:012003. https://doi.org/10.1088/1755-1315/876/1/012003

Alekseev A, Chernikhovskii D, Vetrov L, et al (2021) **Determination of the state of forests based on a regular grid of ground-based sample plots and Sentinel-2B satellite imagery using the k-NN ("nearest neighbor") method.** IOP Conf Ser Earth Environ Sci 876:012002. https://doi.org/10.1088/1755-1315/876/1/012002

André F, de Wergifosse L, de Coligny F, et al (2021) **Radiative transfer modeling in structurally complex stands: towards a better understanding of parametrization.** Ann For Sci 78. https://doi.org/10.1007/s13595-021-01106-8

Aromolo R, Moretti V, Sorgi T (2021) **Setting up optimal meteorological networks: an example from Italy**. Strategic Planning for Energy and the Environment 40(1). https://doi.org/10.13052/spee1048-5236.4013

Bārdule A, Bārdulis A, Polmanis K, et al (2021) **Trends of Scots pine forest health and element flow changes in the ICP Forests monitoring sites in Latvia.** Balt For 27. https://doi.org/10.46490/BF536

Bose AK, Scherrer D, Camarero JJ, et al (2021) **Climate sensitivity and drought seasonality determine post-drought growth recovery of *Quercus petraea* and *Quercus robur* in Europe.** Sci Total Environ 784:147222. https://doi.org/10.1016/j.scitotenv.2021.147222

Brumme R, Ahrends B, Block J, et al (2021) **Cycling and retention of nitrogen in European beech (*Fagus sylvatica* L.) ecosystems under elevated fructification frequency.** Biogeosciences 18:3763–3779. https://doi.org/10.5194/bg-18-3763-2021

Bussotti F, Papitto G, Di Martino D, et al (2021) **Defoliation, recovery and increasing mortality in Italian forests: levels, patterns and possible consequences for forest multifunctionality.** Forests 12:1476. https://doi.org/10.3390/f12111476

Cade SM, Clemitshaw KC, Molina-Herrera S, et al (2021) **Evaluation of LandscapeDNDC Model Predictions of CO_2 and N_2O Fluxes from an Oak Forest in SE England.** Forests 12:1517. https://doi.org/10.3390/f12111517

Cecchini G, Andreetta A, Marchetto A, Carnicelli S (2021) **Soil solution fluxes and composition trends reveal risks of nitrate leaching from forest soils of Italy.** CATENA 200:105175. https://doi.org/10.1016/j.catena.2021.105175

Češljar G, Đorđević I, Brašanac-Bosanac L, et al (2021) **Determination of forest decline due to the action of dominant stress factor through monitoring of defoliation – case study of Maljen, Serbia.** Agriculture & Forestry 67 (2):211–226. https://doi.org/10.17707/AgricultForest.67.2.15

D'Andrea E, Scartazza A, Battistelli A, et al (2021) **Unravelling resilience mechanisms in forests: role of non-structural carbohydrates in responding to extreme weather events.** Tree Physiol 41:1808–1818. https://doi.org/10.1093/treephys/tpab044

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[1] http://icp-forests.net/page/icp-forests-manual

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

De Vos B, Cools N, Verstraeten A, Neirynck J (2021) **Accurate measurements of forest soil water content using FDR sensors require empirical in situ (re)calibration.** Appl Sci 11:11620. https://doi.org/10.3390/app112411620

Ding Y, Leppälammi-Kujansuu J, Salemaa M, et al (2021) **Distinct patterns of below- and aboveground growth phenology and litter carbon inputs along a boreal site type gradient.** For Ecol Manag 489:119081. https://doi.org/10.1016/j.foreco.2021.119081

Du E, Doorn M, de Vries W (2021) **Spatially divergent trends of nitrogen versus phosphorus limitation across European forests.** Sci Total Environ 771:145391. https://doi.org/10.1016/j.scitotenv.2021.145391

Ferretti M (2021) **New appetite for the monitoring of European forests.** Ann For Sci 78. https://doi.org/10.1007/s13595-021-01112-w

Ferretti M, Bacaro G, Brunialti G, et al (2021a) **Tree canopy defoliation can reveal growth decline in mid-latitude temperate forests.** Ecol Indic 127:107749. https://doi.org/10.1016/j.ecolind.2021.107749

Ferretti M, Ghosh S, Gottardini E (2021b) **Stem radial growth is negatively related to tree defoliation and damage in conifers, Northern Italy.** Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.775600

Forsius M, Posch M, Holmberg M, et al (2021) **Assessing critical load exceedances and ecosystem impacts of anthropogenic nitrogen and sulphur deposition at unmanaged forested catchments in Europe.** Sci Total Environ 753:141791. https://doi.org/10.1016/j.scitotenv.2020.141791

Frey B, Walthert L, Perez-Mon C, et al (2021) **Deep soil layers of drought-exposed forests harbor poorly known bacterial and fungal communities.** Front Microbiol 12. https://doi.org/10.3389/fmicb.2021.674160

Gagić-Serdar R, Marković M, Češljar G, et al (2021) **Most common species of defoliating insects of broadleaved forests: ICP Level I monitoring in 2021.** Sustain For Collect 79–92. https://doi.org/10.5937/SustFor2183079G

Gazol A, Camarero JJ (2021) **Compound climate events increase tree drought mortality across European forests.** Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2021.151604

George J-P, Neumann M, Vogt J, et al (2021) **Assessing effects of drought on tree mortality and productivity in European forests across two decades: a conceptual framework and preliminary results.** IOP Conf Ser Earth Environ Sci 932:012009. https://doi.org/10.1088/1755-1315/932/1/012009

Gies H, Hagedorn F, Lupker M, et al (2021) **Millennial-age glycerol dialkyl glycerol tetraethers (GDGTs) in forested mineral soils: C-based evidence for stabilization of microbial necromass.** Biogeosciences 18:189–205. https://doi.org/10.5194/bg-18-189-2021

Greve M, Block J, Schüler G, Werner W (2021): **Long term effects of forest liming on the acid-base budget**. Appl. Sci. 11 (3), 1–14. https://doi.org/10.3390/app11030955

Haesen S, Lembrechts JJ, De Frenne P, et al (2021) **ForestTemp – Sub-canopy microclimate temperatures of European forests.** Glob Change Biol 27:6307–6319. https://doi.org/10.1111/gcb.15892

He H, Jansson P-E, Gärdenäs AI (2021) **CoupModel (v6.0): an ecosystem model for coupled phosphorus, nitrogen, and carbon dynamics – evaluated against empirical data from a climatic and fertility gradient in Sweden.** Geosci Model Dev 14:735–761. https://doi.org/10.5194/gmd-14-735-2021

Heitkamp F, Ahrends B, Evers J, Meesenburg H. (2021) **Spatial 3D mapping of forest soil carbon stocks in Hesse, Germany**. J. Plant Nutr. Soil Sci. https://doi.org/10.1002/jpln.202100138

Högberg P, Wellbrock N, Högberg MN, et al (2021) **Large differences in plant nitrogen supply in German and Swedish forests – Implications for management.** For Ecol Manag 482:118899. https://doi.org/10.1016/j.foreco.2020.118899

Jenssen M, Nickel S, Schröder W (2021a) **Methodology for classifying the ecosystem integrity of forests in Germany using quantified indicators.** Environ Sci Eur 33. https://doi.org/10.1186/s12302-021-00478-y

Jenssen M, Nickel S, Schütze G, Schröder W (2021b) **Reference states of forest ecosystem types and feasibility of biocenotic indication of ecological soil condition as part of ecosystem integrity and services assessment.** Environ Sci Eur 33. https://doi.org/10.1186/s12302-021-00458-2

Journé V, Caignard T, Hacket-Pain A, Bogdziewicz M (2021) **Leaf phenology correlates with fruit production in European beech (*Fagus sylvatica*) and in temperate oaks (*Quercus robur* and *Quercus petraea*).** Eur J For Res 140:733–744. https://doi.org/10.1007/s10342-021-01363-2

Kaarlejärvi E, Salemaa M, Tonteri T, et al (2021) **Temporal biodiversity change following disturbance varies along an environmental gradient.** Glob Ecol Biogeogr 30:476–489. https://doi.org/10.1111/geb.13233

Karlsson P E, Akselsson C, Hellsten S, Pihl Karlsson G (2021) **Twenty years of nitrogen deposition to Norway spruce forests in Sweden**. Science of the Total Environment 809 (2022) 152192. http://doi.org/10.1016/j.scitotenv.2021.152192

Kermavnar J, Kutnar L, Marinšek A (2021) **Disentangling the ecological determinants of species and functional trait diversity in herb-layer plant communities in European temperate forests.** Forests 12:552. https://doi.org/10.3390/f12050552

Klesse S, Abegg M, Hopf SE, et al (2021) **Spread and severity of ash dieback in Switzerland – Tree characteristics and landscape features explain varying mortality probability.** Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.645920

Koulelis PP, Ioannidis K (2021) **Constructing single-entry stem volume models for four economically important tree species of Greece.** Folia Oecologica 48:136–146. https://doi.org/10.2478/foecol-2021-0014

Krüger I, Schmitz A, Sanders TG (2021) **Climate condition affects foliar nutrition in main European tree species.** Ecol Indic 130:108052. https://doi.org/10.1016/j.ecolind.2021.108052

Kwon T, Shibata H, Kepfer-Rojas S, et al (2021) **Effects of climate and atmospheric nitrogen deposition on early to mid-term stage litter decomposition across biomes.** Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.678480

Löfgren S, Stendahl J, Karltun E (2021) **Critical biomass harvesting indicator for whole-tree extraction does not reflect the sensitivity of Swedish forest soils**. Ecological Indicators 132, 108310. https://doi.org/10.1016/j.ecolind.2021.108310

Malinova L, Petrova K, Grigorova-Pesheva B (2021) **Assessment of soil and litter parameters in Yundola stationary sample plot for intensive monitoring of forest ecosystems.** Forestry Ideas 27(1):145–156

Marchetto A, Simpson D, Aas W, et al (2021) **Good agreement between modeled and measured sulfur and nitrogen deposition in Europe, in spite of marked differences in some sites.** Front Environ Sci 9. https://doi.org/10.3389/fenvs.2021.734556

Michopoulos P, Bourletsikas A, Kaoukis K (2021) **Fluxes, stocks and availability of nitrogen in evergreen broadleaf and fir forests: similarities and differences.** J For Res 32(5):2059–2066. https://doi.org/10.1007/s11676-020-01263-y

Michopoulos P, Kostakis M, Thomaidis NS, Pasias I (2021) **The influence of forest types on manganese content in soils.** Folia For Pol 63:1–9. https://doi.org/10.2478/ffp-2021-0001

Mitrović S, Veselinović M, Čule N, et al (2021) **Determination of leaf area index (LAI) at Level II sample plots according ICP manual.** Sustain For Collect 65–77. https://doi.org/10.5937/SustFor2183065M

Morin X, Bugmann H, Coligny F, et al (2021) **Beyond forest succession: A gap model to study ecosystem functioning and tree community composition under climate change.** Funct Ecol 35:955–975. https://doi.org/10.1111/1365-2435.13760

Nussbaumer A, Gessler A, Benham S, et al (2021) **Contrasting resource dynamics in mast years for European beech and oak—A continental scale analysis.** Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.689836

Pisarek P, Bueno M, Thiry Y, et al (2021) **Selenium distribution in French forests: Influence of environmental conditions.** Sci Total Environ 774:144962. https://doi.org/10.1016/j.scitotenv.2021.144962

Ray D, Marchi M, Rattey A, Broome A (2021) **A multi-data ensemble approach for predicting woodland type distribution: Oak woodland in Britain.** Ecol Evol 11:9423–9434. https://doi.org/10.1002/ece3.7752

Richard B, Dupouey J, Corcket E, et al (2021) **The climatic debt is growing in the understorey of temperate forests: Stand characteristics matter.** Glob Ecol Biogeogr 30:1474–1487. https://doi.org/10.1111/geb.13312

Rohner B, Kumar S, Liechti K, et al (2021) **Tree vitality indicators revealed a rapid response of beech forests to the 2018 drought.** Ecol Indic 120:106903. https://doi.org/10.1016/j.ecolind.2020.106903

Roulier M, Bueno M, Coppin F, et al (2021a) **Atmospheric iodine, selenium and caesium depositions in France: I. Spatial and seasonal variations.** Chemosphere 273:128971. https://doi.org/10.1016/j.chemosphere.2020.128971

Roulier M, Bueno M, Coppin F, et al (2021b) **Atmospheric iodine, selenium and caesium depositions in France: II. Influence of forest canopies.** Chemosphere 273:128952. https://doi.org/10.1016/j.chemosphere.2020.128952

Sánchez-Cuesta R, Ruiz-Gómez FJ, Duque-Lazo J, González-Moreno P, Navarro-Cerrillo RM (2021) **The environmental drivers influencing spatio-temporal dynamics of oak defoliation and mortality in *dehesas* of Southern Spain.** For Ecol Manag 485:118946. https://doi.org/10.1016/j.foreco.2021.118946

Sardans J, Vallicrosa H, Zuccarini P, et al (2021) **Empirical support for the biogeochemical niche hypothesis in forest trees.** Nat Ecol Evol 5:184–194. https://doi.org/10.1038/s41559-020-01348-1

Sawicka K, Clark JM, Vanguelova E, et al (2021) **Spatial properties affecting the sensitivity of soil water dissolved organic carbon long-term median concentrations and trends.** Sci Total Environ 780:146670. https://doi.org/10.1016/j.scitotenv.2021.146670

Schlutow A, Schröder W, Jenssen M, Nickel S (2021) **Modelling of soil characteristics as basis for projections of potential future forest ecosystem development under climate change and atmospheric nitrogen deposition.** Environ Sci Eur 33. https://doi.org/10.1186/s12302-021-00526-7

Suz LM, Bidartondo MI, Linde S, Kuyper TW (2021) **Ectomycorrhizas and tipping points in forest ecosystems.** New Phytol 231:1700–1707. https://doi.org/10.1111/nph.17547

Trotsiuk V, Babst F, Grossiord C, et al (2021) **Tree growth in Switzerland is increasingly constrained by rising evaporative demand.** J Ecol 109:2981–2990. https://doi.org/10.1111/1365-2745.13712

Wang Y, Zhang H, Ciais P, et al (2021) **Microbial activity and root carbon inputs are more important than soil carbon diffusion in simulating soil carbon profiles.** J Geophys Res Biogeosciences 126. https://doi.org/10.1029/2020JG006205

Wang S, Zhang Y, Ju W, et al. (2021): **Erratum: Recent global decline of CO fertilization effects on vegetation photosynthesis** (Science (2020) 370:6522 (1295-1300) https://doi.org/10.1126/science.abb7772). Sci. 371 (6529). https://doi.org/10.1126/science.abg8637

PUBLICATIONS

Weldon J, Grandin U (2021): **Weak recovery of epiphytic lichen communities in Sweden over 20 years of rapid air pollution decline.** The Lichenologist 53(2): 203–213. https://doi.org/10.1017/S0024282921000037

Yang Y, Wang A, Cherubini P, et al (2021) **Physiological and growth responses to defoliation of older needles in *Abies alba* trees grown under two light regimes.** For Ecol Manag 484:118947. https://doi.org/10.1016/j.foreco.2021.118947

Zanchi G, Lucander K, Kronnäs V, et al (2021) **Modelling the effects of forest management intensification on base cation concentrations in soil water and on tree growth in spruce forests in Sweden.** Eur J For Res 140:1417–1429. https://doi.org/10.1007/s10342-021-01408-6

Ziche D, Riek W, Russ A, et al (2021) **Water budgets of managed forests in Northeast Germany under climate change—Results from a model study on forest monitoring sites.** Appl Sci 11:2403. https://doi.org/10.3390/app11052403

Zielonka A, Drewnik M, Musielok Ł, et al (2021) **Biotic and abiotic determinants of soil organic matter stock and fine root biomass in mountain area temperate forests—Examples from cambisols under European beech, Norway spruce, and silver fir (Carpathians, Central Europe).** Forests 12:823. https://doi.org/10.3390/f12070823

Zolles A, Schueler S, Gartner K, Scheifinger G (2021) **Continuous Parameterization of Leaf Area Index and Phenological Phases Within Deciduous Forests Based on Temperature Measurements.** Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.768085

Zweifel R, Etzold S, Basler D, et al (2021) **TreeNet – The biological drought and growth indicator network**. Front For Glob Change 4. https://doi.org/10.3389/ffgc.2021.776905

4

NEW DATA REQUESTS FROM PROJECTS USING ICP FORESTS DATA

ICP Forests welcomes scientists from within and outside the ICP Forests community to use ICP Forests data for research purposes. Data applicants must fill out a data request form and send it to the Programme Co-ordinating Centre (PCC) of ICP Forests and consent to the ICP Forests Data Policy. For more information, please refer to the ICP Forests website[1].

The following list provides an overview of all 21 requests for ICP Forests data between January and December 2021. All past and present ICP Forests data uses are listed on the ICP Forests website[2].

ID[3]	Name of Applicant	Institution	Project Title	External/ Internal[4]
220	Jan Peter George, Nenad Potocic, Tanja Sanders	University of Tartu	Monitoring ash dieback with ICP Forests Level I survey data	Internal
221	Susanne Jochner-Oette	Katholische Universität Eichstätt-Ingolstadt	Evaluation of masting behaviour of birch	External
222	Joseph Levillain	INRAE	Evaluation of pedotransfer functions for estimating available water content of soil in a forest context	External
223	Benjamin Stocker	Swiss Federal Institute of Technology ETH Zurich	Next-generation modelling of the biosphere – Including new data streams and optimality approaches	External
224	Enmanuel Rodriguez Paulino, Martin Schlerf	University of Trier, Luxembourg Institute of Science and Technology	Using multi-sensor remote sensing data and deep learning methods to disentangle causes of forest vitality loss	External
227	James Weldon	Swedish University of Agricultural Sciences	Understorey vegetation community stability and drivers of change	External
228	Arthur Gessler	Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)	Illustration of multi-seasonal meteorological pathways to reduced forest productivity in Europe in 2000-2020	External
231	Axel Göttlein	Technische Universität München	Derivation of nutritional threshold values for the element sulphur for the tree species fir	External
232	Ryan McClory	University of Reading	Assessment of weather typologies and remote sensing data to explain and predict acorn production in *Quercus robur* and *Quercus petreae*	External
233	Federico Magnani	University of Bologna	Improved estimation of forest C sequestration from PRISMA retrieval of canopy N and photosynthetic potential	External
234	Hendrik Martin Würz	Fraunhofer Institute for Computer Graphics Research	AI for climate-adapted forest restructuring	External
235	Colin Averill	ETH Zürich	ICP Forests microbiome linkages to soil carbon cycling	Internal

[1] http://icp-forests.net
[2] http://icp-forests.net/page/project-list
[3] ID-numbering started in 2011.
[4] Internal Evaluations can be initialized by the Chairperson of ICP Forests, the Programme Co-ordinating Centre, the Expert Panel Chairs and/or other bodies under the Air Convention. Different rights and obligations apply to internal vs. external data users.

ID[3]	Name of Applicant	Institution	Project Title	External/ Internal[4]
236	Joachim Fallmann	Karlsruhe Institute of Technology	Cloud-based Decision Support System: EDE4.0 - Enhanced Dynamic Felling Planning 4.0	External
237	Raisa Mäkipää	Natural Resources Institute Finland (Luke)	Holistic management practices, modelling and monitoring for European forest Soils (HoliSoils)	External
238	Radoslaw Jagiello	Poznań University of Life Sciences	Interaction between *Viscum album* ssp. *austriacum* and *Pinus sylvestris* on different spatial and temporal scales	External
240	Anita Zolles	Austrian Federal Research and Training Center for Forests, Natural, Hazards and Landscape	Alien plants in managed forests across European forest types and management intensities under climate change	External
241	Mitja Skudnik, Tanja Sanders	Slovenian Forestry Institute	The development of the Machine Learning Forest Growth Simulator (MLFS)	Internal
242	Manuel Ehling, Rainer Duttmann	Christian-Albrechts-Universität Kiel	Temporal-spatial analysis on damages to forests in Germany	External
243	Andrey Lessa Derci Augustynczik	International Institute for Applied System Analysis	European Union Biodiversity and Climate Strategies Assessment (EU BIOCLIMA)	External
244	Aleksandar Dujakovic, Francesco Vuolo	University of Natural Resources and Life Sciences (BOKU)	Quantifying forest net primary production at high spatial resolution	External
245	Eric Andreas Thurm, Stephan Raspe	Landesforst Mecklenburg-Vorpommern	Evidence-based cultivation recommendations under climate change	Internal

5

FORECOMON 2021 – REVIEW OF THE 9TH ICP FORESTS SCIENTIFIC CONFERENCE ON FOREST ECOSYSTEM MONITORING

Marcus Schaub, Lars Vesterdal, Bruno De Vos, Marco Ferretti, Stefan Fleck, Päivi Merilä, Anne-Katrin Prescher, Kai Schwärzel, Liisa Ukonmaanaho

FORECOMON 2021

The 9th ICP Forests Scientific Conference on *Forest Monitoring to assess Forest Functioning under Air Pollution and Climate Change* took place as a hybrid meeting on 7–9 June 2021 at the Swiss Federal Research Institute WSL in Birmensdorf nearby Zurich, Switzerland, followed by a post-conference excursion from 11–12 June 2021 into the Swiss Alps.

The goal of FORECOMON 2021, was to highlight the extensive ICP Forests data series on forest growth, phenology and leaf area index, biodiversity and ground vegetation, foliage and litterfall, ambient air quality, deposition, meteorology, soil and crown condition. We combined novel modeling and assessment approaches and integrated long-term trends to assess air pollution and climate effects on European forests and related ecosystem services. Novel results and conclusions from local to European scale studies were presented and discussed. Despite all challenges imposed by COVID-19, we enjoyed an inspiring conference with new insights from 23 oral and 61 poster presentations with authors and co-authors from 36 countries.

A special issue in *Frontiers in Forests and Global Change* comprises 6 publications presenting the results on resource dynamics in mast years for European beech and oak (Nussbaumer et al. 2021), drought effects on *Fagus sylvatica* based on 37 years of forest monitoring in Switzerland (Braun et al. 2021), continuous parameterization of leaf area index and phenological phases (Zolles et al. 2021), the relationship between stem radial growth and tree defoliation in conifers from northern Italy (Ferretti et al. 2021), TreeNet–the biological drought and growth indicator network (Zweifel et al. 2021), and on variation in leaf morphological traits of European beech and Norway spruce over two decades in Switzerland (Zhu et al. 2022).

For more infos on FORECOMON 2021, see https://forecomon2021.thuenen.de/

The following list includes all oral and poster presentations at the 9th ICP Forests Scientific Conference. All conference abstracts are available from the ICP Forests website[1].

Participants of the excursion to the Swiss Alps

Session 1: The Classics – Long-term trends in forest ecosystem processes as affected by air pollution, drought, or other extreme weather events

Presentations

Magnani F [Keynote]: **Accounting for time: long-term effects of N addition on forest biogeochemistry and C sequestration**

De Witt H, Austnes K: **Trends in water chemistry in Europe and North America**

Dirnböck T, Kobler J, Geiger S, et al: **Chronic nitrogen deposition effects under climate change in an Austrian karst catchment**

Etzold S, Ferretti M, Gessler A, et al: **Nitrogen deposition is the most important environmental driver of continental-scale forest growth in Europe**

Sase H, Takahashi M, Ohizumi T: **Acidification and recovery of forest ecosystems in central Japan during the past few decades**

Vanguelova E: **What is the current carbon storage and future carbon sequestration potential of forest soils in the UK?**

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

Posters

Andreetta A, Cecchini G, Marchetto A, et al: **Trends and fluxes of soil solution chemistry focusing on nitrate leaching responses to air pollution in Italian forest soils**

Aparin BF, Kasatkina GA, Sukhacheva EY, et al: **Long-term monitoring of forest ecosystems of the taiga zone of European Russia**

Braun S, de Witte LC, Hopf SE, et al: **The effect of ozone and nitrogen deposition on the vitality of *Fagus sylvatica* and *Picea abies* in Switzerland**

Ekemen G, Kaya S, Öztürk S: **Evaluation of air temperature and precipitation values in Turkey**

Ferretti M, Ghosh S, Gottardini E: **Tree health and annual and periodical radial growth in coniferous trees in northern Italy**

Fetzer J, Frossard E, Kaiser K, et al: **Phosphorus leaching in beech forest soils as affected by fertilization and seasons**

Fleck S, Ahrends B, Wagner M, et al: **The potential of throughfall measurements for the derivation of canopy attributes**

Hunova I: **Ground-level ozone and nitrogen deposition in the Czech Republic: assessment of long-time trends and spatial changes**

Jochheim H, Wirth S, Paulus S, et al: **Impact of drought on soil CO_2 efflux and vertical partitioning of soil CO_2 production at a beech and a pine forest site in north-east Germany**

Kaya S, Ekemen G, Öztürk S: **Assessment of air pollutants at Level II forest monitoring sites in Turkey**

Krüger I, Schmitz A, Sanders T: **Identifying effects of climate conditions on foliar nutrition**

Michopoulos P, Bourletsikas A, Kaoukis K: **Fluxes and stocks of nitrogen in the litterfall and soil in evergreen broadleaves and fir forests**

Nussbaumer A, Gessler A, Etzold S, et al: **European beech and oak show different resource dynamics in mast years**

Öztürk S, Kaya S, Ekemen G: **Deposition properties in 18 Level II forest monitoring sites in Turkey**

Pascu I-S, Dobra AC, Leca S, et al: **Forest monitoring from the cloud -Soil water content case study**

Pohjanmies T, Genikova N, Hotanen J-P, et al: **Site types revisited: comparison of traditional Russian and Finnish classification systems for European boreal forests**

Salehi M, Thimonier A, Braun S, et al: **Leaf morphological traits and leaf nutrient concentrations in European beech stands across a water availability gradient in ICP Forests Level II plots**

Tatzber M, Fürst A: **Monitoring of mercury in tree foliage in Austria**

Waldner P, Braun S, Raspe S, et al: **Assessing the risk of elevated nitrate leaching from Swiss forests**

Zhu J, Thimonier A, Meusburger K, et al: **Long-term changes in leaf morphological traits of European beech and Norway spruce along multiple gradients in Switzerland**

Session 2: The Exchange – Methodologies and models applied within ICP Forests and beyond

Presentations

Buchmann N, Gharun M [Keynote]: **Responses of Swiss forests to long- and short-term environmental changes**

Anthony M, Crowther T, van der Linde S, et al: **Ectomycorrhizal fungal communities and functional genes drive forest productivity across the ICP Forest Network**

Badea O, Pitar D, Leca S, et al: **Linking in situ measurements with remote sensing in Level I and II ICP Forests network in Romania: Prototyping a national forest monitoring system**

Gessler A, Bächli L, Treydte K, et al: **Where does the water come from? Variations in soil water uptake depth in a beech forest during the 2018 drought**

Guidi C, Brunner I, Hartmann M, et al: **Long-term irrigation in a drought-stressed pine forest accelerates carbon cycling and leads to vertical redistribution of soil organic carbon pools**

Lang F, Krueger J, Bauhus J, et al: **The dimensions of the phosphorus status of European beech forest ecosystems**

Puhlmann H, Habel R: **The water budget of forests – the big unknown outside of our intensive monitoring plots?**

Rohner B, Lanz A, Kumar S, et al: **Canopy and growth response of beech trees after the 2018 drought in Switzerland**

Zolles A, Schüler S, Gartner K, et al: **Continuous approximation of leaf area index and phenological phases within deciduous forests based on temperature measurements**

Posters

Brang P, Frei E, Streit, K et al: **A new experimental plantation network to test the future climatic suitability of 18 tree species in Switzerland**

Cherubini P, Battipaglia G, Innes JL: **Assessing tree vitality to evaluate forest health: can tree-ring stable isotopes be used as indicators?**

Da Ros L, Rodeghiero M, Ventura M, et al: **Canopy nitrogen fertilization of two Italian temperate mountain forests: an isotopic approach to quantify the fate of atmospheric nitrogen depositions**

Fonti P, Martínez-Sancho E, Peters R: **14-years of tree-growth monitoring along a 1400 m elevation transect in the Lötschental**

Helfenstein IS, Schneider FD, Morsdorf F, et al: **Assessing biodiversity from space: Functional diversity across spatial scales and optical sensors**

Iosifescu Enescu I, Haeni M, Plattner G-K, et al: **Architectural requirements for forest monitoring data integration in EnviDat**

Jocher G, Fischer M, Sigut L, et al: **Monitoring forest carbon exchange in complex terrain**

Massey A, Ferretti M, Lanz A: **Design-based improvements in change estimation for the Swiss National Forest Inventory through integration with external monitoring networks and data sources**

Monteleone MC: **Artificial electromagnetic fields (telecoms) as forests' pollutants. Plans for testing monitoring procedures three protected forests of Italy**

Monteleone MC: **A case study for the effects of telecom's microwaves on forest trees**

Paoletti E, Alivernini A, Anav A, et al: **Forest monitoring towards the definition of stomatal-flux critical levels for forest protection against ozone: the MOTTLES approach**

Petibon F, Czyż EA, Ghielmetti G, et al: **Combining spectral and molecular approaches to capture leaf pigment dynamics**

Polevshchikova I, Lezhnin S: **Assessment of land use change on environmental security**

Portier J, Zellweger F: **Bridging forest inventories to improve international reporting on biodiversity**

Temperli C, Blattert C, Stadelmann G, et al: **Trade-offs between ecosystem service provision and the predisposition to disturbances: An NFI-based scenario analysis**

Vitali V, Klesse S, Weight R, et al: **High frequency stable isotope signals as proxy for physiological responses to climate - Dual isotope approach at a European scale**

Vos MAE, Sterck FJ, Veen C, et al: **Ion Exchange Resin method for quantifying bulk (throughfall) deposition**

Wachendorf C, Graefe U, Broll G, et al: **A concept for a consolidated humus form description in forest soil investigations in Europe**

Wójcik R, Kędziora W: **Large-scale mistletoe inventory in Central Poland**

Session 3: The Mechanisms – Air pollution effects on forest ecosystem functioning under extreme and/or prolonged unfavorable climate and weather conditions

Presentations

Hagedorn F, Guidi C, Zimmermann S, et al [Keynote]: **Forest soil carbon cycle under drought-linking experiments, monitoring and natural gradients across Switzerland**

Faralli M, Cristofolini F, Cristofori A, et al: **Environmental factors, leaf traits and ozone visible symptoms are interrelated in *Viburnum lantana***

Meesenburg H, Fleck S, Ahrends B, et al: **Mechanisms explaining N stock and acidity dynamics in German forests between 1990 and 2007 and possible climate change feedbacks**

Martinez Pastur G, Rosas YM, Toro Manríquez M, et al: **Patagonian forests vulnerability to climate change: Consequences for management and conservation**

Ognjenović M, Seletković I, Potočić N, et al: **Beech nutrition depends on defoliation, soil and climate across Croatia**

Verstraeten A, Gottardini E, Bruffaerts N, et al: **Impact of pollen on throughfall biochemistry in European temperate and boreal forests**

Weikl F, Danzberger J, Pretzsch H, et al: **Ectomycorrhizal functionality after 5 years of summer drought in a mature forest**

Wohlgemuth L, Hoch G, Alewell C, et al: **Foliar uptake of gaseous elemental mercury by European forests**

Posters

Adame P, Alberdi I, Cañellas I, et al: **Predicting the spread of Gonipterus scutellatus forest pest under climate change in Spain using Universal Kriging model**

Babur E, Dindaroğlu T: **How soil carbon and nitrogen changes in the topsoil formed under different tree species?**

Ballikaya P, Brunner I, Cocozza C, et al: **Can trees take up airborne nanoparticles through their leaves?**

Batkhuyag E-U, Lehmann M, Cherubini P, et al: **Air pollution and climate change effects on tree growth at Ulaanbaatar city, Mongolia**

Brunner I: **Plasticity of tree fine root traits under drought and irrigation**

Burkhardt J, Zinsmeister D, Grantz D, et al: **The contribution of ambient aerosols to 'wax degradation' and decreasing drought tolerance**

Češljar G, Đorđević, Ilija, Rakonjac L: **Impact of extreme climate factors on forests drought in Republic of Serbia**

Chi C-JE, Zinsmeister D, Chang S-C et al: **Direct impact of atmospheric aerosols on the ecophysiology of *Cinnamomum camphora***

Danzberger J, Weikl F, Buegger F, et al: **Carbon allocation in *Picea abies* (L. Karst) roots during recovery from a five-year long drought**

Günthardt-Goerg M, Vollenweider P, Schulin R: **Above- and belowground metal accumulation and growth responses in young afforestations on model brown field sites**

Hunziker S, Begert M, Gessler A: **Why are Scots pines dying in the Swiss Rhône valley?**

Koch I, Kahmen A, Burkhardt J: **Is foliar water uptake fostered by aerosol deposition?**

Kowalska NB, Šigut L, Stojanović M, et al: **Analysis of floodplain forest sensitivity to drought**

Marqués L, Weng E, Harald H, et al: **Are forests thickening due to rising CO_2? Insights from Swiss forests and mechanistic modelling**

Murazzi ME, Cherubini P, Brunner I, et al: **Can forest trees take up nanoplastic from their roots and transport them in their aboveground tissues?**

Oberhuber W, Gruber A, Wieser G: **Missing adequate growth response of coniferous tree species to climate warming at the Alpine forest line**

Ouyang S, Schönbeck L, Saurer M, et al: **Root carbon-nutrient balance determines downy oak survival and recovery from drought**

Soyol-Erdene T-O, Ganbat G, Baldorj B: **Urban air quality in Mongolia: concentrations, sources and future needs of studies**

Sturm J, Damm A: **Impact of the European drought 2018 on tree health and mortality in Swiss forest ecosystems**

Uslu OS, Babur E, Demir Z, et al: **The effects of land use types on the soil organic carbon content**

Vollenweider P, Schleppi P, Vittoz P: **10-year monitoring of ecosystem responses to understory removal in a dry oak-pine forest of Central Valais, Switzerland**

FORMON 2021

On the same topic, the FORMON 2021 Summer School took place on 22–28 August 2021 in Davos, Switzerland, and complemented the 9th ICP Forests Scientific Conference. The 2021 Summer School was supported by ICP Forests, the SwissForestLab, and the European Network for forest research and higher education NFZ.forest.net. FORMON aimed to provide an in-depth understanding of the concepts, approaches, and available data infrastructure of forest long-term monitoring. Novel modelling and assessment approaches were discussed considering the expectations to future forests from a scientific, forest management, and socio-economic perspective. Students and young scientists were provided an insight into the data treasure of ICP Forests and took advantage of in-depth lectures by renowned scientists on selected topics concerning long-term forest ecosystem research. 24 students from 10 countries attended the lectures held by 19 experts from 9 institutions and 4 countries.

Impressions from FORMON 2021 can be watched at https://youtu.be/Wpx3Pt8UKt8

Special Issue "Forest Soil Monitoring"

A special issue on research in Forest Soil Monitoring was supported by the Scientific Committee and launched through the journal *Applied Sciences*. It focusses on methodological questions in soil monitoring, e.g. of soil gas exchange (Adisaputro et al. 2021, Appl. Sci. 11(4); Maier et al. 2021, Appl. Sci. 10(23)), of labile soil carbon and nitrogen (Zou & Osborne 2021, Appl. Sci. 11(5)), of soil carbon stocks (Russ et al. 2021, Appl. Sci. 11(2)), and of soil water content with FDR sensors (De Vos et al. 2021, Appl. Sci. 11(24)). It also presents new results of long-term forest monitoring from water budget calculations (Ziche et al. 2021, Appl. Sci. 11(5)), base cation budget calculations (Vanguelova et al. 2022, Appl. Sci. 12(5)), modelled liming effects on the acid-base budget (Greve et al. 2021, Appl. Sci. 11(3)), inventories of inorganic and organic pollutants (Riek et al. 2021, Appl. Sci. 11(3)), and repeated assessment of microarthropod assemblages along pH-gradients (Guo & Siepel 2020, Appl. Sci. 10(22)).

PART B

Reports on individual surveys in ICP Forests

6 ATMOSPHERIC DEPOSITION IN EUROPEAN FORESTS IN 2020

Aldo Marchetto, Arne Verstraeten, Peter Waldner, Daniel Žlindra

Introduction

The atmosphere contains a large number of substances of natural and anthropogenic origin. Most of them are ultimately deposited to the ground, either by colliding with surface structures like forest canopies or by wet deposition (rain, snow, etc.).

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

Emitted gaseous sulphur dioxide (SO_2) is scavenged from the atmosphere by rain droplets in contact with water and almost completely transformed into SO_4^{2-}. Sulphur deposition occurs in the form of sulphate (SO_4^{2-}), but also as gaseous sulphur dioxide (SO_2), e.g. taken up through stomata, and as sulphuric acid (H_2SO_4). Natural emissions of SO_4^{2-} derive from marine aerosols and volcanic activity, and from forest fires. Anthropogenic emissions are caused by combustion, including fossil fuels, and have increased since the 1850s, causing an increase in sulphate deposition and deposition acidity, which can be partly buffered by the deposition of base cations, mainly calcium (Ca^{2+}) and magnesium (Mg^{2+}).

Natural sources of nitrogen (N) in the atmosphere are mainly restricted to the emission of nitrous oxides (N_2O) and atmospheric nitrogen (N_2) during denitrification and the decomposition of the nitrogen gas molecule in the air by lightning. However, human activities cause the emission of large amounts of nitrogen oxides (NO_x), from traffic and industrial activities, and of ammonia (NH_3) deriving from agriculture and farming. They are found in atmospheric deposition in the form of nitrate (NO_3^-), ammonium (NH_4^+) and are also deposited as gaseous compounds like nitric acid (HNO_3), nitrogen dioxide (NO_2) and ammonia (NH_3).

Nitrogen compounds have two effects on ecosystems: First, they are important plant nutrients but cause problems of ecosystem eutrophication at high deposition rates, with strong effects on plant metabolism (e.g., Silva et al. 2015), forest ecosystem processes (e.g. Meunier et al. 2016) and biodiversity (e.g., Bobbink et al. 2010). Secondly, they contribute to acidification in addition to sulphur (Bobbink and Hettelingh 2011).

Emission and deposition of oxidized and reduced nitrogen have decreased in the last decade (Waldner et al. 2014; EEA 2016, Rogora et al. 2022).

Starting in March 2020, most European countries enforced lockdown measures aimed at reducing the spread of the COVID-19 pandemic, leading to a large reduction of mobility, a drop in transport and a reduction in productions and industrial activities, with the important exception of agriculture.

In some countries or regions, restrictions were still present at the end of 2020, mainly related to the partial closing of schools, implementation of smart working and restrictions to mobility between countries or between regions. This contributed to a lower-than-average level of road traffic and related emissions. Rogora et al. (2022) showed that the reduction in the emissions of sulphur and nitrogen oxides was mirrored by a significant drop in the wet deposition of sulphate and nitrate in some sites located in the southern slope of the central Alps. The central Alps are an area with usually high deposition of pollutants (Rogora et al. 2016) because of the high amount of rain and snowfall, and the proximity to the Po Valley, one of the most densely populated and urbanized areas in Europe. As mobility restrictions were enforced in most European countries, we verified below, that reduction in SO_4^{2-} and NO_3^- deposition in 2020 was also detected in other areas covered by the ICP Forests network.

Materials and methods

Atmospheric deposition is collected on the ICP Forests permanent Level II plots under tree canopy (throughfall samplers, Fig. 6.1) and in a nearby clearance (open field samplers). Throughfall samples are used to estimate wet deposition, i.e. the amount of pollutants deposited by rain and snow, but they also include dry deposition from particulate matter and gases collected by the canopy. For nitrogen, the deposition of reduced compounds (NH_4^+ and NH_3) and of oxidized compounds (NO_3^-, HNO_3, NO_2, NO) is measured as NH_4^+ and NO_3^- in the throughfall samplers. The total deposition to a forest, however, also includes nitrogen taken up by leaves directly and organic nitrogen compounds. It can be estimated by applying canopy exchange models.

It is important to note the different behaviour of individual ions when they interact with the canopy: In the case of sodium (Na^+) and SO_4^{2-} the interaction is almost negligible and it can be assumed that throughfall deposition includes the sum of wet and dry deposition.

This is not the case for other ions, such as NH_4^+: Tree canopies and the associated microbial communities strongly interact with them, for example tree leaves can take up NH_4^+ ions and release potassium, calcium and magnesium ions, and organic compounds, affecting the composition of throughfall deposition.

Sampling, analysis and quality control procedures are standardized on the basis of the ICP Forests Manual (Clarke et al. 2016).

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

In this report, we analyze the 2020 yearly throughfall deposition, collected in 277 permanent plots, collected following the ICP Forests Manual. Lockdowns only marginally affected deposition monitoring: Ten plots, mainly in Spain and Italy, could not be reached for more than two months. Because of the high probability of sample deterioration, they were not included in the discussion of the results. Fourteen further plots were excluded because the duration of sampling covered less than 90% (329 days) of the year. One hundred other plots were marked as "not validated" because the conductivity check was passed in 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. For seven more sites, data for specific variables were rejected because the laboratory did not pass the test for that variable.

As the deposition of marine aerosol represents an important contribution to the total deposition of SO_4^{2-}, Ca^{2+} and Mg^{2+}, a sea-salt correction was applied, subtracting from the deposition fluxes the marine contribution, calculated as a fraction of the chloride deposition according to the ICP Integrated Monitoring Manual (FEI 2013).

Differences between 2019 and 2020 values of the amount of precipitation and of the deposition of selected ions were compared using a t-test for paired samples on the annual deposition including only values validated in both years.

Results

Atmospheric throughfall deposition in 2020

The uneven distribution of emission sources and receptors and the complex orography in parts of Europe result in a marked spatial variability of atmospheric deposition. However, on a broader scale, regional patterns in deposition emerge. In the case of nitrate, high and moderate throughfall deposition was mainly found in central Europe, including Belgium, Germany, the Czech Republic, Poland, Denmark and Italy, but single plots with high deposition values are also reported in other countries (Fig. 6.2).

The area of high and moderate ammonium throughfall deposition is larger than for NO_3^-, with higher throughfall deposition values particularly in Germany, Belgium and northern Italy, Switzerland, Austria, Slovenia, Slovakia and Poland (fig. 6.3).

It is generally considered that negative effects of nitrogen deposition on forests become evident when the combined inorganic nitrogen deposition of NO_3^- and NH_4^+ is higher than 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 5 and 20 kg ha^{-1} yr^{-1} for forests (Bobbink and Hettelingh, 2011).

In 2020, throughfall inorganic nitrogen depositions higher than 10 kg ha^{-1} yr^{-1} were mainly measured in central Europe, including Germany, Belgium, Northern Italy, Switzerland, and Austria (Fig. 6.4).

Figure 6.1: Snow sampler (left), rain sampler (middle), and stemflow sampler (right) to determine throughfall deposition at an ICP Forests Level II site in south-western Czechia (Images: Peter Waldner)

The area with high and moderate throughfall deposition of sulphate (corrected for the marine contribution) is smaller than for nitrogen compounds (Fig. 6.5): High values are mainly found close to the largest point sources. In the southern part of Europe, SO_4^{2-} deposition is also influenced by volcanic emission and by the episodic deposition of Saharan dust. The area of moderate deposition extends to most of Europe from Belgium to Romania and Sweden to Greece.

Calcium and magnesium are also analyzed in the ICP Forests deposition monitoring network, as their deposition can buffer the acidifying effects of atmospheric deposition, protecting soil from acidification. High values of (sea-salt corrected) Ca^{2+} throughfall deposition are mostly reported in eastern and southern Europe (Fig. 6.6). After correction for sea-salt contribution, the distribution of the highest values of Mg^{2+} includes a large portion of south-eastern and central Europe (Fig. 6.7).

Changes between 2019 and 2020

The amount of precipitation under the tree canopy (throughfall) in 2020 was slightly (-2%) but significantly lower than in 2019 (Fig. 6.8). NH_4^+ deposition was not significantly different between 2019 and 2020. NO_3^- and SO_4^{2-} deposition were significantly and markedly lower in 2020 than in 2019 (30% for SO_4^{2-} and 32% for NO_3^- in the throughfall measurements).

The weather during the spring 2020 lockdown included several unusual warm and sunny weeks in central Europe. Such individual weather phenomena may explain e.g. the lower precipitation but also complicate disentangling the lockdown effect. However, the found 30% and 32% reductions of NO_3^- and SO_4^{2-} deposition compare well to the the 25% to 46% reduction of NO_x concentration in the air for the Swiss Plateau and the Po valley estimated with modelling emissions and air mass movement (Ciarelli et al. 2021).

As discussed by Rogora et al. (2022), it seems thus likely that the pattern is the result of the reduction in N and S oxide emissions due to the lockdown, as mobility and industrial productions were reduced, while agriculture was not affected. This pattern will need to be confirmed with the 2021 deposition values (when available), and in regard to the variations measured for decades in the ICP Forests Level II network. If confirmed, it would suggest that decreases in atmospheric deposition are still possible and to be expected, if emissions can be further reduced.

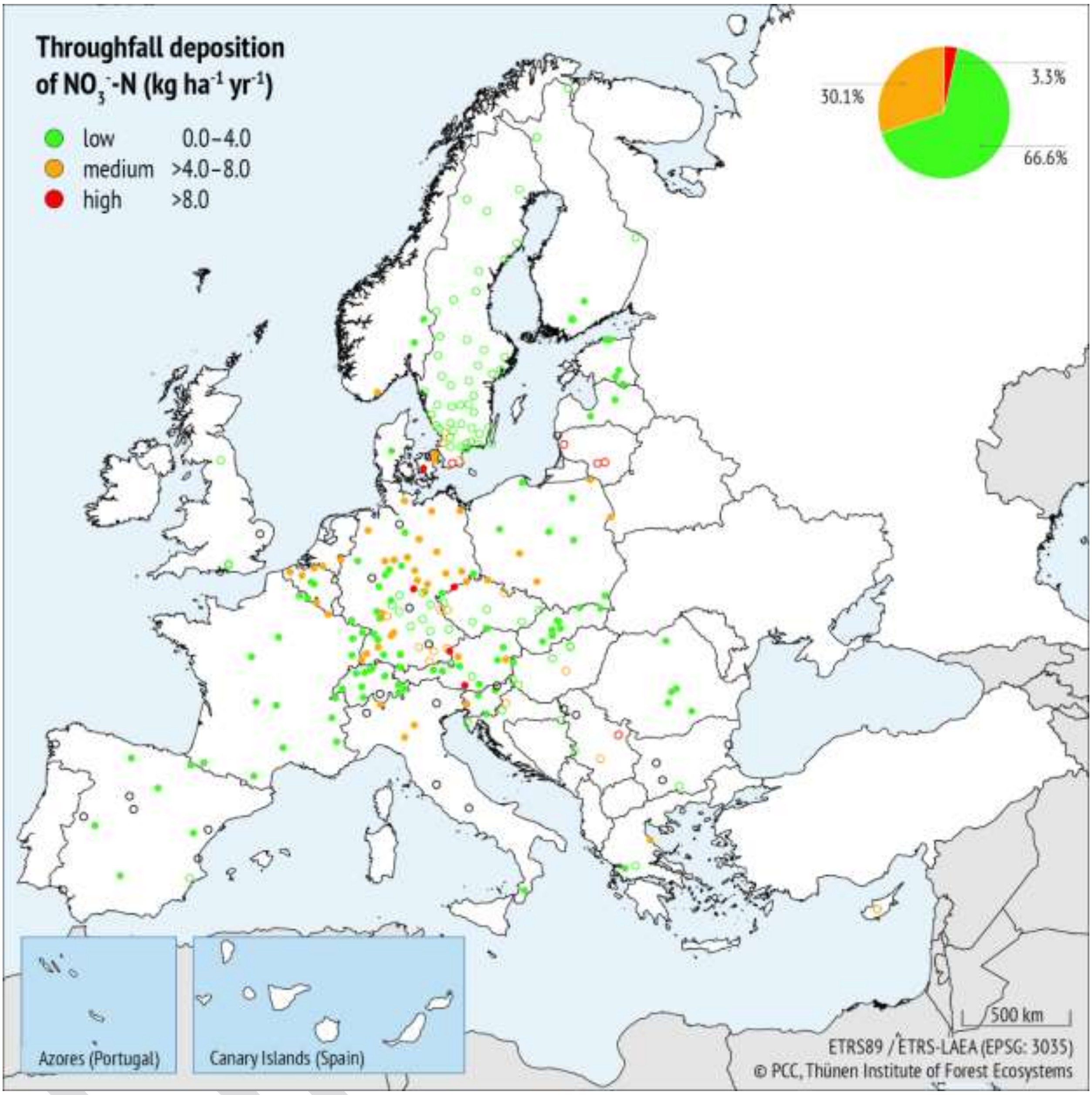


Figure 6-2: Throughfall deposition of nitrate-nitrogen (kg NO_3^--N ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

EVALUATIONS

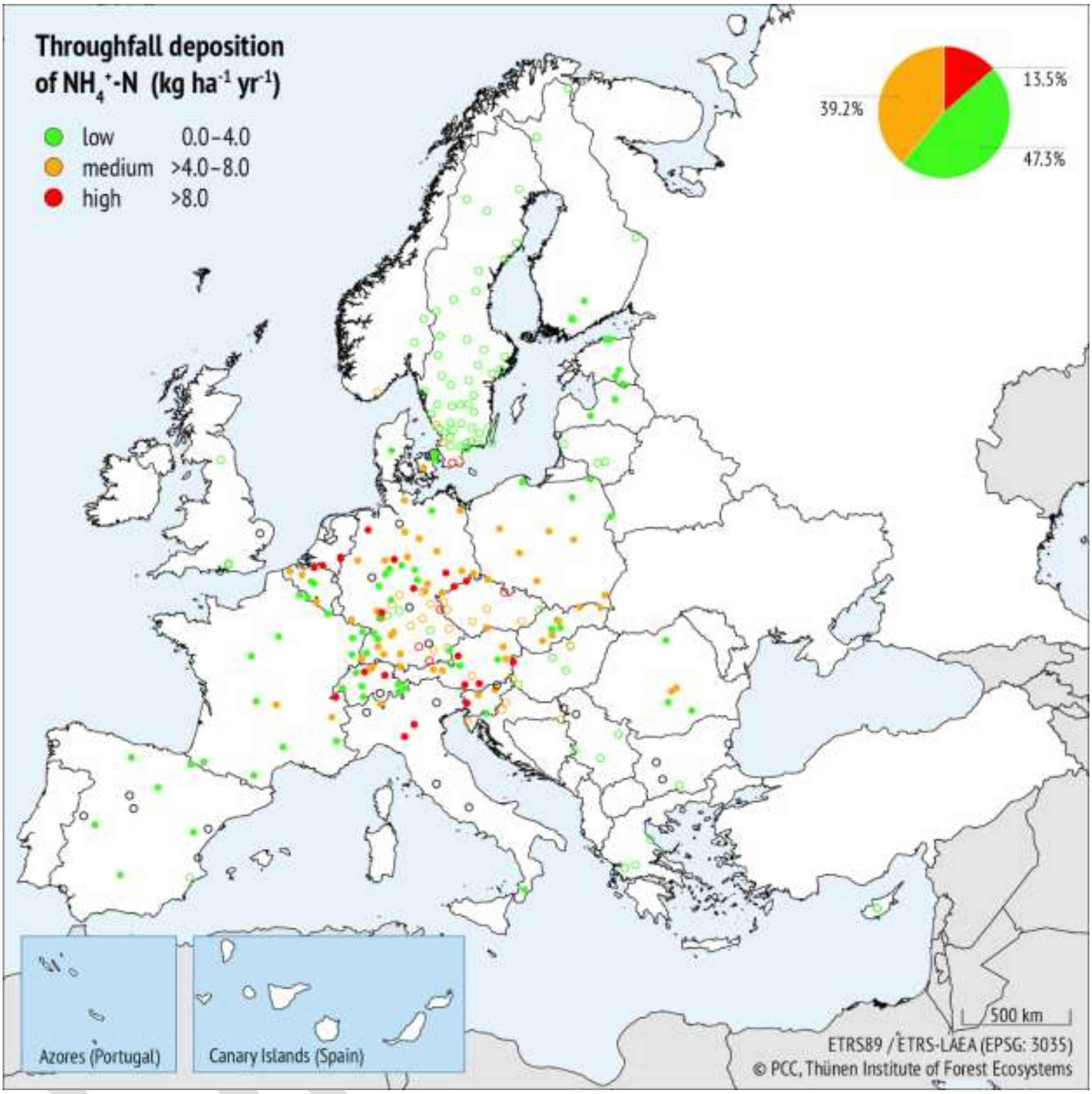


Figure 6-3: Throughfall deposition of ammonium-nitrogen (kg NH_4^+-N ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

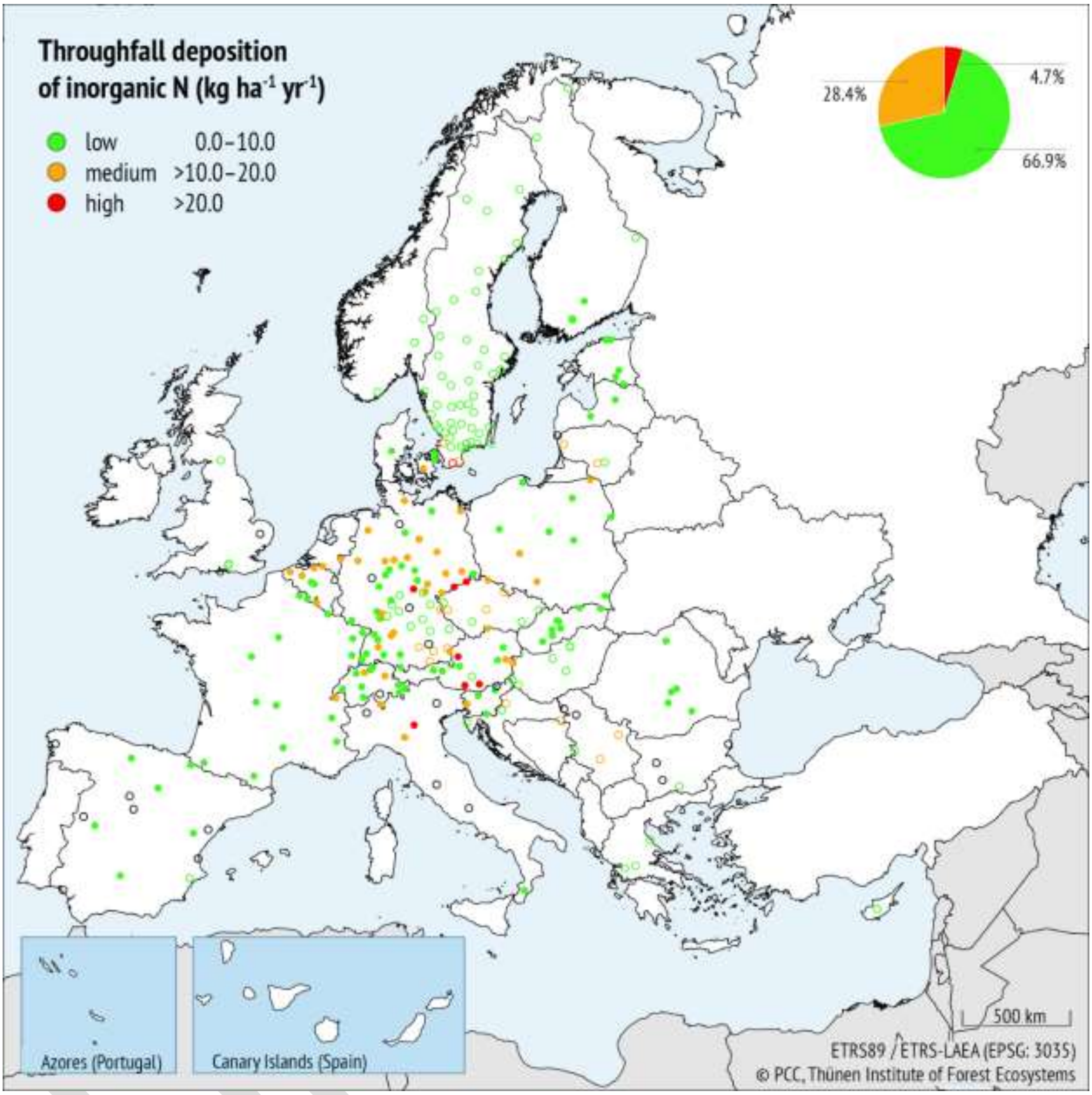


Figure 6-4: Throughfall deposition of inorganic nitrogen (NO_3^--N + NH_4^+-N) kg N ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

EVALUATIONS

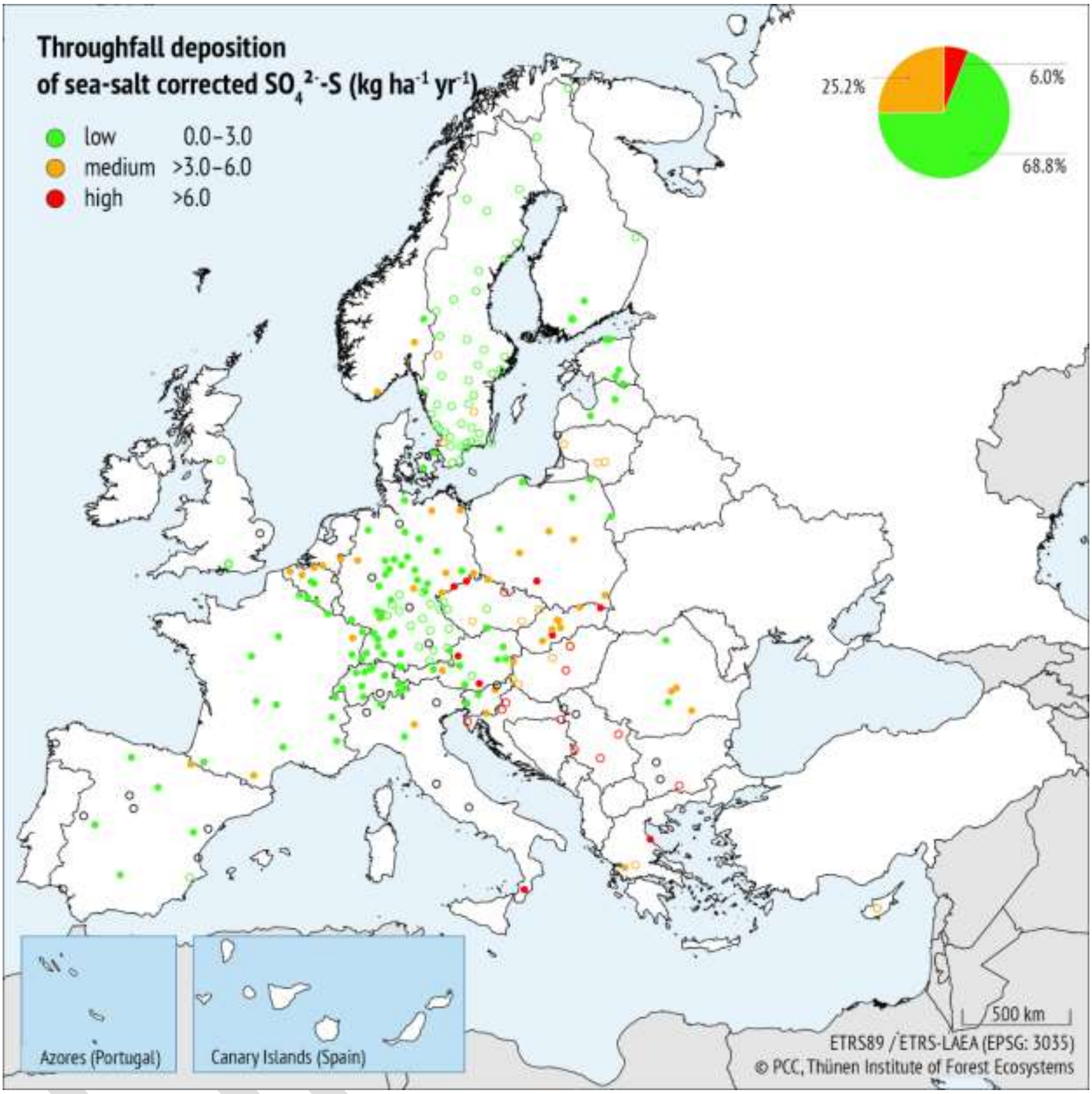


Figure 6-5: Throughfall deposition of sea-salt corrected sulphate-sulphur (kg SO_4^{2-}-S ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

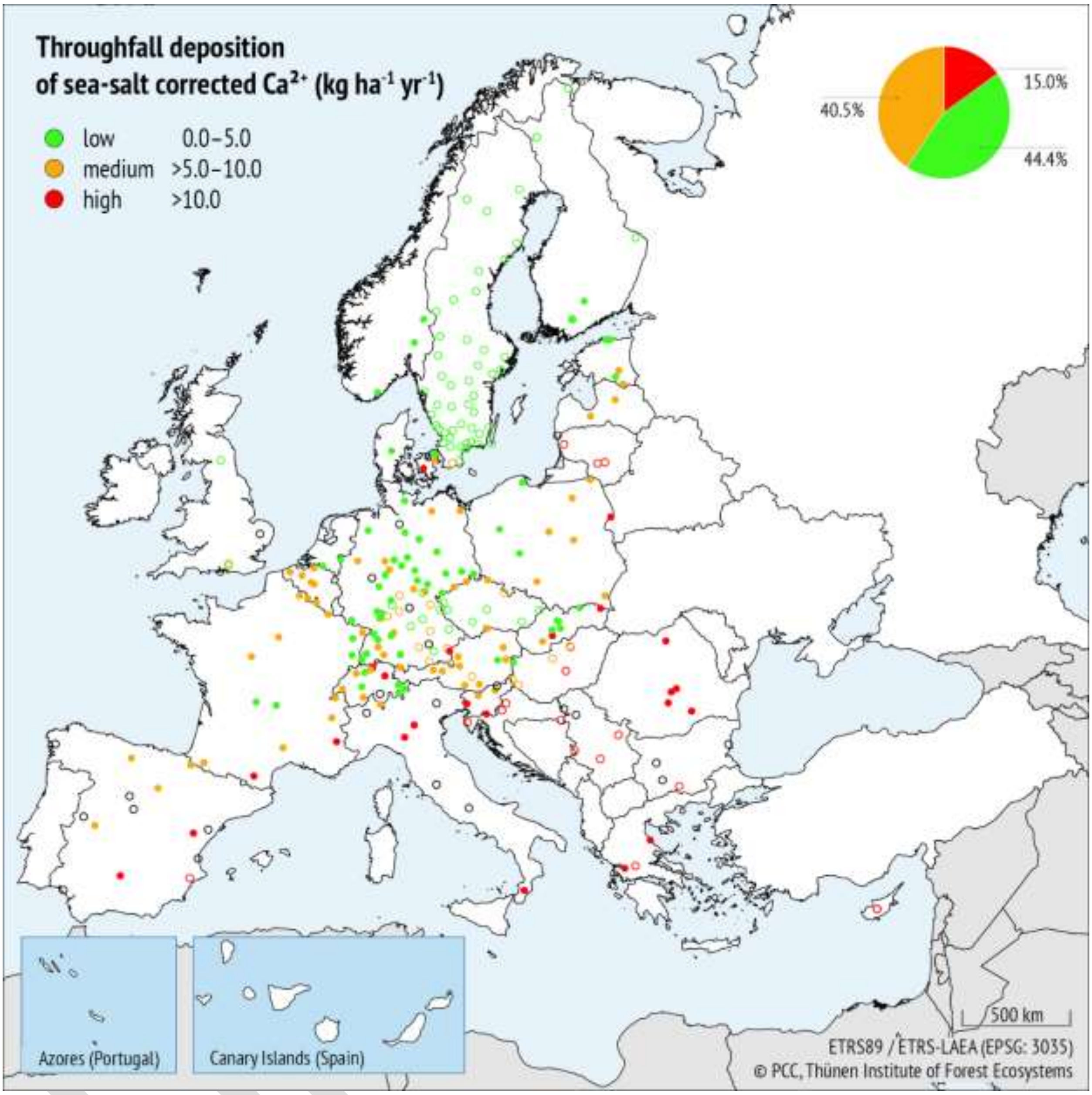


Figure 6-6: Throughfall deposition of sea-salt corrected calcium (kg Ca^{2+} ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

EVALUATIONS

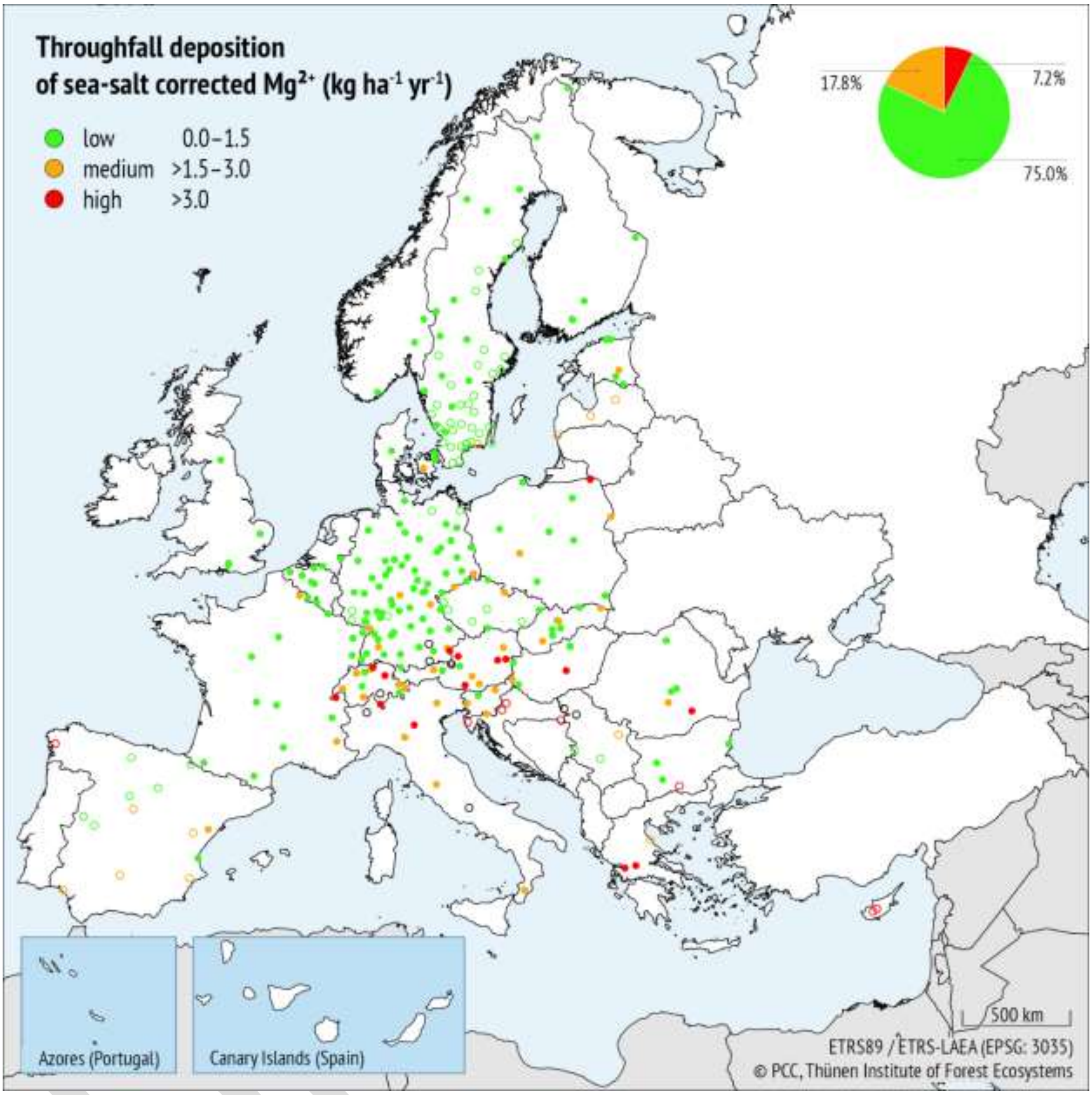


Figure 6-7: Throughfall deposition of sea-salt corrected magnesium (kg Mg^{2+} ha^{-1} yr^{-1}) measured in 2020 on the ICP Forests Level II plots and the Swedish Throughfall Monitoring Network. Colored dots: validated data. Colored circles: not validated data. Black circles: monitoring period shorter than 330 days or irregular sampling.

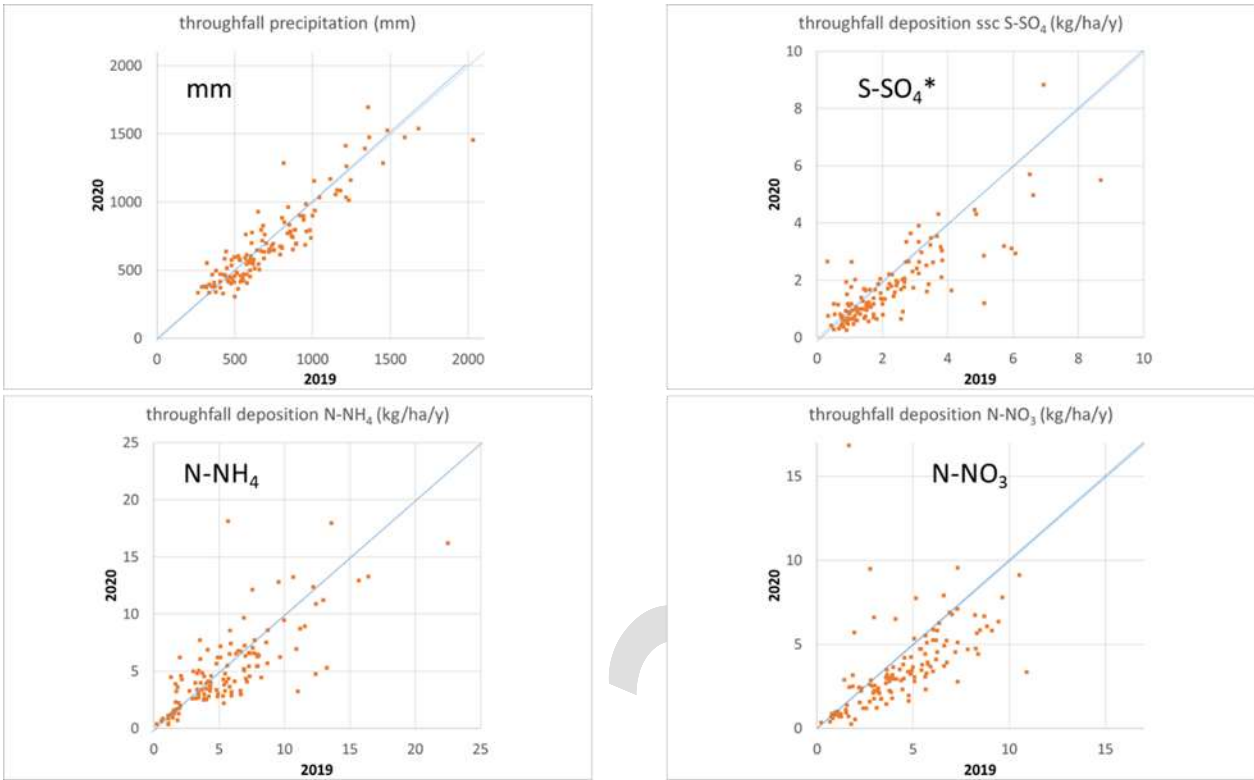


Figure 6-8: Comparison between throughfall amount of precipitation (mm) and deposition of selected ions (kg ha-1 yr-1) measured in 2019 and 2020 in the ICP Forests Level II plots. Only sites validated in both years.

References

Bobbink R, Hettelingh JP, eds (2011) **Review and revision of empirical critical loads and dose-response relationships.** Coordination Centre for Effects, National Institute for Public Health and the Environment (RIVM). ISBN 978-90-6960-251-6. https://rivm.openrepository.com/handle/10029/260510

Bobbink R, Hicks K, Galloway J, et al (2010) **Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis.** Ecol Appl 20:3059. [https://doi.org/10.1890/08-1140.1]

Ciarelli G, Jiang J, El Haddad I, et al (2021) **Modeling the effect of reduced traffic due to COVID-19 measures on air quality using a chemical transport model: impacts on the Po Valley and the Swiss Plateau regions.** Environ Sci: Atmos 1:228. https://doi.org/10.1039/d1ea00036e

Clarke N, Žlindra D, Ulrich E, et al (2016) **Part XIV: Sampling and Analysis of Deposition.** In: UNECE ICP Forests Programme Coordinating Centre (ed): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 32 p + Annex. [http://www.icp-forests.org/manual.htm]

EEA (2016) **Emissions of the main air pollutants in Europe** – European Environment Agency, Copenhagen, Denmark. [https://www.eea.europa.eu/data-andmaps/indicators/main-anthropogenic-air-pollutantemissions/]

FEI (2013) **Data calculation (Annex 7).** In: Manual for Integrated Monitoring. [http://www.syke.fi/nature/icpim] (Accessed 23.04.2020).

König N, Kowalska A, Brunialti G, et al (2016) **Part XVI: Quality Assurance and Control in Laboratories.** In: UNECE ICP Forests Programme Coordinating Centre (ed): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 46 p. + Annex. [http://www.icp-forests.org/manual.htm]

Meunier CL, Gundale MJ, Sánchez IS, et al (2016) **Impact of nitrogen deposition on forest and lake food webs in nitrogen-limited environments.** Glob Change Biol 22: 164–179. https://doi.org/10.1111/gcb.12967

Mosello R, Amoriello M, Amoriello T, et al (2005) **Validation of chemical analyses of atmospheric deposition in forested European sites.** J Limnol 64:93–102

Mosello R, Amoriello T, Benham S, et al (2008) **Validation of chemical analyses of atmospheric deposition on forested sites in Europe: 2. DOC concentration as an estimator of the organic ion charge.** J Limn 67:1–14

Rogora M, Colombo L, Marchetto A, et al S (2016) **Temporal and spatial patterns in the chemistry of wet deposition in Southern Alps.** Atm Envir 146:44–54. https://doi.org/10.1016/j.atmosenv.2016.06.025

Rogora M, Steingruber S, Marchetto A, et al (2022) **Response of atmospheric deposition and surface water chemistry to the COVID-19 lockdown in an alpine area.** Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-20080-w

Silva LCR, Gómez-Guerrero A, Doane TA, et al (2015) **Isotopic and nutritional evidence for species- and site specific responses to N deposition and elevated CO_2 in temperate forests.** J Geophys Res Biogeosci 120:1110–1123. https://doi.org/10.1002/2014JG002865

Waldner P, Marchetto A, Thimonier A, et al (2014) **Detection of temporal trends in atmospheric deposition of inorganic nitrogen and sulphate to forests in Europe.** Atmos Environ 95:363–374. https://doi.org/10.1016/j.atmosenv.2014.06.054

7

TREE CROWN CONDITION IN 2021

Volkmar Timmermann, Nenad Potočić, Mladen Ognjenović, Till Kirchner

Highlights

In 2021, mean defoliation remained at approximately the same level as in 2020 with no change for broadleaves and only a very slight increase for conifers. Deciduous temperate oaks had the highest increase in mean defoliation (+1.4%), while common beech had the largest decrease (-1.7%).

Based on the data of the past 20 years, trends show a considerable increase in defoliation of Austrian pine and evergreen oaks (7.1% and 6.7%, respectively). On the other hand, the increase in defoliation for deciduous temperate oaks (2.6%) and common beech (3.4%) has been relatively low and the trend for Scots pine and Norway spruce shows a moderate increase in defoliation of 4.3 and 3.8%, respectively. No trend was detected for deciduous (sub-) Mediterranean oaks.

There was again a decrease in the number of observed damage symptoms compared to last year. As in previous years, the number of recorded damage symptoms per assessed tree was substantially higher for broadleaves than for conifers. 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 increased again slightly in 2021, mainly due to abiotic factors.

Introduction and scientific background

Tree crown defoliation and occurrence of biotic and abiotic damage are important indicators of forest health. As such, they are considered within the Criterion 2, "Forest health and vitality", one of six criteria adopted by Forest Europe (formerly the Ministerial Conference on the Protection of Forests in Europe – MCPFE) to provide information for sustainable forest management in Europe.

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. Combining the assessment of damage symptoms and their 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.

This chapter presents results from the crown condition assessments on the large-scale, representative, transnational monitoring network (Level I) of ICP Forests carried out in 2021, as well as long-term trends for the main species and species groups.

Methods of the 2021 survey

The assessment of tree condition in the transnational Level I network is conducted according to European-wide, harmonized methods described in the ICP Forests Manual by Eichhorn et al. (2020, see also Eichhorn and Roskams 2013).

Defoliation

Defoliation is the key parameter of tree condition within forest monitoring describing a loss of needles or leaves in the assessable crown compared to a local reference tree in the field or an absolute, fully foliated reference tree from a photo guide. Defoliation is estimated in 5% steps, ranging from 0% (no defoliation) to 100% (dead tree). Defoliation values are grouped into five classes (Table 7-1). In the maps presenting the mean plot defoliation and in Table 7-4, class 2 is subdivided into class 2-1 (> 25–40%) and class 2-2 (> 40–60% defoliation).

Table 7-1: Defoliation classes

Defoliation class	Needle/leaf loss	Degree of defoliation
0	up to 10%	None
1	> 10–25%	Slight (warning stage)
2	> 25–60%	Moderate
3	> 60–< 100%	Severe
4	100%	Dead (standing dead trees only)

Table 7-2 shows countries and the number of plots assessed for crown condition parameters from 2012 to 2021, and the total number of sample trees submitted in 2021. The number of trees used for analyses differs from the number of submitted trees due to the application of various data selection procedures. Both the number of plots and the number of trees vary in the course of time, for example due to mortality or changes in the sampling design.

Table 7-2: Number of plots assessed for crown condition parameters from 2012 to 2021 in countries with at least one Level I crown condition survey since 2012, and total number of sample trees submitted in 2021

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	Plots 2021	Trees 2021
Andorra	3	11	11	12							
Belarus		373		377							
Belgium	8	8	8	8	53	53	52	52	51	51	528
Bulgaria	159	159	159	159	159	160	160	160	160	159	5 570
Croatia	100	105	103	95	99	99	99	97	98	95	2 280
Cyprus	15	15	15	15			15	15	15	15	361
Czechia	135		138	136	136	135	132	132	127	121	4 550
Denmark	18	20	20	20	19	19	19	19	19	18	439
Estonia	97	96	96	97	98	98	98	98	95	95	2 242
Finland	785										
France	553	550	545	542	533	527	521	515	512	509	10 230
Germany	415	417	422	424	421	416	410	421	416	409	9 759
Greece			57	47	23	36	40	45	38	33	771
Hungary	74	68	68	67	67	66	68	68	68	69	1 530
Ireland	20							28	30	33	700
Italy	245	247	244	234	246	247	249	237	240	256	4 700
Latvia	203	115	116	116	115	115	115	115	115	115	1 746
Lithuania	77	79	81	81	82	82	81	81	81	81	1 941
Luxembourg		4	4	4	4	3	3	4	4	4	96
Moldova, Rep. of						9	9				
Montenegro	49	49			49	49	49	49	49	49	1 174
Norway	496	618	687	554	629	630	623	687	604	629	5 205
Poland	369	364	365	361	353	352	348	346	343	343	6 831
Romania	241	236	241	242	243	246	246	247	226	234	5 616
Serbia	121	121	128	127	127	126	126	127	126	126	2 836
Slovakia	108	108	107	106	103	103	101	100	99	97	4 356
Slovenia	44	44	44	44	44	44	44	44	44	44	1 067
Spain	620	620	620		620	620	620	620	620	620	14 880
Sweden	609	740	842	839	701	618	760	849	841	733	2 574
Switzerland	47	47	47	47	47	47	47	47	47	47	1 000
Türkiye	578	583	531	591	586	598	601	597	599	580	13 469
TOTAL	**6 189**	**5 797**	**5 699**	**5 345**	**5 557**	**5 498**	**5 636**	**5 800**	**5 667**	**5 565**	**106 451**

Damage cause assessments

The damage cause assessment of trees consists of three major parts. For a detailed description, please refer to Eichhorn et al. (2020) and Timmermann et al. (2016).

- Symptom description
  Three main categories indicate which parts of a tree are affected: (a) leaves/needles; (b) branches, shoots, buds, and fruits; and (c) stem and collar. A further specification of the affected part along with a symptom description is given.
- Determination of the damage cause (causal agents / factors)
  The main groups of causal agents are insects, fungi, abiotic factors, game and grazing, direct action of man, fire, and atmospheric pollutants. In each group, a more detailed description is possible through a hierarchical coding system.
- Quantification of symptoms (damage extent)
  The extent is the estimated damage to a tree, specifying the percentage of affected leaves/needles, branches or stem circumference due to the action of the causal agent or factor.

Additional parameters

Several other tree, stand, and site parameters are assessed, providing additional information for analysis of the crown condition data. For the full information, please refer to Eichhorn et al. (2020). Analysis of these parameters is not within the scope of this report.

Tree species

For the analyses in this report, the results for the four most abundant species are shown separately in figures and tables. *Fagus sylvatica* is analyzed together with *F. sylvatica* ssp. *moesiaca*. Some species belonging to the *Pinus* and *Quercus* genus were combined into species groups as follows:

- Mediterranean lowland pines (*Pinus brutia*, *P. halepensis*, *P. pinaster*, *P. pinea*)
- Deciduous temperate oaks (*Quercus petraea* and *Q. robur*)
- Deciduous (sub-) Mediterranean oaks (*Quercus cerris*, *Q. frainetto*, *Q. pubescens*, *Q. pyrenaica*)
- Evergreen oaks (*Quercus coccifera*, *Q. ilex*, *Q. rotundifolia*, *Q. suber*).

Of all trees submitted from the Level I network in 2021, *Pinus sylvestris* was the most abundant tree species (17.0% of all trees), followed by *Fagus sylvatica* (11.8%), *Picea abies* (11.5%), *Pinus nigra* (5.0%), *Quercus petraea* (4.3%), *Quercus robur* (4.2%), *Quercus ilex* (3.7%), *Quercus cerris* (3.1%), *Pinus brutia* (2.8%), *Betula pubescens* (2.4%), *Pinus halepensis* (2.4%), *Quercus pubescens* (2.1%), *Abies alba* (2.1%), *Betula pendula* (2.1%), *Pinus pinaster* (1.8%) and *Carpinus betulus* (1.8%). Most Level I plots with crown condition assessments contained one (48.7%) or two to three (38.6%) tree species per plot. On 10.4% of plots, four to five tree species were assessed, and only 2.3% of plots featured more than five tree species. In 2021, 51.4% of the assessed trees were broadleaves and 48.6% conifers. The species percentages differ slightly for damage assessments, as selection of trees for assessments in participating countries varies.

Statistical analyses

For calculations, selection procedures were applied in order to include only correctly coded trees in the sample (Tables 7-4 and 7-5). For the calculation of the mean plot defoliation of all species, only plots with a minimum number of three trees were analyzed. For analyses at species level, three trees per species had to be present per plot. These criteria are consistent with earlier evaluations (e.g. Wellbrock et al. 2014, Becher et al. 2014) and explain the discrepancy in the distribution of trees in defoliation classes between Table 7-4 and Table S1-1 in the online supplementary material[1].

Trends in defoliation were calculated according to Sen (1968) and their significance tested by the non-parametric Mann-Kendall test (tau). These methods are appropriate for monotonous, single-direction trends without the need to assume any particular distribution of the data. Due to their focus on median values and corresponding robustness against outliers (Sen 1968, Drápela and Drápelová 2011, Curtis and Simpson 2014), the results are less affected by single trees or plots with unusually high or low defoliation. The regional Sen's slopes for Europe were calculated according to Helsel and Frans (2006). For both the calculation of Mann-Kendall's tau and the plot-related as well as the regional Sen's slopes, the rkt package in the R statistical software environment (Marchetto 2015) was used.

Figures 7-2a-j show (1) the annual mean defoliation per plot, (2) the change of mean defoliation across plots over the years, and (3) the trend of defoliation based on the regional Sen's slope calculations for the period 2002–2021. For the Mann-Kendall test, a significance level of $p \leq 0.05$ was applied. All Sen's slope calculations and yearly over-all mean defoliation values were based on consistent plot selections with a minimum of three trees per species and per plot. Maps of defoliation trends for the period 2011–2021 can be found in the online supplementary material[1]. For all trend calculations plots were included if assessments were available for at least 80% of the years of interest. All queries and statistical analyses were conducted in the R/RStudio software environment (R Core Team 2016).

Quality assurance and control (QA/QC)

Since ICP Forests is a pan-European monitoring programme, stemming from various national initiatives that had already been in place when the programme started operating, the methods of monitoring employed in ICP Forests partly reflect the initial

[1] http://icp-forests.net/page/icp-forests-technical-report

differences of these systems. In line with that, initially no consistent, 'top-down' quality assurance (QA) approach was adopted and the emphasis was placed more on the quality control (QC) issues. A lot of effort has been invested into the development of the monitoring methodology in terms of harmonization and intercalibration of methods, and, where this was not possible, into the intercomparison of results obtained by different methods.

Quality assurance and control measures for crown condition assessments are organized at multiple levels: At national level, regular calibration trainings of the survey teams and control assessments in the field are conducted. Data submission to the ICP Forests collaborative database is regulated by protocols and check procedures. International cross-comparison courses (field and photo ICCs) ensure the possibility to compare data across participating countries (Eickenscheidt 2015, Dănescu 2019, Meining et al. 2019). In the Photo ICC organized in 2021, participants from 21 countries made 37 047 assessments of photographed trees in total (Table 7-3). Some countries' teams assessed photos from more than one region. Depending on the region, the following tree species were assessed: *Pinus sylvestris, Picea abies, Fagus sylvatica, Quercus petraea & Q. robur, Q. ilex, Pinus pinaster.*

Table 7-3: European regions, countries, and number of teams and assessed photos in the Photo ICC 2021

Region	Country	Teams	Photos (assessable crown: widest span)	Photos (assessable crown: national method)
Northern Europe		43	1 140	2 579
	Denmark	3	180	180
	Estonia	3	180	180
	Ireland	1	60	60
	Latvia	6	360	360
	Lithuania	2	120	119
	Norway	24	0	1 440
	Sweden	4	240	240
Central Europe		135	14 069	14 069
	Belgium	3	330	330
	Croatia	24	1 440	1 440
	Czech Republic	3	360	360
	Denmark	3	329	329
	France	5	600	600
	Germany	64	7 680	7 680
	Hungary	4	480	480
	Ireland	1	120	120
	Italy	8	330	330
	Romania	10	1 200	1 200
	Slovenia	2	240	240
	Switzerland	7	840	840
	Türkiye	1	120	120
Mediterranean Europe		36	2 730	2 460
	Croatia	9	540	540
	Cyprus	1	90	90
	Greece	1	90	90
	Italy	7	390	120
	Spain	17	1 530	1 530
	Türkiye	1	90	90
Total		**214**	**17 939**	**19 108**

National surveys

In addition to the transnational surveys, national surveys are conducted in many countries, relying on denser national grids and aiming at the documentation of forest condition and its development in the respective country. Since 1986, various densities of national grids (1x1 km to 32x32 km) have been used due to differences in the size of forest area, structure of forests, and forest policies. The results of defoliation assessments on national grids are presented in the online supplementary material[1]. Comparisons between the national surveys of different countries should be made with great care because of differences in species composition, site conditions, and methods applied.

Results of the transnational crown condition survey

Defoliation

The transnational crown condition survey in 2021 was conducted on 106 451 trees on 5 565 plots in 27 countries (Table 7-2). Out of those, 101 663 trees were assessed in the field for defoliation (Table 7-4).

The overall mean defoliation for all species was 23.5% in 2021; there was no change for broadleaves and a very slight increase in defoliation for conifers in comparison with 2020 (Table 7-4). Broadleaved trees showed a higher mean defoliation than coniferous trees (23.3% vs. 22.4%). Correspondingly, conifers had a higher frequency of trees in the defoliation classes 'none' and 'slight' (72.9% combined) than broadleaves (70%) and a lower frequency of trees with more than 60% defoliation (2.5% vs. 4.2%).

Among the main tree species and tree species groups, deciduous temperate oaks and evergreen oaks displayed the highest mean defoliation (27.3% and 26.7%, respectively). Common beech had the lowest mean defoliation (20.9%) followed by deciduous (sub-) Mediterranean oaks and Mediterranean lowland pines with 22.0% each. Mediterranean lowland pines had the highest percentage (76.8%) of trees with ≤25% defoliation, while deciduous temperate oaks had the lowest (59.0%). The strongest increase in defoliation occurred in deciduous temperate oaks (+1.4%) and the strongest decrease in common beech (-1.7%).

Mean defoliation of all species at plot level in 2021 is shown in Figure 7-1. More than two thirds (68%) of all plots had a mean defoliation up to 25%, and only 1.2% 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 west 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.

The following sections describe the species-specific mean plot defoliation in 2021 and the over-all trend and yearly mean plot defoliation from 2002 to 2021. For maps on defoliation of individual tree species in 2021, and trends in mean plot defoliation from 2011 to 2021, please refer to the online supplementary material[1].

Table 7-4: Percentage of trees assessed in 2021 according to defoliation classes 0-4 (class 2 subdivided), mean defoliation for the main species or species groups (change from 2020 in parentheses), and the number of trees in each group. Class 4 contains standing dead trees only. Dead trees were not included when calculating mean defoliation.

Main species or species groups	Percentage of trees per defoliation class Class 0 (0-10%)	Class 1 (>10-25%)	Class 2-1 (>25-40%)	Class 2-2 (>40-60%)	Class 3 (>60-99%)	Class 4 (100%)	Mean defoliation	No. of trees
Scots pine (*Pinus sylvestris*)	21.2	52.6	16.1	6.8	2.5	0.7	22.9 (-0.2)	17 792
Norway spruce (*Picea abies*)	29.4	36.3	22.2	7.9	2.9	1.3	22.9 (+0.4)	11 777
Austrian pine (*Pinus nigra*)	28.8	46.8	13.2	6.3	3.9	0.9	22.2 (+0.2)	5 324
Mediterranean lowland pines	16.2	60.6	16.1	5.1	1.3	0.7	22.0 (+0.4)	7 786
Other conifers	32.1	43.2	15.9	5.9	2.4	0.6	20.8 (+/-0)	7 840
Common beech (*Fagus sylvatica*)	35.6	38.4	16.6	5.8	3.5	0.2	20.9 (-1.7)	12 365
Deciduous temperate oaks	18.5	40.5	25.2	10.0	5.2	0.5	27.3 (+1.4)	8 965
Dec. (sub-) Mediterranean oaks	28.9	42.8	18.0	7.3	2.8	0.2	22.0 (+1.1)	7 885
Evergreen oaks	10.2	54.8	21.3	8.5	4.5	0.6	26.7 (-0.3)	4 628
Other broadleaves	29.0	44.6	14.1	6.0	4.7	1.6	22.7 (+0.1)	17 301
TOTAL								
Conifers	24.9	48.0	17.2	6.6	2.5	0.9	22.4 (+0.1)	50 519
Broadleaves	27.0	43.0	17.9	7.1	4.2	0.8	23.3 (+/-0)	51 144
All species	**26.0**	**45.5**	**17.6**	**6.8**	**3.4**	**0.8**	**23.5 (+0.2)**	**101 663**

[1] http://icp-forests.net/page/icp-forests-technical-report

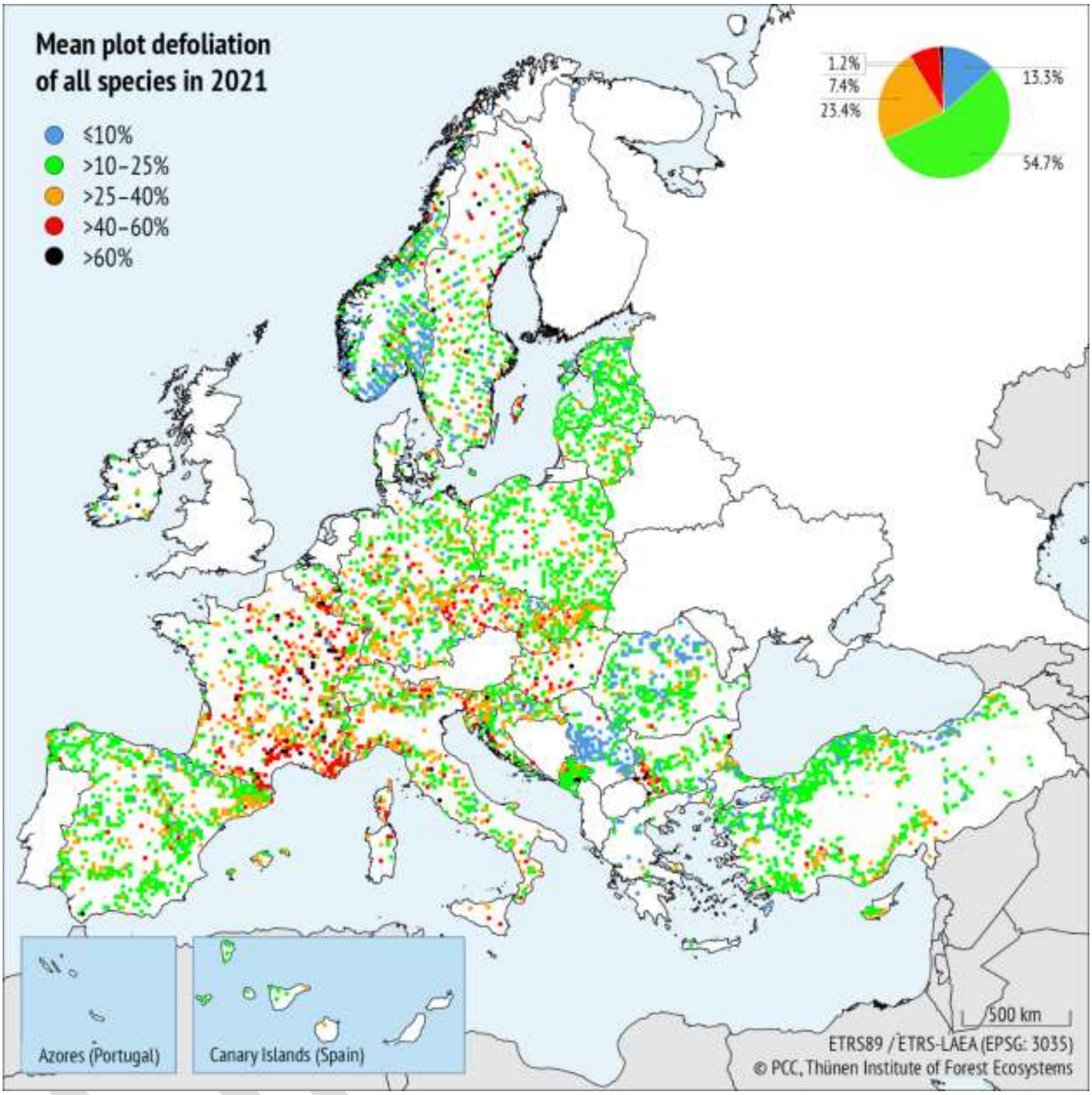
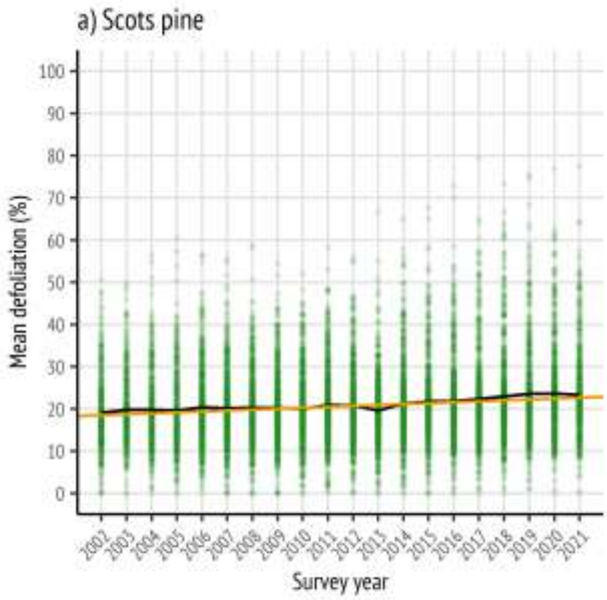
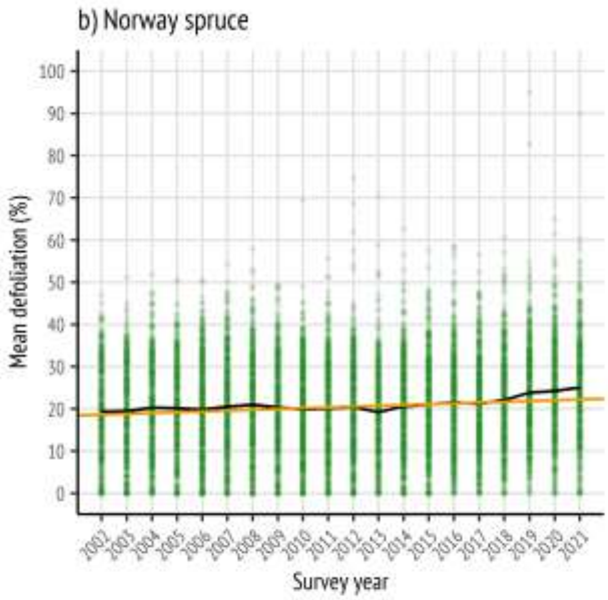
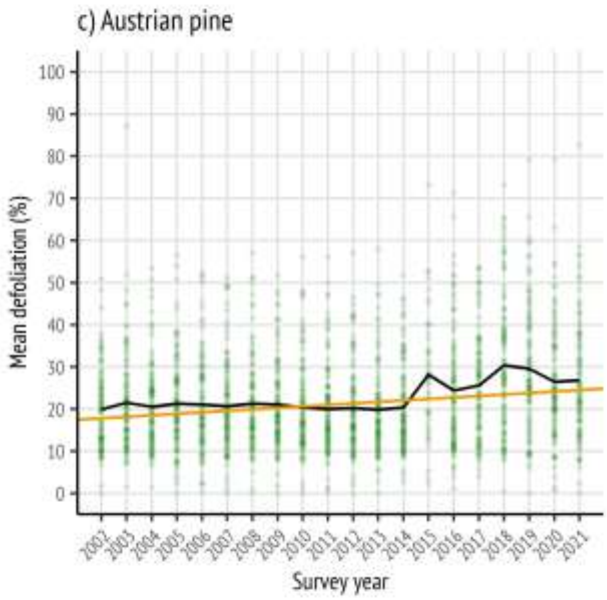
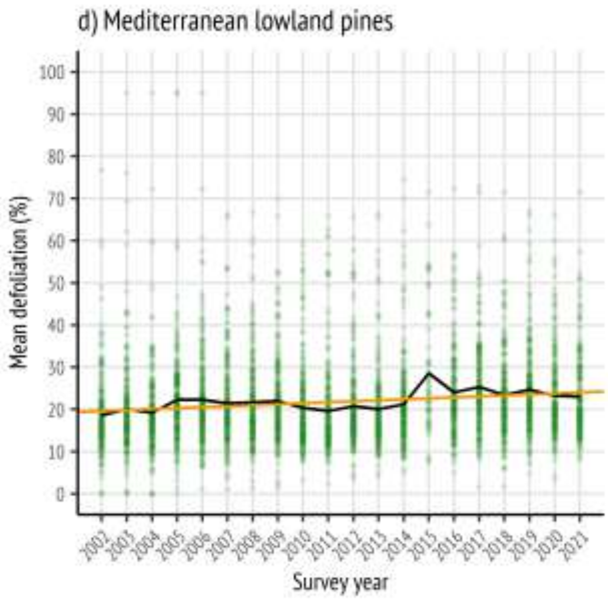


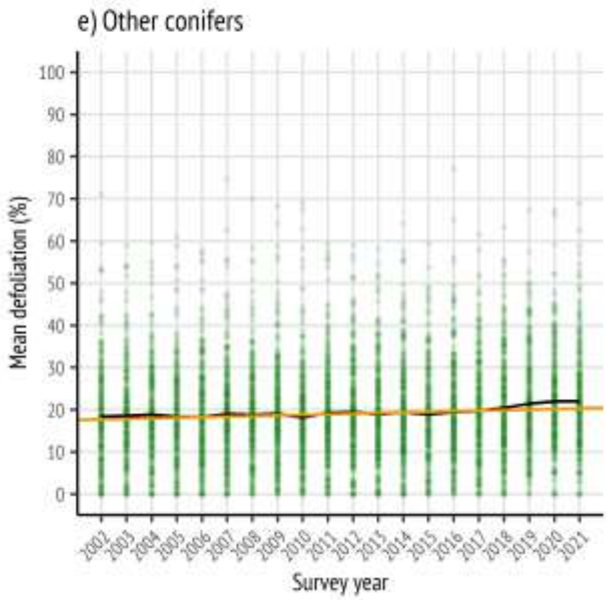
Figure 7-1: Mean plot defoliation of all species in 2021, shown as defoliation classes. The legend (top left) shows defoliation classes ranging from none (blue), slight (green), moderate (orange and red), to severe (black) defoliation. The percentages refer to the needle/leaf loss in the crown compared to a reference tree. The pie chart (top right) shows the percentage of plots per defoliation class. Dead trees are not included.





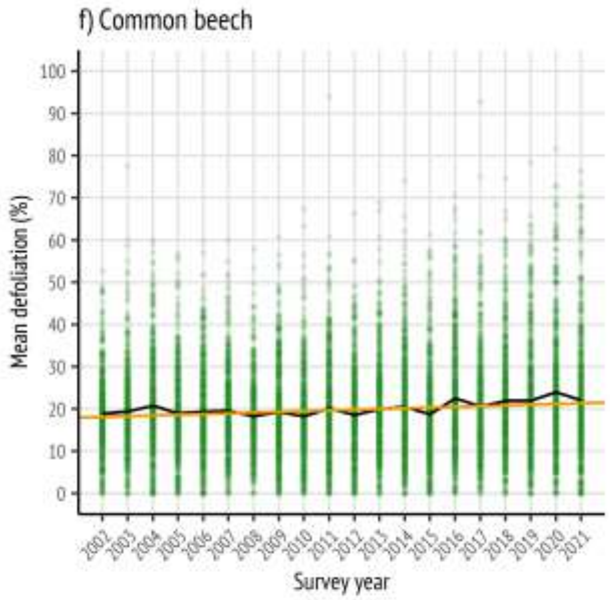


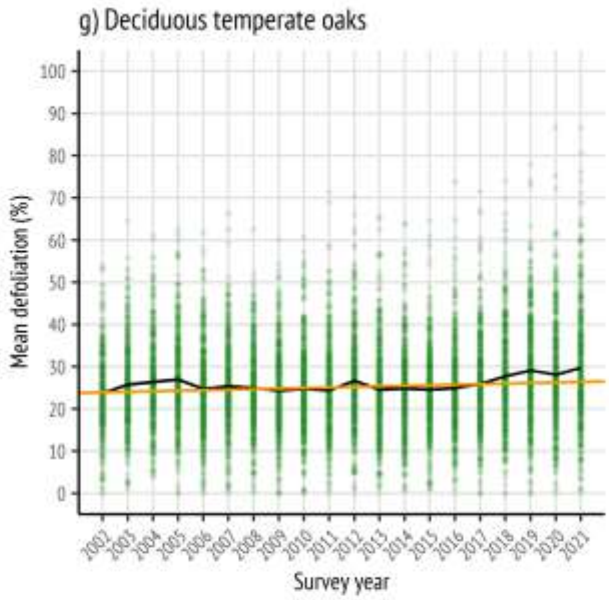


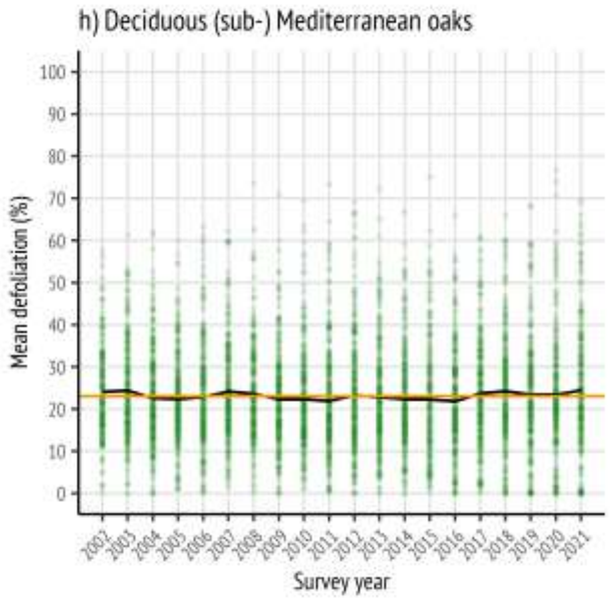


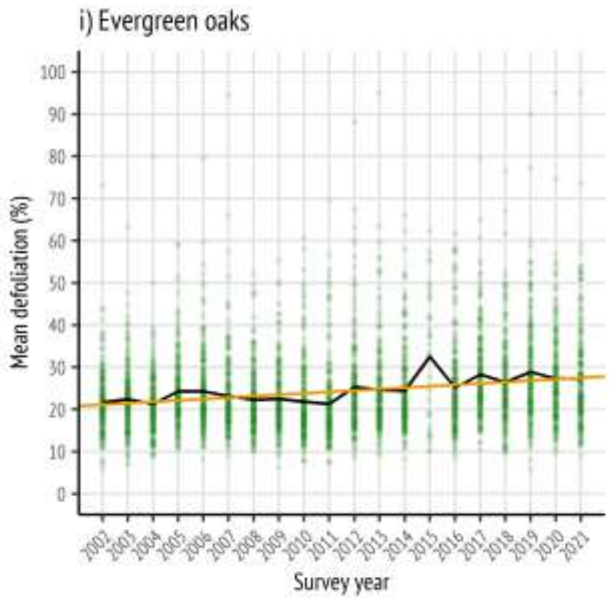
Figures 7-2 a-e: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2002–2021; points represent annual plot mean values:

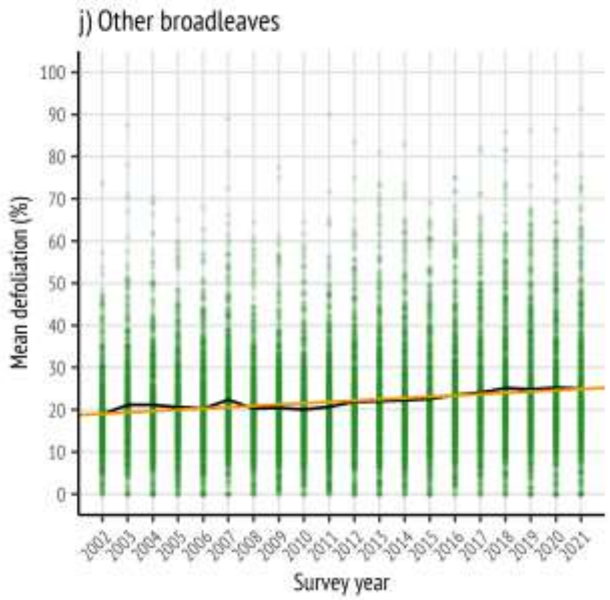
(a) Scots pine (regional Sen's slope = 0.2159, $p < 0.001$)
(b) Norway spruce (regional Sen's slope = 0.1881, $p < 0.001$)
(c) Austrian pine (regional Sen's slope = 0.3534, $p < 0.05$)
(d) Mediterranean lowland pines (regional Sen's slope = 0.2313, $p < 0.01$)
(e) Other conifers (regional Sen's slope = 0.1376, $p < 0.001$)











Figures 7-2 f-j: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2002–2021; points represent annual plot mean values:

(f) Common beech (regional Sen's slope = 0.1683, $p < 0.01$)
(g) Deciduous temperate oaks (regional Sen's slope = 0.1319, $p < 0.05$)
(h) Deciduous (sub-) Mediterranean oaks (regional Sen's slope = 0.0044, *n.s.*)
(i) Evergreen oaks (regional Sen's slope = 0.3330, $p < 0.001$)
(j) Other broadleaves (regional Sen's slope = 0.3071, $p < 0.001$)

n.s. = not significant

Scots pine

Scots pine (*Pinus sylvestris*) is the most frequent tree species in the ICP Forests Level I network (Table 7-4). It has a wide ecological niche due to its ability to grow on dry and nutrient poor soils and has frequently been used for reforestation. Scots pine is found over large parts of Europe from northern Scandinavia to the Mediterranean region and from Spain to Türkiye (and is also distributed considerably beyond the UNECE region).

In 2021, Scots pine trees showed mean defoliation of up to 10% on 13.7% of plots and slight (>10–25%) mean defoliation on 62.5% of the plots (please refer to the online supplementary material[1], Figure S1-1). Defoliation of Scots pine trees on 23.4% of the plots was moderate (>25–60% defoliation, class 2) and only on 0.4% of the plots severe (>60% defoliation, class 3). Plots with the lowest mean defoliation were primarily found in southern Norway, Estonia, Spain, and Türkiye, whereas plots with comparably high defoliation were located in Czechia, western Slovakia, central Germany, south-eastern France, and western Bulgaria.

There has been a significant trend of mean plot defoliation of Scots pine over the course of the last 20 years with an increase of 4.3% (Figure 7-2a). The mean defoliation across plots showed some fluctuation towards the end of the chosen reporting period, with mean defoliation values steadily above the trend line since 2015, and the highest value in 2019.

Norway spruce

Norway spruce (*Picea abies*) is the second most frequently assessed conifer species within the ICP Forests monitoring programme. The area of its distribution within the participating countries ranges from Scandinavia to northern Italy and from north-eastern Spain to Romania. Favoring cold and humid climate, Norway spruce at the southern edge of its distribution area is found only at higher elevations. Norway spruce is very common in forest plantations effectively enlarging its natural distribution range.

In 2021, spruce trees on roughly one fifth (20.4%) of all Norway spruce plots had defoliation up to 10%, and further 42.8% had only slight defoliation (please refer to the online supplementary material[1], Figure S1-2). On 35.4% of the plots, spruce defoliation was moderate (>25–60% defoliation) and severe defoliation was recorded on 1.5% of the plots. Plots with low mean defoliation were found mostly in Scandinavia and the Balkan region. Plots with high mean defoliation values were mostly located in central Europe.

The 20-year trend in mean plot defoliation of Norway spruce shows an increase of 3.8% (Figure 7-2b). The annual mean values have been on a steady rise and above the trendline since 2019.

Austrian (Black) pine

Austrian pine (*Pinus nigra*) is one of the most important native conifers in southern Europe, growing predominantly in mountain areas from Spain in the west to Türkiye in the east, with scattered occurrences as far north as central France and northern Hungary. This species can grow in both dry and humid habitats with considerable tolerance for temperature fluctuations. Two subspecies are recognized, along with a number of varieties, adapted to different environmental conditions.

Austrian pine had a mean defoliation of up to 10% on 12.0% of the plots containing this species, and between 11 and 25% on 64.0% of plots (please refer to the online supplementary material[1], Figure S1-3). Defoliation was moderate on 22.9% of the plots (>25-60% defoliation) and severe on 1.1% of the plots. Plots with less than 10% mean defoliation were mostly located in Türkiye, while plots with higher defoliation were scattered throughout the region.

The 20-year trend in mean plot defoliation of Austrian pine shows a large increase of 7.1% (Figure 7-2c). From 2010 to 2014 the annual mean plot defoliation was lower than the trend, but it has been above the trend line since then, reaching its absolute maximum in 2018.

Mediterranean lowland pines

Four pine species are included in the group of Mediterranean lowland pines: Aleppo pine (*Pinus halepensis*), maritime pine (*P. pinaster*), stone pine (*P. pinea*), and Turkish pine (*P. brutia*). Most plots dominated by Mediterranean lowland pines are located in Spain, France, and Türkiye, but they are also important species in other Mediterranean countries. Aleppo and maritime pine are more abundant in the western parts, and Turkish pine in the eastern parts of this area.

Mediterranean lowland pine plots had mean defoliation of up to 10% on 3.3% of plots and 68.5% of plots had defoliation between 11 and 25% (please refer to the online supplementary material[1], Figure S1-4). Defoliation was moderate on 27.9% of the plots, and severe on 0.3%. Most of plots with defoliation up to 25% were located in Türkiye and Spain. Plots with moderate to severe mean defoliation values (>40% defoliation) were mostly located in the proximity to the coastline of the western Mediterranean Sea.

For Mediterranean lowland pines, the trend shows an increase in defoliation of 4.6% over the past 20 years (Figure 7-2d), with annual values mostly staying close to the trendline.

[1] http://icp-forests.net/page/icp-forests-technical-report

Common beech

Common beech (*Fagus sylvatica*) is the second most frequently assessed species on Level I plots in 2021 and by far the most frequently assessed deciduous tree species within the ICP Forests monitoring programme. It is found on Level I plots from southern Scandinavia in the North to southernmost Italy, and from the Atlantic coast of northern Spain in the West to the Bulgarian Black Sea coast in the East.

In 2021, common beech had up to 10% mean defoliation on 20.5% of the beech plots (please refer to the online supplementary material[1], Figure S1-5). On 46.5% of plots, beech trees were slightly defoliated (>10–25% defoliation), moderate mean defoliation was recorded on 29.2%, and severe defoliation on 3.8% of plots. Most plots with lower mean defoliation were located in eastern Europe, while plots with severe defoliation were predominantly located in France and Germany.

The 20-year trend in mean plot defoliation of common beech shows an increase of 3.4% (Figure 7-2e). Annual mean values generally stay close to the trendline, but there were three larger deviations from this trend, in 2004, 2016 and 2020 (the highest ever mean plot defoliation of 23.9% was recorded in 2020). In 2004, the annual mean plot defoliation was higher than the trend as a result of the drought in the preceding year which affected large parts of Europe (Ciais et al. 2005, Seidling 2007, Seletković et al. 2009).

Deciduous temperate oaks

Deciduous temperate oaks include pedunculate and sessile oak (*Quercus robur* and *Q. petraea*) and their hybrids. They cover a large geographical area in the UNECE region: from southern Scandinavia to southern Italy and from the northern coast of Spain to the eastern parts of Türkiye.

In 2021, mean defoliation of temperate oaks was up to 10% on 7.2% of the plots, and from >10 to 25% on 42.7%, therefore more than half of the plots had no or slight mean defoliation. Moderate mean defoliation (>25–60%) was recorded on 47.5% of plots and severe defoliation (more than 60% defoliation) on 2.6% of the plots (please refer to the online supplementary material[1], Figure S1-6). Plots with severe defoliation were located mostly in France, while plots with mean defoliation up to 25% were mainly found in the east of the continent.

There has been a statistically significant increase in mean plot defoliation for deciduous temperate oaks of 2.6% in the past 20 years. Generally, the changes in the defoliation status are not very fast for deciduous temperate oaks. A good example is the increase of oak defoliation in the drought year 2003, followed by a delayed recovery (Figure 7-2f). The largest deviation of the mean defoliation from the trend line happened in 2019, possibly due to the effects of drought events both in 2018 and 2019 (JRC 2019), and the rise of defoliation continued in 2021.

Deciduous (sub-) Mediterranean oaks

The group of deciduous (sub-) Mediterranean oaks includes Turkey oak (*Quercus cerris*), Hungarian or Italian oak (*Q. frainetto*), downy oak (*Q. pubescens*), and Pyrenean oak (*Q. pyrenaica*). The range of distribution of these oaks is confined to southern Europe, as indicated by their common names.

Mediterranean oaks had mean defoliation up to 10% on 14.3% of the plots, and on 51.0% of the plots between 10 and 25%, yielding a total of 65.3% of plots with mean defoliation up to 25% for these oaks in 2021. Almost a third (33.1%) of plots showed moderate, and 1.6% severe mean defoliation for Mediterranean oaks (please refer to the online supplementary material[1], Figure S1-7). Plots with lower mean defoliation were located predominantly in Serbia, Bulgaria and Türkiye, while plots with higher mean defoliation were found mostly in southeastern France.

There has been no significant trend in mean plot defoliation for deciduous (sub-) Mediterranean oaks for the past 20 years (Figure 7-2g). Mean plot defoliation values generally stay very close to the trendline.

Evergreen oaks

The group of evergreen oaks consists of kermes oak (*Quercus coccifera*), holm oak (*Q. ilex*), *Q. rotundifolia* and cork oak (*Q. suber*). The occurrence of this species group as a typical element of the sclerophyllous woodlands is confined to the Mediterranean basin.

Very few (0.8%) of the evergreen oak plots had mean defoliation up to 10%, and there were 54.3% of the plots in the range >10 to 25% mean defoliation (please refer to the online supplementary material[1], Figure S1-8). Moderate defoliation was recorded on 43.7%, and severe defoliation on 1.2% of plots. The majority of plots with defoliation over 40% were located along the shoreline of the northwest Mediterranean.

Based on the trend analysis, evergreen oaks had an increase in defoliation of 6.7% over the last 20 years (Figure 7-2h). The defoliation development pattern for evergreen oaks is characterized by larger deviations from the trendline lasting for several years.

[1] http://icp-forests.net/page/icp-forests-technical-report

Damage causes

In 2021, damage cause assessments were carried out on 100 732 trees on 5 459 plots and in 26 countries. On 46 790 trees (46.4%) at least one symptom of damage was found, which is 0.8 percentage points less than in 2020 (47.2%). In total, 67 509 observations of damage were recorded (multiple damage symptoms per tree were possible). Both fresh and old damage was reported.

The average number of recorded damage symptoms per assessed tree (ratio, Table 7-5) was higher for the broadleaved tree species and species groups than for the conifers. It was highest for deciduous temperate oaks and evergreen oaks with 1 symptom per tree, and lowest for Norway spruce with 0.39 symptoms per tree. Compared to 2020, both the number of recorded damage symptoms and the ratios have been decreasing for all coniferous species and species groups, as well as for common beech and the groups of other broadleaves, while both have been increasing for the oak groups.

Table 7-5: Number of damage symptoms and assessed trees, and their ratio for the main tree species and species groups in 2021. Multiple damage symptoms per tree and dead trees are included.

Main species or species groups	N damage symptoms	N trees	Ratio
Scots pine (*Pinus sylvestris*)	9 553	17 422	0.55
Norway spruce (*Picea abies*)	4 309	11 043	0.39
Austrian pine (*Pinus nigra*)	2 893	5 328	0.54
Mediterranean lowland pines	4 298	7 794	0.55
Other conifers	4 030	7 668	0.53
Common beech (*Fagus sylvatica*)	8 314	10 965	0.76
Deciduous temperate oaks	8 616	8 506	1.01
Dec. (sub-) Mediterranean oaks	6 793	7 888	0.86
Evergreen oaks	4 612	4 633	1.00
Other broadleaves	14 091	19 485	0.72
Total			
Conifers	25 083	49 255	0.51
Broadleaves	42 426	51 477	0.82
All species	**67 509**	**100 732**	**0.67**

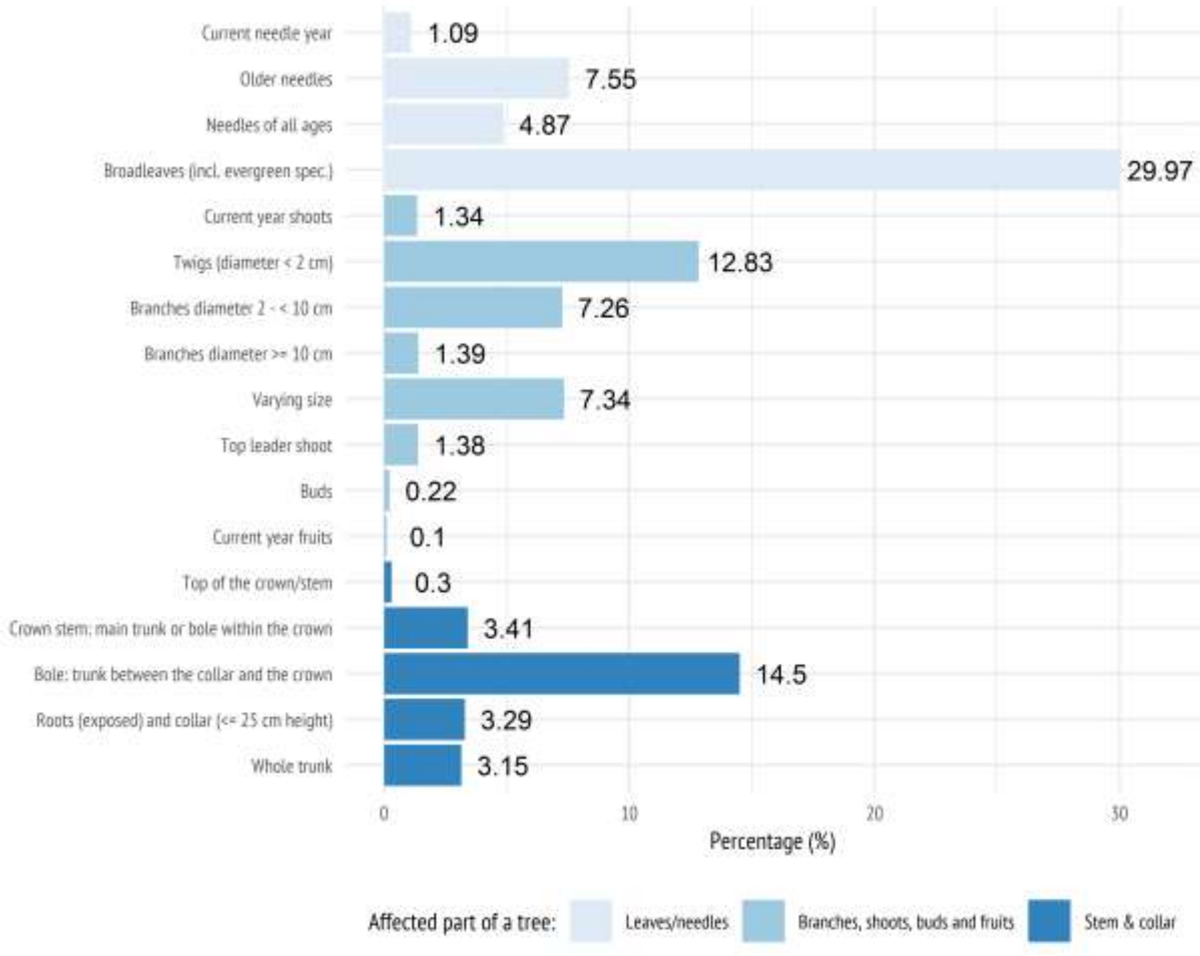


Figure 7-3: Percentage of recorded damage symptoms in 2021 (n=66 434), affecting different parts of a tree. Multiple affected parts per tree were possible. Dead trees are not included.

Symptom description and damage extent

Most of the reported damage symptoms were observed on the leaves of broadleaved trees (30%), followed by twigs and branches (28.8%), and stems (21.4%; Figure 7-3). Needles were also often affected (13.5%), while roots, collar, shoots, buds, and fruits of both broadleaves and conifers were less frequently affected.

More than half (53.8%) of all recorded damage symptoms had an extent of up to 10%, 37.4% had an extent between 10% and 40%, and 8.9% of the symptoms covered more than 40% of the affected part of a tree.

Causal agents and factors responsible for the observed damage symptoms

Insects were the predominant cause of damage and responsible for 24.6% of all recorded damage symptoms (Figure 7-4). Within the group of insects, 41.4% of damage symptoms were caused by defoliators. Wood borers were responsible for 18%, leaf miners for 11.6%, sucking insects for 9.6%, and gallmakers for 6.4% of the damage caused by insects.

Abiotic factors were the second major causal agent group responsible for 16.2% of all damage symptoms. Within this agent group, almost half of the symptoms (46.2%) were attributed to drought, while snow and ice caused 10.8%, wind 9.0%, and frost 4.7% of the symptoms.

The third major identified cause of tree damage were fungi with 11.8% of all damage symptoms. Of those, 22.8% showed signs of decay and root rot fungi, followed by powdery mildew (14.7%), dieback and canker fungi (14.6%), needle cast and needle rust fungi (12.8%), and blight (9.1%).

Direct action of man refers mainly to impacts of silvicultural operations, mechanical/vehicle damage, forest harvesting, or resin tapping. This agent group accounted for 4.6% of all recorded damage symptoms. The damaging agent group 'Game and grazing' was of minor importance (1%). Fire caused 0.7% 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 (0.04% of all damage symptoms). Other causal agents were responsible for 10.6% of all reported damage symptoms. Apart from these identifiable causes of damage symptoms, a considerable number of symptoms (30.5%) could not be identified in the field.

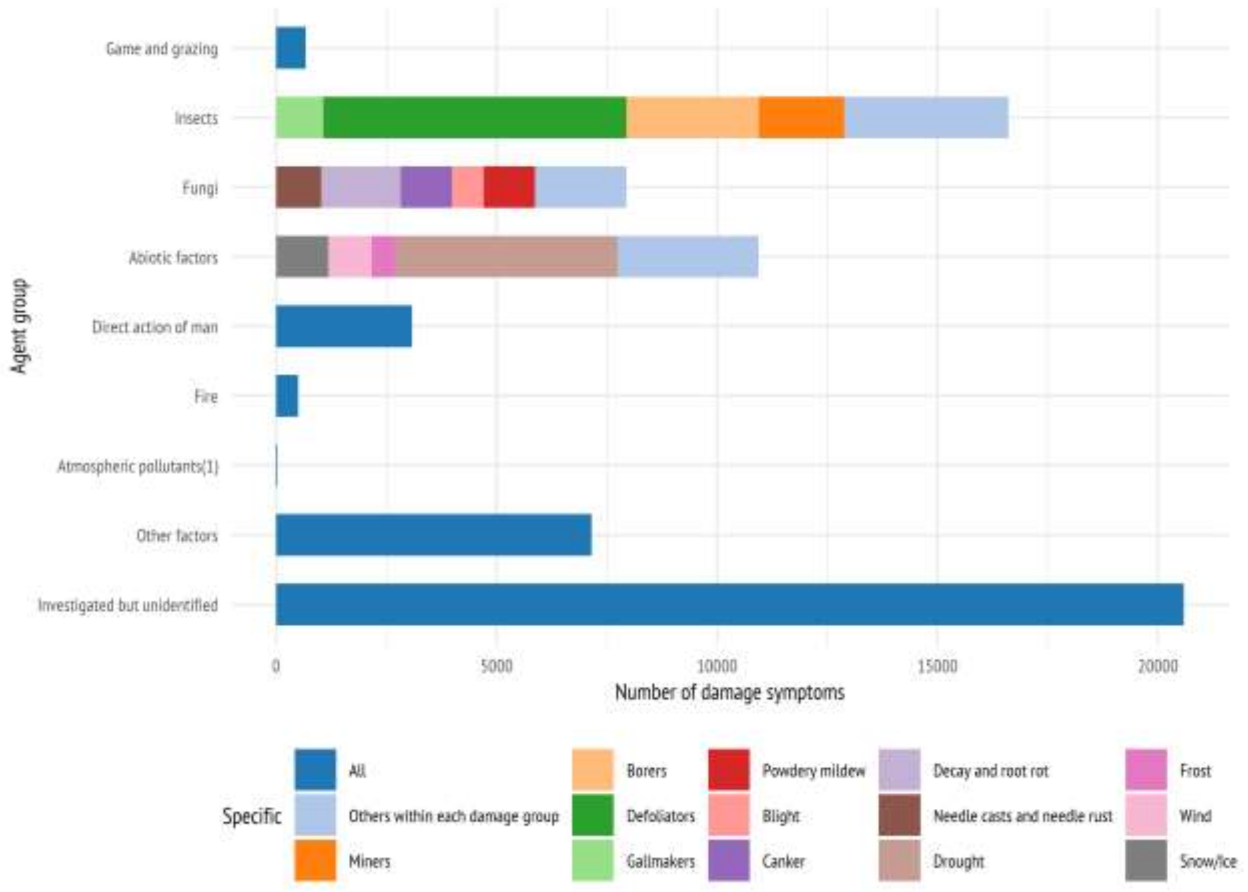


Figure 7-4: Number of damage symptoms (n=67 509) according to agent groups and specific agents/factors in 2021. Multiple damage symptoms per tree were possible, and dead trees are included. (1) Visible symptoms of direct atmospheric pollution impact only

The occurrence of damaging agent groups differed between major species or species groups (Figure 7-5). Insects were the most important damaging agent group for deciduous temperate oaks (causing 38% of all damage), common beech (34.7%) and deciduous (sub-) Mediterranean oaks (33.5%), while insect damage was not so common in Scots pine (8.2%) and Norway spruce (7.6%). Abiotic factors caused by far the most damage in evergreen oaks (42.6%) and Mediterranean lowland pines (35.5%), and the least in Scots pine (7.8%). Fungi were important damaging agents for Austrian pine (17.7%), deciduous temperate oaks (17.3%), and evergreen oaks (16.5%). Direct action of man was of little importance for most species; it had the highest impact on Norway spruce (12.8%) and Scots pine (8.7%). Damage from game and grazing played a minor role for all species and species groups except for Norway spruce (6.6%). Fire affected mostly Mediterranean species – 2.1% of Mediterranean lowland pine trees, 1.3% of Austrian pines and 1% of evergreen oaks were affected. Other identified factors, such as competition and European mistletoe (*Viscum album),* were prominent in Scots pine (25.2%) and Austrian pine (21.3%). The percentage of recorded but unidentified damage symptoms was small in evergreen oaks (10.5%) but large for Norway spruce (45.7%), Scots pine (36.3%), deciduous (sub-) Mediterranean oaks (33.3%) and common beech (33.2%).

The most important specific damaging agents for common beech were mining insects causing 17.8% of the damage symptoms, followed by defoliators (11.2%), silvicultural operations (3.9%), drought (3.8%), and competition (3.6%). Defoliators were also frequently causing damage on deciduous temperate oaks (14.4%), while powdery mildew (11.3%), sucking insects (7.7%), borers (6.5%), drought (3.3%), and competition (3.1%) also were significant. For deciduous (sub-) Mediterranean oaks, defoliators (9.6%) were the most common damaging agents, followed by borers (8.2%), drought (6.1%), sucking insects (6.1%), gallmakers (4.6%), and European ivy (*Hedera helix*) (3.2%). Drought was by far the most important damaging agent for evergreen oaks (37.6%), but also borers (13.9%), decay and root rot fungi (11.7%), defoliators (6%), and blight (3.8%) had an impact on these oak species.

Most damage symptoms in Scots pine were caused by various effects of competition (14%), followed by *Viscum album* (7.3%), borers (5.7%), needle cast/needle rust fungi (5.5%), silvicultural operations (5.5%), and wind (3.2%). For Norway spruce, competition (7.6%), silvicultural operations (8.2%), borers (5.6%) and mechanical/vehicle damage (4.1%) were most important. Defoliators were causing most damage (18.5%) on Austrian pine trees, but *Viscum album* (16.6%), needle cast/needle rust fungi (9.4%), drought (5.8%), blight (5.2%), and competition (3.1%) also caused considerable damage. Mediterranean lowland pines were mostly affected by drought (25.2%), defoliators (7.6%), sucking insects (7%), snow/ice (5.9%), *Viscum album* (5.1%), borers (3.3%), and competition (3.2%).

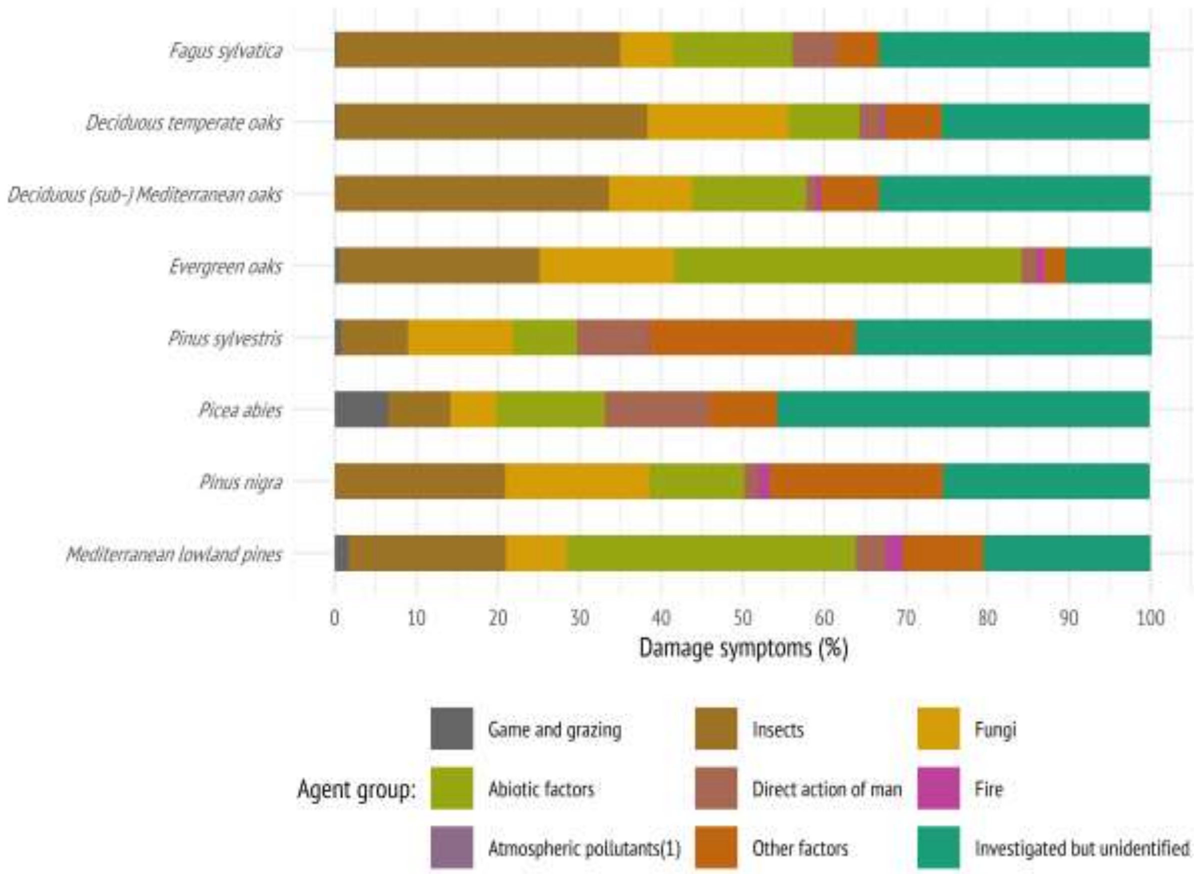


Figure 7-5: Percentage of damage symptoms by agent group for each main tree species and species group in 2021. (1) Visible symptoms of direct atmospheric pollution impact only

Regional importance of the different agent groups

Damage caused by insects in 2021 was observed on 1 782 European Level I plots, which corresponds to 33% of all plots with damage assessments. With some exceptions (Scandinavia, northern Germany, Czechia and the Baltic countries), a high proportion of plots was thus affected by insects throughout Europe.

Damage caused by abiotic factors was reported from 1 802 Level I plots (33%), occurring frequently throughout Europe. Countries most affected by abiotic factors were Spain, Slovenia, Montenegro, and Cyprus.

The agent group 'Fungi' was responsible for damage on 1 391 European Level I plots (25%) in 2021, and was frequently occurring in many countries, most notably in Estonia, Slovenia, Montenegro, parts of Serbia, Poland, Bulgaria, and Spain. Low occurrence of damage by fungi was observed in Norway, Romania, Switzerland, Italy, Türkiye, and Greece.

The damaging agent group 'Direct action of man' impacted trees on 1 013 plots (19%), and was most frequently occurring in eastern parts of Europe and southern Germany.

Damage caused by game and grazing in 2021 was most frequently observed in the Baltic countries, Hungary, and Spain, and in parts of Poland and Germany. In total, 283 Level I plots (5%) had trees damaged by this agent group.

There were 55 plots (1%) with damage inflicted by fire, most of them located in Spain.

For maps showing incidents of various agent groups, please refer to the online supplementary material[1].

Tree mortality and its causes

There were 1 075 (1.1%) new dead trees in the damage assessment 2021 (586 broadleaves and 489 conifers), a slight increase compared to 2020 (942 trees, 0.9%). The highest mortality rates were found for birch (*Betula pubescens* and *B. pendula*) with 3.7% (corresponding to 178 trees) and Norway spruce (1.6%, 178 trees). Mortality rates for other main species and species groups were in the range from 0.7 to 0.9% – except for deciduous (sub-) Mediterranean oaks (0.3%). Most dead trees were reported from Norway (214), France (190), Germany (109), Spain (98), and Bulgaria (94). The main cause of mortality to both conifer and broadleaved trees were abiotic factors (Figure 7-6) followed by insects, fire, and fungi. The determination of the cause of tree mortality is often very difficult; it could not be identified for more than half of the dead trees in 2021.

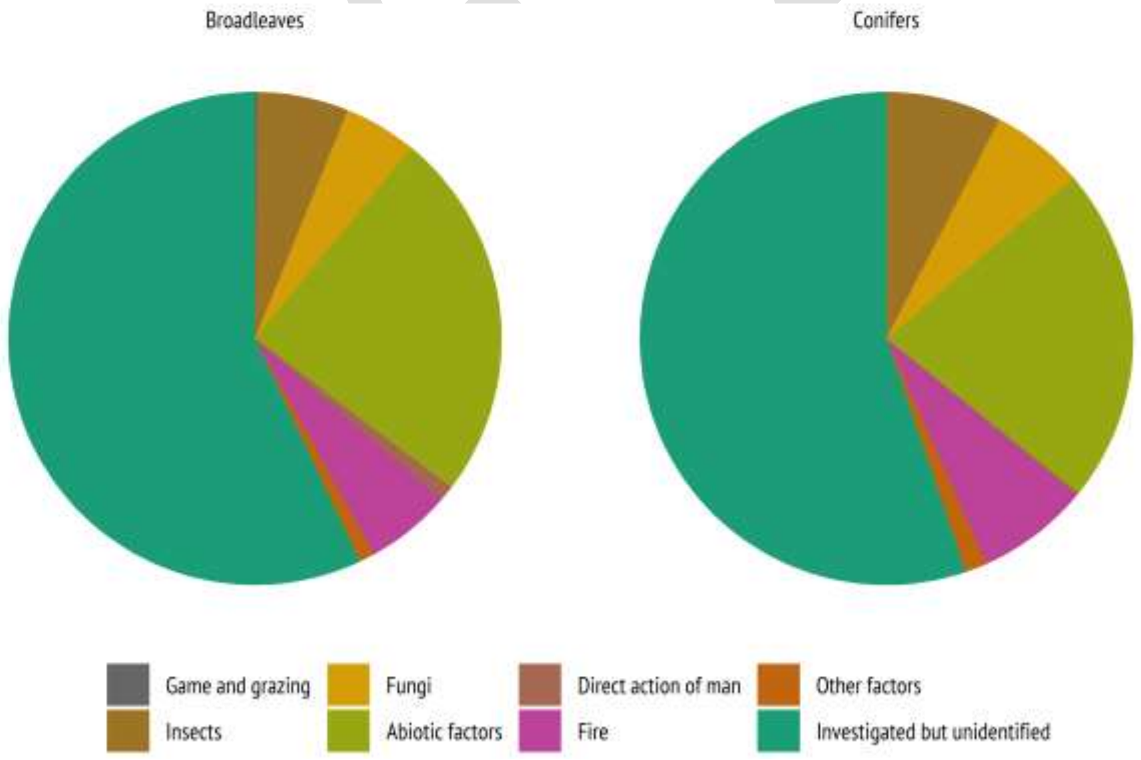


Figure 7-6: Percentage of damaging agent groups causing mortality of broadleaved and coniferous trees in 2021 (n = 1 075)

[1] http://icp-forests.net/page/icp-forests-technical-report

References

Becher G, Lorenz M, Haelbich H, et al (2014) **Tree crown condition and damage causes.** In: Michel A, Seidling W, Lorenz M, et al (eds) Forest Condition in Europe: 2013 Technical Report of ICP Forests, Thünen Working Paper 19:10–54

Ciais P, Reichstein M, Viovy N, et al (2005) **Europe-wide reduction in primary productivity caused by the heat and drought in 2003.** Nature 437:529–533

Curtis CJ, Simpson GL (2014) **Trends in bulk deposition of acidity in the UK, 1988-2007, assessed using additive models.** Ecol Indic 37:274–286

Dănescu A (2019) **Results of the International Cross-Comparison Course 2019 for Central and Northern Europe.** https://www.icp-forests.org/DocsCrown/Report_FieldICC_June_2019-min.pdf

Drápela K, Drápelová I (2011) **Application of Mann-Kendall test and the Sen's slope estimate for trend detection in deposition data from Bílý Kříž (Beskydy Mts., the Czech Republic) 1997-2010.** Beskydy (Brno) 4(2):133–146

Eichhorn J, Roskams P (2013) **Assessment of Tree Condition.** In: Ferretti M, Fischer R (eds) Forest Monitoring – Methods for terrestrial investigations in Europe with an overview of North America and Asia. Elsevier, Amsterdam, 139–167

Eichhorn J, Roskams P, Potočić N, et al (2020) **Part IV: Visual Assessment of Crown Condition and Damaging Agents.** Version 2020-3. In: UNECE ICP Forests Programme Coordinating Centre (ed.): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde, Germany, 49 p. ISBN: 978-3-86576-162-0. http://icp-forests.net/page/icp-forests-manual

Eickenscheidt N (2015) **Results of the International Cross-Comparison Course** in Witzenhausen, Germany, 11–13 June 2014

Helsel DR, Frans LM (2006) **Regional Kendall test for trend.** Environ Sci Technol 40(13):4066–4073

JRC (2019) **Map: Europe – Drought Situation: June–July 2019.** https://erccportal.jrc.ec.europa.eu/ercmaps/ECDM_20190822_Europe_Drought.pdf

Marchetto A (2015) **rkt: Mann-Kendall Test, Seasonal and Regional Kendall Tests.** R package version 1.4. https://CRAN.R-project.org/package=rkt

Meining S, Morgenstern Y, Wellbrock N, et al (2019) **Results of the European Photo International Cross-comparison Course 2017** (Photo-ICC 2017) https://www.icp-forests.org/DocsCrown/Results_Photo%20ICC%202017_final.pdf

R Core Team (2016) **A language and environment for statistical computing.** R Foundation for Statistical Computing. Vienna [http://www.R-project.org/]

Seidling W (2007) **Signals of summer drought in crown condition data from the German Level I network.** Eur J For Res 126:529–544

Seletković I, Potočić N, Ugarković D, et al (2009) **Climate and relief properties influence crown condition of Common beech (Fagus sylvatica L.) on Medvednica massif.** Periodicum Biologorum Vol 111(4):435–442

Sen PK (1968) **Estimates of the regression coefficient based on Kendall's tau.** J Am Stat Assoc 63:1379–1389

Timmermann V, Potočić N, Sanders T, et al (2016) **Tree crown condition and damage causes.** In: Michel A, Seidling W (eds). Forest Condition in Europe: 2016 Technical Report of ICP Forests. BFW-Dokumentation 23/2016, Vienna, pp. 20–59

Wellbrock N, Eickenscheidt N, Haelbich H (2014) **Tree crown condition and damage causes.** In: Michel A, Seidling W (eds) Forest Condition in Europe: 2014 Technical Report of ICP Forests, BFW-Dokumentation 18/2014, Vienna, pp. 11–71

8 HISTORY AND PROGRESS OF THE ICP FORESTS RINGTEST PROGRAMME AND THE WORKING GROUP QA/QC IN LABORATORIES

Alfred Fürst and Anna Kowalska

An important - and mostly little considered - factor in long-term environmental monitoring is consistently good data quality in the laboratory. After all, only actual changes or small trends in nature should be detected - not fluctuations in the quality of laboratory data. This was taken into account at a very early stage in the ICP Forests Level I and Level II surveys. In the early 1990s before the Europe-wide soil and foliage surveys on Level I started, the Expert Panels Soil and Foliar decided to carry out laboratory comparison tests prior to and in parallel with their surveys. We would like to show the progress towards the implementation of the modern ring test web interface compared to earlier versions.

In 1993/94, the first Needle/Leaf Interlaboratory Comparison Test was carried out using two standard reference materials provided by the BCR (European Commission). The main purpose of this first test was to eliminate unsuitable methods. At the second Expert Panel Meeting in Ås/Norway in March 1994, it was decided to continue the ring test programme in parallel with the Level I survey in 1995/1996. The evaluation of the Level I foliage data was to be carried out by the newly established Forest Foliar Co-ordinating Centre (FFCC) at the Austrian Research Centre for Forests BFW in Vienna. The ring test provider for the next four tests was the North Rhine-Westphalia State Environment Agency (LUA). The ringtests were to be conducted every two years and run in parallel with the Level II foliage surveys. During this time, the Level I and II surveys and evaluation as well as the ring tests were funded by the EU (DG Agri). Test evaluation typically took several months, as the data were sent by post or fax to the ringtest provider, entered into the evaluation program, and a printout returned to the laboratories for re-checking. Only after the correctness of all data was confirmed, the evaluation was carried out, and the report was generated and sent to the laboratories.

After the 5th test in 2001/2002, LUA could no longer continue the ring tests and they were taken over by the FFCC. The following difficulties had to be solved first:

- The evaluation time of the ring tests had to be shortened drastically so that the laboratories could react quickly to unsatisfactory results.
- A change in funding was necessary, because the EU (DG Agri) no longer funds the ICP Forests programme.

Out of these needs, the FFCC developed a web-based interface for easy and simple collection of ring test data, which is still used today. It allowed direct input of laboratory data and re-checks via the Internet and had an export function for further evaluation. The costs of the ring test were reduced and can also be covered by laboratories with a participation fee, and ringtests should be opened to other laboratories to share the cost. Ring tests are no longer tied to project funding.

The implementation of soil- (from 2007) and water ring tests (from 2009) was also switched to the WEB interface data collection and adapted by the FFCC to their specific needs. The Air Convention aims at reducing the pressure of air pollutants on the environment and human health, including heavy metals which can lead to soil contamination. Heavy metals can result from human activities and products (e.g. fertilisers, waste) or short-range air pollution from industry (e.g. smelters). Cadmium (Cd), lead (Pb) and mercury (Hg) are common air pollutants, being emitted mainly as a result of various industrial activities. Other trace metals like nickel (Ni), zinc (Zn), chromium (Cr) and copper (Cu) find their origin in the soil parent material.

This study was a first exploration of the occurrence of heavy metals in forest soils measured during two soil inventories (S1: 1985-1996, S2: 2006-2008) on the plots of the ICP Forests Level I network. The objectives of the study were:

- to explore the spatial patterns and hotspots of heavy metals in the forest floors and topsoils throughout Europe;
- to investigate if there is a significant temporal change between the first and second soil survey;
- to evaluate whether the heavy metals concentrations and stocks exceed contamination or pollution levels;
- to compare the observed forest soil concentration levels with reference databases and maps of heavy metals in soils (LUCAS survey) or in mosses (ICP Vegetation survey) at the European scale.

In 2007, the Working Group QA/QC in Laboratories was established. The members came from the respective Expert Panels, the FFCC, and the Forest Soil Co-ordinating Centre (FSCC) of ICP Forests as well as from the laboratory working group located in the Expert Panel Deposition and contributed their experience to the new working group.

The further harmonization of the ring tests and their implementation was an essential task to be continued, building upon the developments made in the years before. When the EU (DG Env) funded the FutMon (Future Monitoring) Life+ project, which started in 2009, it was possible to obtain time and money for the improvement and implementation of the ring test programme. The next major steps were:

- Harmonization of laboratory codes between laboratories for soil, foliage, and deposition/soil solution.
- Harmonization of the method codes to be able to use them in the new LQA files as well.
- Extension of the WEB interface to include a module for standard ringtest evaluation (median-based) and for recording the results of laboratory re-qualifications.
- Creation of online qualification reports for participating laboratories.
- Ring test providers needed to be found to do the practical work of conducting the ring test (tendering the test, collecting and sending samples, invoicing participants, evaluation, etc.).
- Involve PCC and NFCs in their responsibilities to ensure sufficient quality of the monitoring data in the laboratory. This was newly included in the most recent update of the ICP Forests Manual, Part XVI "Quality Assurance and Control in Laboratories" and was more strongly incorporated in the "Manual Part III: Quality Assurance within the ICP Forests Monitoring Programme" during the 2021 revision.
- Create a uniform data extract of the ring test results for the PCC database, and finally link ringtest results to monitoring data as quality indicator.

The implementation of the ring tests is finally a routine task; 45 tests have been conducted to date (24 foliage, 10 soil, and 11 water ringtests). Nearly 100 laboratories participate in the ICP Forests ringtest programme (see Fig. 8-1).

The highest number of participants took part in the tests during the EU Life+ FutMon project (2009-2011).

All ring test reports, the current status of the qualification of the laboratories in the last test, the evaluation limits and other documents (templates for re-qualification, control charts, validation of the measured values, and links to reference material) are available on the ICP Forests homepage, depending on the different matrix (see: http://icp-forests.net/page/working-group-on-quality).

For soil and foliage, ring test samples have also become suitable reference materials for method validation in the laboratory. Ringtests and reference materials are important tools to validate and regularly re-check the performance of analytical methods. This is particularly necessary in case of changes in staff training and experience, and of changes in equipment.

Another important task at the start of the FutMon programme was the creation of the new joint "Manual Part XVI: Quality assurance and control in laboratories". This task was completed in May 2010; the manual has been updated twice so far in 2016 and in 2020. The most important topics in the manual deal with the use and type of reference materials, the use of control charts for lab-internal quality control, the determination and use of detection- and quantification limits, the verification and checks of analytical data, the description and procedure of ring tests, quality indicators, and reports.

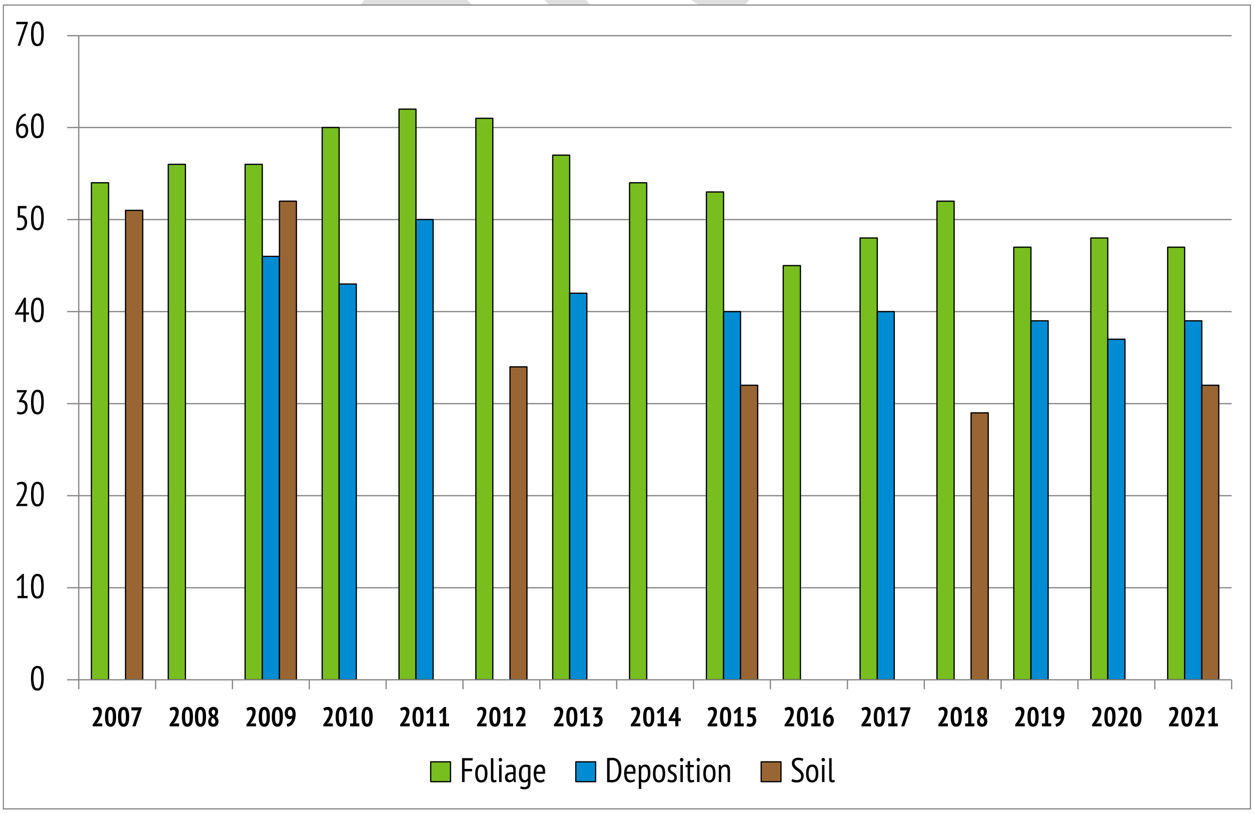


Figure 8-1: Number of participating laboratories in the ringtests from 2007 to 2021

Knowledge sharing was and is an important task of the WG QA/QC in laboratories. During the Forest Focus and FutMon programmes funded by the EU (DG Env and Life+ Regulation) it was possible to raise funds for on-site audits in the laboratories. This made it possible to visit the laboratories and, if problems were found, to fix them immediately or to undertake direct advisory tasks. This option was very efficient but unfortunately also expensive, so it was not possible to continue it after the funding by the EU ended. Perhaps new funded projects will arise here in the future that will allow this laboratory assistance programme to continue. In any case, direct assistance between individual laboratories is possible, as has already been done in the past, if funding is provided by the requesting laboratory.

Another way of sharing knowledge is to hold a regular meeting of the heads of the laboratories. Here, the results of the individual ring tests can be discussed and the participants have the opportunity to address problems and report on new methods. The first meeting of the Heads of the Laboratories with 37 participants took place in Hamburg (Germany) on June 9-10, 2008 and the eighth will be held in Birmensdorf/Switzerland in Mai 2022. Participation in these meetings should also be more strongly encouraged by the NFCs, not only in financial terms. Personal participation in these meetings and direct contact with other colleagues provides the opportunity to discuss problems in the laboratory and hopefully find solutions, even if sometimes English is not perfectly spoken. All contributions from the meetings, as well as the minutes, are available on the ICP Forests website for further use.

To maintain the connection of the Expert Panels Deposition, Soil and Soil Solution, and Foliage and Litterfall with the Heads of the Laboratories, the WG QA/QC in Laboratories always meets together with the Expert Panels at the biennial joint Expert Panel meetings. Tasks from the Expert Panels, e.g. new parameters, LOQ, allowed or new methods, etc., can be easily passed on to the WG QA/QC and are then discussed in the Meeting of the Heads of the Laboratories. Results of the Meetings of the Heads of the Laboratories are communicated back to the individual EPs.

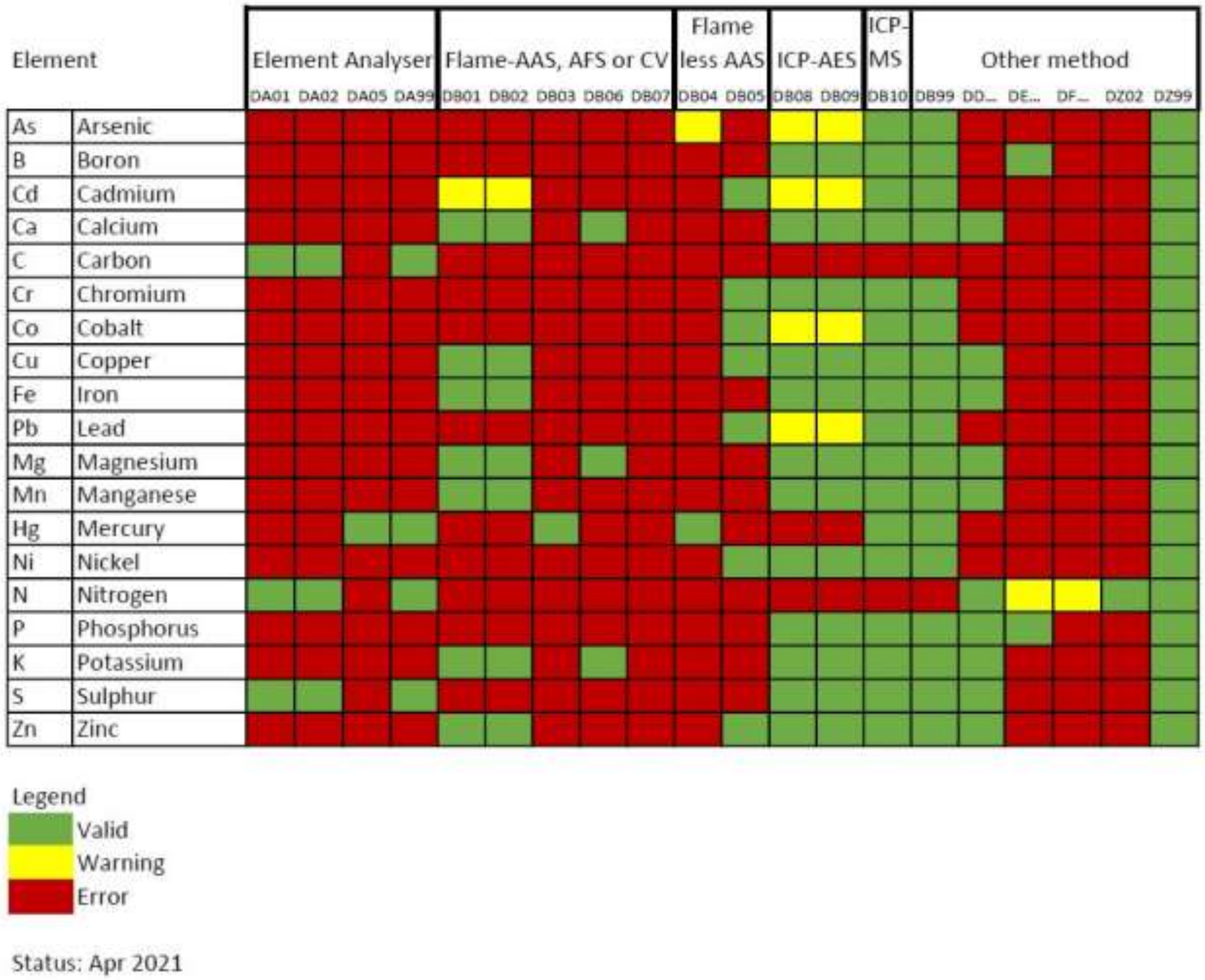


Figure 8-2: Validity database check of determination methods for foliage and litterfall
(see: https://icp-forests.org/documentation/ExplanatoryItems/211.html)

Collecting quality information (analytical methods, LOQ, ringtest results) and linking it to monitoring data is a new task for the PCC's database managers. The first attempts to link the ring test number and the laboratory code to the monitoring data date back to 2005 to the EP Foliage. At that time, this information was simply added to the data files. But during the harmonization of data submission, the WG QA/QC in Laboratories proposed to collect these data in a separate file (LQA-file) and to upload it to the PCC database together with the monitoring data. The ultimate goal is that each measured value for each variable can be linked to the corresponding laboratory quality indicators and ringtest result. For each individual dataset this provides information on the quality and the uncertainties of the data.

A brand new task for the database managers is the introduction of more complex data checks when uploading these LQA files to minimize data entry errors. Here, close cooperation between the Expert Panels, the WG QA/QC in Laboratories, and the ringtest providers with the database managers is important. In addition to simple range checks of the inputs, complex checks of the digestion and determination methods and their combination per parameter were developed in 2021 initially for foliage and litterfall (see example in Fig. 8-2).

The methods coloured green in Figure 8-2 are recommended in the "Manual Part XII: Sampling and analysis of needles and leaves" and are also analytically chemically possible for this parameter and the concentration of the parameter lie within the expected concentration range. The methods coloured yellow are analytically chemically possible for this parameter and are within the expected concentration range. However, they are not explicitly listed in the manual. The methods coloured red are not suitable for this parameter. The current ring tests are a good source for finding out suitable methods; changes and the use of new methods can also be derived from the ring test results. These complex check routines were initially used for foliage and litterfall and will need to be developed for soil, soil solution, and deposition in the future.

As has been shown, quality assurance and control in laboratories is a never-ending continuous task and has to do with constant improvement and, of course, with continuous work, as the saying goes – the better is the enemy of the good.

PART C

National reports of participating countries in ICP Forests

9 NATIONAL REPORTS OF COUNTRIES PARTICIPATING IN ICP FORESTS

All participating countries in ICP Forests were invited to submit summary reports on their ICP Forests activities. Many countries have taken this opportunity to highlight recent developments and major achievements from their many national forest monitoring activities.

All written reports have been slightly edited, primarily for consistency, and are presented below. The responsibility for the national reports remains with the National Focal Centres and not with the ICP Forests Programme Co-ordinating Centre. For contact information of the National Focal Centres, please refer to the Annex.

Andorra

National Focal Centre

Silvia Ferrer Lopez, Maria Salas Sopena
Ministry of Environment, Agriculture and Sustainability

Main activities/developments

The assessment of tree crown condition, Level I, was conducted on 12 plots in the national 4x4 km grid following the ICP Forests Protocol. The assessment included 288 trees, 116 *Pinus sylvestris*, 139 *Pinus uncinata*, 6 *Betula pendula* and 27 *Abies alba*, covering the main subalpine forests in Andorra.

Major results/highlights

Results for 2021 showed a worsening in terms of crown condition. For defoliation there was a very slight improvement compared to 2020, but it was registered an increase in the percentage of discoloration.

After several years of improvement in crown condition (2009–2016), Scots pine (*Pinus sylvestris*) and mountain pine (*Pinus uncinata*) showed the most severe crown deterioration in the last two years. The defoliation of birch (*Betula pendula*) also increased in recent years whereas European silver fir (*Abies alba*) hardly showed any impact.

Unfavorable climatic conditions during 2019, 2020 and 2021, which included low rainfall and higher temperatures during the vegetative period, could explain the worsening of crown condition in the last three years.

The assessment of damage affected 16.7% of the sampled trees. The trend in damage showed that there has been a continuous increase in the number of individuals with some type of damage since 2014. Although the number of damaged trees decreased in 2020 compared to 2019, it increased again in 2021 (the number of individuals was similar from 2018 to 2019).

The types of recorded damage symptoms were similar to recent years. The most common identified causes of damage in 2021 were abiotic (wind damages, lightning scars, etc.) followed by biological agents such as the fungus *Cronartium flaccidum*. It should be highlighted that *Thaumetopoea pityocampa*, *Ips acuminatus* or *Phaenops cyanea* were not detected in 2021.

Austria

National Focal Centre

Anita Zolles, Austrian Research Centre for Forests (BFW)

Main activities/developments

Crown condition assessments on Level I plots and on Level II plots in Austria were already discontinued in 2011 and all 135 Austrian Level I plots were abandoned. Monitoring activities on the 16 Austrian Level II plots are continued.

In 2021 on all 16 plots wet deposition was collected and analyzed. Foliage samples were taken on all 16 plots. On 6 out of the 16 Austrian Level II plots – Level II core plots – also meteorological measurements, including measurements of soil temperature and moisture, were continued as well as collections of litterfall, chemical analyses of soil solution and measurements of tree increment via mechanical and electronic girth bands. Hemispheric Photographs were taken at all 6 Level II core plots to obtain Leaf Area Index. Work on the second soil survey has started in June 2021. The analysis of the collected samples will be finished within 2022. The assessment of ground vegetation biomass has started in spring 2021 and was completed in autumn 2021.

Major results/highlights

The Level II plot Mondsee was damaged by hail in June 2021 and successfully reconditioned during summer. In late spring, early summer, the solar radiation sensor at the station Klausen Leopoldsdorf malfunctioned and was replaced. Data on mercury concentration obtained through the litterfall and foliage analyses was used in the Austrian Minimata report published at the end of 2021 (see section Non-peer-reviewed publications/reports). Using temperature measurements and Leaf Area Index measurements obtained at the Klausen Leopoldsdorf measurement site, a paper was published in the Frontiers Special Issue on Forest Monitoring to Assess Forest Functioning Under Air Pollution and Climate Change (see section Peer-reviewed scientific publications).

The results of the measurements and the chemical analyses on the Austrian Level II plots can be found at: http://www.waldmonitoring.at

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Uhl M, Kaiser A-M, Brielmann H, Dirnböck T, Hartmann C, Kratz K, Lenz K, Liebmann B, Müller-Grabher D, Spangl W, Tesar M, Titz M, Winter B, Fürst A, editors (2021) Umsetzung des Minimata-Übereinkommens über Quecksilber in Österreich (Implementation of the Minimata Convention on mercury in Austria), Umweltbundesamt GmbH Spittelauer Lände 5, 1090 Wien/Österreich

Outlook

The monitoring activities on the 16 plots will be continued on a similar level as within the past years. This includes regular investment in measurement facilities and replacement of broken equipment.

The 6 core-monitoring plots are included in the network of sites for monitoring the negative impacts of air pollution upon ecosystems under the National Emissions Ceilings (NEC) Directive (2016/2284/EU). These plots will form the basis for collecting and reporting the information concerning forest ecosystems required under the NEC Directive.

In 2022, a new project on tree growth and artificial intelligence will start, within the project tree growth characteristics will be assessed. Furthermore, the influence of different obtained parameters on tree growth will be analyzed. As part of the project dendrometers on all 6 core measurement sites will be renewed. Additionally, in 2022 soil water pumps will be replaced.

Belgium Flanders

National Focal Centre

Arne Verstraeten
Research Institute for Nature and Forest (INBO)

Main activities/developments

The Level I survey was performed on 75 plots and 1473 trees (838 broadleaves and 635 conifers, 4x4 km grid). The main tree species are *Pinus sylvestris* (32.2%), *Quercus robur* (26.2%), *Pinus nigra* subsp. Laricio (10.5%), *Fagus sylvatica* (8.8%) and *Q. rubra* (6.3%). A subset with 'other broadleaves' accounts for 15.6% of the sample. The most important species in this subset are *Castanea sativa*, *Quercus petraea*, *Fraxinus excelsior*, *Betula pendula*, *Alnus glutinosa*, *Acer pseudoplatanus* and *Populus* sp. There are only a few 'other conifers' in the survey (0.4%).

Major results/highlights

In Level I, the mean defoliation was estimated to 22.7%. The share of trees with more than 25% defoliation was 19.9%. The mortality rate was 0.7%. Mean defoliation in broadleaves and conifers was 22.9% and 22.4% respectively. The share of damaged trees was 22.8% in broadleaves and 16.2% in conifers.

Defoliation was highest in *Quercus robur* and *Fagus sylvatica*. 27.4% of *Q. robur* and 20.9% of *F. sylvatica* were classified as being damaged. In *Q. rubra* and 'other broadleaves' the damage level was lower, with 14.0% and 19.6% of the trees in defoliation classes 2-4. The level of damage was higher in *P. nigra* compared to *P. sylvestris*, with 19.4% and 15.2% of the trees rated damaged.

Moderate to severe discoloration was assessed on 9.1% of the trees. In contrast to previous years, heat waves and drought periods did not occur. Storm damage was almost completely absent. Weather conditions promoted fungal infection. 29.5% of *Q. robur* showed more than 10% discolouration, caused by mildew (*Microsphaera alphitoides*). Compared to 2020, more insect defoliation and fungal infection was observed on oaks. Moderate to severe insect defoliation was recorded on 7.7% of the sample trees, most on *Quercus robur* (26.4%).

Seed production was low. 2.3% of *Q. robur* showed scarce fruiting but common to abundant fruiting was not observed. In *F. sylvatica* seed production was more frequent, with 17.1% of the trees with scarce fruiting and 5.4% with moderate to high fructification.

Crown condition improved compared to previous survey. Mean defoliation decreased with 0.7% points and the share of trees showing more than 25% defoliation resulted 4.4% points lower. *F. sylvatica*, *P. nigra* and the 'other broadleaves' revealed a significant improvement of the crown condition. *Q. robur*, *Q. rubra* and *P. sylvestris* showed no significant changes. In spite of this overall improvement, in several plots a deterioration of the crown condition was observed.

Over the last 25 years, crown condition deteriorated. The negative trend is significant in *F. sylvatica* and the total of all broadleaves. There is no significant trend in Q. robur, *Q. rubra*, *P. sylvestris* and the total of all conifers. *P. nigra* is the only species showing a significant improvement of the crown condition.

Hymenoscyphus fraxineus is causing severe damage in *Fraxinus excelsior* since 2010. In 2014 a crown condition survey was started, with 29 plots and 252 sample trees. This survey is partly executed in Level I plots. The share of ash trees with more than 25% defoliation did not change in 2021 but mean defoliation increased. From 2014 to 2021, 24.2% of the sample trees died.

For Level II the calibration of FDR-sensors in 5 plots was finalized, using monthly data on the gravimetric soil water content collected in situ for two years.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Sioen G, Verschelde P, Roskams P (2021) Bosvitaliteitsinventaris 2020. Results of the crown condition survey (Level I). Research Institute for Nature and Forest, Report 2021 (20). INBO, Brussels (in Dutch). ISSN:1782-9054, https://doi.org/10.21436/inbor.34283136

Outlook

The Level I and the Level II program will be continued, as well as the additional survey on the condition of *Fraxinus excelsior.*

Belgium Wallonia

National Focal Centre

Elodie Bay, SPW – Public Service of Wallonia

Main activities/developments

In 2021, data were collected in 7 plots for Level II/ III (a spruces plot was cut down because of *Ips typographus*) and in 48 plots for Level I.

Major results/highlights

Several species began their season of vegetation with a notable late budburst. This was due to abnormaly cold temperatures in April and May. Those temperatures had also positive effects: emergence of *Ips typographus* was delayed by 6 weeks, which did not allow insect populations to increase as much as they did in the last years. The crisis in spruces seems to go to an end. The summer was marked by torrential rains. 2021 has been quite a wet year. After these years of drought, it will have allowed some forests to recover. However, the effects will not have been as beneficial on waterlogged soils. This humid atmosphere also favored the development of pathogens. More particularly, here are some tendencies for the following species:

- Spruce largely benefits of the decreasing of *Ips typographus* populations. Level of defoliation still stay high with around 45%.
- Douglas fir still faces serious insect damages (*Contarinia pseudotsugae*). Young trees are more impacted.
- The degraded status of beeches is maintained. Defoliation has slighty but regulary increased from the 10 past years, to reach 44% in 2021.
- Oak seems to be affected by the droughts of previous years. Defoliation has an average increase of 10%. Declines were observed at sites where oaks grow on difficult soil.
- Larches have been added to the network in 2019. Their average defoliation reaches 40%. There is no specific damage that could explain this high rate.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

See our annual reporting on forest health (in French) which includes ICP Forests data on http://owsf.environnement.wallonie.be. Data are also included in the Walloon Regional Environmental Report (in French) on http://etat.environnement.wallonie.be.

Outlook

Future developments of the ICP Forests infrastructure: A complete revision of the plots is under conduct. The aim is to keep representativity that was lost with time (cut down, aging,...). Sampling surface will be enlarged. Some plots will probably be replaced.

Planned research projects, expected results: A full analyse of phenology data is under conduct.

Bulgaria

National Focal Centre

Genoveva Popova, Executive Environment Agency (ExEA)

Main activities/developments

Level I

In 2021, large-scale forest monitoring (Level I) was conducted in 160 permanent sample plots on 5570 sample trees. Evaluations were carried out on four coniferous species: *Pinus sylvestris*, *Pinus nigra* Arn., *Picea abies* (L.) Karst and *Abies alba* Mill. in addition to nine deciduous tree species - *Fagus sylvatica* L., *Fagus orientalis* Lipsky, *Quercus cerris* L., *Quercus frainetto* Ten., *Quercus petraea* (Matt.) Liebl., *Quercus rubra* L., *Carpinus* *betulus* L., *Castanea sativa* Mill. and *Tilia platyphyllos* Scop. The total number of monitored coniferous trees was 2430 (43.6%), while that of deciduous trees was 3140 (56.4%).

Within the Level I forest monitoring, in 2021 the following activities were conducted:

- crown condition assessments in all 160 Level I sample plots (SPs);
- collection and analysis of leaves/needles samples (foliar analysis) in 39 Level I SPs;
- collection and analysis of soil samples in 20 Level I SPs - the physical and physicochemical properties, chemical composition by genetic horizons and layers;
- estimation of growth and yield of stands in 20 Level I SPs - determination of diameter, height and volume of stand.

Level II

The following activities were conducted within the framework of the intense forest monitoring:

- assessment of tree crowns and damage factors in 4 permanent Level II sample plots (SPs);
- collection and analysis of atmospheric deposition in all 4 Level II SPs;
- collection and analysis of soil solution in all 4 Level II SPs;
- collection and analysis of litterfall samples in 3 Level II SPs;
- monitoring of air quality indicators – all 4 PPs from Level II;
- monitoring of meteorological parameters in all 4 Level II SPs;
- evaluation of ozone injuries in 2 Level II SPs;
- phenological survey in the Vitinya core-plot (SP0001).

The Forest monitoring programme in Bulgaria operates within the framework of the National System for Environmental Monitoring (http://eea.government.bg/bg/nsmos). Monitoring activities are carried out in collaboration with the Forest Research Institute under the Bulgarian Academy of Sciences and University of Forestry.

Major results/highlights

The results of the large-scale monitoring programme conducted in relation to defoliation showed that in 2021 both the state of coniferous and deciduous trees remained the same as in 2020. The monitored deciduous trees were in better condition, with 76.8% showing class 0 (not defoliated) and 1 (slightly defoliated). That percentage among coniferous trees was 53.2%. Overall, there was an estimated increment in the number of healthy and slightly defoliated trees, with 0.3% and 1.3% respectively for deciduous and coniferous trees. The share of class 4 (dead) trees among deciduous trees was 0.8% lower, whereas among coniferous tree species it was 1.8% higher.

The observations in the sample plots for intensive monitoring (Level II) were focused on the influence of different stressors and the reaction of the ecosystem. The results of 2020 showed the following:

The main stress factor in the coniferous monitoring sample plots Yundola (SP0003) and the complex background station (CBS) Rozhen (SP0005), in consecutive years, has been ozone again. Irrespective of the fact that for the last two years the AOT40 indicator in the Yundola station region decreased, over the last five years the short-term target norm for vegetation protection was exceeded 1.2 times, while that for forest protection 2.3 times. The calculated values of AOT40 for CBS Rozen in 2020 also decreased, as the short-term target norm for vegetation protection was not exceeded, and it is still 2 times higher than the target norm for forest protection. The ozone concentration in the area of the SP Staro Oryahovo is also higher, as the calculated AOT40 is 1.5 times higher than the target norm for forest protection.

The combination of dry weather conditions and high temperature on different days in the summer months (July and August) continues to have an adverse effect on the condition of different tree species and remains one of the main stressors.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Kadinov G (2021) Comparative assessment of tropospheric ozone loads of two *Fagus sylvatica* sites. J Balkan Ecol 24(2):157-172.

Kuzmanova R (2021) Phenological studies of common beech (*Fagus sylvatica* L.), Sofia, Sejani LtD, 154, ISBN 978-619-91033-0-2.

Pavlova E, Pavlov D, Doncheva M, et al (2021) Forest Ecosystem Monitoring. Biological indikators. Region Middle Rhodopes, ISBN: 978-954-749-124-3, 143 p.

Outlook

The programme for forest ecosystem monitoring (Level I and II) in Bulgaria is permanent and is operationalized as part of the National System for Environmental Monitoring.

All Level II sample plots are included in the national network of monitoring sites in accordance with Art 9(1) of the NEC directive. The data collected from these sites will provide a significant part of the information related to indicators used for monitoring the impacts of air pollution on terrestrial ecosystems (Art 10 (4(a))).

Croatia

National Focal Centre

Nenad Potočić, Croatian Forest Research Institute

Main activities/developments

NFC Croatia activities in 2021 were standard despite the COVID-19 pandemic. The annual intercalibration course for crown condition assessment was successfully completed, and the annual crown condition survey was conducted on Level I plots. Level II activities were continued with the full set of measurements on all seven intensive monitoring plots.

Major results/highlights

Level I

Ninety-five sample plots (2280 trees) on the 16 x 16 km grid network were included in the survey 2021, 1954 broadleaved and 326 conifer trees.

The percentage of trees of all species within classes 2-4 has been relatively stable through the years – in 2021 it was 31.8% compared to 29.3% in 2020 and 30.3% in 2019. Broadleaves had lower defoliation (30.4%) than conifers (46.0%) within defoliation classes 2-4, respectively.

Most defoliated tree species in Croatia in 2021, based on the percentage of trees in classes 2-4, were *Pinus nigra* (92.0%), *Fraxinus angustifolia* and *Quercus petraea* (57.1%). The least defoliated species were *Fagus sylvatica* (16.6%) and *Pinus halepensis* with 28.7% of trees in classes 2-4.

The most widespread was damage to leaves (35.4% of all recorded damage), followed by damage to branches, shoots, and buds (33.3 %), and finally on the trunk and butt end (31.3%). Most of tree damage was caused by insects (26.3% of all damage), especially sucking insects (13.3%). Next were abiotic agents with 13.7%, and fungi with 8.2% of all damage. Direct human activity accounted for 6.7% of all damage to forest trees. In 2021, drought was not a major damage factor. Despite a large number of recorded damage symptoms, damage extent was mostly in category 1 (0-10%).

Level II

Crown condition on our intensive monitoring plots depends a lot on biotic factors. *Corythuca arcuata* continues to cause significant damage to leaves of pedunculate oak trees – we recorded leaf necrosis as the consequence of oak lace bug attack on all trees on plots 109 and 110. Damage from beech leaf-mining weevil – *Rhynchaenus fagi* was recorded on almost all trees on plots 103 and 105, and damage from leaf-eating weevils (Coleoptera: *Curculionoidea*) on all *Quercus pubescens* trees on plot 108.

Monitoring deposition in 2021 was resumed (6 out of 7 Level II plots) after the reduced financing in 2020. A reduced deposition of nitrogen and acid compounds recorded on all our Level II plots in 2020 was not continued in 2021, and the values were back to the pre-pandemic level.

Ground-level ozone concentrations in summer months were close to limit values. Nevertheless, leaf symptoms suggesting oxidative stress were not found.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Ognjenović M, Seletković I, Potočić N, et al (2022) Defoliation change of European beech (*Fagus sylvatica* L.) depends on previous year drought. Plants 11: 730. DOI: 10.3390/plants11060730

Potočić N, Seletković I, Jakovljević T, et al (2022) Oštećenost šumskih ekosustava Republike Hrvatske – izvješće za 2021. godinu [The damage status of forest ecosystems in Croatia – a report for 2021] Hrvatski šumarski institut/Croatian Forest Research Institute. Jastrebarsko, Croatia. http://www.icp.sumins.hr

Outlook

Despite the reduced financing of the national forest monitoring programme in 2022, all standard NFC activities related to Level I and Level II monitoring are planned, with the exception of growth, ozone, and deposition data from Level II plot 111.

Cyprus

National Focal Centre

Soteres Soteriou, Konstantinos Rovanias

Silviculture, Management and Publicity Sector – Research Section

Main activities/developments

General Information

Cyprus has been participating in the ICP Forests Program since 2001. The network of 19 permanent plots established in Cyprus State forests aims to collect the necessary data to support:

- visual assessment of the forest crown condition,
- sampling and analysis of forest soil,
- sampling and analysis of forest soil solution,
- sampling and analysis of needles and leaves of forest trees,
- estimation of growth and yield of forest stands,
- sampling and chemical analysis of deposition (precipitation, snow, hail),
- meteorological observations,
- assessment of forest ground vegetation, and
- monitoring of air quality and assessment of ozone injury on forests.

These plots are divided into two categories according to the type of observations to be done and data to be collected:

- Systematic large-scale monitoring plots

  Fifteen plots, covering an area of 0.1 ha each, have been established for monitoring Calabrian pine (*Pinus brutia*), Black pine (*Pinus nigra*), and Cyprus cedar (*Cedrus brevifolia*) ecosystems. In these plots, annual observations of crown condition and periodic sampling and analysis of soil and needles are carried out.

- Intensive monitoring plots

  Four plots, covering an area of 1 ha each, have been established for monitoring Calabrian pine (*Pinus brutia*) and Black pine (*Pinus nigra*) ecosystems. In two of these plots, all research activities, mentioned above, are carried out. These plots are equipped with appropriate instruments and equipment for the collection of samples, data and information. The other two plots are partially equipped and only some research activities are carried out.

Cooperation and Submission of Data and Results

There is a close cooperation of the Cyprus Department of Forests and the ICP Forests Programme Co-ordinating Centre (PCC) in Eberswalde. There is also co-operation with Expert Panels which are responsible for the scientific work of the programme.

For the implementation of the program, collaboration has been developed among the Department of Forests and other governmental departments such as the Department of Agriculture, Department of Labor Inspection, and the Department of Meteorology. The chemical analysis of water and soil solution had been undertaken by the Department of Agriculture, while we are at close conduct with the Cyprus Agricultural Research Institute for any future supplementary chemical analysis. Furthermore, there is exchange of information between the National Focal Centre and the Department of Labor Inspection, which runs the program "Network on Assessing Atmospheric Air-Quality in Cyprus". The Meteorological Service contributes to the program with technical support and maintenance of the Automatic Weather Stations.

Processing and submission of the relevant data is the responsibility of the Cyprus Department of Forests.

Major results/highlights

Using ICP Forests findings, along with the expertise and long experience of the scientific personnel of the department, the Department of Forests adopts and applies mostly repeated actions, which are designed to adapt forest stands (natural and artificial) to face climate change. The objective of these actions is the reduction of emissions and the increase of the absorption of greenhouse gases. These actions can be grouped into three main areas as listed in the Statement of Forest Policy:

- protecting forests against forest fires,
- adaptation of forests to climate change and enhancing the contribution of forests in addressing climate change and improvement of main forests and forested areas,
- improvement and expansion of forests.

Such measures are:

- protection of forests from illegal logging: with the implementation of Law 139 (I) / 2013 is controlled most the available firewood locally and criminal penalties for any illegal or uncontrolled logging and/or disposal of the local timber market without authorization,
- reforestation of Amiantos asbestos Mine as well as restoration of abandoned mines in cooperation with the Competent Authorities (the Department of Geological Survey and the Mines Service), and
- protection of forests and enhancement of their structure and resistance to climate change through the Rural Development Program 2014–2020.

In particular, in the Rural Development Program, a number of activities and actions have been integrated under Measure 8 (Investments in forest area development and improvement of the viability of forests). The Action 8.5.3 includes thinning operations in thick stands created by afforestation/reforestation, with the purpose of:

- Improving the structure of forests created by afforestation or/and reforestation operations. Furthermore, they will help in the adaptation of forest stands to climate change as well as contribute to the adaptation of forest stands to climate change, the reduction of emissions and increase the absorption of greenhouse gases.
- The implementation of targeted thinning is expected to improve stability and resilience to other disturbances, such as drought, increase in average temperatures and prolonged heat waves (as a result of climate change).

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Until now, no publications/reports have been published with regard to ICP Forests data and/or plots.

Outlook

- The Cyprus Department of Forests will continue to participate in the ICP Forests Program under the current regime.
- Although not falling under the ICP Forests targets, the Cyprus Department of Forests is running a number of research projects such as on biomass production and the investigation of different techniques in order to reduce the irrigation rate in new plantations during the summer period.

Czechia

National Focal Centre

Vít Šrámek, Forestry and Game Management Research Institute (FGMRI)

Main activities/developments

Regular assessment of Level I continued on 122 plots in 2021. Defoliation and other parameters related to the tree crown condition were evaluated on 4254 trees in total. Czech University of Life Sciences in Prague and Institute of Botany of the Academy of Sciences of the Czech Republic in cooperation with NFC carries out on selected plots continuous monitoring of stem size variation using point dendrometers along with measurements of microclimate parameters (atmospheric humidity and temperature, soil moisture and temperature).

As for Level II plots, 15 plots in total were evaluated in 2021. On Level II core plots, i.e. on seven plots, the maintenance and partial upgrade of technical equipment was underway.

Major results/highlights

In 2021, the characteristics of the growing season were also much more favorable in comparison with the preceding years. The elevated temperature at the beginning of summer (June 3.0 °C and July 1.0 °C deviation from the 1981-2010 long-term average, respectively) was compensated by sufficient rainfall in the period from May to August that amounted to 111-143% of the long-term average (1981-2010). In spite of this more positive climate pattern during the growing season the increased mortality of forest tree species was observed to continue, but the mortality rate was lower than in the preceding years. The continuation of dispersal of subcortical insects particularly in spruce (*Picea abies*) as well as in pine (*Pinus sylvestris*) and larch (*Larix decidua*) contributed to increased mortality. Spruce stands were attacked by bark beetles even at altitudes above 900 m a.s.l. (western Bohemia).

In the commercially most important category of mature coniferous species, similarly like in the last year there was a smaller change in the representation of defoliation class 2 (>25-60%) that increased from 66.0% in 2020 to 69.1% in 2021 while the percentage of defoliation class 0 and class 1 (0-10%, >10-25%) decreased. Significant differences were recorded between two major coniferous species, spruce and pine, in their long-term development of defoliation. The pine, unlike the spruce, shows a pronounced long-term trend of increasing defoliation. Its very moderate improvement in the last two years may not indicate a positive change in long-term development, but it can be only a response to a decrease in the intensity of bark beetle outbreak and more benign pattern of climatic conditions in the growing season.

In younger coniferous species (less than 59 years of age), the percentage of defoliation class 0 (0-10%) decreased from 39.2% in 2020 to 34.3% in 2021 while representation in defoliation classes 1 and 2 increased.

In broadleaved species of the older age category (forest stands older than 59 years), compared to the last year there was a moderate improvement in beech (*Fagus sylvatica*) and oak (*Quercus* sp.) as a result of a slight increase in percentage in lower defoliation classes and of a simultaneous decrease in all higher classes. In long-term development the oak shows a dominant percentage of defoliation in class 2 while the beech has the highest percentage of defoliation in lower class 1. In ash (*Fraxinus excelsior*), the percentage of defoliation class 1 decreased from 48.9% in 2020 to 41.3% in 2021 and representation in higher classes increased. In alder (*Alnus* sp.), mortality increased markedly when the percentage in class 4 (100%) increased from 0.0% in 2020 to 4.2% in 2021.

In younger broadleaves (forest stands less than 59 years of age), a moderate improvement was observed in oak when its representation in defoliation was shifted from higher defoliation classes to the lower ones. In birch (*Betula pendula*) the situation was much worse when percentage of defoliation class 2 increased from 53.7% in 2020 to 70.0% in 2021 and percentages of lower defoliation classes 0 and 1 decreased at the same time.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

See our national reporting on forest condition (in Czech and English) which includes ICP Forests data on https://www.vulhm.cz/en/monitoring-of-forest-state/icp-forests-2/download/

Outlook

Further improvement of technical equipment will continually be carried out on Level II core plots. Changes in carbon and nutrient cycles will be monitored on Level II plots felled due to bark beetle outbreaks.

Denmark

National Focal Centre

Morten Ingerslev, Department of Geosciences and Natural Resource Management, University of Copenhagen

Main activities/developments

Forest monitoring (Level II, Level I and NFI plots)

Participating in the Photo-Cross-Comparison-Course 2021 (Photo ICC 2021) - Central Europe and Northern Europe.

Major results/highlights

The national crown condition survey showed continued improvement in health for most species, with lower average defoliation and fewer damaged trees. The frequency of damaged trees (defoliation above 25%) dropped from 26% in 2020 to 15% in 2021 for all monitored broadleaves, and from 22% to 13% for conifers. Similarly, the average defoliation for both broadleaves and conifers dropped to 16% in 2021, compared to 20-22% in the previous two years. Average beech defoliation decreased from 21% in 2020 to 15% in 2021, and for oak average defoliation improved from 24% in 2020 to 19% in 2021. Ash is still impacted by ash dieback caused by *Hymenoscyphus fraxineus*, but due to removal of sick trees remaining population has an average defoliation of 24%. This is the first time average ash defoliation has dropped below 25% since before the disease began to have a widespread impact in Danish forests in 2006; however, the monitoring results are based on small numbers of trees. Both Norway and Sitka spruce had reductions in defoliation, but Sitka spruce showed the largest improvement with a decrease in defoliation from 25% in 2020 to 14% in 2021. Similarly, the frequency of damaged Stika spruce fell from 41% in 2020 to only 18% in 2021, which is a clear sign that the recent green spruce aphid (*Elatobium abietinum*) outbreak is over. The effects of the 2018 drought are gradually becoming less obvious, and there have been no outbreaks of bark beetles in Norway spruce.

In the autumn of 2021, we sampled soils from all four Level II plots. The samples are currently being analysed.

Two Danish plots, Vestskoven (DK-85) and Suserup (DK-74) are included in LTER Denmark. Up till now LTER Denmark has ony been sparsely funded. However, in 2021 we applied for national funding for LTER Denmark and were succesful. This is important for the two ICP Forests plots as the infrastructures here can be improved and extended in the coming years, and hopefully attract scientists to include these plots in their research.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Nord-Larsen T, Kvist Johannsen V, Riis-Nielsen T, Thomsen IM, Jørgensen BB (2021) Skovstatistik 2020 [Forest Statistics 2020] University of Copenhagen, 60 pp. [In Danish with English summary]. https://static-curis.ku.dk/portal/files/283138747/Rapport_Skovstatistik_2020_web.pdf

Estonia

National Focal Centre

Vladislav Apuhtin, Estonian Environment Agency

Main activities/developments

The health status of 2498 trees was assessed on the observation points of Level I forest monitoring network and on the sample plots of intensive forest monitoring (Level II). 1638 trees were Scots pines (*Pinus sylvestris*), 601 Norway spruces (*Picea abies*) and 259 deciduous species, mainly Silver birch (*Betula pendula*). Observation period lasted from July 2– November 13, 2021.

On Level II the following forest monitoring activities were carried out in 2021:

- chemical analyses of the deposition water collected throughout the year on 6 sample plots;
- chemical analyses of soil solution collected during 8 months (from March to October) on 5 sample plots;
- samples of litterfall were collected on one plot;
- foliar samples were collected on 6 Level II sample plots in December 2021;
- soil samples were collected on 29 Level I plots.

Major results/highlights

Level I

The total share of non-defoliated trees, 47.4%, was 1.1% lower than in 2020. The share of non-defoliated conifers, 46.8%, was lower than the share of non-defoliated broadleaves, 52.1%, in 2021.

The share of trees in classes 2 to 4, moderately defoliated to dead, was 7.8% in 2021 and 6.2% in 2020. Share of conifers and broadleaves in defoliation classes 2 to 4 were 7.7% and 8.9%, respectively.

The share of non-defoliated pines (defoliation class 0) was 47.1% in 2021, 0.3% higher than in 2020. Share of pines in classes 2 to 4, moderately defoliated to dead, was 0.2%, higher than in 2020. The defoliation of Scots pines slightly improved in 2021. However, long-term trend of Scots pine defoliation shows no significant changes since 2010.

The health status of Norway spruces decreased in 2021. The share of spruces without crown damages was 45.9% and the share of trees with defoliation rate 10–25% was 41.8%. A long-term increase of defoliation of Norway spruce may be observed.

Compared to 2020, the share of healthy birches was unchangeble in 2021, but the share of moderately damaged birches (defoliation rate 26–60%) has increased by 4%.

Numerous factors determine the condition of forests. Climatic factors, diseases and insects as well as other natural factors have an impact on tree vitality. All trees included in the crown condition assessment on Level I plots are also regularly assessed for damage.

In 2021, 3.9% of the living trees observed had some insect damages and 17.6% of them (mainly Scots pines) had symptoms of fungal diseases. Overall 44.4% of trees had no identificable symptoms of any damage.

Visible damage symptoms recorded on Scots pine were mainly attributed to pine shoot blight (pathogen *Gremmeniella abietina*). Symptoms of shoot blight were recorded on 10% of the observed pine trees in 2021, compared to 10.7% in 2021. Norway spruces mostly suffered due to new bark beetle (*Ips typographus*) attacks, old moose damages and root rot (pathogen *Heterobasidion parviporum*).

Level II

The annual average pH of the precipitation under throughfall was varying mainly between 5.5 and 6.5. In 2021 observations showed some slight decrease of pH compared to 2020 on all plots. The content of chemical elements and compounds in analysed precipitation water was low. Compared to several past years, content of calcium decreased in bulk deposition on all plots. Generally, the amount of precipitation in 2021 was similar to previous year.

The pH of the soil solution varied between 3.8 and 6.4 throughout the observation period. The content (concentration) of the nutrition elements and chemical compounds dissolved in the soil water of pine stands was in most cases also below the level of 2.5 mg l^{-1}. In 2021, similarly to the past years, the content of Ca^{2+} and Cl^{-} in soil solution was considerably higher than 2.5 mg l^{-1} on all spruce sample plots. The concentration of Na^{+}, Mg^{2+} and SO_4-S in spruce stand at Karepa was essentially higher than the level of 2.5 mg l^{-1}.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Apuhtin V, Timmusk T, Karu H FOREST MONITORING, Report of the survey 2021, Estonian Environment Agency, Tartu 2021.

Asi E (2021) Metsamullast metsakasvukohatüübini [Atlas of Estonian Forest Soil and Forest Site Types]. https://keskkonnaagentuur.ee/keskkonnaagentuuri-tegevusvaldkonnad/mets/valjaanded-ulevaated

Yearbook Forest 2020, Estonian Environment Agency

Outlook

The forest monitoring activity in Estonia will continue for both levels (Level I and Level II).

Finland

National Focal Centre

Päivi Merilä, Natural Resources Institute Finland (Luke)

Main activities/developments

In 2021, all eight active Level II plots were equipped with new instrumentation for monitoring of soil temperature and moisture (three depths, three replicates each). All these plots were monitored for atmospheric deposition, soil solution chemistry, meteorology, and stand growth. As two of the plots are in sapling stands, monitoring activities on the six plots representing mature forests included also litterfall, crown condition, and stand growth. In addition, tree increment was monitored using girth bands by manual recordings. The monitoring data of the year 2019 was submitted to the ICP Forests data base.

All Finnish Level II plots belong to eLTER network and three of them also belong to ICP Integrated Monitoring Programme. The data from these three plots are also used to fulfill the information needs of national emission ceiling directive (NECD).

Major results/highlights

Ding et al. (2021) studied three mature and one young Pinus sylvestris forests along a site type gradient in southern Finland; one of the sites belonged to the Level II plot network. The forests were measured for fine root biomass, fine root longevity, below- and aboveground growth phenology and annual litter input from tree and understorey vegetation. The results showed that distinct dimensions of below- and aboveground litter inputs are influenced by site types. The results emphasized that the ectomycorrhizal mycelia and the understorey vegetation significantly contribute to the belowground C inputs and should therefore always be considered in carbon balances and carbon reporting in boreal coniferous forests.

Outlook

Monitoring activities will continue on eight Level II plots in Finland, and the data is continuously utilized in research and to fulfill the information needs of NEC directive. In addition to UNECE ICP Forests programme, two EU related initiatives, NEC directive and development of eLTER research infrastructure onto the EU's ESFRI roadmap strengthen the Level II programme in Finland.

France

National Focal Centre

Level I: Frédéric Delport, Fabien Caroulle, Ministère de l'Agriculture et de l'Agroalimentaire

Level II: Manuel Nicolas, Office National des Forêts

Main activities/developments

Level I

Our ICP Forests plots are helpful to follow the main trends in forest health in France; and thus, are very useful to fulfill the requirements of sustainable management indicators. Throughout their evolution, we can assess:

- The impact of droughts on forests (especially broadleaf forests)
- The impact of invasive species such as *Hymenoscyphus fraxineus* on ash trees.

Level II

As the French Level II monitoring network (RENECOFOR) has reached its initially defined 30-yr horizon, an agreement was found to prolonge its long-term activities with fundings from the Ministry of Ecological Transition and the Ministry of Agriculture and Food.

Thus in 2021, monitoring activities were continued on the 102 plots of the Level II network, with the same objectives and surveys. In detail, tree assessments (phenology, health, annual growth, and foliar nutrition) were performed on all these plots, while atmospheric deposition, meteo, soil solution and litterfall have been monitored only on a subset of plots. Also, the ground vegetation assessment campaign, that was impeded by the exceptional containment measures taken against the Covid-19 epidemic in 2020, was successfully conducted in 2021 on all the plots.

However, an additional effort is required to make the RENECOFOR network able to run for potentially 100 years or more, with the same capacity to detect the effects of air pollution and other environmental factors on forest ecosystems. This involves gradually replacing the plots that have been severely disturbed or have entered the stand regeneration phase, and which no longer meet the site conditions required by the network design (adult stand, dominated by a tree species of interest, and homogeneous over the plot area). An evaluation was started about the situation of each of them, to identify those which may recover suitable conditions within 15 years, and those that really need to be relocated in another site. In parallel, a field campaign was launched to precisely georeference all trees and devices within each plot, so to keep able to reuse the same exact location in the future, even after severe storm damage or plot replacement. Tree coordinates will also be useful to evaluate the heterogeneity of the stand, and the effect of tree competition on measured growth. Eighteen plots were mapped, so far.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Goudet M. Systematic network of forest damages, 2020 overview. https://agriculture.gouv.fr/telecharger/126086?token=7896fc57d3874bc3de5d9e7d1ced2ddd2b36066ba8126b5933bc70e0809fc50b

Outlook

Level II

As the first conifer plots will reach their final cut in 2023, the data series initiated in 1992 must be completed with a 3rd soil sampling and a final growth survey before trees are fallen. In addition, the sample trees, that have been surveyed every year for their crown condition and phenology, will be cored to retrospectively measure their annual growth, and sampled for a genetic characterization. If possible, a terrestrial Lidar scan will also be implemented to keep a full picture of the vegetation cover. Future options will be explored for the reinstalment of each of these plots, either at the same location (after soil preparation and replantation) or in some new site of interest (e.g., in warm and/or dry margins of tree species distribution, where impacts of climate change are more likely to be observed).

Germany

National Focal Centre

Juliane Beez, Federal Ministry of Food and Agriculture
Scientific support: Thünen Institute of Forest Ecosystems

Main activities/developments

Level I

The 2021 crown condition survey took place on 409 Level I plots with a total number of 9904 sample trees. 38 tree species are recorded in the survey. Around 80% of this is accounted for by the four main tree species: spruce, pine, beech and oak (pedunculate and sessile oak are evaluated together). All other tree species are combined into the groups "other conifers" and "other broadleaf trees" for the statistical evaluation. Around 72% of the trees recorded are older than 60 years.

The national training course for the forest condition survey in Germany took place 21–24 June 2021 in Freising, Germany. The course was organized by the Thünen Institute of Forest Ecosystems in co-operation with Bayerische Landesanstalt für Wald und Forstwirtschaft.

Level II

In 2021 a working group formed itself to develop a nationally harmonized method using UAVs to assess crown parameters, tree height, and phenology. In 2022 structured field experiments shall aid this development to add a new perspective to the established monitoring, especially to document the increasing disturbances occurring on our plots.

Major results/highlights

Level I

In 2021, defoliation on 35% of the forest area was classified as moderate to severe. Mean crown defoliation decreased from 26.5% in 2020 to 25.7% in 2021.

Picea abies: The percentage of defoliation classes 2 to 4 increased from 44% to 46%. 32% (2020: 35%) of the trees were in the warning stage. The share of trees without defoliation was 22% (2020: 21%). Mean crown defoliation increased from 29.4% to 29.8%.

Pinus sylvestris: The share of defoliation classes 2 to 4 in 2021 decreased slightly from 26% to 25%. The share of the warning stage was 59% (2020: 54%). Only 16% showed no defoliation (2020: 20%). Mean crown defoliation increased from 22.6% to 22.9%.

Fagus sylvatica: The share of trees in the defoliation classes 2 to 4 has fallen from 55% in 2020 to 45%. 39% (2020: 34%) were in the warning stage. The share showing no defoliation was 16% (2020: 11%). Mean crown defoliation decreased from 31.3% to 28.1%.

Quercus petraea and *Q. robur*: The share of moderately to severely defoliated trees increased from 38% to 41%. The share of trees in the warning stage decreased from 42% to 40%. The share without defoliation decreased from 20% to 19%. Mean crown defoliation increased from 25.3% to 26.9%.

The mortality rate of spruce, pine and other conifers and deciduous trees decreased in 2021. In the case of the tree species beech and oak mortality increased.

While severe droughts and temperatures above the long-term average during the vegetation periods 2018 to 2020 harmed tree growth widely, the weather conditions in 2021 were favourable for tree growth due to sufficient rain and moderate temperatures during the vegetation period so far. The ongoing *Ips typographus* gradation was slowing down. Extraordinary fellings due to drought and bark-beetle damage in 2021 sum up to 40.6 million cubic meters (2018 to 2020: 170.8 million cubic meters) in Germany. An area of estimated 99 400 ha needs to be reforested.

Level II

Our national working group on environmental monitoring of forests conducted a survey on the current state and envisaged changes in the coming five years on the 68 Level II plots. At the time of the survey in March 2021, twelve of the 68 German Level II plots had been subject to major disturbances that might affect measurements. Seven of these were in spruce forests, but major disturbances on three beech, one oak and one pine plot were also reported. Insect calamities (seven plots), fungi and windthrow (two plots each) as well as complex disease in oak (one plot) were reported as origins. In addition to disturbances, the forest ecosystems are continuously evolving. A higher tree species diversity is expected in the future as well as more structural diversity between the plots. Currently, occurrence of at least a second tree species is reported for 38 of the 68 Level II plots. To face changes on the Level II plots in a harmonized and coordinated way, the national expert will prepare a decision tree for each survey to describe a common way to document the changes across all German Level II plots.

A joint project between several Federal states and Thünen-Institute shows that measurement of wet mercury deposition is possible with adapted bulk deposition samplers. The technique, developed by the Northwest German Forest Research Institute, includes an evaporation protection and cools samples by placement in the soil. In contrast to temperature-controlled systems, the novel samplers do not require an external power supply. Mercury deposition measurements are in line with established systems, showing that the newly developed samplers offer a cost-effective alternative to measure mercury without quality loss. The project shows a close connection between precipitation amount and measured mercury deposition. Dry deposition through sedimentation appears insignificant on the studied plots. The methods have been documented and the addition to the ICP Forests Manual on deposition is planned.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Zimmerman L, Raspe S, Dietrich H-P, et al (2020) Dürreperioden und ihre Wirkungen auf Wälder. LWF aktuell 126, S. 18–23

Wauer A, Klemmt H-J (2020) Klimawandel aus Nord(west)en! LWF aktuell 125:26 – 29

Wauer A (2020): Vom sauren Regen zum Klimawandel – Dokumentation stillen Leidens. In: Hamberger, J. (ed): Forstliche Forschungsberichte Nr. 218, München

Wauer A, Klemmt H-J (2021) Waldzustand 2021: Nord-Süd-Gefälle und keine Entwarnung. LWF aktuell 133:12–14

Josten C (2020) Steil, mühsam und schön – Eindrücke von der WZE im Gebirge. Zentrum Wald Forst Holz Weihenstephan <https://spark.adobe.com/page/Rq0Fdg6Swh0sa/>

Geppert F, Schad T, König N, et al (2021) Techniques for the measurement of wet mercury depositions under forest canopy. Eberswalde: Thünen Institute of Forest Ecosystems, 2 p, Project Brief Thünen Inst 2021/24a,

König N, Krinninger M, Schad T, et al (2021) Entwicklung und Test von Methoden zur Messung der nassen Quecksilberdeposition unter dem Kronendach von Wäldern. [Development and test of different techniques to measure wet mercury deposition under forest canopy] Dessau: Umweltbundesamt, 137 p, Texte UBA 157

Wang S, Zhang Y, Ju W, et al. (2021): Response to Comments on "Recent global decline of CO2 fertilization effects on vegetation photosynthesis". In: Sci 373 (6562). DOI: 10.1126/science.abg7484

Outlook

The publication of gap filled temperature and precipitation data for German Level II plots based on spatial interpolation procedures using a hybrid approach of linear regression and inverse distance weighting is intended in 2022.

Greece

National Focal Centre

Panagiotis Michopoulos, Kostas Kaoukis, Athanassios Bourletsikas
Hellenic Agricultural Organization – DEMETER, Institute of Mediterranean Forest Ecosystems (www.fria.gr)

Main activities/developments and major results/highlights

Level I

Crown condition assessment

For the assessment of the crown condition in 2021 data was collected from 33 plots representing a 33% percentage of the total number of the Level I plots in our country. More specifically, in 2021 the number of trees counted was 768, whereas in 2020 the number of trees was 886. From the 768 trees, 314 were conifers and 454 broadleaves.

The following table shows the results of the crown assessment for all tree species.

Crown assessment (Level I plots) (in %)

	All tree species	Conifer species	Broadleaf species
No defoliation	59.2	42.4	70.9
Slight defoliation	24.1	35.7	24.1
Moderate defoliation	15.1	21.0	11.0
Severe defoliation	0.5	0.6	0.4
Dead trees	0.9	0.0	1.5

It was found that 83.3% of all trees belonged to the classes "No defoliation" and "Slight defoliation". The corresponding values were 78.0% and 87.0% for conifers and broadleaves, respectively. The major damage causes for needle loss in conifers were insects, European mistletoe and abiotic factors. With regard to broadleaves, the most important agents for the leaf loss were insect attack and abiotic factors.

Level II

In Greece, there are four Level II plots. Plot 1 has an evergreen broadleaved vegetation (maquis, with mainly *Quercus ilex*), plot 2 has Hungarian oak (*Quercus frainetto*), plot 3 has beech (*Fagus sylvatica*) and plot 4 has Bulgarian fir (*Abies borisii-regis*). Full scale activities take place in plots 1, 2 and 4.

The average rainfall heights and temperature values in the four plots were derived from 49 years in the maquis, 25 years in the oak and beech and 49 years in the fir plots. There was a significant increase in rainfall in 2020 for the maquis plot (18%), whereas for the other plots the rainfall height was close to the average one (see table below).

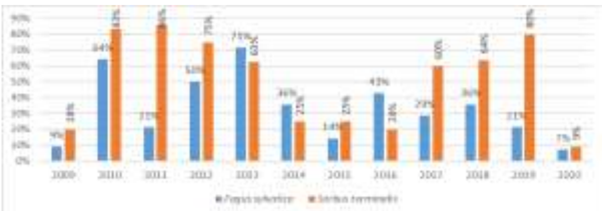
In addition, in all plots, the average annual air temperature was higher than the plot station's average value. More specifically, the increase was 2.6% in the maquis plot, 8.7% in the oak and beech plots and 8.9% in the fir plot (see table below).

Rainfall and temperature values in three forested plots in 2020

	Maquis plot		Oak and beech plots		Fir plot	
	Temp. [°C]	Rain [mm]	Temp. [°C]	Rain [mm]	Temp. [°C]	Rain [mm]
2020	15.8	866	13.8	1289	11.0	1488
Mean	15.4	1050	12.7	1274	10.1	1450

Ozone Injury

With regard to the symptoms of ozone injuries we have the following results: In the fir and maquis plot, no injury was observed, whereas in the oak and beech plot, which happen to be in the same mountain, we had few visible symptoms in beech (*Fagus sylvatica*) and checker trees (*Sorbus torminalis*). The percentages of damage are shown in the below figure.



Crown condition assessment (Level II)

The crown assessment for the year 2020 in the four Level II plots comprised a total number of 164 trees (35 conifers and 129 broadleaves). The results showed an improvement for the tree health in comparison with the results of the last previous years (see the following table).

Crown assessment (Level II plots) (in %)

Species	Year	No defoliation	Slight defoliation	Moderate defoliation	Severe defoliation	Dead trees
Conifers	**2014**	47.1	20.6	23.5	2.9	5.9
	2015	38.2	23.5	32.4	2.9	2.9
	2016	29.4	47.1	17.6	5.9	0.0
	2017	31.4	54.3	8.6	5.7	0.0
	2018	40.0	34.3	22.9	2.7	0.0
	2019	48.6	40.0	8.6	0.0	2.9
	2020	42.9	37.1	20.0	0.0	0.0
Broadleaves	**2014**	48.5	41.2	7.4	2.2	0.7
	2015	47.1	35.3	10.3	4.4	2.9
	2016	43.2	41.7	9.8	5.3	0.0
	2017	49.6	33.8	10.5	5.3	0.8
	2018	51.5	33.3	9.8	1.5	3.8
	2019	39.2	26.2	29.2	3.9	1.5
	2020	54.3	31.8	11.6	1.6	0.8

Deposition

The table below shows the deposition fluxes (bulk and throughfall) of the major ions in the maquis, oak and fir plots in 2020. The slight differences in rainfall in the tables is due to the fact that in the table below the data concerns the periods in which the rainfall was collected as sample for analysis, whereas in the other table the rainfall height is related to calendar dates. It can be seen that there was retention of ammonium-N by the canopy of all plots (throughfall < bulk fluxes), whereas the nitrate-N retention took place in the fir and oak plots. This finding shows the efficiency of forests to absorb N from any source. As was expected, the fluxes of magnesium and potassium were higher in the throughfall deposition for all plots. The sulphate-S fluxes were also higher in the throughfall in all plots. The sulphate-S is mostly deposited in dry form, whereas the Mg and K depositions are connected with ion leaching from inside the plant cells. The dry deposition of sulphate-S in the oak and fir plots may have been derived from fossil fuel combustion for heating purposes.

Fluxes (kg ha^{-1} yr^{-1}) of major ions in deposition (throughfall (T) and bulk (B)) in three forest plots in 2019

Plots	Dep.	Ca	Mg	K	$SO4^{2-}$-S	NH_4^+-N	NO_3^--N	mm
Maquis	T	15.1	3.99	36.7	5.1	1.60	2.32	615
	B	15.7	2.07	3.3	4.2	2.33	2.11	883
Oak	T	38.9	7.83	44.4	14.7	2.26	4.10	1268
	B	16.6	7.70	6.0	12.1	6.86	4.55	1621
Fir	T	17.4	4.74	41.8	10.1	2.34	2.14	1287
	B	13.7	1.51	4.0	5.3	4.89	3.57	1571

Litterfall

The percentage of foliar litter with regard to the total foliar mass was higher in the oak plot (76%). In the rest of the plots, the percentages were: 73% for the maquis, 58% for the beech and 61% for the fir plot. The fluxes of all nutrients in the foliar fraction were higher in the oak plot probably because of the high quantites in foliar litterfall in 2020. The N flux in the foliar litterfall fraction was high in the oak plot but it had similar values (around 30 kg ha^{-1} yr^{-1}) in the rest of the plots).

In the non-foliar litter, the beech plot had the highest mass amount and the highest stock of all nutrients with the exception of N, which was higher in the fir plot. Apart from N in the fir plot, the non-foliar litter contributed an appreciable amount of P, K and S in the beech and fir plots. The beech forest is situated on a mica schist parent material, which gives rise to acid soils. In these kinds of soils P and S are absorbed from Fe and Al oxides. During decomposition, the non-foliar litter releases P and S in the surface horizon which can be easily taken up by forest plants. For this reason, it is advised that the logging remains should stay in forest soils to enrich the latter with nutrients.

Total masses (TM, Mg ha-1 yr-1) and fluxes (kg ha^{-1} yr^{-1}) of major nutrients in litterfall in four forest plots in 2020

Foliar	**TM**	**Ca**	**Mg**	**K**	**S**	**N**	**P**
Maquis	3.40	45.6	4.85	11.1	4.04	34.4	1.86
Oak	5.45	68.7	11.7	17.0	6.34	45.0	3.23
Beech	3.37	42.5	5.33	4.61	3.48	30.0	1.61
Fir	2.80	60.4	3.72	7.96	3.34	30.7	2.95
Non-foliar	**TM**	**Ca**	**Mg**	**K**	**S**	**N**	**P**
Maquis	1.27	9.7	1.42	4.65	1.19	9.0	0.79
Oak	1.71	11.9	1.47	6.60	1.64	11.8	0.68
Beech	2.44	14.8	2.35	8.39	2.23	16.7	1.27
Fir	1.76	13.7	2.01	6.74	2.42	18.3	1.26

Outlook

We are planning to enrich the scientific team dealing with the forest ecosystems taking part in the ICP Forests monitoring to include for example forest genetics.

Hungary

National Focal Centre

Kinga Nagy, András Lászlók
National Land Centre, Department of Forestry

Main activities/developments

Level I, the large-scale health condition monitoring, is coordinated and carried out by the experts of the National Land Centre – Department of Forestry. The annual survey includes 78 permanent sample plots with 1872 potential sample trees in total, on a 16 x 16 km grid.

In 2021, 78 permanent plots with 1863 sample trees were included in the crown condition assessment. The survey was carried out between 15 July and 15 August. The percentage of broadleaves was 90.9%, while the percentage of conifers was 9.1%.

Major results/highlights

From the total number of sample trees surveyed, 22.8% were without visible defoliation which shows a decrease in comparison with 2020 (27.3%). The percentage of the slightly defoliated trees was 29.6%, and percentage of all trees within ICP Forests defoliation classes 2-4 (moderately damaged, severally damaged and dead) was 47.6%. The rate of the dead trees was 1.8% and 0.6% of them died in the surveyed year. The dead trees remain in the sample till they are standing but the trees died newly can be separated. The mean defoliation for all species was 30.5%.

Relatively big differences can be observed between the tree species groups in respect of the defoliation rates. In 2021 *Quercus robur* (Pedunculate oak) was the most defoliated and damaged tree species group. For several years now, a long-term decline in the health condition could be observed on *Quercus robur*, in 2021 only 3% of the assessed sample trees were in the ICP Forests defoliation class 0. In recent years the *Pinus nigra* (Black pine) was the most defoliated and damaged tree species group, but in 2021 the percentage of the sample trees in the healthy category was around 9.1% (last year 3%) which is a moderate increase.

With the percentage of the healthy trees (59.3%), *Carpinus betulus* (common Hornbeam) was the least defoliated tree species in 2021.

Discoloration can rarely be observed in the Hungarian forests, 94.3% of living sample trees did not show any discoloration.

Although the damages caused by insects, abiotic causes and fungi were dominant in general, the rates of the damaging agents showed differences in proportions between the tree species groups respectively.

In 2021, the insects were the most frequent damaging agents (29.8%). Most of the observed damages were caused by defoliators and sucking insects, which in most cases occurred on *Quercus robur*, *Q. petraea*, and other softwood species.

In recent years, the oak lace bug (*Corythucha arcuata*) has been spreading across the Hungarian forests (as well as in Europe's) and it has become a common and dangerous pest of *Quercus* species.

Abiotic damages (23.2%) were the second most frequent damaging agents: most of the observed damages were due to drought, or frost and wind.

Fungal damages (22.3%) were observed on *Quercus* species, other hardwood species, and Pinus nigra at the highest rate. The relatively high frequency correlates with the bad condition of the prior species groups (which, in the case of *Quercus* species, mostly caused by *Microsphaera quercina*).

The rates of the damages caused by other biotic agents (10.2%) and direct actions of man (6.0%) have not changed significantly compared to the previous years. The game damages were generally not frequent (5.2%) but in some tree species groups (Poplars, Beech, other hardwood species and mostly Hornbeam) appeared more often. The frequency of the damages with unknown origin was only 3.0%. The signs of fire damage were barely observed in the assessed stands (only 0.5%).

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

"Erdeink egészségi állapota 2021-ben" The annual national report on the health condition of the Hungarian forests which includes ICP Forests plot data is available (in Hungarian) online: http://www.nfk.gov.hu/EMMRE_kiadvanyok__jelentesek__prognozis_fuzetek_news_536

"Erdészeti Mérő- és Megfigyelő Rendszer, 2021" An annual leaflet about the key findings of the Forest Monitoring and Observation System (FMOS, Hungarian acronym: EMMRE). Forest health condition monitoring is an important part of the FMOS. The leaflet is available online in Hungarian: http://www.nfk.gov.hu/EMMRE_kiadvanyok__jelentesek__prognozis_fuzetek_news_536

Outlook

Examination of the health status of forests in Hungary is one of the priority areas of forestry monitoring. We are committed to maintain the current large-scale health monitoring system, the provision and development of the necessary infrastructure and human resources are ongoing.

Ireland

National Focal Centre

Thomas Cummins, University College Dublin
John Redmond, Department of Agriculture, Food and the Marine

Main activities/developments

Monitoring of Level I forest crown condition has been undertaken in 2021. No monitoring activity has been carried out on Level II plots since 2017.

Outlook

Under the NEC Directive, a new National Ecosystems Monitoring Network (NEMN), operated by Ireland's Environmental Protection Agency, is being developed. Ireland's ICP Forests Level II sites Brackloon (11) and Roundwood (1, 18), are prioritized as Level 2 sites within NEMN for progressive installation of deposition monitoring, and ammonia passive sampling initially.

Italy

National Focal Centre

Giancarlo Papitto – Projects, Conventions, Environmental Education Office, Carabinieri Corps

Main activities/developments

The survey of Level I in 2021 took into consideration the condition of the crown of 4700 selected trees in 256 plots belonging to the EU Level I network on a 16x16 km grid. The results given below relate to the distribution of frequencies of the indicators used, especially transparency - which in our case we use for the indirect assessment of defoliation and the presence of damage from known causes attributable to both abiotic and biotic factors. For the latter, not so much the indicators we analyzed the frequencies of affected plants, but the comments made as to each plant may have multiple symptoms and more agents.

Six Italian ICP Forests Level II sites are included in the NEC Italy Network for the implementation of the National Emission Ceiling Directive (2016/2284). The Office is in charge of the co-ordination of this Network in co-operation with the Ministry of Ecological Transition. Moreover, CUFA is the Co-ordinating Beneficiary of project LIFE MODERn (NEC) (LIFE20GIE/IT/000091) for the implementation of Art. 9 of the NEC Directive, concerning the study of the effects of atmospheric pollution on forest and freshwater ecosystems. One of the project's aims is the selection of new monitoring forests and freshwater sites for the NEC Network, to be chosen within the ICP Forests/Waters programmes. For more details about the project please refer to http://www.lifemodernec.eu.

Major results/highlights

Defoliation data are reported according to the usual categorical system (class 0:0-10%; class 1: >10-25%; class 2: >25-60%; class 3: >60%; class 4: tree dead). Most trees (80.9%) are included in the classes 1 to 4; 42.1% are included in the classes 2 to 4.

By analyzing the sample for conifers and broadleaves, it appears that deciduous trees have a lower transparency than conifers: 24.8% of conifers versus 17.1% of broadleaves in the class 0 of transparency, while 41.6% of deciduous trees versus 43.2% of conifers are included in the classes 2 to 4.

From a survey of the frequency distribution of the parameter for transparency species divided into two age categories (<60 and ≥60 years), among the young conifers (<60 years), *Pinus sylvestris* has (34.5%) of trees in the classes 2 to 4, *Pinus nigra* has 40.2% of trees in the classes 2 to 4, while *Picea abies* with 12.5% in the young conifers is in the best condition.

Among the old conifers (≥60 years), the species appearing to be of the worst quality of foliage was *Pinus sylvestris* (66.7%) of trees in the classes 2 to 4, then *Picea abies* (57.1%), *Larix decidua* (37.2%) and *Abies alba* with 37.8% in the classes 2 to 4, while *Pinus cembra* (34.1%) was the conifer species with the best condition.

Among the young broadleaves (<60 years), *Castanea sativa*, *Ostrya carpinifolia*, *Quercus pubescens* and *Fagus sylvatica* have respectively 69.0%, 48.7%, 47.3%, and 44.4% of trees in the classes 2 to 4, while *Quercus cerris* has a frequency of 22.5% in classes 2 to 4.

Among the old broadleaves (≥60 years) in the classes 2 to 4, *Castanea sativa* has 79.6%, *Quercus pubescens* 47.5%, *Fagus sylvatica* 26.8%, *Fraxinus ornus* 27.2%, while with 17.1% *Quercus ilex* has the lowest level of defoliation of trees in the classes 2 to 4.

Out of a total of 4700 trees monitored, 7508 symptoms were detected. Of the trees with symptoms 3459 (46.1%) were recognized, while 4049 (54.0%) symptoms were not identified.

Most of the observed symptoms were attributed to insects (19.0%), subdivided into defoliators (14.7%), galls (1.3%), following symptoms could be attributed to fungi (4.7%), the most significant were attributable to "dieback and canker fungi" (2.8%). Of those assigned to abiotic agents, the most significant were attributable to hail (3.1%) and drought (1.7%).

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Papitto G, Quatrini V, Cindolo C, Cocciufa C (eds) 2021 Rete NEC Italia – Monitoraggio degli ecosistemi terrestri. Lo stato delle foreste italiane. Pubblicato da Arma dei Carabinieri, Comando Unità Forestali, Ambientali e Agroalimentari. Roma, 116 pp. (TITLE: Monitoring of terrestrial ecosystems. The status of Italian forests)

Outlook

- The recent LIFE MODERn (NEC) project plans to extend monitoring to four additional forest sites. The Level I CONECOFOR network sites are not currently included in the NEC network. This is why we are trying to identify an indicator suitable for monitoring air quality even at this level.

  In this regard, lichens are widely recognized as excellent indicators of the effects of air pollution. However, the method of detection of lichen biodiversity used at European level also in the forestry field (ICP Forests and ICP IM) requires specialized training and for this reason it is used in Italy only in the Level II network, where the surveys are carried out by highly qualified personnel. The goal will also be to create a platform that, starting from the acquisition of photographic images of lichens on tree trunks, provides an artificial intelligence algorithm to recognize key groups of lichen species or single species. The subsequent statistical processing of the data collected will make it possible to obtain information on lichen communities and, consequently, on the trend of air quality in Italian forests.

- Monitoring of multi and hyper spectral anomalies in Italian forests through remote sensing from a satellite platform for the continuous monitoring of the consistency of terrestrial carbon stocks and their general conservation status, of the identification of threats both abiotic from extreme events (avalanches, landslides, wind storms, and droughts) connected to climate change, and biotic from parasitic attacks or anthropogenic (authorized and illegal forest uses).

Latvia

National Focal Centre

Level I: Uldis Zvirbulis
Level II: Andis Lazdiņš, Linards Ludis Krumšteds
Latvian State Forest Research Institute "Silava"

Main activities/developments

Latvia continued its assessment at Level I. The forest condition survey 2021 in Latvia was carried out on 115 Level I NFI plots. The major results of 2021 are based on data from this dataset.

In 2021, the relevant works were performed within the framework of the Level II monitoring:

- national crown condition survey
- deposition monitoring from bulk, throughfall, stemflow, lysimeters
- litterfall sampling twice a month in months with no snow cover (usually March–November/December, may differ from year-to-year basis)
- air quality monitoring, using diffusive samplers twice a month (June–October).

Major results/highlights

On Level I plots defoliation and damage symptoms of 1724 trees were assessed, of which 74% were conifers and 26% broadleaves. Of all tree species, 12.2% were not defoliated, 83.8% were slightly defoliated and 3.8% moderately defoliated to dead. Comparing to 2020, the proportion of not defoliated trees has increased by 2.2%, proportion of slightly defoliated has decreased by 2.7%, but proportion of moderately defoliated to dead trees has increased by 0.4%. In 2021, the proportion of not defoliated conifers was by 4.1% higher than that of not defoliated broadleaves, the proportion of slightly defoliated broadleaves was by 8.0% higher than that of slightly defoliated conifers. Proportion of trees in defoliation classes moderatly defoliated to dead for conifers was 3.9% higher than for broadleaves.

Mean defoliation of *Pinus sylvestris* was 19.6% (19.8% in 2020). The share of moderately damaged to dead trees constituted 5.5% (3.3% in 2020). Mean defoliation of *Picea abies* was 17.3% (16.9% in 2020). Share of moderately damaged to dead trees for spruce increased at 4.1% (1.5% in 2020). The mean defoliation level of *Betula* spp. was 18.7% (19.3% in 2020). The share of trees in defoliation classes moderately to dead was 1.1% (compared to 3.8% in 2020).

Visible damage symptoms were observed on 16.5% of the assessed trees (17.3% of the assessed trees in 2020). Most frequently recorded damages were caused by direct action of men (28.9%;27.2% in 2020), animals (26.8%; 26.5% in 2020), insects (13.7%; 18.5% in 2020), abiotic factors (14.1%; 12.8% in 2020) and fungi (13.0%; 10.7% in 2020), but unknown cause (3.5%; 4.4% in 2020). The greatest share of trees with visible damage symptoms was recorded for *Picea abies* (26.7%), *Pinus sylvestris* (14.7%) and the smallest for *Betula* spp (9.2%).

Level II monitoring is perfomed in 3 plots – Valgunde, Taurene, Rucava. Although no major results have been detected to highlight, a general data report is available. Average defoliation and damage symptoms in each plot are determined at 15.5% in Rucava, 18.1% in Taurene, and 17% in Rucava. The average cone yield is 2 at Valgunde, 1.6 at Taurene, and 1.8 in Rucava which are varying between a few cones to medium yield. Also, a precipitation water deposition is monitored, in the year 2021 Valgunde plot in total collected 692mm of precipitation in the open field, 605mm through tree crown, and 33mm from bark collectors. The average pH of precipitations from the open field, from tree crowns and from stem bark collectors are 6.4, 6.0 and 5.0, respectively. Soil solution waters through lysimeters in Valgunde plot in total collected 6.3 liters in 0-10cm layer, 3.1 liters in 20-40cm layer and 4.1 liters in 40-70cm layer. Average pH in soil depth layers of 0-10cm, 20-40cm and in 40-70cm are 5.0, 5.5 and 5.3, respectively.

Air quality monitoring, using diffusive samplers is performed in the Valgunde plot throughout the period from June to October, to detect SO_2, NH_3, NO_2, O_3 concentrations. In the year 2021 average SO_2 is 0.41 µg m^{-3}, average NO_2 is 1.65 µg m^{-3}, average NH_3 is 3.28 µg m^{-3}, average O_3 is 43.5 µg m^{-3}.

Outlook

Latvia has 115 NFI Level I plots and it is planned to continue observations at this level. Level II monitoring plots are regularly and continuously maintained for more than a decade. Data gathering, processing, and reporting have not stopped since the beginning of the installment of the monitoring plots which also provide confirmation for the continuity of the project in the future. The main goal is to maintain tasks established in Level II monitoring plots to continue to provide the long-term data stream of the monitoring sites for future use of data to continue to understand current conditions, historic conditions, and changes in the monitoring plots.

Lithuania

National Focal Centre

Marijus Eigirdas, Lithuanian State Forest Service

Main activities/developments

Level I

In 2021 forest condition survey was carried out in 988 sample plots from which 81 plots were on the transnational Level I grid and 907 plots in the National Forest Inventory grid. In total 5652 sample trees representing 17 tree species were assessed. The main tree species assessed were *Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens, Populus tremula, Alnus glutinosa, Alnus incana, Fraxinus excelsior, Quercus robur.*

Level II

In 2021, the activities of intensive forest monitoring were carried out in nine Intensive Monitoring Plots (IMP). The activities performed in nine IMP included the visual assessment of crown condition and damaging agent, the assessment of ozone injury, foliage sampling and analysis. In three Level II plots, the following surveys were conducted: soil solution collection and analysis, atmospheric deposition in bulk and throughfall, and litterfall sampling. In addition, from May to October, the concentration of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH_3) were determined in the ambient air with passive samplers. Phenological observations for Norway spruce, Scots pine, and pedunculate oak were performed in three IMP. The crown condition was assessed for a total of 505 model trees in 2021.

Major results/highlights

Level I

During one year the mean defoliation of all tree species slightly increased up to 22.3% (22.0% in 2020). 14.5% of all sample trees were not defoliated (class 0), 65.6% were slightly defoliated and 19.9% were assessed as moderately defoliated, severely defoliated and dead (defoliation classes 2-4).

Mean defoliation of conifers slightly increased up to 23.0% (22.5% in 2020) and for broadleaves also slightly increased up to 21.3% (21.1% in 2020).

Pinus sylvestris is a dominant tree species in Lithuanian forests and composes about 38% of all sample trees annually. Mean defoliation of *Pinus sylvestris* slightly increased up to 24.4% (23.8% in 2020). A slightly increasing trend in defoliation was observed in 2008-2021.

Populus tremula had the lowest mean defoliation and the lowest share of trees in defoliation classes 2-4, since 2006. Mean defoliation of *Populus tremula* was 15.8% (17.4% in 2020) and the proportion of trees in defoliation classes 2-4 was 3.9% comparing with 6.3% in 2020.

Fraxinus excelsior condition remained the worst between all observed tree species. This tree species had the highest defoliation since year 2000. Mean defoliation slightly decreased to 31.4% (32.3% in 2020). The share of trees in defoliation classes 2-4 decreased to 34.7% (42.9% in 2020).

28% of all sample trees had some kind of identifiable damages symptoms. The most frequent damage was caused by abiotic agents (about 8.7% in 2021) in the period of 2011 – 2021. The highest share of damage symptoms was assessed for *Fraxinus excelsior* (57%), *Alnus incana* (42%), *Picea abies* (36%), *Populus tremula* (31%), the least for *Betula* sp. (17%) and *Alnus glutinosa* (20%).

Level II

The mean defoliation of all tree species varied insignificantly from 1997 to 2021, and the growing conditions of Lithuanian forests can be defined as relatively stable.

The average defoliation of trees in Level II plots ranged from 14–20% over the last 5 years. Over the last decade, the number of trees with visually identifiable biotic and abiotic damage was 10.4%, and the average tree mortality was 0.8%.

Air pollution deposition surveys, carried out since 2000, showed that sulphur deposition under tree crowns has constantly decreased. During the last decade, the amount of sulphur deposition in the open area has varied between 3–5 kg ha^{-1} yr^{-1}. Average nitrate deposition (NO_3–N) both in the open area and under tree crowns has varied from 5–7 kg ha^{-1} yr^{-1}.

In 2021, average SO_2 concentration was 0.47 µg/m^3 in IMP. The average NO_2 concentration was 7.3 µg/m^3, and it was lower than the multi-annual value (10.37 µg/m^3) (2008-2020). The average NH_3 concentration was 2.6 µg/m^3 being slightly lower than in 2020.

Multi-annual (2017-2021) observations of visible ground-level ozone-related damages showed that the most frequently damaged tree species were *Alnus incana, Fraxinus excelsior* and *Alnus glutinosa*. In 2021, visually visible ground-level ozone-related damages were assessed on nine IMP. No foliage damages possibly caused by ground-level ozone were recorded.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Armolaitis K, Varnagirytė-Kabašinskienė I, Žemaitis P, et al (2022) Evaluation of organic carbon stocks in mineral and organic soils in Lithuania. Soil Use and Management 38(1):355–368.

Stakėnas V, Varnagirytė-Kabašinskienė I, Kabašinskas A (2021) A methodological approach for the assessment of basic crown parameters in Scots pine stands. Baltic Forestry 27(1): article id 551.

Luxembourg

National Focal Centre

Philippe Schmitz, Martine Neuberg, Pascal Armborst
Administration de la nature et des forêts

Main activities/developments

Every year we present our results of the national plant-health inventory. This inventory is based on the analysis of crown condition, which is carried out on about 50 plots throughout the country. The survey is based on a 4x4 km grid. This data is also part of our Level I data submission.

Major results/highlights

In 2021, five forestry experts analyzed 1200 trees on 50 plots spread over the entire forest of the Grand Duchy. The crown condition for all the species has slightly improved, but stays still on a high negative level.

The condition of *Fagus silvatica* and *Picea abies* are still very negative but have stayed on the same level through the last analysis-period. The condition op coppice forest (*Quercus* sp.) has improved.

16.1 % of the trees have no damage (damage class: 0).

32.7 % of the trees are slightly damaged (damage class: 1).

51.3 % of the trees are clearly and/or heavily damaged (generally dying) or dead trees (damage class: 2, 3 and 4).

Outlook

In the future, we plan to evaluate other Level II data in addition to the crown condition data. We will do this together with the environmental administration. Level I crown condition data will be uploaded again after the upcoming survey period.

Norway

National Focal Centre

Volkmar Timmermann, Norwegian Institute of Bioeconomy Research (NIBIO)

Main activities/developments

Norway is represented in 6 Expert Panels (Soil, Foliage, Crown, Growth, Vegetation and Deposition), in the Working Group QA/QC, and is holding the co-chair in EP Crown. In 2021 we participated in several expert panel meetings, in the Task Force meeting in June (online) and in the QA/QC and PCG meeting in November (online). We contributed to the chapter on crown condition in ICP Forests Technical Report and to ICP Forests Brief No. 5 *Tree health is deteriorating in the European forests*. Our lab participated in the 24th Needle/Leaf Interlaboratory Comparison Test and in the 11th Deposition and Soil Solution Ringtest 2021/2022. We also took part as partner in the Norwegian LTER network.

Level I / Norwegian national forest monitoring

The Norwegian national forest monitoring is conducted on sample plots in a systematic grid of 3 x 3 km in forested areas of the country. The plots are part of the National Forest Inventory (NFI), who also is responsible for crown condition assessments including damage. The NFI has five-year rotation periods, and since 2013 monitoring has been following these with five-year intervals, i.e. monitoring is not carried out annually on the same plots. The plots are circular with an area of 250 m2, and sample trees are selected with relascope. Defoliation assessments are done on Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) only, while damage assessments are conducted on all tree species present on the plots.

Our national forest monitoring in 2021 included defoliation assessments on 5941 Norway spruce and 4963 Scots pine trees on 1904 plots, and damage assessments on 19315 trees (28+ species incl. spruce and pine) on 2593 plots in total from mid of May until mid of October. The regular national field calibration course for the field workers from the NFI had again to be cancelled due to the Covid-19 pandemic. However, all 24 field workers from the NFI/national monitoring participated in ICP Forests Photo ICC in 2021.

In 2021, 629 plots were part of the transnational ICP Forests Level I grid (16x16 km = 1 plot pr. 256 km^2), and defoliation and/or damage data for 5205 trees belonging to 19 species were reported to ICP Forests' database.

Level II

At our three Level II sites, the following surveys are conducted by NIBIO: Crown condition and damage, tree growth, foliar chemistry, ground vegetation, soil solution chemistry and atmospheric deposition in bulk and throughfall. Chemical analyses are carried out in-house. Ambient air quality (incl.

ozone) is measured at two plots (Birkenes and Hurdal) and meteorology at one (Birkenes) by the Norwegian Institute for Air Research (NILU). Data from the Level II surveys carried out by NIBIO are reported to ICP Forests annually.

Major results/highlights

Norwegian national forest monitoring

In 2021, mean defoliation for Norway spruce was 16.4%, and 12.8% for Scots pine in our national monitoring. There was a slight decrease in mean defoliation for both spruce (-0.1%) and pine (-1.1%) compared to 2020.

When dividing into defoliation classes, 45.5% of the spruce trees and 50.1% of the pine trees were classified as not defoliated (Defoliation class 0) in 2021. Class 1 (slight defoliation) comprised 34.8% of the spruce trees and 40.7% of the pine trees, while 15.9% and 8.1% of the spruce and pine trees fell into class 2 (moderate defoliation). Severe defoliation (class 3) was recorded for 3.4% of the spruce trees and for only 0.9% of the pine trees.

Mortality rates were 3.9‰ for Norway spruce, 2.0‰ for Scots pine, 8.3‰ for birch, 10.3‰ for other deciduous species and 5.5‰ on average for all assessed tree species in 2021.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Timmermann V, Beachell AM, Brurberg MB, et al (2021) Skogens helsetilstand i Norge. Resultater fra skogskadeovervåkingen i 2020. [The state of health of Norwegian forests. Results from the national forest damage monitoring 2020.] NIBIO Rapport 7(166): 79 pp. https://hdl.handle.net/11250/2826864 (abstract in English).

Timmermann V, Børja I, Solheim H, et al (2021) Skogens helsetilstand. [Forest health.] In: Svensson, A. & Dalen, LS. (eds.). Bærekraftig skogbruk i Norge. [Sustainable forest management in Norway.] NIBIO nettrapport: https://www.skogbruk.nibio.no. Online report, updated 31.1.2021.

Viken, K.O. 2021 Landsskogtakseringens feltinstruks – 2021. [Manual of the Norwegian NFI – 2021.] NIBIO BOK 2021: 154 s + vedlegg. https://hdl.handle.net/11250/2826859

Outlook

- Monitoring at Level I will continue as part of our national forest monitoring conducted by the NFI.
- We plan to participate in the 25th Needle/Leaf and the 12th Deposition/Soil Solution ringtests.
- The ICOS C-flux tower started its measurements at one of our Level II sites (Hurdal) in 2021. At this site NILU also has one of their EMEP sites, opening for a broad collaboration between ICOS, EMEP and ICP Forests.
- Our Level II sites in Birkenes and Hurdal will become part of the eLTER network in near future.

Poland

National Focal Centre

Paweł Lech, Forest Research Institute (IBL)

Main activities/developments

The Forest Research Institute is responsible for the implementation of all forest monitoring activities in Poland and works closely with the Ministry of Environment (MŚ), the General Inspectorate of Environmental Protection (GIOŚ) and the State Forests Enterprise (LP). Poland is represented in six Expert Panels (Soil & Soil Solution; Forest Growth; Biodiversity; Crown Condition and Damage Causes; Deposition; Meteorology, Phenology & LAI) as well as in the Working Group QA/QC in Laboratories, where our representative Dr Anna Kowalska is co-chair.

Level I

In 2021, the forest condition survey was conducted on 2068 Level I plots (8 km x 8 km grid) and a total number of 41360 trees were assessed. Of these, the results of the assessment of 343 plots on a 16 km x 16 km grid (European network) with 6860 trees were submitted to ICP Forests database. The fieldwork took place in July and August.

Level II

In 2021, measurements of weather parameters, air quality, and chemical analysis of deposition (outside canopy and throughfall) and soil solution were conducted on 12 Level II plots. In addition, continuous measurements of dbh and water availability of the trees were carried out on one plot with an oak as the main tree species.

Major results/highlights

Level I

The average defoliation of all species was 22.4%, that of conifers 22.6% and that of deciduous trees 21.9%. The percentage of healthy trees (with leaf loss of 10% or less) was 9.7% for all species, and the percentage of trees with leaf loss of more than 25% was 17.1%.

The percentage of healthy trees (14.3%) and the percentage of trees with leaf loss of more than 25% (17.9%) were higher for deciduous species than for coniferous species (6.8% and 16.6%, respectively). The percentage of trees in the early warning class with leaf loss between 11% and 25% was 73.2% for all species, 76.5% for conifers and 67.8% for broadleaves.

Among the three main conifer species, *Abies alba* had the lowest mean defoliation of 18.4%, with 21.4% of trees falling into class 0 and 10.1% into classes 2-4. *Pinus sylvestris* was characterised by a lower proportion of trees in class 0 (6.2%), a higher proportion of trees in classes 2-4 (16.4%) and a higher mean defoliation (22.6%) than *Abies alba*. *Picea abies* was characterised by a higher proportion of trees in classes 2-4 (24.0%) and a higher mean defoliation (25.5%) compared to Scots pine and Silver fir. The proportion of spruce with a leaf loss of up to 10% was very low at 3.6%.

In 2021, as in the previous year, the highest average defoliation among deciduous trees was observed in *Quercus* spp. - 25.9%. Only 4.2% of oaks had a leaf loss of 10% or less and 31.2% of trees fell into leaf loss classes 2-4. A slightly better condition was observed for *Betula* spp. (8.6% of trees in class 0, 17.4% of trees in classes 2-4 and the mean defoliation was 22.8%). *Fagus sylvatica* remained the deciduous tree species with the lowest defoliation. A proportion of 28.5% of the beech trees showed no symptoms of defoliation, only 7.4% were in leaf loss classes 2-4 and the mean defoliation was 17.0%. *Alnus* spp. was slightly more defoliated (17.9% of trees in class 0, 9.9% of trees in classes 2-4 and the mean defoliation was 19.4%) than *Fagus sylvatica*.

In 2021, the condition of the trees (all species combined) improved slightly compared to the previous year. A significant improvement was observed in the deciduous trees: *Fagus sylvatica*, *Quercus* spp. and *Betula* spp. The proportion of trees with a defoliation level of 10% or less increased by 9.3, 2.0 and 3.7 percent points, respectively. The proportion of trees with more than 25% defoliation decreased by 3.4, 9.4 and 6.9 percent points, respectively. The average defoliation decreased by 2.3, 2.3 and 2.1 percent points, respectively.

Level II

Meteorological measurements on 12 Level II plots showed that it was much colder in 2021 than in 2020, with a mean annual temperature about 1.3 °C lower. The annual precipitation total was higher in 2021 on seven plots (on three over 100 mm - northeast Poland) and lower on five plots. For the growing season, the differences in precipitation sum between 2021 and 2020 were even greater, reaching over 200 mm at two sites and between 100-200 mm at another four sites.

The results of deposition and concentration of elements in soil solution on 12 Level II plots will be evaluated in the second half of 2022. The SO_2 concentration in the air in 2021 ranged from 73% to 174% of the concentration in 2020 and the NO_2 concentration ranged from 84% to 124%. On about half of the plots, the SO_2 and NO_2 concentrations in the air in 2021 did not follow the general trend of decreasing concentrations of air pollutants observed in recent years.

Outlook

In addition to routine monitoring activities, the following projects were started in 2018 and 2019 and continued in 2020 using forest monitoring data and/or infrastructure:

- Evaluation of acidification and eutrophication of forest ecosystems in Poland in respect to critical load concept.
- Water cycle in forest ecosystems under climate change conditions.
- Coefficients of dieback/survivorship of trees on the forest monitoring Level I plots in Poland in the years 2007-2017 and their usability in health condition assessment of major forest tree species.

Romania

National Focal Centre

Ovidiu Badea, Stefan Leca
National Institute for Research and Development in Forestry (INCDS) "Marin Drăcea"

Main activities/developments

The Romanian National Institute for Research and Development in Forestry (INCDS) „Marin Drăcea"(NFC) is responsible for the implementation of all the ICP Forests Level I and Level II monitoring activities. The INCDS specialists are involved in all expert panels (Ambient Air Quality, Crown Condition and Damage Causes; Deposition; Forest Growth; Soil & Soil Solution; Biodiversity and Ground Vegetation; Meteorology, Phenology & LAI) as well as in the Working Group on QA/QC in Laboratories. Since 2020 our representative holds the chair position of the Ambient Air Quality Expert Panel.

In accordance with the ICP Forests activities the Romanian forest monitoring experts participated in the following events:

- Joint Meeting of the ICP Forests Expert Panels, 8–12 March 2021, online
- 9th ICP Forests Scientific Conference, 7–9 June 2021, WSL Birmensdorf, Switzerland
- 37th Task Force Meeting of ICP Forests, 10–11 June 2021, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
- Air Pollution threats to Plant Ecosystems (postponed from 2020), 11–15 October 2021, Paphos, Cyprus
- Annual National Crown Condition Intercalibration Course, 29 June 2021, Brasov, Romania

In 2020, all the ICP Forests monitoring related activities were carried out as scheduled, in both Level I and Level II monitoring plots as follows:

- annual crown condition assessments on Level I plots (16x16 km);
- forest monitoring activities on Level II plots: crown condition (12 plots); continuous and permanent measurements of tree stem variation (4 core plots); foliar samples for broadleaves and conifers (12 plots);

phenological observations (4 plots); litterfall and LAI measurements (3 plots); ground vegetation assessments (12 plots); atmospheric deposition (5 plots); air quality measurements (4 plots); meteorological measurements (4 plots)

- Chemical analysis for deposition samples, air pollutants passive samples (O_3, NO_2, NH_3), soil solution and foliar nutrients.
- Validating and submitting the data base for all monitoring activities (Level I and Level II).

Major results/highlights

In 2021, on the 16x16 km Level I network 246 plots were assessed. For a total number of 5616 trees crown condition and damage symptoms were evaluated. The share of damaged trees (defoliation classes 2-4) was 12.0% being 0.9 percent points lower than in 2020. Conifer trees represented 16.4% (923 trees) and broadleaves 83.6% (4693 trees).

For all species 51.9% were rated as healthy (defoliation class 0), 36.0% as slightly defoliated (class 1), 10.3% as moderately defoliated (class 2), 1.1% as severely defoliated (class 3) and 0.6% were found dead (class 4).

The share of damaged bradleaves trees was 11.2% with 0.9 percent points lower than in 2020. Again, as in previous yeas *Fagus sylvatica* had the lowest share of damaged trees (6.5%), and the highest values were registered by *Populus* spp. (26.6%), and *Q. cerris* (19.6%).

For conifers 16.4% of trees were assessed as damged, *Abies alba* and *Picea abies* being the least affected species with a share of damaged trees of 13.5% and 14.4%, respectively.

For all trees and species, the mortality rate is still low (0.6%), the highest values being registered for *Populus* spp. and *Robinia pseudoacacia* (1.0%).

Damage symptoms were reported for 35% of the total number of trees. The most important causes were attributed to defoliators, xylophage insects and fungi.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

The Annual Report of the Romanian Environment Status in 2020. VI.1.3. Forest health status. Ministry of Environment, Waters and Forests.

The Annual Report of the Romanian Forest Status in 2020. Ministry of Environment, Waters and Forests.

The ICP Forests Technical Report – The 2020 Assessment

Outlook

In 2022, all the ICP Forests Level I and Level II monitoring activities will be carried out under the coordination of the National Institute for Research and Development in Forestry (INCDS) „Marin Drăcea" (NFC). The Romanian NFC of ICP Forests is continuously updating and maintaining the monitoring system and seeking financing possibilities for developing new research (related to climate change effects on different forest indicators) in order to fulfill the reporting obligations regarding the negative impacts of air pollution on forest ecosystems under the National Emissions Ceilings (NEC) Directive (2016/2284/EU) and other national and international technical reports. Also, inline with recent ICP Forests strategy the novel forest monitoring and forecasting methods based on integration of remote sensing sensors, Earth-Observation (EO) data and in situ measurements developing will be continued.

Serbia

National Focal Centre

Dr Ljubinko Rakonjac, Principal Research Fellow
Institute of Forestry, Belgrade

Main activities/developments

The National Focal Center at the Institute for Forestry has been continuously participating in the international programme ICP Forests, with the goal of achieving further improvement and harmonization with other approaches to forests and forest ecosystem monitoring. Monitoring is conducted on 130 Level I sample plots and 5 Level II sample plots. The main activities in 2021 included the improvement of the work within the ICP Forests programme through the implementation of new and enhancement of the existing infrastructure with the application of modern technologies. This includes the improvement of current instruments within Level II sample plots, as well as the improvement of internal database storage. In 2021, activities on measuring leaf area index were established, and by that, all activities within the Expert Panel on Meteorology, Phenology and Leaf Area Index are now conducted. During 2021, bases for additional activities within this programme have been established, since there is initiative to start work in the Expert Panel on Ambient Air Quality. Through this programme, the Institute of Forestry constantly works on strengthening the cooperation with all relevant institutions in the field of forestry and environmental protection: forest estates of public enterprise "Srbijašume" and "Vojvodinašume", public enterprises that manage national parks, as well as forest owners and other users of forest resources.

Major results/highlights

The total number of trees assessed on all Level I sampling plots was 2928 trees, of which 359 were conifer trees and a considerably higher number (2569) were broadleaf trees.

Defoliation for conifer species (%) are: *Abies alba* (None 95.5, Slight 1.5, Moderate 1.5, Severe 1.5 and Dead 0.0); *Picea abies* (None 97.9, Slight 1.4, Moderate 0.0, Severe 0.7 and Dead 0.0); *Pinus nigra* (None 41.8, Slight 17.9, Moderate 29.9, Severe 10.4 and Dead 0.0); *Pinus silvestris* (None 95.0, Slight 3.8, Moderate 0.0, Severe 1.2 and Dead 0.0). The degree of defoliation calculated for all conifer trees is as follows: no defoliation 86.4 % trees, slight defoliation 5.0% trees, moderate 5.8% trees, severe defoliation 2.8% trees and dead 0.0% trees.

Individual tree species defoliation (%) for broadleaf species are: *Carpinus betulus* (None 96.6, Slight 3.4, Moderate 0.0, Severe 0.0, Dead 0.0); *Fagus sylvatica* (None 94.4, Slight 3.3, Moderate 1.2, Severe 1.1, Dead 0.0); *Quercus cerris* (None 77.6, Slight 16.8, Moderate 5.3, Severe 0.4, Dead 0.0); *Quercus frainetto* (None 88.9, Slight 8.8, Moderate 1.5, Severe 0.8, Dead 0.0); *Quercus petraea* (None 73.2, Slight 23.5, Moderate 1.1, Severe 2.2, Dead 0.0) and the rest (None 72.0, Slight 11.8, Moderate 11.8, Severe 4.4, Dead 0.0). Degree of defoliation calculated for all broadleaf species is as follows: no defoliation 84.1% trees, slight defoliation 10.1% trees, moderate 4.2%, severe defoliation 1.6% trees and dead 0.0% trees.

Besides the work on Level I, work in following Expert Panels were done: Ground Vegetation, Crown Condition and Damage Causes, Deposition, Soil and Soil solution, Foliage and Litterfall, Forest Growth and Meteorology, Phenology and Leaf Area Index. Detailed results are presented in provided publications.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

All national publications are available at our site: http://www.forest.org.rs/?icp-forests-serbia

Rakonjac Lj, Đorđević I, Češljar G, et al (2021) Monitoring and assessment of air pollution impacts and its effects on forest ecosystems in Republic of Serbia – forest condition monitoring, Level I and II. Institute of forestry, Belgrade

Outlook

In the next period, development of ICP Forests Infrastructure will be mainly on strengthening work in our laboratories and involvement in different ring test analysis. This will also include acquiring new ICP spectrometer for conducting different chemical analyses. Also, activities on starting monitoring of ambient air quality have been initiated. During 2022 effort will be on adding this survey to the permanent monitoring. Cooperation with Environmental Protection Agency of Serbia has been made and during 2022 NFC Institute of Forestry will try to include their data on ambient air quality, since their monitoring station is near to our sample plot Level II on Kopaonik. For 2022, the paper under title "Unfavorable climatic factors and their impact on the decline of spruce at the Kopaonik national park (Central Serbia)" is accepted for publishing in peer-reviewed journal Fresenius Environmental Bulletin. Also, in 2022 publishing of a peer-reviewed paper is planned under title "The impact of extremely dry period with high temperatures on tree defoliation as an indicator of the condition of the forests in Serbia".

Slovakia

National Focal Centre

Pavel Pavlenda, National Forest Centre – Forest Research Institute Zvolen (NFC-FRI Zvolen)

Main activities/developments

Crown condition assessment on Level I plots (16 x 16 km grid) was conducted between 12 July and 6 August 2021. The number of Level I plots is decreasing due to bark beetle outbreaks and sanitary fellings and relatively large areas with young forest plantations. In the last two decades, the share of Norway spruce in tree species composition in forests of Slovakia fell from 26.8% to 22.5%, which is reflected also in the number of Level I plots and the decreasing number of assessed Norway spruce trees.

Standard activities of intensive monitoring continued on seven Level II monitoring plots at a rate of twice per month. Defoliation, increment, atmospheric deposition, meteorology and phenology are being monitored at all these Level II plots but other surveys (soil solution, air quality, litterfall) are limited only to selected plots. After a gap of several years, sampling of needles and leaves was also conducted in 2019 and 2021.

After an introductory study for large-scale soil sampling elaborated in 2020, sampling and laboratory analyses started in 2021 (about 20 % of Level I monitoring plots). The survey will continue in 2022 and next years. We plan to finish the field work in 2024 and analyses in 2025.

Several other national research projects have been submitted to support research of specific topics related to forest ecology and activities of forest monitoring. A new research project aiming for forests´ adaptation to climate change was successfully prepared and in 2022 begins also the partial project focussed at complex forest monitoring. The team of NFC continues to open cooperation with other research institutions and research programmes (e.g. validation of BGC Biome model for Central European region, integration of meterologocal data in forest landscape), as well as with environmental institutions and agencies (Slovak Environmental Agency: NEC Directive obligation, Slovak Hydrometeorological Intstitute: UNFCCC reporting, mitigation potential of forests and CO2 removals)

Major results/highlights

On the basis of average defoliation, the results of the crown condition survey for the last four years show a stabilized state in deciduous trees and a slight deterioration in coniferous trees. The share of trees in defoliation classes 2-4 in 2021 was 28.8% in broadleaves (33.8% in 2020) and 54.0% in conifers (51.0% in 2020). Mean defoliation of all tree species together was 27.2%, with mean defoliation of broadleaves 24.5% and conifers 31.7%. The highest level of damage was observed in *Fraxinus excelsior* (mean defoliation 49.0%), *Larix decidua* (39.0%), *Robinia pseudoacacia* (36.7%) and *Pinus sylvestris* (36.0%). In particular, the poor condition of *Fraxinus excelsior* in lowland areas caused by drought and fungal infestation by *Chalara fraxinea* is alarming. On the other hand, the only tree species with continuous decrease of defoliation from the very beginning of forest monitoring (1988) is *Abies alba.* The highest mortality was observed in *Picea abies* in the last decade.

The trend of radial growth of *Fagus sylvatica*, *Carpinus betulus* and *Pinus sylvestris* has been declining in the last two decades (correlated with an increase in defoliation), while the growth of *Picea abies* and *Quercus* sp. is still relatively stable. The defoliation and growth of the surviving *Picea abies* trees is without a rising or falling trend, but a large number of trees died very quickly due to the bark beetle outbreaks, which led to a decrease in the number of trees evaluated. *Abies alba* is the only tree species with a positive trend not only in defoliation but also in growth and after a decline in the 80s of the 20th century it shows a recovery.

Deposition of sulphur and nitrogen does not show further decrease in the last years. The annual deposition of sulphur (in throughfall) varies between 3 and 9 kg ha^{-1} at all monitoring plots, and the annual deposition of nitrogen (in throughfall) varies between 5 and 10 kg ha^{-1}. Meteorological extremes have strong effect on tree vitality and increment.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

A national report on forest condition is not published annually, but the main defoliation data are included in the national green report (forestry status). Specific evaluations related to forest meteorology and utilisation of monitoring data for process-based modelling were conducted and published.

Selected articles:

Hlásny T, Merganičová K, Sitková Z, et al (2021) Forest management under climate change: From empirical to process-based approaches. APOL 2(1):141–146 (in Slovak).

Lembrechts J, van den Hoogen J, Aalto J et al (2021) Global maps of soil temperature. Global Change Biology. https://onlinelibrary.wiley.com/doi/epdf/10.1111/gcb.16060

Pavlenda P (2021) Sustainability of forest soil functions: threats and solutions. In: Tóthová S, Gergel T (eds): Proceedings of the Conference LignoSilva 2021 held 28 September 2021 Zvolen, National Forest Centre, ISBN 978-80-8093-327-2. s. 59-65 (in Slovak).

Sitková Z, Barka I (2021) Climatic trends and monitoring of tree growth response in Kysuce region. In: Tóthová S, Gergel T (eds): Proceedings of the Conference LignoSilva 2021 held 28 September 2021 Zvolen, National Forest Centre, ISBN 978-80-8093-327-2. s. 66-74 (in Slovak).

Outlook

All standard acivities for Level I and Level II forest monitoring are planned for 2022. The priority of the forest monitoring is to maintain the system and sustain the continuity of time series and data quality. Development of field infractructure and laboratory instruments depends on additional financing, e.g. specific projects for infrastructure support or big research projects.

The main aim of NFC for next years at national level is to improve the activities in research projects related to forest ecology. Besides standard evaluations, aspects of carbon storage and adaptation to climate change will be developed.

Bilateral cooperation with NFC Czechia will continue in 2022 by seminar hosted by the Czech NFC in Podyjí National Park and possibly in 2024 in Slovakia.

Slovenia

National Focal Centre

Dr Mitja Skudnik, Daniel Žlindra, Anže Martin Pintar, Slovenian Forestry Institute (SFI)

Main activities/developments

In 2021, the Slovenian national forest health inventory was carried out on 44 systematically arranged sample plots (grid 16 x 16 km) (Level I). The assessment encompassed 1056 trees, 347 coniferous and 709 broadleaved trees. The sampling scheme and the assessment method was the same as in the previous years (at each location four M6 (six-tree) plots).

In 2021, deposition and soil solution monitoring was performed on all four Level II core plots. On all ten plots the ambient air quality monitoring (ozone) was done with passive samplers and ozone injuries assessed on six of them. On eight plots the phenological observations were carried out. On six plots, growth was monitored with mechanical dendrometers.

Major results/highlights

- The mean defoliation of all tree species was estimated to be 30.7% (compared to last year the situation is worse).
- Mean defoliation in 2021 for coniferous trees was 29.4% (in 2020 it was 26.7%).
- Mean defoliation in year 2021 for broadleaves was 31.3% (in 2020 it was 28.4%).

- The defoliation of conifers is remaining on a very high level, with sign of increase in 2021. The main reason is the bark beetle outbreak after a large ice storm break in 2014, stretching all over 2016, 2017, 2018.
- The defoliation of broadleaves is increasing over the past six years. The main reason could be the effect of ice storm (fungi effect) and some other insect attacks.
- The total share of damaged and dead trees (with more than 25% defoliation) again increased compared to the previous years from 33.8% to 38.1%, to 42.4% in 2021.
- The percentage of damaged broadleaves has persistently increased from 34% in 2018, 35% in 2019, 36.5% in 2020 to 41.3% in 2021.
- The percentage of damaged conifers has increased from 40.6% in 2017 to 42.7% in 2019. In 2020, it has slightly decreased to 41.1% and then increased to 44.1% in 2021.
- Average ozone concentrations in the growing season of 2021 ranged from 18 to 54 µg/m^3 on monitored plots which is on the same level as in the previous year. On all of 10 plots the 14-days ozone concentrations remain under 80 µg/m^3 during the whole growing season. On two plots with higher ozone concentrations, we measured top values of 71 and 74 µg/m^3 in 14-days period. On two additional plots the maximum ozone concentrations rised to 62 and 65 µg/m^3. On the rest of the plots the ozone didnot exceed the value of 60 µg/m^3 in 14-days average.
- The highest 14-days average concentration was 71 µg/m^3 and 54 µg/m^3 on the most ozone-polluted plot.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Skudnik M, Ferlan M, Grah A, Kermavnar J, Kutnar L, Ogris N, Pintar AM, Planinšek Š. (author, editor), RUPEL M, SIMONČIČ P, ŽLINDRA D (author, editor) (2021) Poročilo o spremljanju stanja gozdov za leto 2020 = Report on health status of forests 2020. Ljubljana: Slovenian Forestry Institute, pp 135. https://www.gozdis.si/f/docs/publikacije/Porocilo-o-stanju-gozdov-2020.pdf, http://dirros.openscience.si/IzpisGradiva.php?id=14193

Planinšek Š, Skudnik M (2021) Poškodovanost gozdov in osutost dreves: kazalci po letih: 2021. = Forest decline and tree defoliation: Indicators by year: 2021. Ljubljana: Slovenian Environment Agency. http://kazalci.arso.gov.si/sl/content/poskodovanost-gozdov-osutost-dreves-4

Ogris N, Skudnik M (2021) Naraščanje osutosti bukve 1993-2019: online predavanje na 11. Seminarju in delavnici iz varstva gozdov, 1. in 2. 6. 2021 = Beech defoliation in Slovenia is increasing (1993-2019): online lecture at 11. Seminar and workshop on forest protection

Ogris N, Skudnik M (2021) Beech defoliation in Slovenia is increasing. Gozdarski vestnik: slovenska strokovna revija za gozdarstvo 79: 5/6:226-237

Outlook

In 2021 one meteorological station was completely renewed/ repaired and additionally fenced. Some minor repair work has been done on IM (level II) plots and will continue in 2022. Construction of the fence is planned for 2022 on one Level II plot.

Spain

National Focal Centre

Maria Pasalodos, Elena Robla – Ministry for the Ecological Transition and the Demographic Challenge

Main activities/developments

Spanish forest damage monitoring comprises:

- European large-scale forest condition monitoring (Level I): 14 880 trees on 620 plots
- European intensive and continuous monitoring of forest ecosystems (Level II): 14 plots

Despite the pandemic situation, Level I and Level II surveys were carried out in 2021.

Main activities were:

- National Intercalibration Course was organized online due to the pandemic situation in Spain.
- March 2021: Attendance at ICP Forests Combined Expert Panel Meeting (video conference)
- June 2021: Attendance at 37th Task Force Meeting of ICP Forests (video conference)
- June 2021: Attendance at the FORECOMON 2021 conference
- Others: Continuously updating the website

Major results/highlights

Level I

Mean defoliation observed in 2021 of all the trees of the Level I sample is 21.7%. Dead trees due to harvests were not included when calculating mean defoliation.

Results obtained from the 2021 surveys show a slight improvement in general assessed tree status, compared with mean values from the last 5-year period: The percentage of healthy trees has increased (78.8%, compared to 75.8% on average in the last 5-year period), and damaged trees have decreased (18.9% of the assessed trees have defoliation over 25%, while the average is 21.5%). However, the percentage of dead or missing trees decreased slightly as well (2.3% in 2021 compared to 2.7% on average). Comparing broadleaves and conifers, both groups experience improvement, more clearly in conifers. In this group, the percentage of healthy trees increased slightly (81.6% in 2021, compared to 76.5% on average in the last 5-year period); and the percentage of damaged trees decreased (16.9% of trees). In the case of broadleaves, the percentage of healthy trees increased as well (76.0%, compared to 75.1% on average); the percentage of damaged trees decreased (20.9%).

Level II

Results of Level II are complex and diverse. A summary can be obtained by consulting the publications mentioned in the next chapter.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Level I

Forest Damage Inventory 2021 (Inventario de Daños Forestales 2021)

Maintenance and Data Collection. European Large-scale forest condition monitoring (Level I) in Spain: 2021 Results. (Mantenimiento y toma de datos de la Red Europea de seguimiento a gran escala de los Bosques en España (Red de Nivel I): Resultados 2021

Level II

European intensive and continuous monitoring of forest ecosystems, Level II. 2020 Report. (*Red europea de seguimiento intensivo y continuo de los ecosistemas forestales, Red de Nivel II*).

Spanish versions are available for download.

Outlook

Nowadays, data from ICP Forests Level I monitoring are providing very useful information to fulfil the international requirements of climate change information. Litter, deadwood, and soil surveys are, and are going to be in the near future, the main source of data to assess the variation of carbon in these forestry pools.

Spanish National Forest Inventory-type plots have been installed with the same center plot location as Level I plots, in order to fill in the gaps in area estimation and complete the information as regards the living biomass and stand variables. Dasometric parameters such as mean diameter, basal area, and mean height of living trees are already measured in all Level I plots.

Moreover, regional Level I surveys are being carried out by different regions (autonomous communities) in Spain. An integrated database, containing data both from national and regional sources, has been constructed in the framework of a collaboration between the National Institute for Agricultural and Food Research and Technology (INIA) and the Ministry for the Ecological Transition and the Demographic Challenge.

Sweden

National Focal Centre

Sören Wulff, Swedish University of Agricultural Sciences (SLU)

Main activities/developments

Main activities/developments Monitoring activities continued on Level I. In 2009 a revised sampling design for Level I plots was implemented, where an annual subset of the Swedish NFI monitoring plots are measured. The Swedish NFI is carried out on a five years interval and accordingly the annual Level I sample is remeasured every fifth year. Defoliation assessments are carried out only on Picea abies and Pinus sylvestris, while damage assessments are done on all sample trees. The Swedish Throughfall Monitoring Network (SWETHRO) has delivered data on deposition, soil solution and air quality to the Level II programme. Sweden participated in some of the meetings of the 2021 Joint Expert Panel Meeting of ICP Forests.

Major results/highlights

The major national results, based on the whole Swedish NFI sample, but concern only forests of thinning age or older and outside forest reserves. The proportion of trees with more than 25% defoliation is for Picea abies 23.1 % and for Pinus sylvestris 12.7 %. Large temporal annual changes is seen on a regional level, however, for Pinus sylvestris a slight increased defoliation in northern Sweden is observed during the last 10 years. The increased defoliation seen for Picea abies in southern Sweden in recent years seems to have decline. The mortality rate in 2020 was for Pinus sylvestris 0.70% and for Picea abies 0.81%. The severe damage caused by spruce bark beetle (Ips typographus) in southern Sweden has continued after the dry summer in 2018. A Target-tailored Forest Damage Inventory (TFDI) of spruce trees killed by spruce bark beetle was undertaken. The results from the inventory showed that 8.2 million m3 Norway spruce forest was killed during 2021. In northern Sweden, there is a strong concern for the young forest, mainly the pine forest. Several causes of damage interact. Most important among them are resin top disease (Cronartium flaccidum) and browsing by ungulates – mainly elk. Otherwise as before significant damage problems in Sweden are due to pine weevil (Hylobius abietis) (in young forest plantations), browsing by ungulates, mainly elk, (in young forest), and root rot caused by Heterobasidion annosum. Data from Sweden on forest condition, deposition, soil solution and air quality are besides in the ICP Forests Technical Report also included in several national reports. Data are used in many “data requests”, where participating researcher gain access to Swedish data.

NATIONAL REPORTS

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

National reports are available for the Swedish NFI SLU National Forest Inventory | Externwebben (https://www.slu.se/en/Collaborative-Centres-and-Projects/the-swedish-national-forest-inventory/) and the SWETHRU Publications - IVL Svenska Miljöinstitutet (https://www.ivl.se/english/ivl/publications.html).

Outlook

Monitoring activities on Level I will continue as previously. Also, data from SWETHRO on the Level II programme will continue. Several studies are ongoing and among them studies on Nitrogen deposition causes distinct eutrophication in bryophyte communities. In 2022, Target Tailored Forest Damage Inventories (TFDI) of damages caused by spruce bark beetle and of damage in young forest in northern Sweden will be carried out. Sweden will participate in the H2020 project HoliSoils in harmonizing maps of soil carbon.

Switzerland

National Focal Centre

Arthur Gessler, Peter Waldner, Marcus Schaub, Anne Thimonier, Katrin Meusburger, Swiss Federal Research Institute WSL

Main activities/developments

Besides the regular monitoring activities and data analyses on the Level I and Level II plots, particular emphasis was put on the following topics:

- Additional Sanasilva inventories on an 8x8 km grid within a test region were carried out on 21 plots. These assessments will be continued in the coming inventories. If the 8x8 km grid proves to better capture spatial tree vitality patterns, the test region will be gradually enlarged.
- The ICP Forests - SwissForestLab - NFZ Summer School on FORMON Forest Monitoring to assess Forest Functioning under Air Pollution and Climate Change took place between 22–28 August 2021 in Davos, Switzerland.
- The 9th ICP Forests Scientific Conference "Forest Monitoring to assess Forest Functioning under Air Pollution and Climate Change" took place between 7–12 June 2021 in Birmensdorf, Switzerland.
- First tests of the assessments of defoliation and other physiological parameters (such as the photochemical reflectance index) with drone-based methods on selected plots – comparison with classical methods.
- A joint activity was started to advance the monitoring design and integrate future needs into the joint monitoring plots of the Sanasilva Inventory (Swiss ICP Forests Level I) and the Swiss National Forest Inventory.
- Ground Vegetation Survey (16 1x1m quadrats and 1-2 circular 30 m^2, 200 m^2 and 500 m^2 plots) and Leaf Area Index (LAI) surveys have been carried out on the Level II plots in 2021.
- The first repetition of the Soil Inventory on the 8x8 km grid, including the Level I plots, started in autumn 2021.

Major results/highlights

The mean defoliation of all tree species remained constant between 2020 and 2021. However, there were opposite defoliation changes of conifers and broadleaf trees. The defoliation of conifers increased again after a clear decrease in 2020, which followed high defoliation values in 2019 due to the extremely dry year 2018. Broadleaf trees, in contrast, did not show signs of recovery in 2020, but in 2021 defoliation decreased strongly.

The summer of 2021 (especially July and August) was relatively wet compared to e. g. the dry year 2018. There was sufficient precipitation in most regions, even local or regional flood events and punctual hail storm damage, but no distinct longer dry periods in most regions.

Results from an extraordinarily extended monitoring on the Level I and National Forest Inventory plots in 2018 revealed a rapid response of beech crown condition to the extraordinary dry periods in summer 2018 in the Central Plateau, the Jura hills and at some inner alpine valleys sites in Switzerland with shallow soils (Rohner et al. 2021). Several Swiss Level II sites have been part of a set of plots for which Anthony et al. (2022) found effects of mycorrhiza community composition on tree growth that were later confirmed in a laboratory experiment

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Etzold S, Eugster W, Braun S, Thimonier A, Waldner P, Zweifel R (2021) Stickstoffdeposition – ab wann ist es zu viel für das Baumwachstum? [Nitrogen deposition - When is it too much for tree growth?] Wald und Holz 11/21: 15-18.

Ferretti M (2021) Origin, features, vision and objectives of the Swiss AIM initiative. In M. Ferretti, C. Fischer, & A. Gessler (Eds.), WSL Berichte: Vol. 106. Towards an advanced inventorying and monitoring system for the Swiss forest (pp. 7-15). Swiss Federal Institute for Forest, Snow and Landscape Research WSL.

Ferretti M, Fischer C, Gessler A (2021) Swiss AIM in the perspective of WSL research units, programmes and centres. In M Ferretti, C Fischer & A Gessler (Eds.), WSL Berichte: Vol. 106. Towards an advanced inventorying and monitoring system for the Swiss forest (pp. 16-22). Swiss Federal Institute for Forest, Snow and Landscape Research WSL

Nussbaumer A, Meusburger K, Schmitt M, Waldner P, Gehrig R, Haeni M, Rigling A, Brunner I, Thimonier A (2021) Verfrühter Fruchtabwurf in Schweizer Buchenbeständen im Hitze- und Trockensommer 2018 [Premature fruit fall in Swiss beech stands during the hot and dry summer of 2018]. Schweizerische Zeitschrift für Forstwesen 172(3):166-175. DOI:10.3188/szf.2021.0166

Outlook

We aim on the one hand to better integrate both ICP Forests plots and the Swiss National Forestry plots into an integrated monitoring network and add additional features that allow, e.g. a better linkage of ground-based assessments to remote sensing (e.g. via drone-based proximal sensing). Moreover, we will implement additional close-to-realtime measurements and nowcasting tools in our monitoring portfolio to better understand the impacts of extreme events on forest ecosystem functioning.

In addition, it is planned to add experimental manipulation of temperature and precipitation on subplots of selected Swiss Level II plots to better understand the impact of climate change on forest ecosystems.

Furthermore, we aim to improve our understanding of the observed long-term changes in tree nutrition by updating element budgets, comparing it to long-term changes in the soil nutrient pools, and assessing the impact of driving factors and synergies to e. g. drought effects.

Türkiye

National Focal Centre

Sıtkı Öztürk, Ministry of Forestry and Water Works, General Directorate of Forestry, Department of Combating Forest Pests

Main activities/developments

We have participated in the ICP Forests monitoring network since 2006 in order to monitor the health of forests in our country. Level I and Level II programs were implemented on the monitoring plots.

As of 2021:

- Every year, on 603 Level I and 52 Level II monitoring plots the crown status and visual damage assessment is conducted and annual reports are published.
- The preparations were completed to carry out the classified analyses on 680 Level I and 52 Level II monitoring plots suitable for taking soil samples from the 850 monitoring plots set up in 2015. The analyses will be finalized in 2022 and uploaded to the ICP Forests database.
- Needle-leaf samples were taken on 52 Level II monitoring plots in 2015, 2017, 2019, and 2021. Analyses are continuing. The analyses of the samples taken in 2015, 2017 and 2019 have been completed. After checking, the data will be transferred to the database in 2022. Analysis of the samples taken in 2021 continues.
- All measurements and production related to tree growth were completed for the first 5 years on 52 Level II monitoring plots. In 2020, the second 5-year measurements were made.
- Intensive monitoring was planned for 18 of the 52 Level II monitoring plots. Precipitation, deposition, litterfall, soil solution, phenological observations and air quality sampling began to be studied. The analyses of the samples taken in the years 2017-2020 have been completed and will be transferred to the database after internal checking.
- Since 2014, meteorological data have been been obtained from 51 automatic meteorology observation stations. The 2014-2021 results of the meteorological stations will be uploaded to the ICP Forests database in 2022.
- Each year, 52 Level II monitoring plots are monitored for ozone damage. No ozone damage was found.
- A laboratory was established in İzmir for the analysis of the samples taken from the monitoring plots in the Directorate of Aegean Forestry Research Institute. All requirements are completed and activated. In 2018, 2019 and 2021, water and needle-leaf and rash and soil ring tests were performed and passed.
- The collected data are stored in the national database and the reports are taken from the database.
- We contributed to the National Forest Inventory studies conducted by the Forest Administration and Planning Department.

Major results/highlights

- Ozone damage was encountered on the Level II monitoring plots 8, 12, 18, 29, 30, 51, and 52 within the scope of air quality monitoring made in 2017, 2018, 2019, 2020, and 2021
- On 621 Level I and 52 Level II monitoring plots, 21478 trees in total are monitored.
- 29 kinds of insects, fungi, viruses, etc. that cause damage on the selected trees observed are monitored.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Forest Ecosystems Monitoring Level I and Level II Programmes in Turkey. TEMERİT A, ADIGÜZEL U, FIRAT Y, KİP HS, BİLGİ M. National Focal Centre. ISBN: 978-975-8273-92-8

Health State of Forests in Turkey (2008-2012). ÖZTÜRK S, Prof. TOLUNAY D, KARAKAŞ A, TAŞDEMİR C, AYTAR F, Umut ADIGÜZEL U, AKKAŞ ME. National Focal Centre. ISBN: 978-605-4610-44-0

Monitoring Of Forest Ecosystems Crown Status Evaluation Photo Catalog. ÖZTÜRK S. National Focal Centre. ISBN: 978-605-393-038-9

Turkey Oaks Diagnosis and Diagnostic Guide. ÖZTÜRK S. National Focal Centre. ISBN: 978-975-8273-92-8

ÖZTÜRK A (2016) Some Botanical Characteristics of Maple (*Acer*) Species Naturally Occurring in Turkey. National Focal Centre. General Directorate of Forestry. Journal of Forestry Research 2016/2 A, Volume 1(4), ISSN: 2149-0783

Outlook

Future developments of the ICP Forest infrastructure

In our country, the installation of the observation areas, which are planned to be installed at 16x16 km intervals in the Level 1 program, has been completed. Work started on the visual assessment of crown condition and damage factors, vegetation and biodiversity, tree growth, and soil sampling. A study on biodiversity was planned. Every 5 years, the studies are reported. In 2022, the report covering the years 2008-2021 will be prepared and shared by the end of June 2022.

Planned research projects, expected results

A chamber surveillance project was prepared to monitor the effects of climate change in 18 Level II plots where intensive monitoring is performed. It is also planned to put some meteorological data (soil temperature and humidity, etc.) and automatic air quality sampling sensors on the watchtowers to be established with this project.

United Kingdom

National Focal Centre

Suzanne Benham, Forest Research

Main activities/developments

Another challenging year for monitoring with the limitations imposed due to COVID-19, however monitoring was maintained with very few disruptions. Monitoring activities continue at 5 sites. Sample collections for deposition, soil solution, litterfall have been carried out and monthly growth recording using permanent girth tapes continues. Foliar samples were taken for chemical analysis from the crown in all plots.

The weather in the UK was around average for 2021 with none of the record breaking seen in 2020, however the weather in spring was both dry and warm leading to an early budburst but May was very wet, so drought was not a problem.

The area of woodland in the UK is estimated to be 3.2 million hectares. The main research focus continues to be the threat to UK forests from pests, diseases, and climate change with just 7% of UK woodlands assessed as being in good ecological condition. A cluster of issues to do with oak health has been identified in the South of the UK and a major field experiment has begun into the effects of predisposition factors such as drought and pathogen interactions.

Following routine health surveillance activities Phytophthora pluvialis has been detected on mature Western Hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) in the UK. Control areas have been introduced to prevent the spread. Surveillance and diagnostic analysis are underway to understand more about the pathogen. This includes extensive ground and aerial surveillance as part of a UK-wide survey, and comprehensive research and modelling to explore factors such as climatic and potential species susceptibility and to help inform the management response.

The demand for planting new trees and woodland continues to escalate with a target of 30000 ha of new woodland in England by 2025. Research and monitoring on the sustainability of such planting is under development.

Major results/highlights

- Long Term Trends of the Base Cation Budgets of Forests in the UK have been calculated.
- The contribution of deadwood to soil carbon dynamics in temperate forest ecosystems has been quantified.
- DOC fractionation of soil solution to investigate effect of drought and rewetting on the carbon release from soils on the UK has been undertaken.

Publications/reports published with regard to ICP Forests data and/or plots and not listed in Chapter 2

Perks M, Vanguelova E (2020) The importance of soil carbon in forest management. ISSUE 61 Reforesting Scotland SPRING/SUMMER 2020.

Future Proofing Plant Health. Report to Defra April /2020 Vanguelova E, Brown N, Benham S, Ashwood F, Foster J, and Denman S

Vanguelova E, Benham S, Broadmeadow S (2021) Ammonia reduction from trees. Report on tree growth, leaf morphology and nutrient uptake at tree shelterbelts at Cumbria farms. Forest Research report to Natural England.

Outlook

- Monitoring for ecological condition is rapidly climbing the agenda in England. Whilst monitoring obligations under ICP Forests continue at five sites, an additional two sites are currently under development as part of National Capital Ecosystem Assessments (NCEA), and these will include ICP Forests monitoring where possible. The ecosystem selected for these new sites are an ancient oak woodland in the south and a riparian woodland in the southwest of England.
- As part of the Action Oak initiative the Forest Condition Survey was re-introduced at 85 of the original UK oak plots from the 1987–2007 survey and monitoring of these plots will continue going forward. Preliminary assessments seem to indicate that tree health condition continues to decline.

Planned research projects, expected results

- Investigating the change in vegetation communities across forest plots using Ellenberg.
- PhD study on forest management impacts on NO_3 leaching.
- Under the English National Capital Ecosystem Assessments (NCEA) additional monitoring will be undertaken within the UK-ICP Forests programme:
  - BioSoil sample plots will be resampled for soil analysis with additional soil biodiversity recording undertaken at each of the plots.
  - Air pollution recording using passive diffusion tubes (NO_x, SO_2, O_3) and alpha samplers from the UK Ammonia monitoring network (NH_4), will start at all Level II plots from Jan 2022. This will enable the evaluation of the risk for vegetation in areas not covered by the UK air quality monitoring networks.
  - Tree talkers capable of measuring water uptake and transport within trees, diametrical spectral characteristics of leaves and microclimatic parameters as well as growth, stem humidity, girth and axis movement, air temperature and humidity will be installed at all Level II plots to enable the parametrization of forest function and the identification of change.
  - Soil moisture probes will be installed.
  - Automatic camaras will be installed to monitor phenology.

ANNEX

CONTACTS

as of 1 July 2022

UNECE and ICP Forests

UNECE – LRTAP Convention

Krzysztof Olendrzynski
United Nations Economic Commission for Europe – LRTAP Convention Secretariat
Palais des Nations, 8-14, Ave. de la Paix
1211 Geneva 10, SWITZERLAND
Phone: +41 22 917 23 58
Email: krzysztof.olendrzynski@unece.org

ICP Forests Lead Country

Juliane Henry
Federal Ministry of Food and Agriculture - Ref. 515
Postfach 14 02 70
53107 Bonn, GERMANY
Phone: +49 99 529-3588
Email: juliane.henry@bmel.bund.de; 515@bmel.bund.de

ICP Forests Chairperson

Marco Ferretti
Swiss Federal Research Institute WSL
Zürcherstr. 111
8093 Birmensdorf, SWITZERLAND
Phone: +41 44 739 22 51
Email: marco.ferretti@wsl.ch

ICP Forests Programme Co-ordinating Centre (PCC)

Kai Schwärzel, Head of PCC
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, GERMANY
Phone: +49 3334 3820-375
Email: kai.schwaerzel@thuenen.de
http://icp-forests.net

Expert panels, working groups, and other coordinating institutions

Expert Panel on Ambient Air Quality

Diana Pitar, Chair
National Institute for Research and Development in Forestry "Marin Drăcea" (INCDS)
Bd. Eroilor 128
077190 Voluntari, Judetul Ilfov, ROMANIA
Email: diana.silaghi@icas.ro

Elena Gottardini, Co-Chair
Fondazione Edmund Mach
Via Mach 1
38010 San Michele all'Adige, ITALY
Phone: +39 0461 615 362
Email: elena.gottardini@fmach.it

Expert Panel on Biodiversity and Ground Vegetation Assessment

Roberto Canullo, Chair
Camerino University
Dept. of Environmental Sciences
Via Pontoni, 5
62032 Camerino, ITALY
Phone: +39 0737 404 503/5
Email: roberto.canullo@unicam.it

Leena Hamberg, Co-Chair
Natural Resources Institute Finland LUKE
Latokartanonkaari 9
00790 Helsinki, FINLAND
Phone: +358 29 5325400
Email: leena.hamberg@luke.fi

Expert Panel on Crown Condition and Damage Causes

Nenad Potočić, Chair
Croatian Forest Research Institute (CFRI)
Cvjetno naselje 41
10450 Jastrebarsko, CROATIA
Phone: +385 1 6273 027
Email: nenadp@sumins.hr

Volkmar Timmermann, Co-Chair
Norwegian Institute of Bioeconomy Research (NIBIO)
P.O. Box 115
1431 Ås, NORWAY
Phone: +47 971 59 901
Email: volkmar.timmermann@nibio.no

Expert Panel on Deposition

Arne Vestraeten, Chair
Research Institute Nature and Forests (INBO) | Gaverstraat 4
9500 Geraardsbergen, BELGIUM
Email: arne.verstraeten@inbo.be

Peter Waldner, Co-Chair
Swiss Federal Research Institute WSL
Zürcherstr. 111
8903 Birmensdorf, SWITZERLAND
Phone: +41 44 739 2502
Email: peter.waldner@wsl.ch

Andreas Schmitz, Co-Chair
State Agency for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV) | Leibnizstraße 10
45659 Recklinghausen, GERMANY
Phone: +49 2361-305-3466
Email: andreas.schmitz@lanuv.nrw.de

Expert Panel on Foliar Analysis and Litterfall

Pasi Rautio, Chair
Natural Resources Institute Finland (LUKE)
PO Box 16, Eteläranta 55
96301 Rovaniemi, FINLAND
Phone: +358 50 391 4045
Email: pasi.rautio@luke.fi

Liisa Ukonmaanaho, Co-Chair (Litterfall)
Natural Resources Institute Finland (LUKE)
Latokartanonkaari 9
00790 Helsinki, FINLAND
Phone: +358 29 53 25 115
Email: liisa.ukonmaanaho@luke.fi

Expert Panel on Forest Growth

Tom Levanič, Chair
Slovenian Forestry Institute (SFI)
Večna pot 2
1000 Ljubljana, SLOVENIA
Phone: +386 1200 78 44
Email: tom.levanic@gozdis.si

Tanja Sanders, Co-Chair
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, GERMANY
Phone: +49 3334 3820-339
Email: tanja.sanders@thuenen.de

Monika Vejpustková, Co-Chair
Forestry and Game Management Research Institute | Strnady 136
252 02 Jíloviště, CZECHIA
Phone: +420 257 892 206
Email: vejpustkova@vulhm.cz

Expert Panel on Meteorology, Phenology and Leaf Area Index

Lothar Zimmermann, Chair
Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF)
Hans-Carl-von-Carlowitz-Platz 1
85354 Freising, GERMANY
Phone: +49 8161 4591 – 230
Email: lothar.zimmermann@lwf.bayern.de

Stephan Raspe, Co-Chair (Phenology)
Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF)
Hans-Carl-von-Carlowitz-Platz 1
85354 Freising, GERMANY
Phone: +49 81 61 71 49 21
Email: stephan.raspe@lwf.bayern.de

Stefan Fleck, Co-Chair (LAI)
Northwest German Research Institute NW-FVA | Grätzelstr. 2
37079 Göttingen, GERMANY
Phone: +49 551 694 01 -144
Email: stefan.fleck@nw-fva.de

Expert Panel on Soil and Soil Solution

Bruno De Vos, Chair
Research Institute for Nature and Forest (INBO) | Gaverstraat 4
9500 Geraardsbergen, BELGIUM
Phone: +32 54 43 71 20
Email: bruno.devos@inbo.be

Nathalie Cools, Co-Chair
Research Institute for Nature and Forest (INBO) | Gaverstraat 4
9500 Geraardsbergen, BELGIUM
Phone: + 32 54 43 61 75
Email: nathalie.cools@inbo.be

Tiina M. Nieminen, Co-Chair (Soil Solution)
Natural Resources Institute Finland (LUKE)
Latokartanonkaari 9
00790 Helsinki, FINLAND
Phone: +358 40 80 15 457
Email: tiina.m.nieminen@luke.fi

Forest Soil Co-ordinating Centre (FSCC)

Nathalie Cools, Chair
Research Institute for Nature and Forest (INBO) | Gaverstraat 4
9500 Geraardsbergen, BELGIUM
Phone: + 32 54 43 61 75
Email: nathalie.cools@inbo.be

Forest Foliar Co-ordinating Centre (FFCC)

Michael Tatzber, Chair
Austrian Research Centre for Forests BFW
Seckendorff-Gudent-Weg 8
1131 Wien, AUSTRIA
Phone: +43 1 878 38 - 1176
Email: michael.tatzber@bfw.gv.at

Tamara Jakovljević, Co-Chair
Croatian Forest Research Institute CFRI
Cvjetno naselje 41
10450 Jastrebarsko, CROATIA
Phone: +385 1 6273 025
Email: tamaraj@sumins.hr

Quality Assurance Committee

Manuel Nicolas, Chair
Office National des Forêts
Boulevard de Constance
77300 Fontainebleau, FRANCE
Phone: +33 1 60 74 92 -28
Email: manuel.nicolas@onf.fr

Working Group on Quality Assurance and Quality Control in Laboratories

Anna Kowalska, Chair
Forest Research Institute
Sękocin Stary, 3 Braci Leśnej Street
05-090 Raszyn, POLAND
Phone: +48 22 71 50 300
Email: a.kowalska@ibles.waw.pl

Lars Vesterdal, Co-Chair
University of Copenhagen, Department of Geosciences and Natural Resource Management
Rolighedsvej 23
1958 Frederiksberg C, DENMARK
Phone: +45 35 33 16 72
Email: lv@ign.ku.dk

Scientific Committee

Marcus Schaub, Chair
Swiss Federal Research Institute WSL
Zürcherstr. 111
8903 Birmensdorf, SWITZERLAND
Phone: +41 44 739 25 64
Email: marcus.schaub@wsl.ch

Ministries and National Focal Centres (NFC)

Albania
Ministry

Ministry of the Environment, Forests and Water Administration (MEFWA)
Dep. of Biodiversity and Natural Resources Management
Rruga e Durrësit, Nr. 27, Tirana, ALBANIA
Phone: +355 42 70 621, +355 42 70 6390
Email: info@moe.gov.al

NFC

National Environment Agency
Bulevardi "Bajram Curri", Tirana, ALBANIA
Phone: +355 42 64 903 and +355 42 65 299/64 632 | Email: jbeqiri@gmail.com, kostandindano@yahoo.com
Julian Beqiri (Head of Agency),
Kostandin Dano (Head of Forestry Department)

Andorra
Ministry, NFC

Ministeri de Turisme I Medi Ambient
Departament de Medi Ambient
C. Prat de la Creu, 62-64, 500 Andorra la Vella, Principat d'Andorra, ANDORRA
Phone: +376 87 57 07
Email: silvia_ferrer_lopez@govern.ad
Silvia Ferrer

Austria
Ministry

Bundesministerium für Landwirtschaft, Regionen und Tourismus
Stubenring 1, 1010 Wien, AUSTRIA
Phone: +43 1 71 100 72 14
Email: vladimir.camba@bmlrt.gv.at
Vladimir Camba

NFC

Austrian Research Centre for Forests (BFW)
Seckendorff-Gudent-Weg 8
1131 Wien, AUSTRIA
Phone: +43-1-87838-2228
Email: anita.zolles@bfw.gv.at, silvio.schueler@bfw.gv.at
Anita Zolles, Silvio Schüler

Belarus
Ministry

Ministry of Forestry of the Republic of Belarus
Myasnikova st. 39
220048 Minsk, BELARUS
Phone +375 17 200 46 01
Email: mlh@mlh.gov.by
Petr Semashko

NFC | Forest Inventory Republican Unitary Company "Belgosles"
Zheleznodorozhnaja st. 27
220089 Minsk, BELARUS
Phone: +375 17 22 63 053
Email: mlh@mlh.gov.by
Valentin Krasouski

Belgium
Wallonia
Ministry
Service public de Wallonie (SPW), DGARNE, Département de la Nature et des Forêts - Direction des Ressources Forestières
Avenue Prince de Liège, 15
5100 Jambes, BELGIUM
Phone: +32 81 33 58 42, +32 81 33 58 34
Email: didier.marchal@gov.wallonie.be
Didier Marchal

NFC for Level I
Environment and Agriculture Department/ Public Service of Wallonia
Avenue Maréchal Juin, 23
5030 Gembloux, BELGIUM
PHONE: +32 81 626 452
Email: elodie.bay@spw.wallonie.be
Elodie Bay

NFC for Level II
Earth and Life Institute / Environmental Sciences (ELI-e)
Université catholique de Louvain
Croix du Sud, 2 - L7.05.09
1348 Louvain-La-Neuve, BELGIUM
Phone: +32 10 47 25 48
Email: hugues.titeux@uclouvain.be
Hugues Titeux

Flanders
Ministry
Vlaamse Overheid (Flemish Authorities)
Agency for Nature and Forest (ANB)
Koning Albert II-laan 20
1000 Brussels, BELGIUM
Phone: +32 2 553 81 22 | Email: carl.deschepper@lne.vlaanderen.be
Carl De Schepper

NFC
Research Institute for Nature and Forest (INBO)
Gaverstraat 4
9500 Geraardsbergen, BELGIUM
Email: arne.verstraeten@inbo.be
Arne Verstraeten

Bulgaria
Ministry
Ministry of Environment and Water
National Nature Protection Service
22, Maria Luiza Blvd.
1000 Sofia, BULGARIA
N.N.

NFC
Executive Environment Agency at the Ministry of Environment and Water
Monitoring of Lands, Biodiversity and Protected Areas Department
136 Tzar Boris III Blvd., P.O. Box 251
1618 Sofia, BULGARIA
Phone: +359 2 940 64 86
Email: forest@eea.government.bg
Genoveva Popova

Canada
Ministry, NFC
Natural Resources Canada
580 Booth Str., 12th Floor
Ottawa, Ontario K1A 0E4, CANADA
Phone: +1 613 947 90 60
Email: Pal.Bhogal@nrcan.gc.ca
Pal Bhogal

Environment and Climate Change Canada / Government of Canada
Phone: +1 819 420 7738
Email: dominique.pritula@canada.ca
Dominique Pritula

Croatia
Ministry, NFC
Croatian Forest Research Institute
Cvjetno naselje 41
10450 Jastrebarsko, CROATIA
Phone: +385 1 62 73 027
Email: nenadp@sumins.hr
Nenad Potočić

Cyprus
Ministry, NFC
Ministry of Agriculture, Rural Development and Environment
Research Section - Department of Forests
P.O Box 24136, 1701 Nicosia, CYPRUS
Phone: +357 22 80 55 72
Email: ssotiriou@fd.moa.gov.cy
Soteris Soteriou

Czechia
Ministry
Ministry of Agriculture of the Czech Republic
Forest Management
Tešnov 17, 117 05 Prague 1, CZECHIA
Phone: +420 221 81 2677
Email: tomas.krejzar@mze.cz
Tomáš Krejzar

NFC
Forestry and Game Management Research Institute (FGMRI)
Strnady 136, 252 02 Jíloviště, CZECHIA
Phone: +420 602 260 808
Email: sramek@vulhm.cz
Vít Šrámek

Denmark Ministry	Ministry of Environment and Food; Environmental Protection Agency Slotsholmsgade 12 1216 Copenhagen, DENMARK Phone: +45 72 54 40 00 Email: mst@mst.dk Pernille Karlog
NFC	University of Copenhagen Department of Geosciences and Natural Resource Management Rolighedsvej 23 1958 Frederiksberg C, DENMARK Phone: +45 35 33 18 97 Email: moi@ign.ku.dk Morten Ingerslev
Estonia Ministry	Ministry of the Environment Forest Department Narva mnt 7a, 15172 Tallinn, ESTONIA Phone: +27 26 26 0726 Email: maret.parv@envir.ee Maret Parv, Head of Forest Department
NFC	Estonian Environment Agency (EEIC) Mustamäe tee 33, Tallinn 10616, ESTONIA Phone: +372 733 93 97 Email: vladislav.apuhtin@envir.ee Vladislav Apuhtin
Finland Ministry	Ministry of Agriculture and Forestry Forest Department Hallituskatu 3 A, P.O. Box 30 00023 Government, FINLAND Email: tatu.torniainen@mmm.fi Tatu Torniainen
NFC	Natural Resources Institute Finland (LUKE) Oulu Unit |PO Box 413 90014 Oulun yliopisto, FINLAND Phone: +358 29 532 4061 Email: paivi.merila@luke.fi Päivi Merilä
France Ministry, NFC for Level I	Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt Direction générale de l'alimentation Département de la santé des forêts 251, rue de Vaugirard 75732 Paris cedex 15, FRANCE Phone: +33 1 49 55 51 03 | Email: frederic.delport@agriculture.gouv.fr, fabien.caroulle@agriculture.gouv.fr Frédéric Delport, Fabien Caroulle (crown data)
NFC for Level II	Office National des Forêts Département recherche, développement, innovation - Bâtiment B Boulevard de Constance 77300 Fontainebleau, FRANCE Phone: +33 1 60 74 92 -28 Email: manuel.nicolas@onf.fr Manuel Nicolas (Level II)
Germany Ministry, NFC	Bundesministerium für Ernährung und Landwirtschaft (BMEL) - Ref. 515 Rochusstr. 1, 53123 Bonn, GERMANY Phone: +49 99 529-3588 Email: juliane.henry@bmel.bund.de; 515@bmel.bund.de Juliane Henry
Greece Ministry	Hellenic Republic – Ministry of Environment, Energy and Climate Change (MEECC) – General Secretariat MEEC 31 Chalkokondyli, 10164 Athens, GREECE Phone: +30 210 212 45 97, -75 | Email: k.koutla@prv.ypeka.gr, p.drougas@prv.ypeka.gr; Katerina Koutla, Panagiotis Drougas
NFC	Hellenic Agricultural Organization "DEMETER" Terma Alkmanos 11528 Ilissia, Athens, GREECE Phone: +30 210 77 84 850, -240 Email: mipa@fria.gr Panagiotis Michopoulos
Hungary Ministry	Ministry of Agriculture Department of Forest Management Kossuth Lajos tér 11 1055 Budapest, HUNGARY Phone: +36 1 79 53 911 Email: andras.szepesi@am.gov.hu András Szepesi
NFC	National Land Centre Department of Forestry Frankel Leó út 42-44 1023 Budapest, HUNGARY Phone: +36 1 37 43 201 Email: kinga.nagy@nfk.gov.hu Kinga Nagy

Draft 2

Ireland Ministry	Department of Agriculture, Food and the Marine – Forest Sector Development Agricultural House, Kildare Street, Dublin 2, D02 WK12, IRELAND Phone: +353 87 140 1242 Email: shane.flanagan@agriculture.gov.ie Shane Flanagan
NFC	University College Dublin (UCD) UCD Soil Science, UCD School of Agriculture and Food Science Belfield, Dublin 4, IRELAND Phone: +353 1 7167744 Email: thomas.cummins@ucd.ie Thomas Cummins
Italy Ministry, NFC	Comando Unità Tutela Forestale, Ambientale e Agroalimentare Carabinieri Carabinieri Corps – Office for Studies and Projects Via Giosuè Carducci 5, 00187 Roma, ITALY Phone: +39 06 466 567 163 Email: giancarlo.papitto@carabinieri.it Giancarlo Papitto
Latvia Ministry	Ministry of Agriculture Forest Department Republikas laukums 2, Riga 1981, LATVIA Phone: +371 670 27 285 Email: lasma.abolina@zm.gov.lv Lasma Abolina
NFC	Latvian State Forest Research Institute „Silava" 111, Rigas str, Salaspils, 2169, LATVIA Phone: +371 67 94 25 55 Email: uldis.zvirbulis@silava.lv Uldis Zvirbulis
Liechtenstein Ministry, NFC	Amt für Umwelt (AU) Dr. Grass-Str. 12, Postfach 684, 9490 Vaduz, FÜRSTENTUM LIECHTENSTEIN Phone: +423 236 64 02 Email: olivier.naegele@llv.li Olivier Nägele
Lithuania Ministry	Ministry of Environment A. Juozapaviciaus g. 9 2600 Vilnius, LITHUANIA Phone: +370 686 16804 Email: nerijus.kupstaitis@am.lt Nerijus Kupstaitis
NFC	Lithuania State Forest Service Pramones ave. 11a 51327 Kaunas, LITHUANIA Phone: +370 687 72931, +370 386 72821 Email: albertas.kasperavicius@amvmt.lt, gintaras.kulbokas@amvmt.lt Albertas Kasperavicius, Gintaras Kulbokas
Luxembourg Ministry, NFC	Ministère de l'Environnement, du Climat et du Développement durable - Administration de la nature et des forêts 81, avenue de la Gare 9233 Diekirch, LUXEMBOURG Phone: +352 24756 618 Email: martine.neuberg@anf.etat.lu, pascal.armborst@anf.etat.lu, philippe.schmitz@anf.etat.lu Martine Neuberg, Pascal Armborst, Philippe Schmitz
Moldova, Rep. of Ministry, NFC	Agency Moldsilva 124 bd. Stefan cel Mare 2001 Chisinau, REPUBLIC OF MOLDOVA Phone: +373 22 27 23 06 Email: icas@moldsilva.gov.md Dumitru Galupa
Montenegro Ministry	Directorate for Agriculture, Hunting and Water Management Rimski trg 46, PC "Vektra" 81000 Podgorica, MONTENEGRO Phone: +382 (20) 482 272 Email: ranko.kankaras@mpsv.gov.me Ranko Kankaraš
NFC	University of Montenegro, Faculty of Biotechnology Mihaila Lalića 1 81000 Podgorica, MONTENEGRO Email: ddubak@t-com.me Darko Dubak
Netherlands Ministry, NFC	National Institute for Public Health and Environment RIVM Antonie van Leeuwenhoeklaan 9 3721 MA Bilthoven, THE NETHERLANDS Phone: + 31 (0)30 274 9111 Email: albert.bleeker@rivm.nl Albert Bleeker

North Macedonia
Ministry

Ministry of Agriculture, Forestry and Water Economy, Dep. for Forestry and Hunting
2 Leninova Str., 1000 Skopje,
NORTH MACEDONIA
Phone: +398 2 312 42 98
Email: vojo.gogovski@mzsv.gov.mk
Vojo Gogovski

NFC

Ss. Cyril and Methodius University
Faculty of Forestry
Department of Forest and Wood Protection
Blvd. Goce Delcev 9, 1000 Skopje,
NORTH MACEDONIA
Phone: +389 2 313 50 03 150
Email: nnikolov@sf.ukim.edu.mk,
irpc@sumers.org
Nikola Nikolov, Srdjan Kasic

Norway
Ministry

Norwegian Environment Agency
P.O. Box 5672 Torgarden
7485 Trondheim, NORWAY
Phone: +47 73 58 05 00
Email: gunnar.skotte@miljodir.no
Gunnar Carl Skotte

NFC

Norwegian Institute of Bioeconomy Research (NIBIO)
P.O.Box 115, 1431 ÅS, NORWAY
Phone: +47 971 59 901
Email: volkmar.timmermann@nibio.no
Volkmar Timmermann

Poland
Ministry

Ministry of the Environment
Department of Forestry
Wawelska Str. 52/54
00922 Warsaw, POLAND
Phone: +48 22 579 25 50 | Email:
Departament.Lesnictwa@mos.gov.pl
Edward Lenart

NFC

Forest Research Institute
Sękocin Stary, 3 Braci Leśnej Street
05-090 Raszyn, POLAND
Phone: +48 22 715 06 57
Email: j.wawrzoniak@ibles.waw.pl,
p.lech@ibles.waw.pl
Jerzy Wawrzoniak, Pawel Lech

Portugal
Ministry, NFC

Instituto da Conservação de Natureza e das Florestas (ICNF)
Avenida da República, 16 a 16B
1050-191 Lisboa, PORTUGAL
Email: helena.martins@icnf.pt,
jose.uva@icnf.pt
Helena Martins, José Sousa Uva

Romania
Ministry

Ministry of Environment, Waters and Forests, Directorate Policies and Strategies in Silviculture
Calea Plevni 46-48, Sector 1
010233 Bucharest, ROMANIA
Phone: +40 21 316 44 65
Email: claudiu.zaharescu@mmediu.ro
Claudiu Zaharescu

NFC

National Institute for Research and Development in Forestry "Marin Drăcea" (INCDS)
Bd. Eroilor 128
077190 Voluntari, Judetul Ilfov, ROMANIA
Phone: +40 21 350 32 38
Email: obadea@icas.ro
Ovidiu Badea

Russian Federation
Ministry, NFC

N.N.

Serbia
Ministry

Ministry of Agriculture and Environment Protection
Directorate of Forests
SIV 3, Omladinskih brigada 1
11070 Belgrade, SERBIA
Phone: +381 11 311 76 37
Email: sasa.stamatovic@minpolj.gov.rs
Sasa Stamatovic

NFC

Institute of Forestry
Kneza Viseslava 3
11000 Belgrade, SERBIA
Phone: +381 11 35 53 454
Email: ljubinko.rakonjac@forest.org.rs;
ljrakonjac@yahoo.com
Ljubinko Rakonjac

Slovakia
Ministry

Ministry of Agriculture of the Slovak Republic
Dobrovičova 12
81266 Bratislava, SLOVAKIA
Phone: +421 2 59 26 63 08
Email: henrich.klescht@land.gov.sk
Henrich Klescht

NFC

National Forest Centre - Forest Research Institute
ul. T.G. Masaryka 22
962 92 Zvolen, SLOVAKIA
Phone: +421 45 531 42 02
Email: pavlenda@nlcsk.org
Pavel Pavlenda

Slovenia

Ministry

Ministry of Agriculture, Forestry and Food (MKGP)
Dunajska 56-58
1000 Ljubljana, SLOVENIA
Phone: +386 1 478 90 38
Email: simon.poljansek@gov.si, robert.rezonja@gov.si
Simon Poljansek, Robert Režonja

NFC

Slovenian Forestry Institute (SFI)
Večna pot 2, 1000 Ljubljana, SLOVENIA
Phone: +386 1 200 78 00
Email: mitja.skudnik@gozdis.si, primoz.simoncic@gozdis.si, marko.kovac@gozdis.si
Mitja Skudnik, Primož Simončič, Marko Kovač

Spain

Ministry

Subdirectorate General for Forest Policy and the Fight against Desertification, Directorate General for Biodiversity, Forests and Desertification - Ministry for the Ecological Transition and the Demographic Challenge
Gran Vía de San Francisco, 4-6, 6ª pl.
28005 Madrid, SPAIN
Email: GFCenteno@miteco.es
Guillermo José Fernández Centeno

NFC

Directorate General for Biodiversity, Forests and Desertification - Ministry for the Ecological Transition and the Demographic Challenge
Gran Vía de San Francisco, 4-6, 5ª pl.
28005 Madrid, SPAIN
Phone: +34 91 347 5835, -5831
Email: mdpasalodos@miteco.es, erobla@miteco.es, zubieta@miteco.es
María D. Pasalodos Tato, Elena Robla, Belén Zubieta

Sweden

Ministry

Swedish University of Agricultural Sciences, Box 7050, 75007 Uppsala, SWEDEN
Phone: +46 1867 3104,
Email: ulf.grandin@slu.se
Ulf Grandin

NFC

Swedish University of Agricultural Sciences, Department of Forest Resource Management, Skogsmarksgränd 17, 901 83 Umeå, SWEDEN
Phone: +46 90-78 68 352, +46 70-6761736, Email: soren.wulff@slu.se
Sören Wulff

Switzerland

Ministry

Department of the Environment, Transport, Energy and Communications (DETEC), Federal Office for the Environment (FOEN), Forest Division
3003 Bern, SWITZERLAND
Phone: +41 58 462 05 18
Email: sabine.augustin@bafu.admin.ch
Sabine Augustin

NFC

Swiss Federal Research Institute WSL
Zürcherstr. 111, 8903 Birmensdorf, SWITZERLAND
Phone: +41 44 739 25 02
Email: peter.waldner@wsl.ch
Peter Waldner

Türkiye

Ministry

General Directorate of Forestry
Foreign Relations, Training and Research Department
Beştepe Mahallesi Söğütözü Caddesi No: 8/1, 06560 Yenimahalle-Ankara, TÜRKIYE
Phone: 0090 312 296 30 17
Email: ozlemaktas@ogm.gov.tr
Özlem Aktaş

NFC

General Directorate of Forestry
Department of Forest Pests Fighting
Beştepe Mahallesi Söğütözü Caddesi No: 8/1
06560 Yenimahalle-Ankara, TÜRKIYE
Phone: +90 312 296
Email: sitkiozturk@ogm.gov.tr, uomturkiye@ogm.gov.tr
Sıtkı Öztürk

Ukraine

Ministry

State Forest Resources Agency of Ukraine
International Cooperation, Science and Public Relation Division
9a Shota Rustaveli, 01601 KYIV, UKRAINE
Phone: +380 44 234 26 35
Email: lpolyakova@ukr.net
Liubov Poliakova

Ukraine

Ministry

State Forest Resources Agency of Ukraine
International Cooperation, Science and Public Relation Division
9a Shota Rustaveli, 01601 KYIV, UKRAINE
Phone: +380 44 234 26 35
Email: lpolyakova@ukr.net
Liubov Poliakova

NFC	Ukrainian Research Institute of Forestry and Agroforestry Melioration (URIFFM) Pushkinska 86 Kharkiv 61024, UKRAINE Phone: +380 57 707 80 57 Email: buksha@uriffm.org.ua; buksha@ukr.net Ihor Buksha
United Kingdom Ministry	Minister of State (Minister for the Pacific and the International Environment) Seacole Building 2 Marsham Street, London SW1P 4DF, UNITED KINGDOM The Rt Hon Lord Goldsmith
NFC	Centre for Forest Management – Forest Research Alice Holt Lodge, Wrecclesham Farnham Surrey GU10 4LH, UNITED KINGDOM Phone: +44 300 067 5620 Email: sue.benham@forestresearch.gov.uk Sue Benham
United States of America Ministry, NFC	N.N.

Authors

Roberto Canullo
Camerino University
Camerino, ITALY
Email: roberto.canullo@unicam.it

Nathalie Cools
Research Institute Nature and Forests (INBO) | Geraardsbergen, BELGIUM
Email: nathalie.cools@inbo.be

Bruno De Vos
Research Institute Nature and Forests (INBO) | Geraardsbergen, BELGIUM
Email: bruno.devos@inbo.be

Marco Ferretti
Swiss Federal Research Institute WSL
Birmensdorf, SWITZERLAND
Email: marco.ferretti@wsl.ch

Stefan Fleck
Northwest German Research Institute NW-FVA | Göttingen, GERMANY
Email: stefan.fleck@nw-fva.de

Alfred Fürst
Austrian Research Centre for Forests (BFW) | Vienna, AUSTRIA
Email: alfred.fuerst@bfw.gv.at

Leena Hamberg
Natural Resources Institute Finland (Luke) | Helsinki, FINLAND
Email: leena.hamberg@luke.fi

Anna Kowalska
Forest Research Institute
Raszyn, POLAND
Email: a.kowalska@ibles.waw.pl

Elena Gottardini
Fondazione Edmund Mach
San Michele all'Adige, ITALY
Email: elena.gottardini@fmach.it

Till Kirchner
Programme Co-ordinating Centre (PCC) of ICP Forests | Thünen Institute of Forest Ecosystems
Eberswalde, GERMANY
Email: till.kirchner@thuenen.de

Tom Levanič
Slovenian Forestry Institute (SFI)
Ljubljana, SLOVENIA
Email: tom.levanic@gozdis.si

Aldo Marchetto
National Research Council (CNR), Institute of Ecosystem Study (ISE)
Verbania (VB), ITALY
Email: aldo.marchetto@cnr.it

Alexa Michel
Programme Co-ordinating Centre (PCC) of ICP Forests | Thünen Institute of Forest Ecosystems
Eberswalde, GERMANY
Email: alexa.michel@thuenen.de

Tiina M. Nieminen
Natural Resources Institute Finland (Luke) | Helsinki, FINLAND
Email: tiina.m.nieminen@luke.fi

Mladen Ognjenović
Croatian Forest Research Institute
Jastrebarsko, CROATIA
Email: mladeno@sumins.hr

Diana Pitar
National Institute for Research and Development in Forestry "Marin Drăcea" (INCDS)
Voluntari, Judetul Ilfov, ROMANIA
Email: diana.silaghi@icas.ro

Nenad Potočić
Croatian Forest Research Institute
Jastrebarsko, CROATIA
Email: nenadp@sumins.hr

Anne-Katrin Prescher
Programme Co-ordinating Centre (PCC) of ICP Forests | Thünen Institute of Forest Ecosystems
Eberswalde, GERMANY
Email: anne.prescher@thuenen.de

Pasi Rautio
Natural Resources Institute Finland (Luke) | Rovaniemi, FINLAND
Email: pasi.rautio@luke.fi

Tanja Sanders
Thünen Institute of Forest Ecosystems
Eberswalde, GERMANY
Email: tanja.sanders@thuenen.de

Marcus Schaub
Swiss Federal Research Institute WSL
Birmensdorf, SWITZERLAND
Email: marcus.schaub@wsl.ch

Kai Schwärzel
Programme Co-ordinating Centre (PCC) of ICP Forests | Thünen Institute of Forest Ecosystems
Eberswalde, GERMANY
Email: kai.schwaerzel@thuenen.de

Volkmar Timmermann
Norwegian Institute of Bioeconomy Research (NIBIO) | Ås, NORWAY
Email: volkmar.timmermann@nibio.no

Liisa Ukonmaanaho
Natural Resources Institute Finland (Luke) | Helsinki, FINLAND
Email: liisa.ukonmaanaho@luke.fi

Arne Verstraeten
Research Institute Nature and Forests (INBO) | Geraardsbergen, BELGIUM
Email: arne.verstraeten@inbo.be

Lars Vesterdal
University of Copenhagen, DENMARK
Email: lv@ign.ku.dk

Peter Waldner
Swiss Federal Research Institute WSL
Birmensdorf, SWITZERLAND
Email: peter.waldner@wsl.ch

Daniel Žlindra
Slovenian Forestry Institute (SFI)
Ljubljana, SLOVENIA
Email: daniel.zlindra@gozdis.si