ICP Forests

THE IMPACT OF NITROGEN DEPOSITION AND OZONE ON THE SUSTAINABILITY OF EUROPEAN FORESTS

ICP FORESTS 2014 EXECUTIVE REPORT

2014

ICP Forests networks, data and methods

ICP Forests data comprise data taken from two networks: Level I and Level II. Level I consists of approx. 6000 large-scale monitoring plots selected on a systematic basis across Europe with the aim of providing representative data on the spatial and temporal variability of forest condition. Level II consists of 250-800 (depending on the set-up) intensive monitoring plots selected on a purposive basis across the range of the most frequent forest tree species in Europe, with the aim of providing data on forest condition, air quality, deposition of pollutants, the chemical and physical status of soil, the biomass and chemistry of litterfall and foliage, biodiversity, tree growth and productivity, and climate. These data are used for correlative studies, and are requested by scientists both within and outside the ICP Forests community, with more than 80 data requests having been received over the last few years.

The strength of ICP Forests is in its focus on (i) the long-term and broad geographical and ecological coverage of European forests; (ii) the long-term process of harmonisation and standardisation, initiated as early as the 1980s; and (iii) the continuous efforts being made in Quality Assurance and Quality Control. Methods for each investigation are detailed in the ICP Forests Manual, available at http://icp-forests.net/page/icp-forests-manual.

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

www.icp-forests.net

EDITED BY
Marco Ferretti[1], Tanja Sanders[2], Alexa Michel[2]

AUTHORS (in alphabetic order)
Vicent Calatayud[3], Nathalie Cools[4], Marco Ferretti[1], Elena Gottardini[5], Matthias Haeni[6], Karin Hansen[7], Alexa Michel[2], Nenad Potočić[8], Tanja Sanders[2], Marcus Schaub[6], Volkmar Timmermann[9], Serina Trotzer[2], Elena Vanguelova[10]

AFFILIATIONS
[1] TerraData environmetrics, Via L. Bardelloni 19, 58025 Monterotondo M.mo (GR), Italy
[2] Thünen Institute of Forest Ecosystems, Alfred-Möller-Str. 1, Haus 41/42, 16225 Eberswalde, Germany
[3] Fundacion Centro de Estudios Ambientales del Mediterraneo CEAM, Parque Tecnologico, Paterna, Spain
[4] INBO Research Institute for Nature and Forest, Gaverstraat 4, Geraardsbergen, 9500, Belgium
[5] Research and Innovation Centre, Fondazione Edmund Mach FEM, Via E. Mach 1, 38010 San Michele all'Adige (TN), Italy
[6] Swiss Federal Research Institute WSL, Zürcherstraße 111, 8908 Birmensdorf, Switzerland
[7] IVL Swedish Environmental Research Institute, P.O. Box 210 60, 100 31 Stockholm, Sweden
[8] CFRI Croatian Forest Research Institute, Cvjetno naselje 41, Jastrebarsko, 10450, Croatia
[9] NIBIO Norwegian Institute of Bioeconomy Research, Pb 115, 1431 Ås, Norway
[10] Forest Research, Alice Holt Lodge, Farnham, Surrey GU10 4LH, UK

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FOREWORD

George Amorgianiotis
Special Secretariat for Forests

Forests are a valuable resource for humanity and as such they must be protected and preserved for future generations. The long-term monitoring of forests is a valuable tool for assessing the impact of climate change on forest ecosystems, but monitoring is not restricted to that activity alone. Plant diseases, insect attacks and anthropogenic effects such as high levels of nitrogen deposition and ozone as well as the interactions between abiotic and biotic factors are written down and assessed statistically to give us a better understanding of forest health in Europe.

Forest monitoring started in the decade beginning in 1980, when the concern about a possible sudden death of forests in central Europe alarmed both scientists and the general public. It was at that time that the plot grid we now call Level I was first created. In Greece that grid consisted of approximately 100 plots. In 1995, the intensive monitoring programme known as Level II was launched. Within the framework of thisprogramme, four experimental plots of representative forest ecosystems in Greece were established by the personnel of the Forest Research Institute of Athens.

Here I would like to add that Greece is one of the most mountainous countries in Europe and hosts rich biodiversity within its forests. In the past, a whole population lived out of the forests. Unfortunately, after World War II, young people left the mountains and went to live in big cities, or emigrated in their quest to find a better future. Today, under the financial crisis and the threat of unemployment, young people are returning to their parental villages in the country. This means that forest management is taking on a new role.

Going back to the monitoring programme, I would like to stress that never in the past has Europe had serial forest science data collected over a long period. Results derived only from laboratories give us indications, but without field observations they lack the concreteness of evidence. It is our obligation to preserve and hand on the experimental plots to future generations of scientists.

George Amorgianiotis

Hellenic Republic
Ministry of Environment, Energy and Climate Change
Special Secretariat for Forests

OVERVIEW

ACTIVITY UNDER THE UNECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION (LRTAP) focuses on developing and implementing clean air policies across Europe and North America. There has been great success in reducing sulphur emissions over the past decades, but the concentration of nitrogen (N) compounds in the atmosphere, the level of N deposited in forest ecosystems, and tropospheric ozone (O_3) concentrations are still high. These are threats to forest health, productivity and diversity, and therefore to the sustainability of European forests.

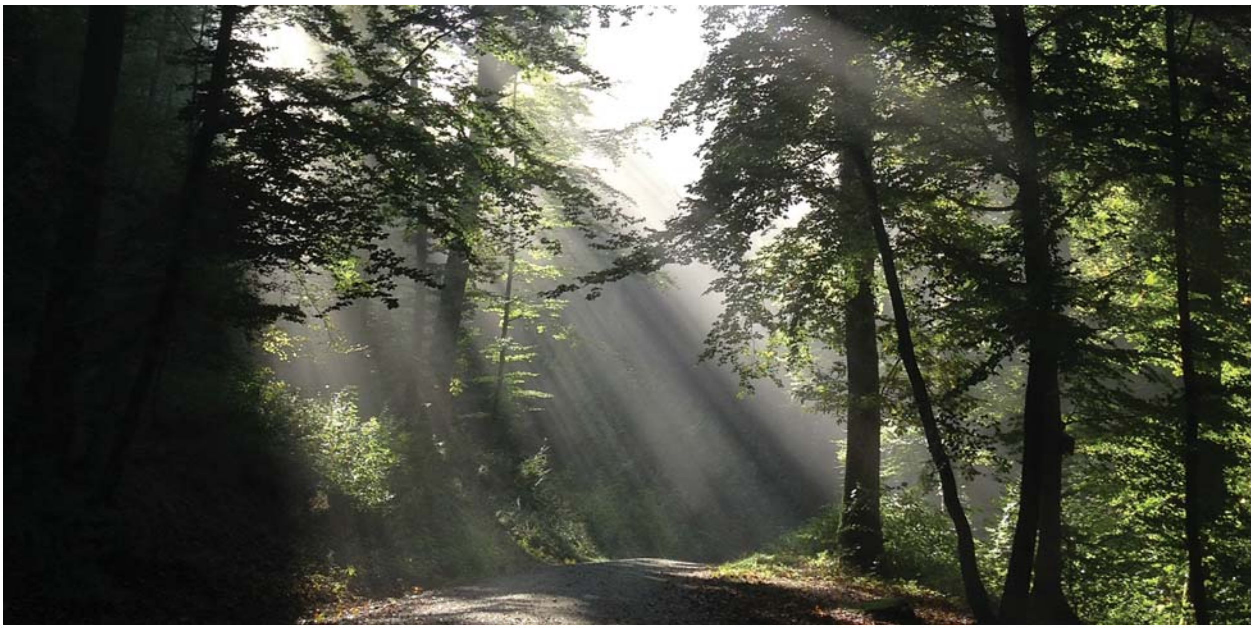
MEASURING NITROGEN DEPOSITION AND THE EXPOSURE TO OZONE OF EUROPEAN FORESTS is one of the core activities of ICP Forests. The measurements provide site-specific open field and throughfall deposition estimates for N (and other relevant atmospheric inputs), and O_3 concentration. Data are of considerable value to foresters, ecologists, vegetation scientists and modellers, and provide policy makers with key information on topical environmental issues.

ORGANISMS WITHIN FOREST ECOSYSTEMS SHOW WIDE-RANGING RESPONSES TO NITROGEN. Mosses and lichens may have little relevance in economic terms, but for forest biodiversity and as bioindicators, these organisms have considerable value. The response of key organisms like mycorrhizal fungi towards N input is particularly important. Mycorrhizal fungi represent the interface between forest trees – most of which are of considerable economic value – and the soil. Changes shown by these organisms may have considerable influence on ecosystem services. Data are thus of great relevance, not only for conservation reasons (in the conservation of rare lichen or moss species, for example), but in a much broader societal context.

ASSESSING THE DIRECT AND INDIRECT RESPONSES OF FORESTS to N deposition and O_3 is another core activity of ICP Forests. Forest health and productivity are key elements of sustainable forest management. Trees are long-living organisms and may cope with changing environmental conditions and complex interactions with a range of biotic and abiotic factors. There are, however, crucial questions to be answered if we are to fully understand the responses of individual trees to the entire forest ecosystem. This challenge is increasingly being addressed by scientists, and distinct evidence has emerged for the impact of N on forest health, growth and diversity, while the response to O_3 is less clear.

Tree of heaven (*Ailanthus altissima*) forest in Hungary.

WHAT HAPPENS TO NITROGEN AS IT MOVES FROM THE ATMOSPHERE, THROUGH THE TREE CANOPY, INTO THE SOIL AND DOWN INTO THE GROUNDWATER has become much better known over the past decades. Many different biologically- or chemically-driven processes occur during this passage, and N is a key element for all types of soil organisms. As ICP Forests continues with its intensive measurements of nitrogen levels in open field and throughfall fluxes, forest soils and soil solution, more details will become known. This work is of major importance for future decisions relating to silviculture, particularly in combination with the projected future climate changes.



1. FOREST HEALTH AND VITALITY IN EUROPE

DRIVERS FOR FOREST CONDITION IN A CHANGING CLIMATE

The quantification of forest ecosystem responses to environmental changes with respect to both climate (page 10) and air pollution (page 18) is fundamental for sustainable forest management and the goods and services provided by forest ecosystems.

Climatic impacts on crown condition seem to be easier to detect, quantify and interpret than air pollution impacts. The crown condition of European beech (*Fagus sylvatica*), for instance, is significantly influenced by drought. While there has not been any clear trend for defoliation on the majority of ICP Forests Level I monitoring plots, there are regions (e.g. southern and eastern part of France, clusters of plots in Spain, Italy, Croatia, Czech Republic, Slovakia, Poland, and Baltic countries) that have shown deteriorating crown condition over the past few years.

Species-specific responses to climate change-driven drought underlying a complex geographical mosaic have been revealed in a study from Spain. The sensitivity of Norway spruce (*Picea abies*) to variations in climate conditions has been documented in Lithuania. A study from France reported precipitation deficiency as the main factor affecting defoliation trends over time. In Turkey, drought seems to be one of the main drivers for defoliation, especially in broadleaves. Climatic factors, and in particular drought stress, appear to be primary drivers for changes in forest crown condition, while the effects of air pollution seem to be species-specific and limited in time and space.

ABIOTIC AND BIOTIC DAMAGING AGENTS AND INVASIVE SPECIES

Damage to forests is an important aspect for sustainable forest management. Studies conducted on data from the ICP Forests monitoring networks point out the importance of both biotic and abiotic damaging factors (page 14) in the light of a changing climate.

In 2014, damage cause assessments were carried out throughout Europe on almost 100,000 trees in the ICP Forests Level I network, and approx. 40% of the trees showed signs of damage, mostly caused by insects, fungi and abiotic factors. Among the biotic factors, non-native, invasive species are a cause of considerable concern, also for sustainable forest management. An example of such a species is the ash dieback fungus *Hymenoscyphus fraxineus*, which is threatening European ash (*Fraxinus excelsior*) on a continental scale.

Participants at inter-comparison course in Norway assess crown condition.

Tree of heaven (*Ailanthus altissima*) forest in Hungary.

Field equipment on a Level II plot.

GROUND-LEVEL OZONE – OF RISING CONCERN FOR ITS IMPACT ON FOREST HEALTH

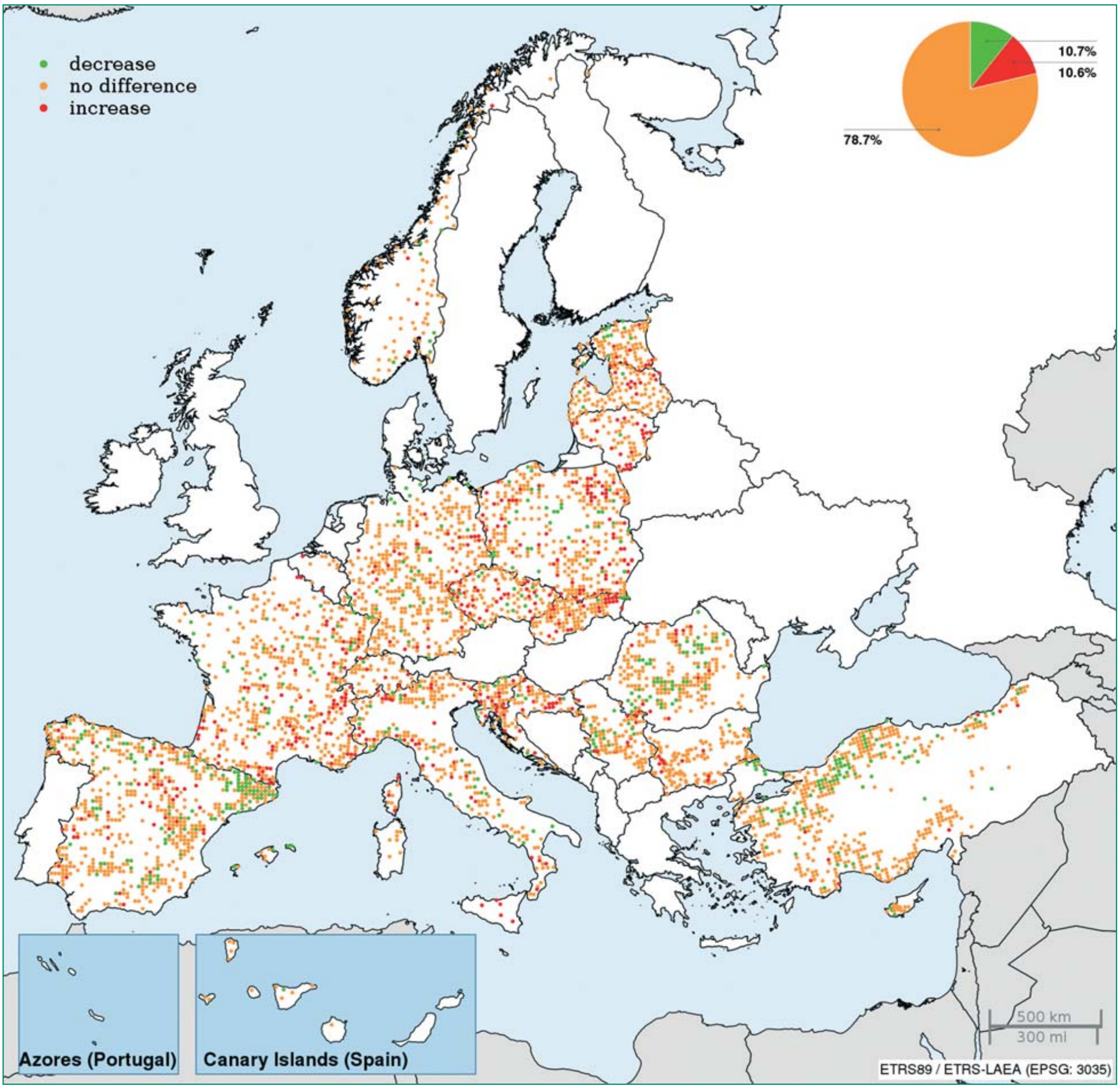
Ground-level O_3 is an air pollutant (page 22) with harmful effects on sensitive species. Current O_3 levels are substantially higher than in pre-industrial times. According to climate scenarios, O_3 levels can be expected to rise in future, thereby increasing the risk of damage to forest trees. A meta-database study of European forest monitoring networks revealed that ground-level O_3 is probably underestimated, both in terms of levels, and harmful effects. While concern is justified, findings from ICP Forests data are not univocal in identifying the impact of O_3 on forest health and growth.

NITROGEN – STILL AN ISSUE

Research based on a large set of soil, foliar and defoliation data from the ICP Forests Level I network, paired with both modelled climate, and deposition data (page 18), has shown the significant importance of both N deposition and climatic parameters as predictors for defoliation in certain tree species. The intensive monitoring plots (Level II) permit more direct comparisons of crown condition with measured N deposition data, and recently published results show that N-related variables improve defoliation models. Higher N throughfall correlates with a higher proportion of European beech and Norway spruce trees displaying more than 25% defoliation (the opposite effect is true for Scots pine, *Pinus sylvestris*). Furthermore, the proportion of trees with defoliation above 25% increases with increasing ratios of foliar N to other nutrients for all tree species considered, indicating nutrient imbalances.

Forested valley in Austria.

The map presents an overview on the trends in mean plot defoliation (Mann-Kendall test) of all species between 2006 and 2014 on plots with a minimum assessment length of 5 years.



Tree of heaven (*Ailanthus altissima*) forest in Hungary.

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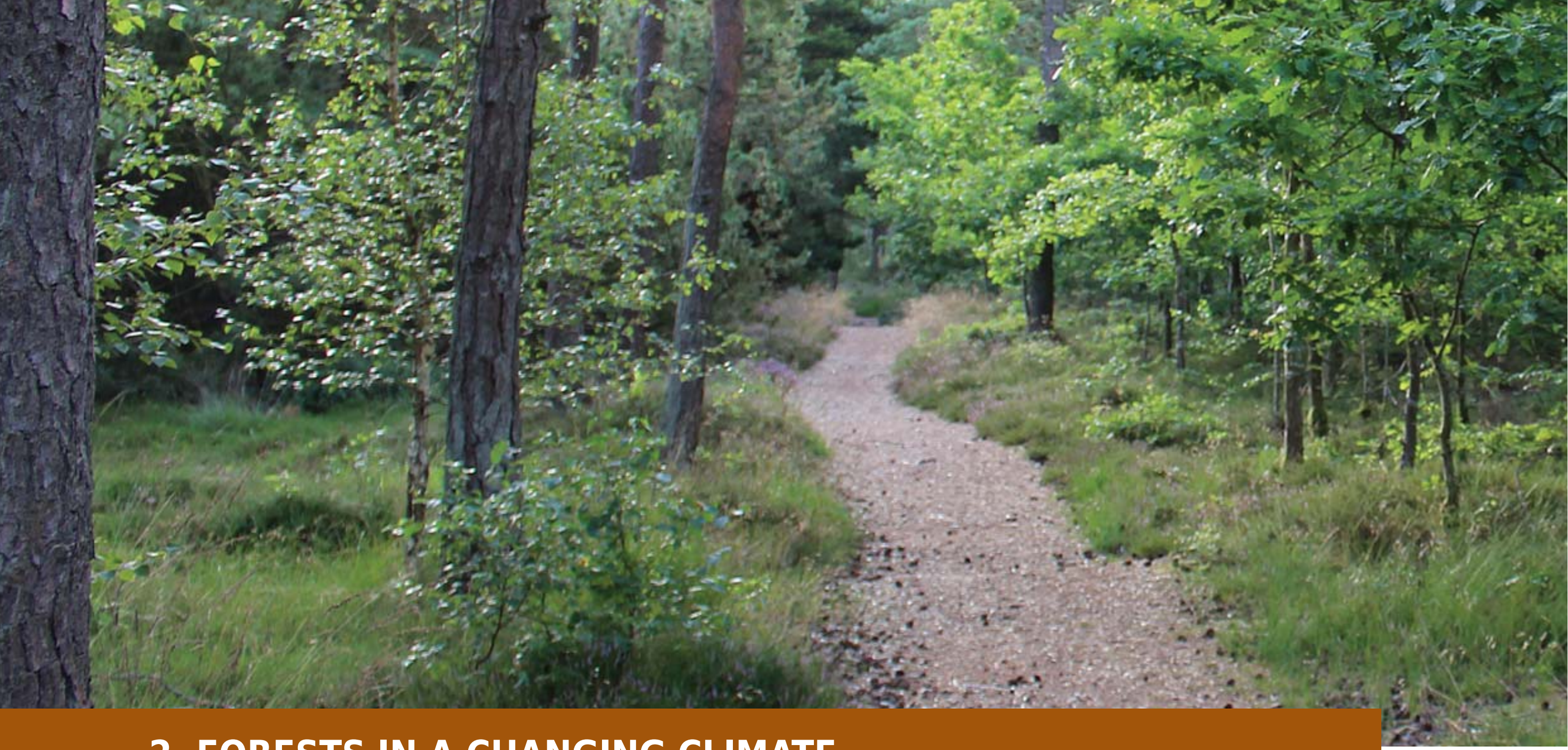


2. FORESTS IN A CHANGING CLIMATE

Climate is the main natural driver for forest ecosystems. It influences health, productivity, species composition, nutrient cycling and phenological cycles, among other things. Climate change may affect plant-insect interaction, causing a mismatch between plant and insect development and changing the occurrence of biotic damaging agents. But the direct impact of meteorological events such as storms and extreme drought and precipitation is also reflected in increasing and often large-scale damage to the forest. Furthermore, interactions between the atmospheric deposition of pollutants and climate influence the biogeochemistry of the forest soil.

Across Europe, more than 200 intensive forest monitoring (Level II) plots are equipped with meteorological stations, permitting measurements of air temperature, relative humidity, precipitation, wind velocity and direction, and solar radiation.

Meteorological data from forest sites are highly valuable in relation with national weather stations, which may be situated in urban or agricultural areas. They are used to evaluate forest climate and the effects of forest stands on airflow or temperature, for example. This is useful for a range of scientific evaluations, including the calibration of models and the validation of model outputs.

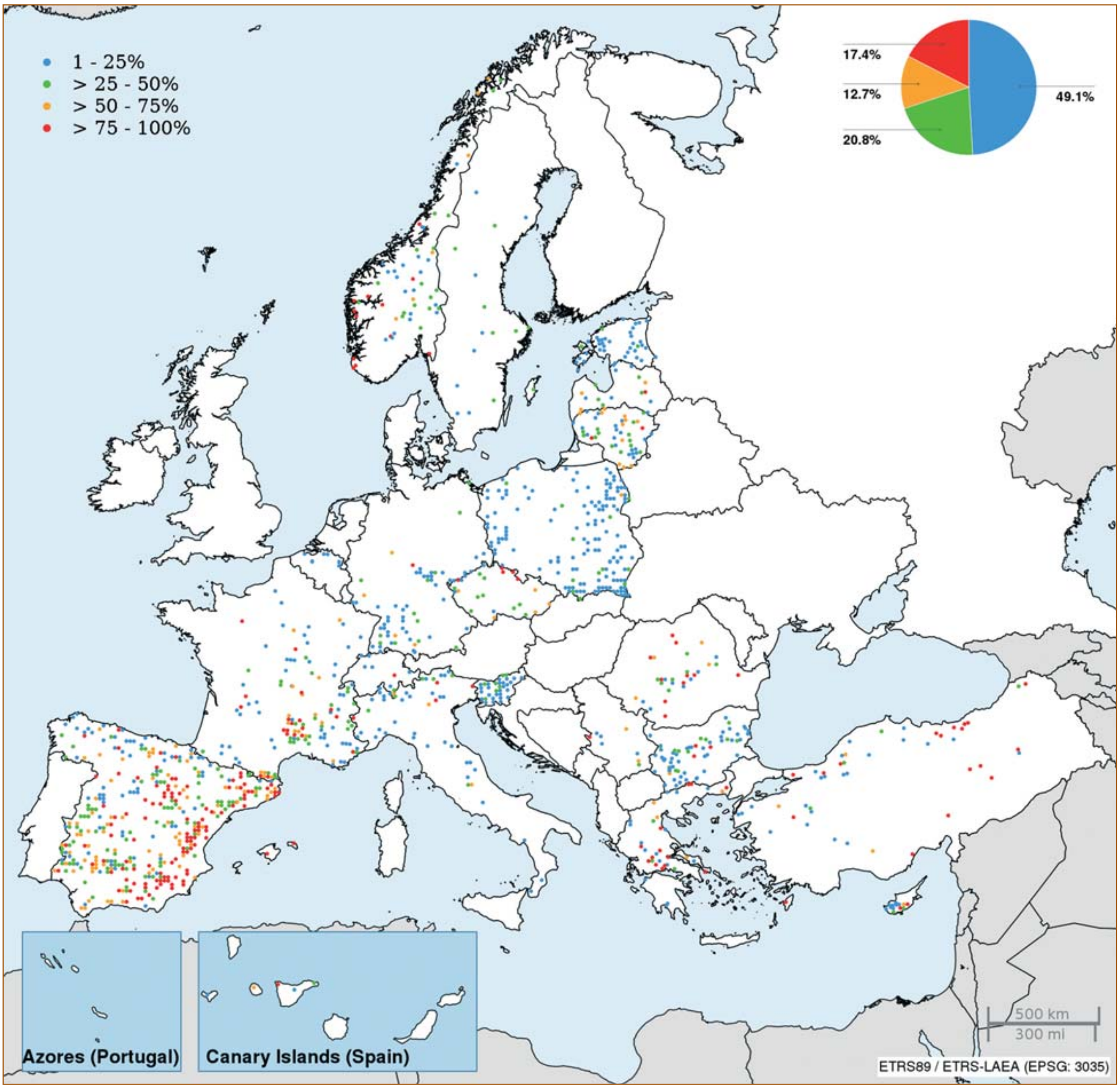
Under-growth dominated by oak (*Quercus robur*) and birch (*Betula pendula*) in a Scots pine forest in Denmark.

Current results show the influence of a changing climate on future forest productivity and highlight the significant role of drought for crown condition. The influence of the interaction between atmospheric deposition and climate on crown condition and soil biogeochemistry plays a crucial role. The analysis of tree species occurrence within their climatic niche shows that between 33% and 65% of the target species will be outside their current niche by 2100. Severe consequences on the economic value of forest land were predicted as a consequence of climate change.

Temperature/humidity sensor in a German beech forest.

Phenological observations help to identify changes in the vegetation period; here the leaf unfolding of sycamore (*Acer pseudoplatanus*).

The map provides an overview on the percentage of trees per plot with a recorded abiotic damage in the year 2014 on the systematic ICP Forests Level I network.



Under-growth dominated by oak (*Quercus robur*) and birch (*Betula pendula*) in a Scots pine forest in Denmark.

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3. ROLE AND DISTRIBUTION OF ABIOTIC AND BIOTIC DAMAGING AGENTS

Climate change can alter pest and disease outbreaks, as well as the resilience of forest ecosystems. The Intergovernmental Panel on Climate Change (IPCC) has identified a need for research to "improve [the] understanding of the role of disturbance regimes, i.e., frequency and intensity of episodic events (drought, fire, insect outbreaks, diseases, floods and wind-storms) […] to climate change itself and pollution […]".

Senescent oak tree in a German beech forest.

Avalanche damage in the Swiss Lötschental valley.

Within ICP Forests, damage cause assessments were performed on 5 400 plots across Europe in the year 2014. A total of 40% of the trees were affected by one or more damaging agents, with insects being the most important agent group (28%), followed by abiotic factors (16%) and fungi (12%). This standardised assessment is one of the key components of the annual crown condition survey, which is now in its 30th year. Data are used for national and international reporting (e.g. FOREST EUROPE State of the European Forests) and in scientific publications. It is also crucial for the further development and validation of forest models.

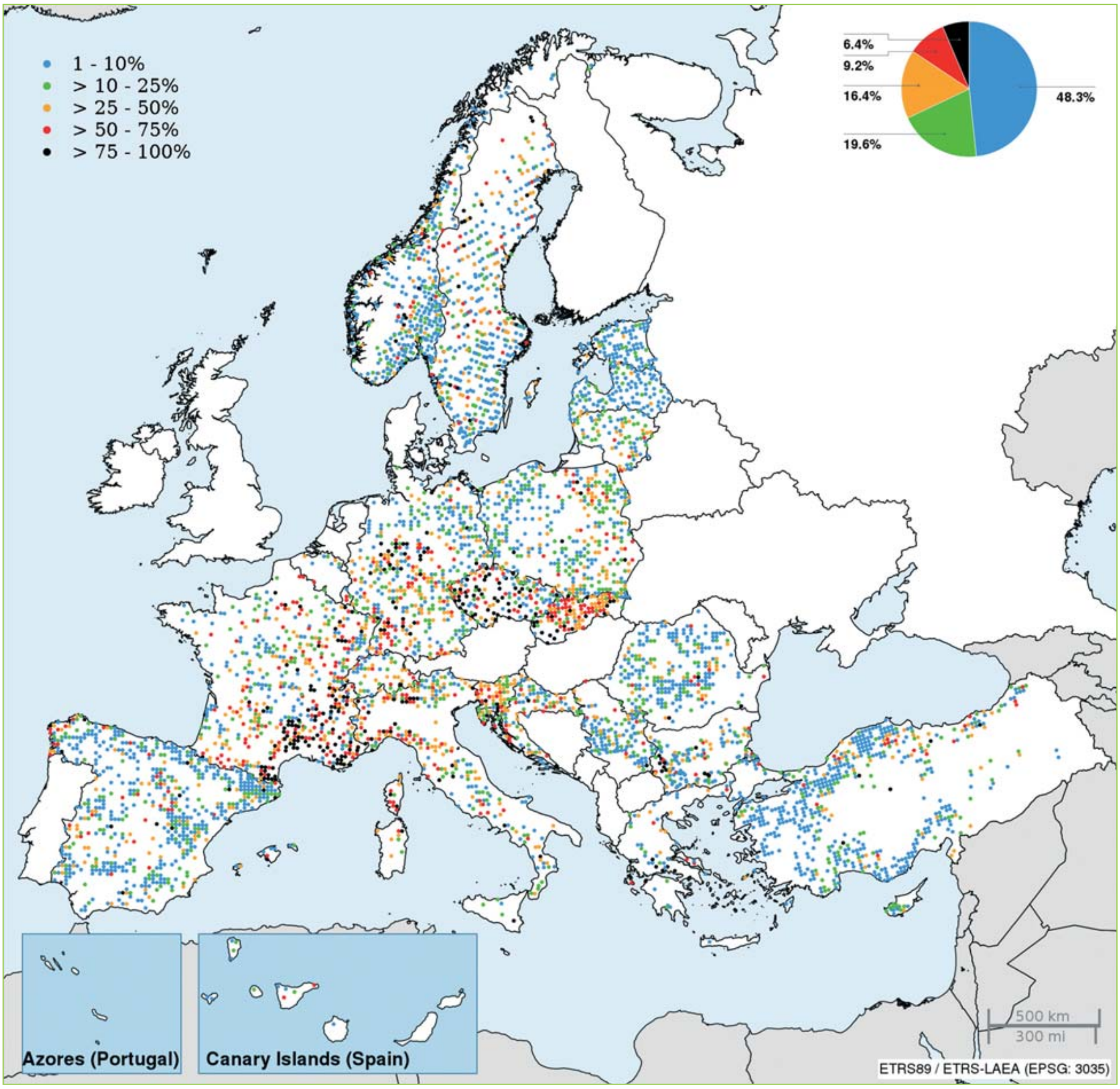
Light needle blight on pine in Denmark.

The main objective of the assessment of damage causes is to provide information about their impact on tree health and vitality. An increase in the frequency of drought episodes and other weather extremes such as storms is predicted to occur in the future as a consequence of a changing climate. At the same time, damaging insect and fungal species might expand their distribution range.

Studies conducted using data from ICP Forests have pointed out the importance of both biotic and abiotic damaging factors for a proper understanding and interpretation of the current role of air pollution and climate change.

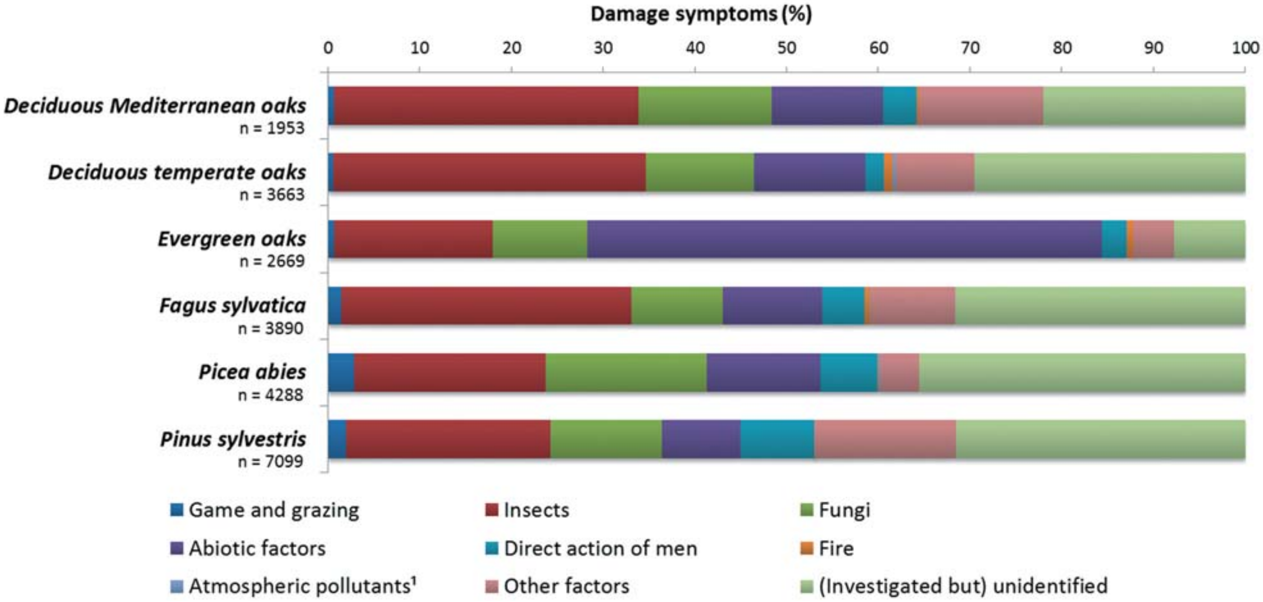
Tortrix and mildew infestations of oak in the United Kingdom.

The map provides an overview on the percentage of trees with a recorded damage per plot in the year 2014 on the systematic ICP Forests Level I network.



Light needle blight on pine in Denmark.

This graph shows the frequency (%) of recorded damage types on main tree species in 2014.
([1] Visible symptoms of direct atmospheric pollution impact only.)



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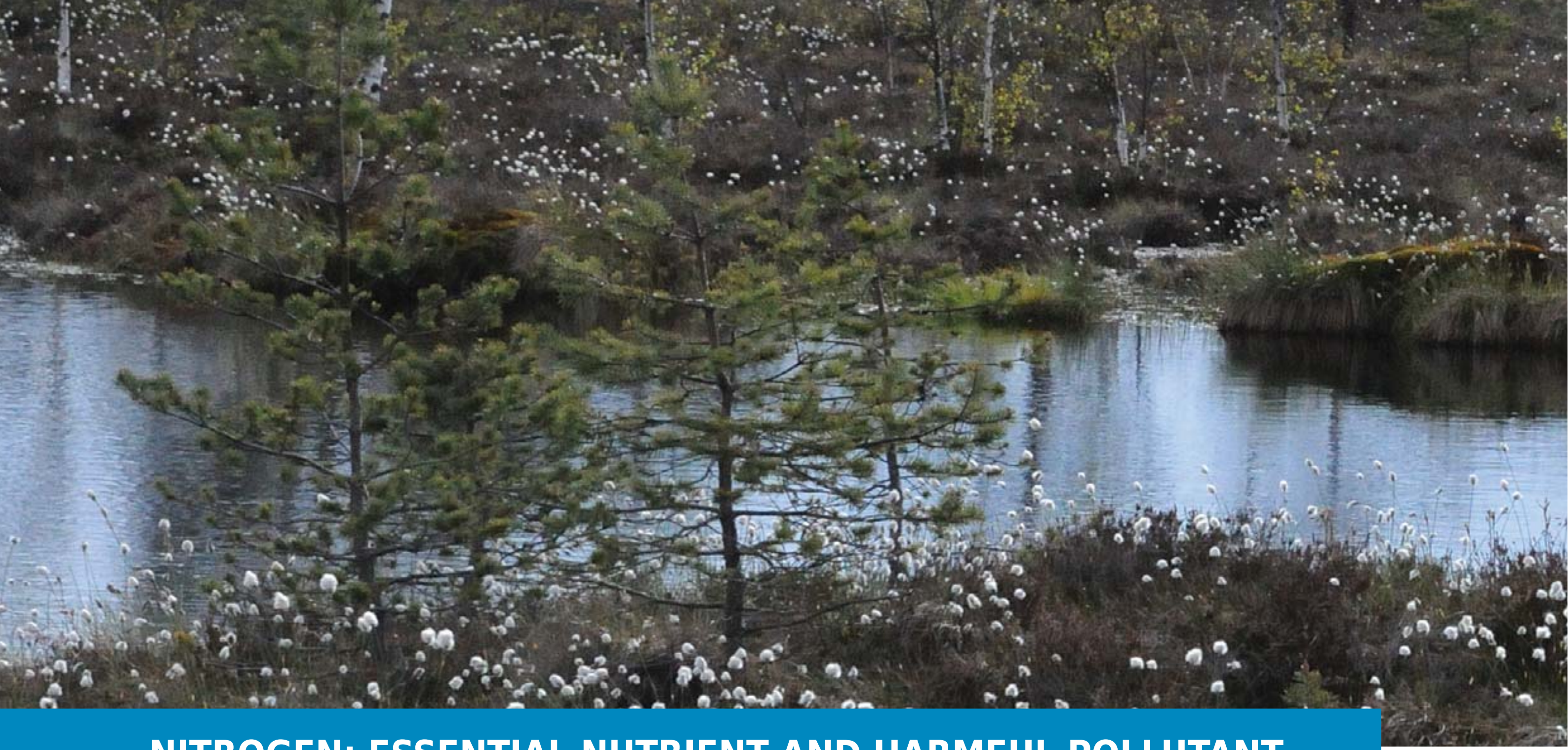


NITROGEN: ESSENTIAL NUTRIENT AND HARMFUL POLLUTANT

Nitrogen (N) deposition is, beside O_3, of particular concern on political and scientific agendas and has considerable implications for the climate change mitigation potential of our forests. At global level, total atmospheric emissions of NO_x and NH_3 increased from 23 Tg N yr^{-1} (1 teragram, Tg = 1 million tons) in 1860 to 93 Tg N yr^{-1} by the early 1990s, and they are projected to rise to 189 Tg N yr^{-1} by 2050, with a three- to five-fold increase in deposition of reactive N, and deposition projected to increase by a factor of 2.5 by the end of this century.

Recent modelling studies suggest that NH_3 emissions in Europe will remain quite stable until 2050 (4.04 Tg yr^{-1} in 2050 against 3.99 Tg yr^{-1} in 2005), while NO_x emissions will be reduced (4.1 Tg yr^{-1} in 2050 against 12.5 Tg yr^{-1} in 2005). The potential effects of high N deposition on forests embrace almost all aspects of the forest ecosystem, including vegetation, soil, soil biota, soil water chemistry, and run-off. Nitrogen availability governs the productivity of many ecosystems and its role in stimulating growth and enhancing carbon (C) uptake is considerable. Nitrogen deposition is considered an essential driver of the residual terrestrial C sink of 2.4±0.8 Pg C yr^{-1} (1 petagram or Pg = 1000 million tons).

The effects of N deposition on growth and C sequestration are related to three main mechanisms: accelerated photosynthesis, C allocation shift (decreased allocation to roots and increased wood formation), and decreased respiration and decomposition, which leads to the accumulation of surface litter and soil organic matter.

Although atmospheric deposition levels have been reduced, local industries can still have an effect on trees.

Throughfall measurements for the year 2013 are available for 237 Level II plots across Europe. Deposition rates of N (derived from nitrate and ammonium) are calculated by multiplying the yearly amount of precipitation by the volume-weighted mean concentration of the respective element. Distinctly high levels of ammonium deposition are frequent in central Europe.

Collection of precipitation on a Hungarian Level II plot.

Surface waters recover from acidification but depositions are still stored in the soils.

Deposition data are used in national and international reporting (e.g. the FOREST EUROPE State of the European Forests), for model calibration and validation (e.g. ForSAFE), in research, and for political advisories.

Lichens fix nitrogen and can therefore be analysed for received nitrogen load.

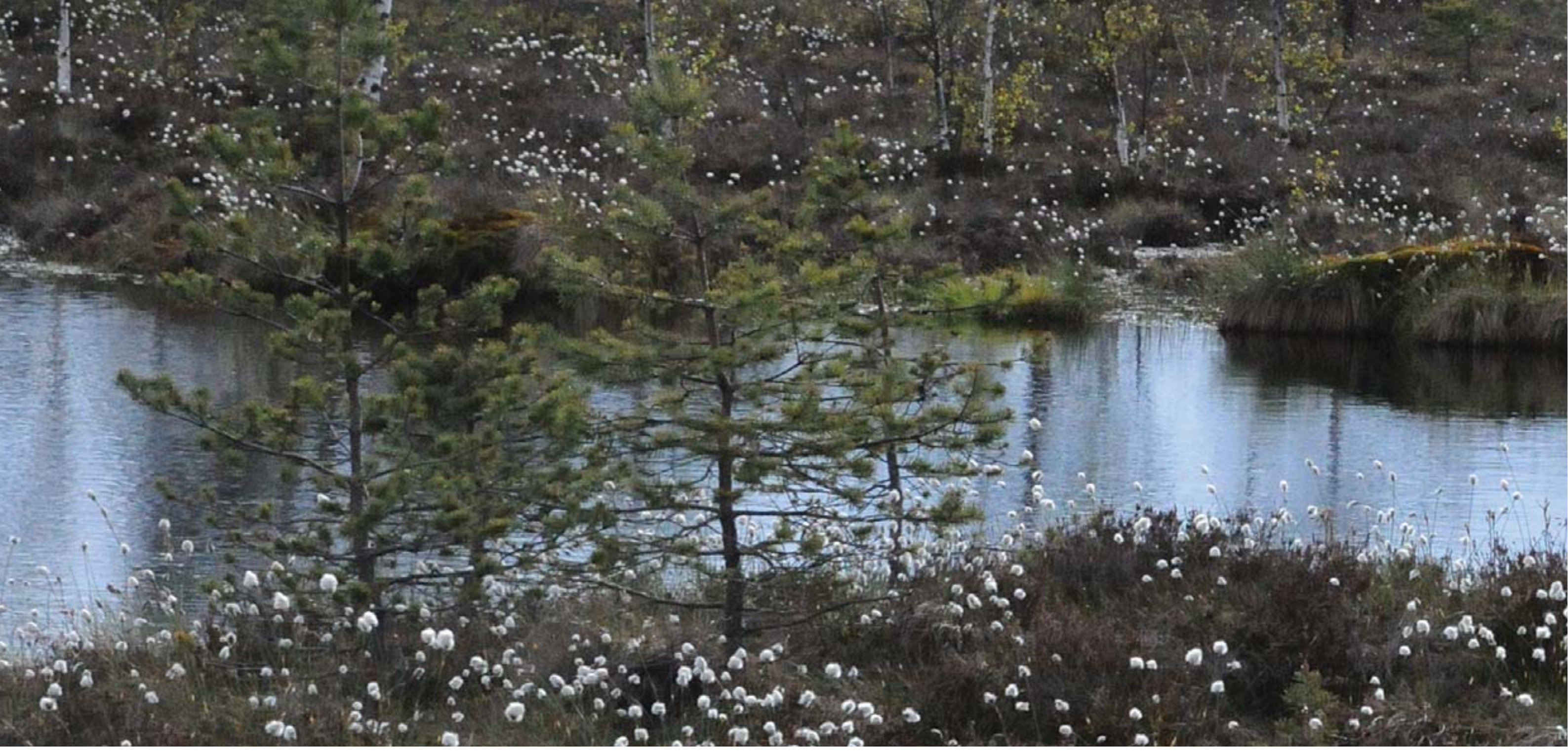
The effects of N deposition on soil chemistry, tree nutrition, and tree growth and health were clearly demonstrated, although multiple interacting factors were also identified (e.g. management/thinning practices, forest/tree age, climate). Further effects were reported on the development of mycorrhiza and biodiversity, including macro-lichens and ground vegetation. A gradual replacement of oligotrophic species by eutrophic species was observed at high N deposition level.

Nitrogen deposition may alter nutrient limitations and lead to increased tree growth and C sequestration, at least in the short-term. In Finland, where N deposition is relatively low compared to the rest of Europe, the N enrichment of the forest ecosystem was found to have a positive effect on tree growth. In boreal coniferous forests, N deposition accumulating during a rotation period is able to compensate for the export of N caused by conventional stem-only-harvest in final felling. Positive effects of N deposition on growth were also observed in Italy and Switzerland.

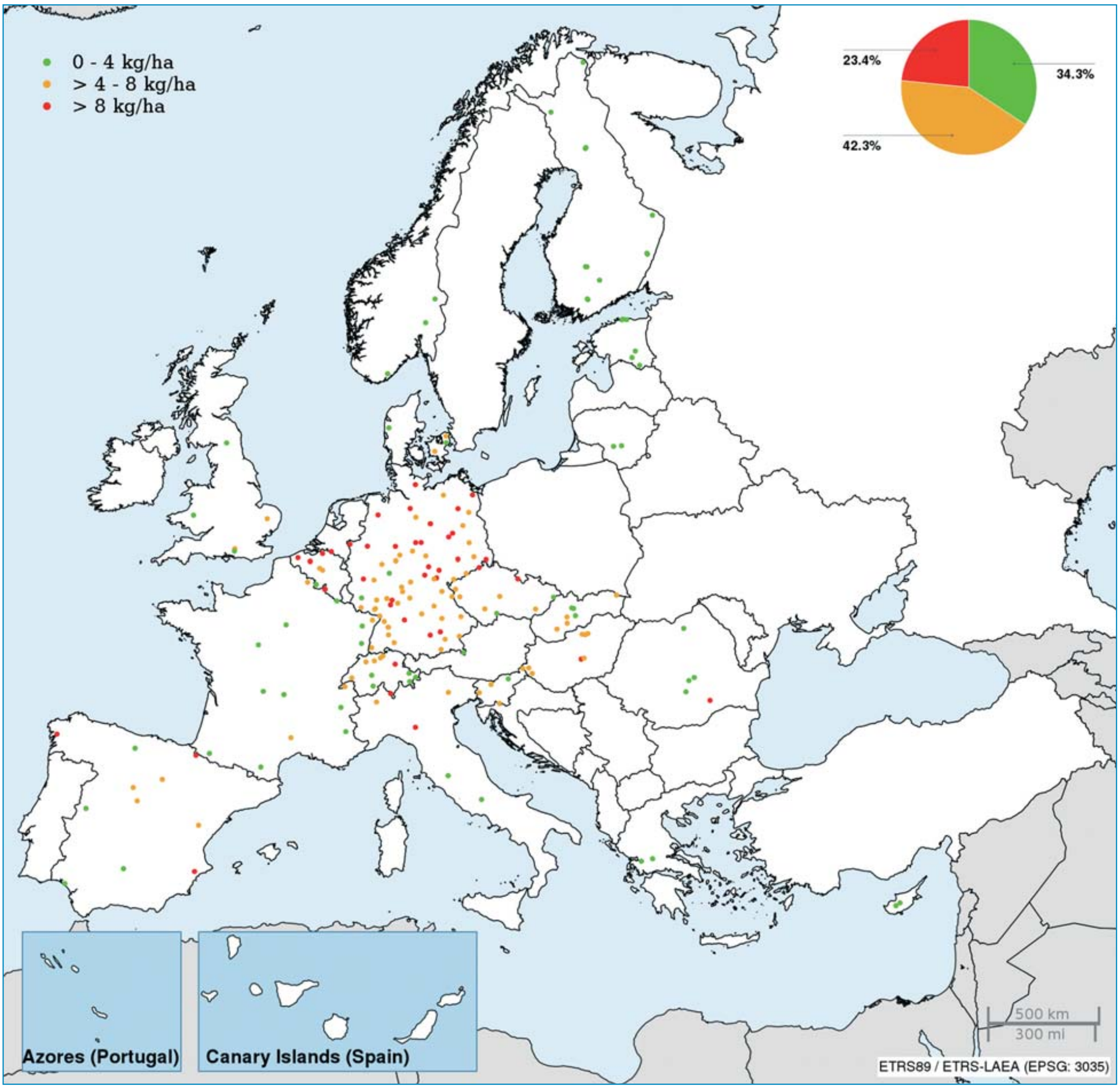
Excessive input of N, however, accelerates eutrophication effects in soils, with e.g. loss of nutrients by leaching and elevated nitrate levels in percolation and run-off water.

European forests seem to be moving from N towards phosphorus (P) limitation. Phosphorus, sulphur and potassium in foliar nutrition have deteriorated in comparison to N nutrition over the past 20 years.

Research based on a large set of soil, foliar and defoliation data paired with modelled climate and deposition data has shown N deposition and climatic parameters to be important predictors of defoliation in several tree species. Higher defoliation and discolouration were also related to a high foliar N:P ratio. Nitrogen deposition was found to influence the foliar N:P ratio, supporting the idea of enhanced defoliation (or discoloration) with higher N deposition above a certain threshold.



The map provides an overview on the measured throughfall and, where applicable, stemflow deposition of ammonium nitrogen (NH_4-N) on the European intensive forest monitoring plots (Level II) in 2013.



Surface waters recover from acidification but depositions are still stored in the soils.

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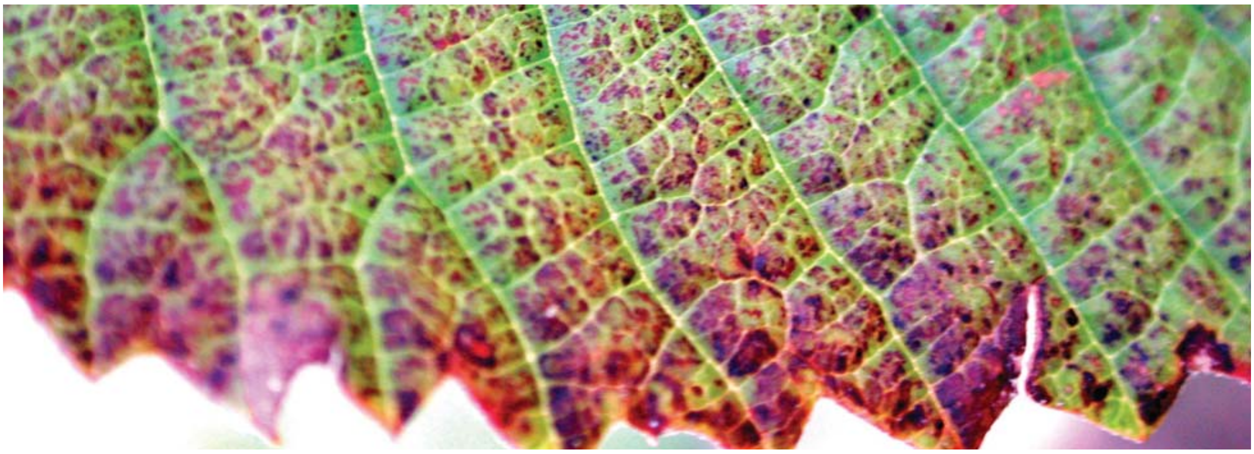
5. GROUND LEVEL OZONE AND ITS IMPACT ON EUROPEAN FORESTS

Tropospheric ozone (O_3) is a gaseous air pollutant that can impact forest vegetation, causing effects ranging from visible injury to the reduced growth and C sink strength of forest trees. As such, it represents a priority for the UNECE LRTAP Convention and a threat to the sustainable management of European forests. Emissions associated with fossil fuels and the burning of biomass mean that global mean tropospheric O_3 concentrations have approximately doubled, and further increases are predicted for the twenty-first century.

As a strong oxidant, O_3 causes several types of visible symptoms, including chlorosis and necrosis, and it decreases photosynthetic activity, resulting in reduced plant growth and impairment to water-use efficiency and other functions. It has been estimated that increased ozone levels have led to a 7% decrease in forest biomass growth in the northern hemisphere. Plants weakened by O_3 may also be more susceptible to pests, disease, and drought.

Ozone visible symptoms on European dwarf elder (*Sambucus ebulus*).

Ozone injury was assessed on 87 plots in 17 countries and ozone concentration was measured on 166 plots in 18 countries between 2009 and 2013. Data are used in the reporting to the UNECE Working Group on Effects and in scientific evaluations.



Ozone visible injury on wayfaring tree (*Viburnum lantana*).

Beech (*Fagus sylvatica*) is considered as ozone sensitive.

The AOT40 threshold of O_3 exposure, set to protect forests from adverse effects, was exceeded in almost all countries from 2000-2013. However, there was a decreasing trend of 0.35 ppb per year overall during the time period from 2000 to 2013. This decreasing trend matches the latest findings from the European Monitoring and Evaluation Programme (EMEP). It is also consistent with a number of studies reporting a flattening out or even reduction in levels. However, there are also European reports showing no downward trends in ground-level O_3. Unlike the spatial distribution of mean concentrations with an apparent north-south gradient, the temporal trend analyses did not reveal any uniform patterns across Europe, indicating strong, site-specific annual variation.

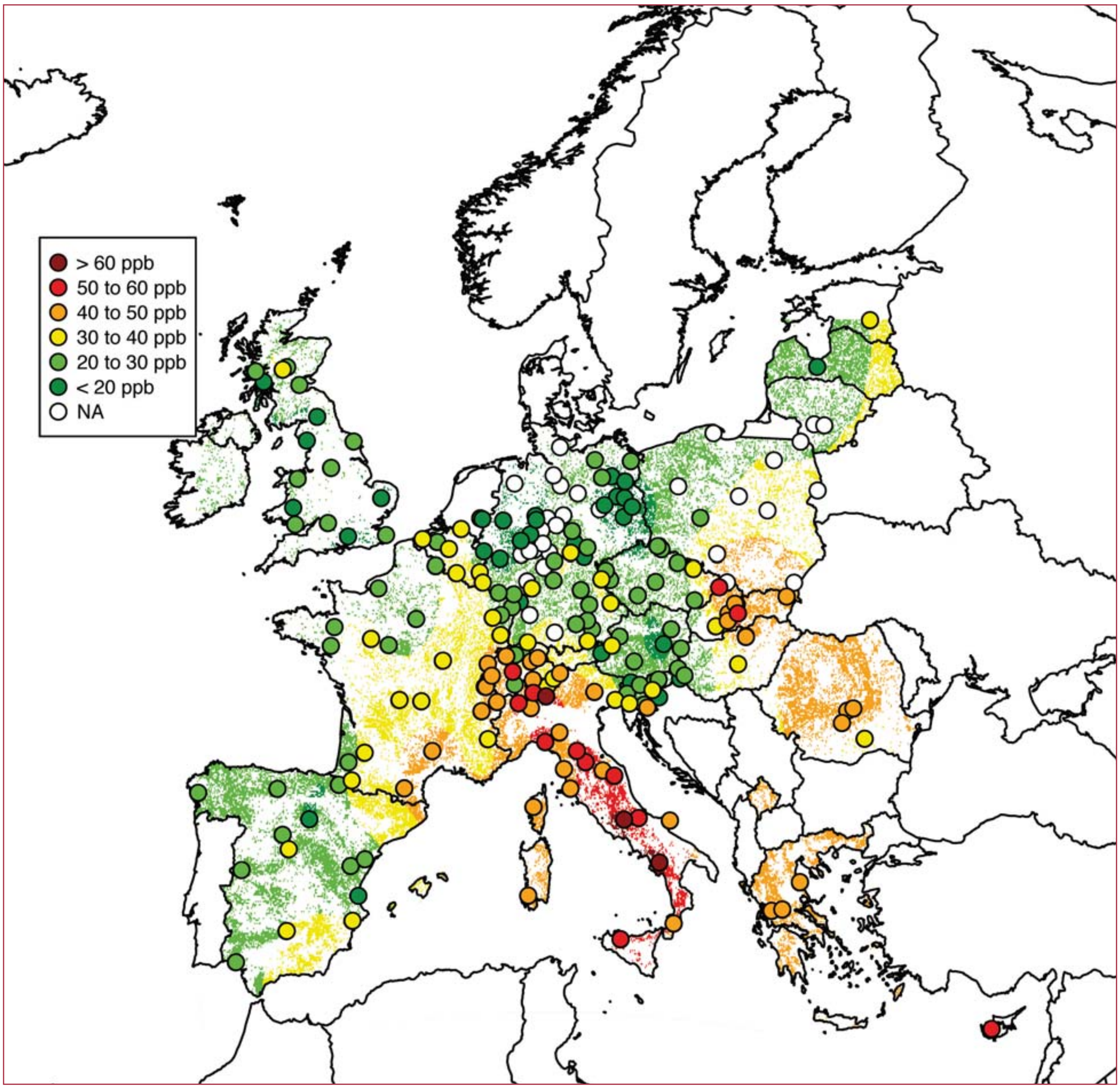
While the effects of O_3 were reported in terms of visible foliar injury to a variety of species across Europe, their impact on growth and health was less univocal, and general conclusions on this cannot – on the basis of ICP Forests data – be drawn for mature forest trees across Europe. Here, the role of interacting factors is even more pronounced. Future studies will focus on trend analyses based on more extended data series, and on the relationships between O_3, O_3-induced symptoms, tree health, and growth.

Ozone data may be combined with extensive meteorological data series in order to apply and test it for ozone flux modelling, and to compare it with the respective EMEP outputs.

Bronzing as typical ozone visible symptom on beech (*Fagus sylvatica*).

Ozone visible symptoms on black cherry (*Prunus serotina*).

Spatial distribution of April-September mean ozone concentrations (ppb) from passive samplers on 203 plots and 20 countries during 2000-2013.



Beech (*Fagus sylvatica*) is considered as ozone sensitive.

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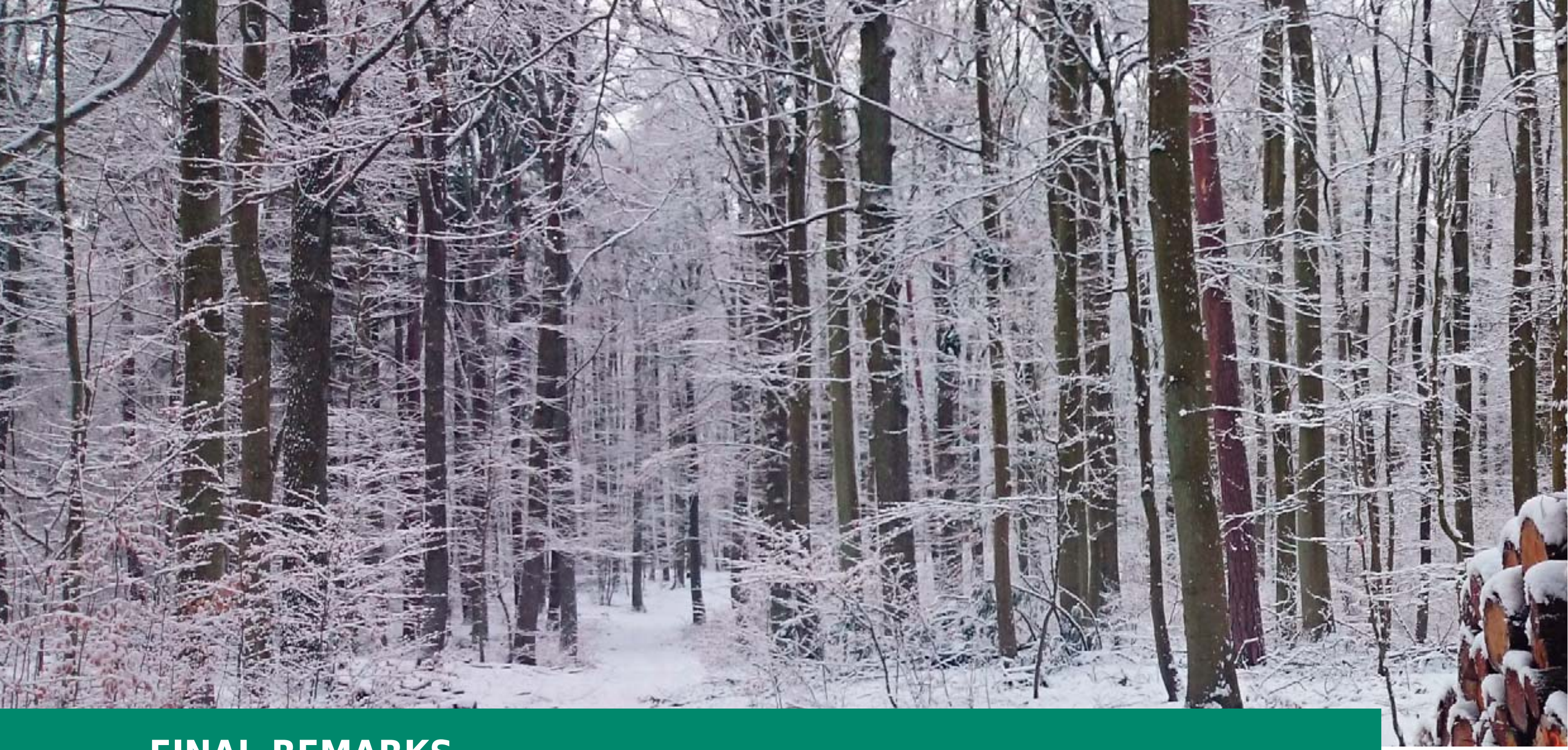

FINAL REMARKS

THE WEALTH OF DATA COLLECTED BY ICP FORESTS DATA SUBSTANTIATE THAT

(i) air pollution, namely N deposition and ground-level O_3, has an impact on the health, productivity and diversity of European forests, thus presenting a challenge to be overcome for sustainable forest management,

(ii) European environmental policies seem effective in reducing air pollution levels and loads,

(iii) the Level I and II networks are able to track changes in the status of European forests, provide proof of measurable effects, and supply the political and scientific communities and processes with high quality data.

Long-term ecological monitoring is acknowledged as an important tool for policy-making (provision of key data and information), intergovernmental relationships (standardising processes and methods, formalising information flows and activities, and developing shared concepts), and for ecological research (provision of consistent long-term data series). ICP Forests can be considered exemplary in this respect, having worked internationally for 30 years now at political and inter-governmental level, delivering information and data to various different communities, from policy- and decision-makers, to scientists and society at large.

As demonstrated by the main chapters of this report, evidence of environmental impact on forests can be identified only by means of long-term observation work carried out on a large scale. The main future objective of the ICP Forests is to continue serving the UNECE LRTAP Convention, science, and society by performing this essential task.

PARTICIPATING COUNTRIES AND CONTACTS

ALBANIA: National Environment Agency, Tirana. Julian Beqiri, Kostandin Dano (jbeqiri@gmail.com, kostandin.dano@akm.gov.al)

ANDORRA: Ministeri de Turisme I Medi Ambient, Dep. De Medi Ambient, Andorra la Vella. Silvia Ferrer, Anna Moles (silvia_ferrer_lopez@govern.ad, anna_moles@govern.ad)

AUSTRIA: Austrian Research Centre for Forests (BFW), Wien. Ferdinand Kristöfel, Markus Neumann (ferdinand.kristoefel@bfw.gv.at, markus.neumann@bfw.gv.at)

BELARUS: Forest inventory republican unitary company "Belgosles", Minsk. Valentin Krasouski (belgosles@open.minsk.by)

BELGIUM-FLANDERS: Research Institute for Nature and Forest (INBO), Geraardsbergen. Peter Roskams (peter.roskams@inbo.be)

BELGIUM-WALLONIA: Earth and Life Institute / Environmental Sciences (ELI-e)/Université catholique de Louvain, Louvain-la-Neuve. Hugues Titeux (hugues.titeux@uclouvain.be). Environment and Agriculture Department / Public Service of Wallonia, Gembloux. Elodie Bay (elodie.bay@spw.wallonie.be)

BULGARIA: Executive Environment Agency at the Ministry of Environment and Water, Sofia. Genoveva Popova (forest@eea.government.bg)

CANADA: Natural Resources Canada, Ottawa. Pal Bhogal (pal.bhogal@nrcan.gc.ca). Ministère des Ressources naturelles Direction de la recherche forestière, Québec. Rock Ouimet (rock.ouimet@mrnf.gouv.qc.ca)

CROATIA: Croatian Forest Research Institute, Jastrebarsko. Nenad Potočić (nenadp@sumins.hr)

CYPRUS: Ministry of Agriculture, Natural Resources and Environment, Nicosia. Andreas Christou (achristou@fd.moa.gov.cy)

CZECH REPUBLIC: Forestry and Game Management Research Institute (FGMRI), Jíloviště. Bohumír Lomský (lomsky@vulhm.cz)

DENMARK: University of Copenhagen, Department of Geosciences and Natural Resource Management, Frederiksberg. Morten Ingerslev (moi@ign.ku.dk)

ESTONIA: Estonian Environment Agency (EEIC), Tartu. Endla Asi (endla.asi@envir.ee)

FINLAND: Natural Resources Institute Finland (LUKE), Oulu. Päivi Merilä (paivi.merila@luke.fi)

FRANCE: Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, Paris. Jean-Luc Flot, Fabien Caroulle (jean-luc.flot@agriculture.gouv.fr, fabien.caroulle@agriculture.gouv.fr). Office National des Forêts, Fontainebleau. Manuel Nicolas (manuel.nicolas@onf.fr)

GERMANY: Bundesministerium für Ernährung und Landwirtschaft (BMEL), Bonn. Sigrid Strich (sigrid.strich@bmel.bund.de)

GREECE: Hellenic Agricultural Organization "DEMETER", Institute of Mediterranean Forest Ecosystems and Forest Products Technology, Athens. Panagiotis Michopoulos (mipa@fria.gr)

HUNGARY: National Food Chain Safety Office (NFCSO), Forestry Directorate, Budapest. László Kolozs (kolozsl@nebih.gov.hu)

IRELAND: University College Dublin, School of Agriculture and Food Science, Dublin. Jim Johnson (jim.johnson@ucd.ie)

ITALY: Ministry for Agriculture and Forestry Policies, National Forest Service, Rome. Angela Farina, Laura Canini (a.farina@corpoforestale.it, l.canini@corpoforestale.it)

LATVIA: Latvian State Forest Research Institute "Silava", Riga. Zane Lībiete-Zalite (zane.libiete@silava.lv)

LIECHTENSTEIN: Amt für Umwelt (AU), Vaduz. Olivier Nägele (olivier.naegele@llv.li)

LITHUANIA: State Forest Survey Service, Kaunas. Albertas Kasperavicius (alber_k@lvmi.lt)

LUXEMBOURG: Administration de la nature et des forêts, Luxembourg. Elisabeth Freymann (elisabeth.freiymann@anf.etat.lu)

FYR OF MACEDONIA: Ss. Cyril and Methodius University, Skopje. Nikola Nikolov (nnikolov@sf.ukim.edu.mk)

REPUBLIC OF MOLDOVA: Agency Moldsilva, Chisinau. Stefan Chitoroaga (icaspiu@starnet.md)

MONTENEGRO: Ministry of Agriculture, Forestry and Water Management, Podgorica. Ranko Kankaras, Milosavom Andelicem (ranko.kankaras@mpr.gov.me, milosav.andjelic@gov.me)

THE NETHERLANDS: National Institute for Public Health and the Environment (RIVM), Bilthoven. Esther Wattel-Koekkoek (esther.wattel@rivm.nl)

NORWAY: Norwegian Institute of Bioeconomy Research (NIBIO), Ås. Dan Aamlid (dan.aamlid@nibio.no)

POLAND: Forest Research Institute, Raszyn. Jerzy Wawrzoniak, Pawel Lech (j.wawrzoniak@ibles.waw.pl, p.lech@ibles.waw.pl)

PARTICIPATING COUNTRIES AND CONTACTS

PORTUGAL: Instituto da Conservação de Natureza e das Florestas (ICNF), Lisboa.
Maria da Conceição Osório de Barros (conceicao.barros@icnf.pt)

ROMANIA: National Research and Development Institute (ICAS), Ilfov. Romica Tomescu, Ovidiu Badea (biometrie@icas.ro, obadea@icas.ro)

RUSSIAN FEDERATION: Centre for Forest Ecology and Productivity of the Russian Academy of Sciences, Moscow. Natalia Lukina (lukina@cepl.rssi.ru)

REPUBLIC OF SERBIA: Institute of Forestry, Belgrade. Radovan Nevenic (nevenic@eunet.rs)

SLOVAK REPUBLIC: National Forest Centre, Zvolen. Pavel Pavlenda (pavlenda@nlcsk.org)

SLOVENIA: Slovenian Forestry Institute (SFI), Ljubljana. Marko Kovač, Primož Simoncic (marko.kovac@gozdis.si, primoz.simoncic@gozdis.si)

SPAIN: Ministerio de Agricultura, Alimentacion y Medio Ambiente, Madrid. Roberto Vallejo, Belén Torres (rvallejo@magrama.es, btorres@magrama.es)

SWEDEN: Swedish Forest Agency, Jönköping. Sture Wijk (sture.wijk@skogsstyrelsen.se)

SWITZERLAND: Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf. Peter Waldner (peter.waldner@wsl.ch)

TURKEY: General Directorate of Forestry Department of Forest Pests Fighting, Ankara. Sıtkı Öztürk, (sitkiozturk@ogm.gov.tr, uomturkiye@ogm.gov.tr)

UKRAINE: Ukrainian Research Institute of Forestry and Forest Melioration (URIFFM), Kharkiv. Igor F. Buksha (buksha@uriffm.org.ua)

UNITED KINGDOM: Forest Research Station, Alice Holt Lodge, Farnham Surrey. Sue Benham (sue.benham@forestry.gsi.gov.uk)

UNITED STATES OF AMERICA: USDA Forest Service – Pacific Southwest Research Station, Riverside, CA. Andrzej Bytnerowicz (abytnerowicz@fs.fed.us)

Autumn colouring of a mature beech (*Fagus sylvatica*) forest.

ANNEX

PHOTO REFERENCES

PAGE	NAME
10,11	Elodie Bay
7	Stefan Fleck
7, 18, 26	Alfred Fürst
Title, 4-7, 18, 28	András Koltay
11	Lehmann
Title, 4, 5	Pavel Pavlenda
15	Rona Pitman
Title, 10-13, 14-17, 19, 26	Tanja Sanders
5, 22-25	Marcus Schaub
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