ICP Forests

LRTAP
Long-range Transboundary Air Pollution

Forest Conditions

ICP Forests
2017 Executive Report

2017

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ICP Forests

Forest Conditions

ICP Forests 2017 Executive Report

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)

For further information, please contact:

Programme Co-ordinating Centre (PCC) of ICP Forests
Dr. Walter Seidling, Alexa Michel
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, Germany

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Editor
Walter Seidling

Authors
Section 2.1
Stephan Raspe, Hans-Peter Dietrich,
Desirée Köhler, Alfred Schubert, Joachim Stiegler
Section 2.2
Rossella Guerrieri, Josep Peñuelas,
Maurizio Mencuccini
Section 2.3
Maija Salemaa, Päivi Merilä, Antti-Jussi Lindroos,
Raisa Mäkipää, Aino Smolander
Section 3.1
Elena Vanguelova, Nathan Brown,
Samantha Broadmeadow, Sandra Denman
Section 3.2
Ionel Popa, Stefan Leca, Ovidiu Badea

Copy editing
Carolyn Symon
(carolyn.symon@btinternet.com)

Layout
Simon Duckworth, Burnthebook
(simon@burnthebook.co.uk)

Print
Mertinkat, Eberswalde/Germany

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Moss surfaces are populated by microbes, among them cyanobacteria. Under certain conditions, these can fix large amounts of atmospheric nitrogen

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Stem increment is one of the most important features of trees, not only in economic terms but also for tree survival. Measuring stem increment without disturbing the tree is an important aspect of monitoring activities

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Preface

I am honoured to introduce the 2017 Executive Report of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). Romania has participated in the forest monitoring programme since 1990, hosted the 33rd Task Force Meeting in 2017, and the Romanian Ministry of Research, Development and Innovation strongly supports the work of the programme.

Forests exhibit the highest levels of biodiversity of all types of ecosystems, providing habitats for a wide range of animal and plant species. With their considerable potential for carbon sequestration they are one of the most important elements of the global carbon cycle. In addition to their great importance to the earth's climate and biodiversity, forests play a significant role in the development of rural areas and provide many recreational opportunities for people, as well as providing protective functions for soil, water and infrastructure, and contributing goods and services to the economic sector.

In Europe, the decline in forest ecosystem health, reported in the early 1980s and highlighted through research performed at the international level has been mainly caused by the interaction of atmospheric pollution and various biotic and abiotic factors, as well as other disturbances, such as those resulting from human activities or fire. In order to understand and describe the changes in forest health status, foresters and forestry researchers have initiated periodic monitoring at the Europe-wide level of the main tree-health indicators, namely tree crown defoliation and discoloration.

A significant part of this process, through the provision of scientific information, has been taken over by ICP Forests established by the Convention on Long-range Transboundary Air Pollution (CLRTAP), under the United Nations Economic Commission for Europe in 1985.

The successful implementation of protocols regarding control of pollutant emissions by the CLRTAP signatory countries and of special monitoring programmes (ICP Forests, the EU Scheme on Protection of Forests against Air Pollution, Forest Focus Regulation, and LIFE+ project FutMon), has led to a significant reduction in industrial pollution in most European countries over the past few decades. It has also led to the establishment of a well-organised trans-disciplinary monitoring system of forest ecosystems and to efforts to determine the effects of the main factors disrupting forested ecosystems, especially air pollution and climate change.

One of the most important achievements of the European Forest Monitoring System involves deploying specific well-developed and uniform indicators and criteria related to forest health, as well as the development of common forest monitoring methodologies. Their uniform application makes it possible to directly compare different sets of results and so develop long-term data series, which contribute to the forest knowledge base needed to better understand the complex environmental and societal challenges facing the forest sector.

I further encourage the work and efforts of everyone involved in the ICP Forests monitoring programme, and I wish you all – one of the most united and professional international scientific communities – great success.

Puiu Lucian GEORGESCU
Minister of Research,
Development and Innovation, Romania

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Introduction

1

The integrated and ecosystem-orientated approach followed by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) over its past 30 years of existence has now reached an advanced level of expertise in forest-related research and monitoring. The established ecological research infrastructure allows advanced studies based on the principle of co-location, meaning research is conducted at sites already equipped with basic research facilities and with datasets covering the past few decades. Both preconditions provide an important contribution to terrestrial ecosystem research within a broader context, where atmospheric deposition and climate change effects although important are not the only drivers of ecosystem processes. The scientific conferences of ICP Forests, held back-to-back with the annual Task Force meetings, provide a forum to present and discuss recent research within and associated with the ICP Forests programme and to highlight the benefits of long-term monitoring. ICP Forests plot data are used by scientists to foster wider research and links with different programmes and research communities.

This Executive Report highlights basic and advanced research activities presented at the 6th Scientific Conference of ICP Forests in Bucharest, Romania. The first contribution expounds the long-term nitrogen balance in forest ecosystems in central Europe. This is followed by two studies that make use of advanced technologies to increase understanding of the metabolic contributions of epiphytic microbes: one about nitrifying bacteria on leaves or needles of forest trees and the other on nitrogen-fixing microorganisms on mosses. Two further studies focus on the response of trees to environmental change. One demonstrates the likely environmental predisposing factors to a disease syndrome in oaks, while the other demonstrates the detailed registration of growth responses of individual forest trees.

Nitrogen budgets and nitrogen cycling

2

Nitrogen is an essential nutrient for life on earth. But despite inert nitrogen gas (N_2) representing the main constituent (78%) of the planet's atmosphere, reactive plant-available nitrogen has been the main factor limiting plant growth for aeons. Organisms evolving under these conditions became adapted to the nitrogen-deficient environment and this led to the development of a multitude of physiological pathways in plants, archaea and bacteria, fungi, and animals to cope with this shortage. However, owing to the commercial production of nitrogen fertilisers – initially through the Frank-Caro process (developed in 1895) and then through the more efficient Haber-Bosch process (developed in the 1920s) – there has been a fundamental change, and ammonia has become available in such quantities that environmental levels of reactive nitrogen are now significantly higher. Today, around half of mankind's nutrition is based on Haber-Bosch nitrogen. Widespread use of combustion engines and other technological developments have further increased the sources of reactive nitrogen.

This overall increase in reactive nitrogen has not only had major implications for agriculture, but also for other environmental systems since reactive nitrogen compounds occurring as gases, dissolved in water and attached to dust particles are transported through the atmosphere and deposited on a wide range of ecosystems, especially – due to their high aerodynamic resistance – forests. An enormous increase in the availability of a formerly limiting nutrient is likely to have major consequences for nitrogen pathways and species dynamics within forest ecosystems.

Quantitative basic information on nitrogen pathways (fluxes) through forest ecosystems is needed to understand the potentially far-ranging changes involved. The first study summarised here (Section 2.1) reports on nitrogen fluxes and stocks at several plots in typical forest ecosystems in Bavaria, Germany. Long-term studies like this are needed to provide basic knowledge of fluxes and stocks of nitrogen (and other substances) in forest ecosystems. The second study (Section 2.2), undertaken in the United Kingdom (and extended to several ICP Forests sites in Europe), examines nitrification by microbes in tree canopies, especially under high deposition loads. This process has so far received little attention. The final study (Section 2.3), undertaken in Finland, demonstrates activity of moss-associated nitrogen-fixing cyanobacteria. While the first study underlines the value of rigorous investigations of nitrogen (and other element) stocks and fluxes in forest ecosystems over the long term, the other two show that there are pathways and sources of nitrogen about which little is known, and this should be addressed in future research initiatives.

Further reading

Smil V, 1997: Global population and the nitrogen cycle. Scientific American, July 1997: 76-81.

2.1 Nitrogen budget in forest stands

Annual nitrogen throughfall deposition and losses via seepage water were estimated for soils at 22 ICP Forests Level II (intensive) monitoring plots in Bavaria, Germany (Figure 2-1).

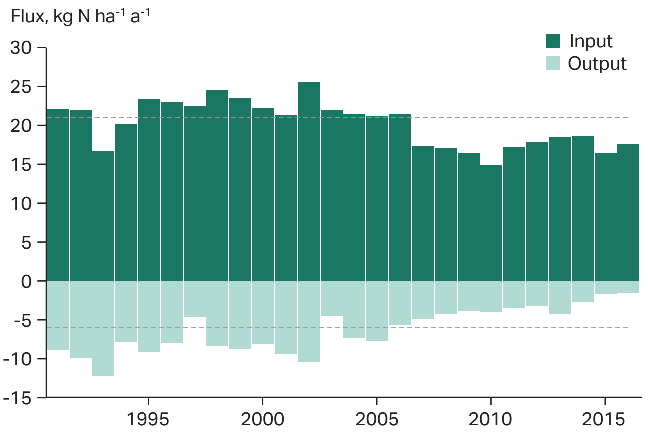

Figure 2-1: Annual average nitrogen throughfall deposition (input) and losses with seepage water (output) at 22 ICP Forests Level II (intensive) monitoring plots in Bavaria, Germany, since the early 1990s. Dashed horizontal lines show the long-term average.

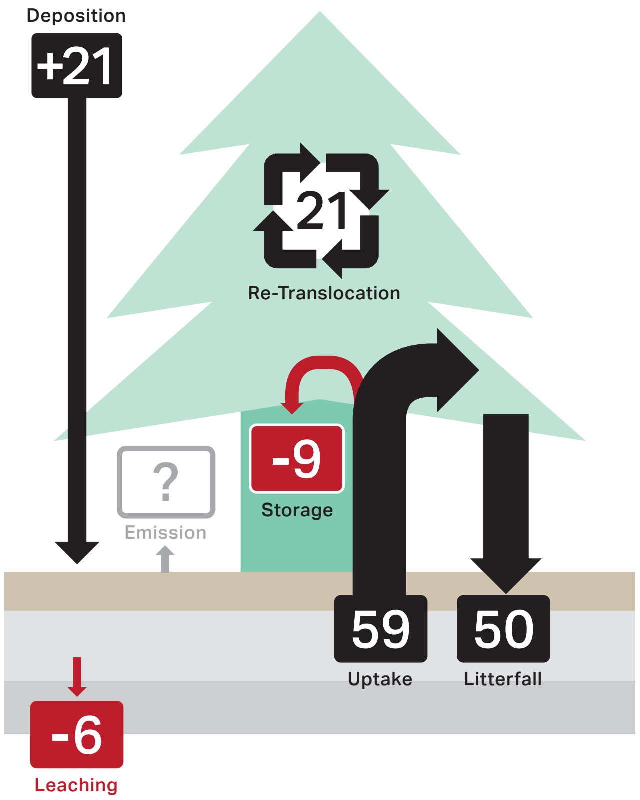

Figure 2-2: Mean annual nitrogen fluxes (kg N ha^{-1}) for the period 1991–2015 based on data from 22 Level II (intensive) forest monitoring sites in Bavaria, Germany. Arrow thickness is proportional to flux value.

Besides calculating nitrogen inputs/outputs to/from forest ecosystems over the past 25 years based on measured data, the study also looked at nitrogen cycling within forest ecosystems. The calculations were based on data from various Level II surveys: including deposition data, meteorological variables, soil chemical and physical values as well as information from soil solution chemistry, forest growth and the nutrient content of foliage and litterfall. Measured data were used to model water budgets and estimate nitrogen fluxes. Results show a total deposition of about 21 kg N ha^{-1} a^{-1} to these central European forest ecosystems. Losses through leaching from the soil (6 kg N ha^{-1} a^{-1}) and net uptake by trees based on the annual increment of woody biomass (9 kg N ha^{-1} a^{-1}) were similar. An ongoing nitrogen accumulation of 6 kg N ha^{-1} a^{-1} was calculated for the forest ecosystems studied.

Nitrogen cycling within forests is very high. The flux through annual litterfall varies widely (average 50 kg N ha^{-1} a^{-1}), and is lowest for pine stands (20 kg N ha^{-1} a^{-1}) and highest for oak stands (70 kg N ha^{-1} a^{-1}). Foliage uptake also varies widely (average 60 kg N ha^{-1} a^{-1}), and is again lowest for pine (30 kg N ha^{-1} a^{-1}) and highest for oak (110 kg N ha^{-1} a^{-1}). These data reveal a mean re-translocation ratio of 21 kg N ha^{-1} a^{-1}. Despite the continued net uptake of nitrogen by forest soils, there was no clear tendency for an increase in internal fluxes over the 25-year study period.

Although the potential for loss of nitrogen by gaseous emission from the forest soils due to denitrification is not yet quantified, this nitrogen budget indicates ongoing nitrogen accumulation within the forest ecosystems in Bavaria. This highlights the problem of ongoing nitrogen saturation found in many central European forests.

2.2 Nitrification in tree canopies

After more than 20 years of continuous monitoring at the ICP Forests Level II (intensive) monitoring plots, it is clear that tree canopies play a significant role in both intercepting rainfall and altering its chemical composition, thus affecting the nutrient input to the soil. Significant differences in terms of nitrogen fluxes have been observed between rainfall in the open field and below forest canopies (so-called throughfall) at many sites. However, the processes responsible for these differences are still unclear.

In an earlier study, nitrogen fluxes (particularly nitrate, NO_3) were examined in combination with stable nitrogen (δ^{15}N) and oxygen isotope compositions (δ^{18}O, δ^{17}O) of NO_3 in rainfall and throughfall. This approach provided the first unequivocal isotopic evidence that biological nitrification, i.e. microbial transformation of ammonia (NH_3) or ammonium (NH_4) to NO_3, occurs

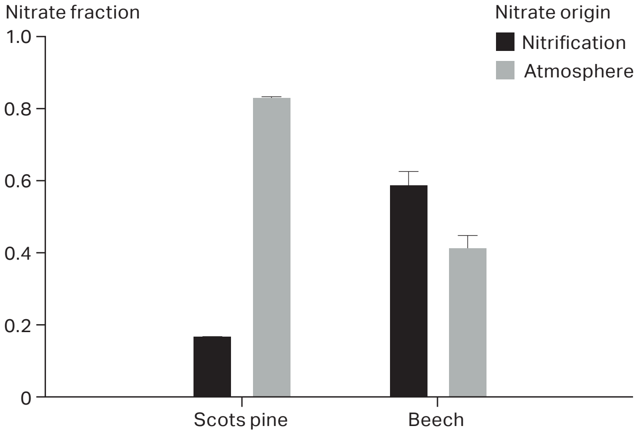

Figure 2-3: Relative fractions of nitrate (NO_3) originating from nitrification and the atmosphere based on the stable oxygen isotope compositions (δ^{18}O and δ^{17}O) of NO_3 in rainfall and throughfall collected during the 2011 growing season at a Scots pine forest stand and a common beech forest stand in the United Kingdom. Data show mean ± standard error.

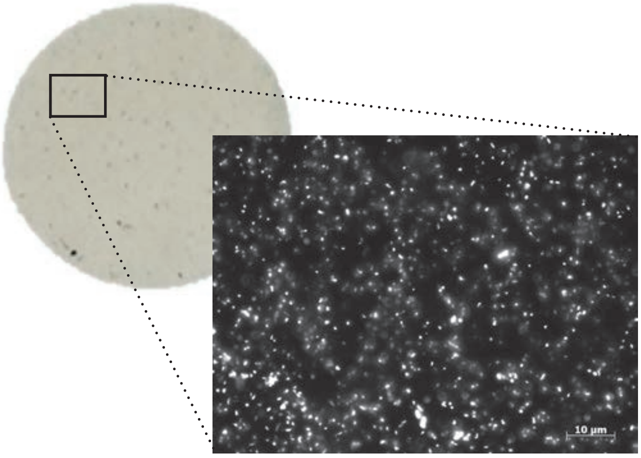

Figure 2-4: One of the 0.2 µm pore size polycarbonate filters used to filter throughfall at a site in Spain, plus an image obtained by epifluorescence microscopy on DAPI-stained cells showing bacteria (white dots) on part of the filter. Observations were made by Joan Cáliz and Mateu Menéndez-Serra (Centre for Advanced Studies of Blanes, Spain).

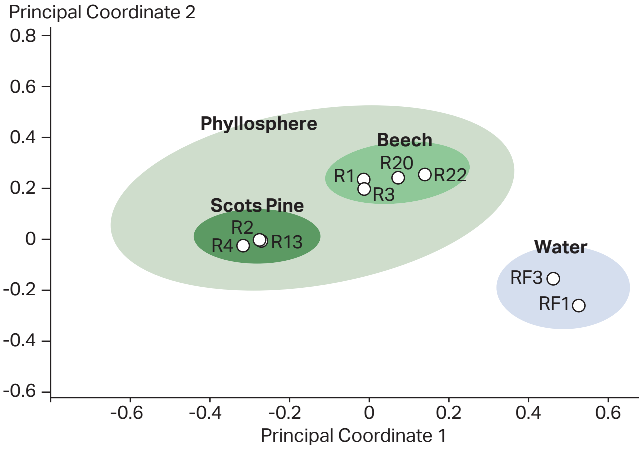

Figure 2-5: Results of a multivariate ordination analysis (NMDS) showing clustering in the bacterial communities of different sample types. Samples with similar community composition form 'clusters', such as phyllosphere (i.e. leaves and needles) versus water (i.e. rainfall or throughfall), and Scots pine needles versus common beech leaves.

on the surfaces and/or inside leaves or needles (the so-called phyllosphere) in tree canopies (Figure 2-3). Biological nitrification was responsible for changes in the amount of NO_3 in throughfall versus rainfall at two UK forest sites receiving high atmospheric nitrogen inputs. This strongly suggests that microbes (bacteria and/or archaea) living in the phyllosphere control important pathways of nitrogen compounds in tree canopies. As microbes are mainly connoted with their role as pathogens it seems that there is still much to be understood about their effects on nitrogen cycling.

The current study has two aims. First, to characterise bacterial communities within tree canopies for common beech (*Fagus sylvatica*) and Scots pine (*Pinus sylvestris*) using meta-genomic techniques and to identify those microbial groups related to nitrogen cycling. Second, to quantify the proportion of NO_3 flux originating from bacterial activity in tree canopies relative to that from atmospheric deposition, by combining nitrogen fluxes with measurements of nitrogen and oxygen isotope ratios in NO_3 from rainfall and throughfall. The study includes six common beech and six Scots pine ICP Forests Level II (intensive) monitoring sites along a climate and nitrogen-deposition gradient from Fennoscandia to the Mediterranean area.

Preliminary results from metagenomic analyses on a subset of sites revealed the presence of bacteria in throughfall (Figure 2-4), with over 300 species identified. Bacterial community composition was clustered for rainfall and throughfall versus phyllosphere, and for

Terminology

Isotopes are atoms of an element, such as nitrogen (N) or oxygen (O), that have the same atomic number (number of protons), but different atomic mass (total number of protons and neutrons). The **stable isotope composition**, i.e. the so-called delta (δ) notation, is the isotopic ratio ($^{15}N/^{14}N$, $^{18}O/^{16}O$, $^{17}O/^{16}O$) of the analysed samples relative to an internationally accepted standard as: $\delta^{XX}E = (R_S/R_{St} - 1) \times 1000$, where E is the element of interest (such as N or O), ^{XX} is the atomic mass of the heaviest isotopes (i.e., ^{15}N, ^{18}O, ^{17}O), R is the isotopic ratio (e.g., $^{15}N/^{14}N$) of the sample (S) and the standard (St).

Metagenomics is the study of the metagenome – the collective genome of microorganisms obtained directly from environmental samples, as opposed to the approach of working with traditionally cultured bacteria. A metagenomics workflow classifies organisms based on a specific gene (i.e., 16S rRNA) and its specific region (in this case V5-V6 of the 16S rRNA gene, which does not overlap with plant DNA).

common beech versus Scots pine (Figure 2-5). The most abundant families found in the phyllosphere were Acetobacteraceae and Acidobacteraceae, which are known to include bacteria related to nitrogen-cycling (i.e. nitrogen-fixation and denitrification). However, a more comprehensive characterisation of microbial communities – especially nitrifying bacteria – will only be available after completing the analyses at all sites.

Further reading

Guerrieri R, Vanguelova EI, Michalski G, Heaton THE, Mencuccini M, 2015: Isotopic evidence for the occurrence of biological nitrification and nitrogen deposition processing in forest canopies. Global Change Biology 21: 4613-4626.

2.3 Mosses and nitrogen fixation by epiphytic bacteria

Mosses (scientific: bryophytes) cover a substantial part of the forest floor in boreal regions. Their surface is populated by microbes, among them cyanobacteria (previously referred to as 'blue-green algae'). In nitrogen-limited northern forests, biological nitrogen gas (N_2) fixation by bryophyte-associated cyanobacteria is a significant source of plant-available nitrogen.

During 2009 and 2013, nitrogen stocks in mosses were estimated at the ecosystem level for 12 ICP Forests Level II (intensive) monitoring plots along a latitudinal gradient in Finland. Nitrogen uptake through N_2 fixation by cyanobacteria associated with the mosses (Figures 2-6 and 2-7) was also estimated. The total biomass of the green part of the bryophytes varied from 600 to 1500 kg ha^{-1}, and the nitrogen stocks varied from 5 to 20 kg N ha^{-1}. The bryophyte-related N_2 fixation rate increased from south to north, with the highest rates around 1 to 2 kg N ha^{-1} a^{-1}. This is similar to nitrogen deposition in northern Finland (1.5 kg N ha^{-1} a^{-1}).

In comparison, the annual flux of nitrogen to the nutrient cycle via needle litterfall and other tree litter in this region is about 5 kg N ha^{-1} a^{-1}. The moisture level of mosses as well as light and temperature conditions strongly regulate the rate of bacterial N_2-fixing. The results show that the moss layer makes a significant contribution to the nitrogen budget of boreal forests, and that the cyanobacteria associated with mosses might be sensitive indicators of change in nitrogen dynamics within these ecosystems. The rate of N_2 fixation found in southern Finland was very low, probably because cyanobacterial activity was inhibited by anthropogenic nitrogen deposition.

Hannu Nousiainen (Luke)

Figure 2-6: *Hylocomium splendens*, one of the two feather moss species studied; *Dicranum majus,* a smaller acrocarpic moss is also seen.

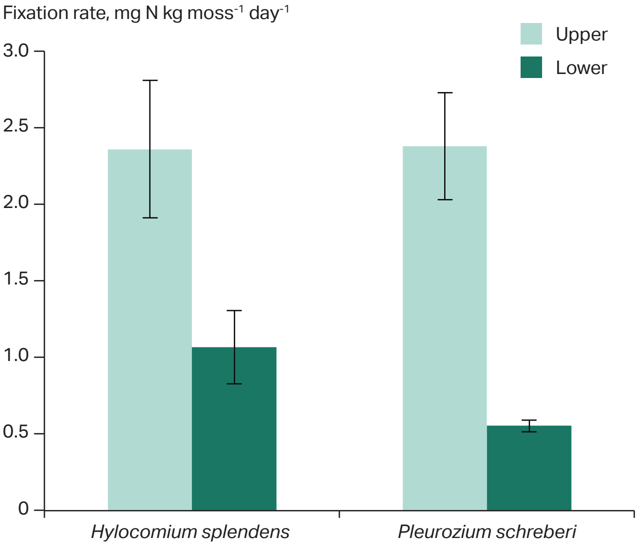

Figure 2-7: Atmospheric nitrogen gas (N_2) fixation rates for epiphytic cyanobacteria on the upper and lower parts of the feather mosses *Hylocomium splendens* and *Pleurozium schreberi*. Measurements made at the ICP Forests Level II plot Pallasjärvi in northern Finland. Data show mean ± standard error, n=3.

Further reading

Leppänen S, Salemaa M, Smolander A, Mäkipää R, Tiirola M, 2013: Nitrogen fixation and methanotrophy in forest mosses along a N deposition gradient. Environmental and Experimental Botany 90: 62-69.

Forest responses to environmental stressors

3

Trees, the major components of forests, are long-lived organisms. This induces long-term stability for life conditions on, within and under these dominant plants. This is why forests, as generally complex ecosystems provide habitats for many other plants and huge numbers of animals, fungi and microbes.

Typically, these organisms coexist in a kind of balance. If environmental conditions change, some tree species can become stressed and in their weakened state may enable parasitic or herbivorous organisms to grow and propagate excessively. Two major drivers interact in terms of their effects on forest trees: nitrogen deposition and a changing climate. Both have direct and indirect effects on trees and on the organisms living on them (such as herbivores, fungi, and microbes). As nutrient and water balances may be disturbed in a weaker host, mutual relationships could attain more parasitic or pathogenic features.

Such changes need understanding through careful monitoring of various tree and environmental parameters. This is why standardised methods are applied across the ICP Forests plots in order to observe key features of tree performance (e.g. stem diameter increment or foliage density in tree crowns) and key environmental factors (e.g. atmospheric deposition and climate variables such as rainfall and temperature). Studies highlight the importance of predisposing environmental factors to oak decline in the United Kingdom (Section 3.1) and of measuring stem growth in trees to identify physiological reactions to seasonal climatic conditions, especially water availability (Section 3.2).

3.1 Predisposing factors for Acute Oak Decline

Acute Oak Decline (AOD) affects both native species – pedunculate oak (*Quercus robur*) and sessile oak (*Q. petraea*) – in England and Wales. Affected trees are easily identified by the dark liquid that seeps from cracks between bark plates (Figure 3-1 B) and because underlying tissue rots forming cavities in the food and water-conducting tissues of the tree (Figure 3-1 C). Galleries of the native beetle *Agrilus biguttatus* are also present (Figures 3-1 D and 3-1 E). Many trees die prematurely. Similar symptoms have been described across Europe in conjunction with *A. biguttatus* colonisation. This is of great concern because oak represents an important component of native broadleaf woodlands in the United Kingdom. AOD is a specific condition with diagnostic symptoms within the wider complex of oak decline. As AOD appears to fit the traditional description of forest decline it is likely that affected trees are first weakened by exposure to predisposing factors, including drought.

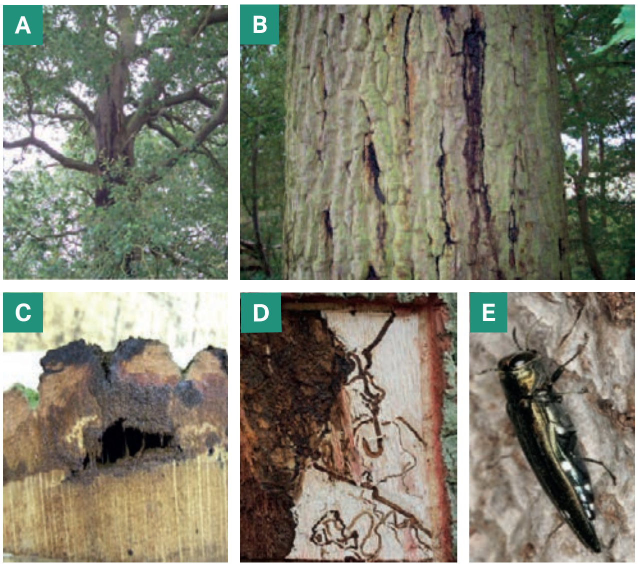

Figure 3-1: AOD syndrome has several visible effects – profuse bleeding extending up to the tree canopy (A) and dried fluid crusted in bark splits (B, C), and galleries (D) by the beetle *Agrilus biguttatus* (E).

A survey with more than 500 study sites was used to examine correlations between AOD occurrence and environmental factors that may act to predispose woodlands to decline. Factors considered include soil type, climate and atmospheric deposition (nitrogen, sulphur and base cations). Results show that the presence of AOD in England and Wales is significantly

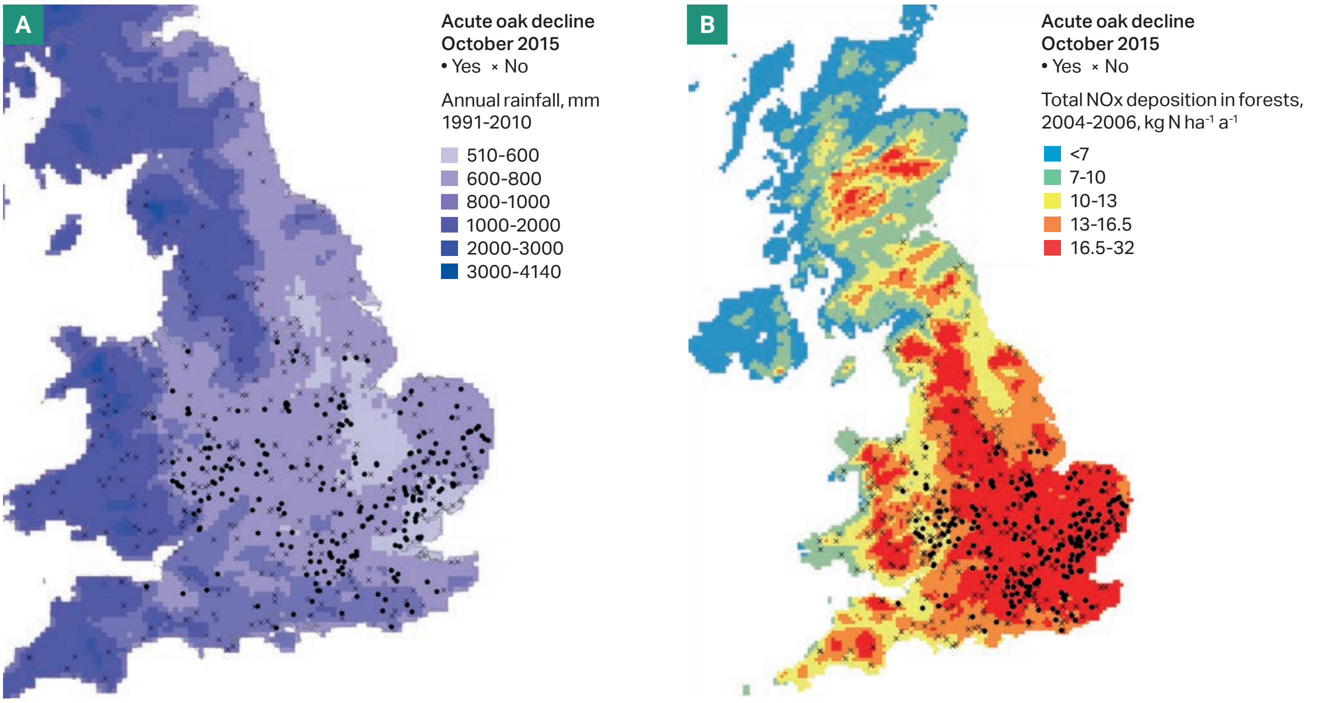

Figure 3-2: Survey sites for AOD in England and Wales overlain by modelled rainfall (A) and total dry nitrogen deposition (B).

influenced by rainfall (Figure 3-2 A), air temperature, and elevation, with AOD more likely to occur in low-lying areas with low rainfall and high temperatures. Results also show that high dry nitrogen deposition (Figure 3-2 B), low dry sulphur deposition and high base cation deposition, are positively correlated with AOD occurrence. Although the analyses highlighted differences between soil type and soil moisture, these require further investigation at site and tree level. This new understanding of AOD has informed risk mapping and will help to develop best practice management advice. This spatial study re-emphasises the importance of predisposing factors in the oak decline syndrome, and highlights the need to investigate not only the impact of biotic agents and their interactions, but also the ecosystem as a whole beginning with the links to environmental factors.

Further reading

Brown N, Vanguelova E, Parnell S, Broadmeadow S, Denman S, 2018: Predisposition of forests to biotic disturbance: Predicting the distribution of Acute Oak Decline using environmental factors. Forest Ecology and Management 407: 145-154.

3.2 Measuring and interpreting changes in stem increment

Trees are long-lived organisms that adapt slowly – through natural regeneration – to changes in climatic conditions, atmospheric pollution, and other biotic, abiotic and anthropogenic stress factors. Some of these stressors are currently advancing faster than the natural adaptation capacity of forest trees. This is

Figure 3-3: Permanent girth band mounted on a Norway spruce tree.

Figure 3-4: Point dendrometer mounted on an oak tree.

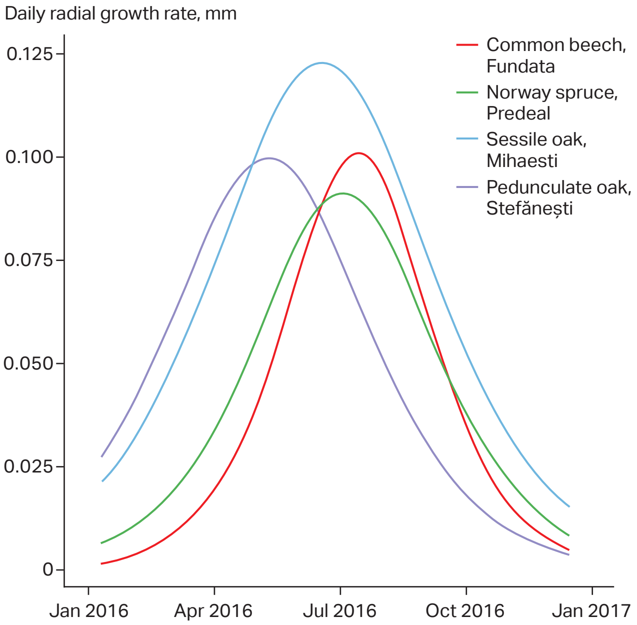

Figure 3-5: Average daily stem radial growth for four tree species on Romanian plots throughout 2016: common beech (*Fagus sylvatica*), Norway spruce (*Picea abies*), sessile oak (*Quercus petraea*), and pedunculate oak (*Q. robur*).

especially true for anthropogenic stress factors and implies a threat to the existence of many tree species, possibly leading to a loss in forest biodiversity. Periods of extreme drought and severe heat can cause decreased tree growth, high levels of tree mortality, and other negative multi-year effects. While carbon availability is increasing due to carbon dioxide release through human activities, tree growth stimulated by nitrogen deposition can help attenuate climate change by sequestering some of this excess carbon in forests.

Changes in tree stem diameter include irreversible woody stem growth and reversible circumference changes related to the water status of trees. Based on the information provided by manually read permanent girth bands (Figure 3-3) and continuous measurements of stem circumference by point dendrometers (Figure 3-4), it is possible to determine stem growth rates as well as the physiological responses of trees to seasonal climatic conditions, especially water availability. This makes it possible to explain the integrated impact of stressors such as ozone and other phytotoxic pollutants, dry and wet deposition, precipitation, and air temperature.

A comparison of change in stem diameter in four tree species as recorded by permanent girth bands over the course of a year (Figure 3-5) shows growth

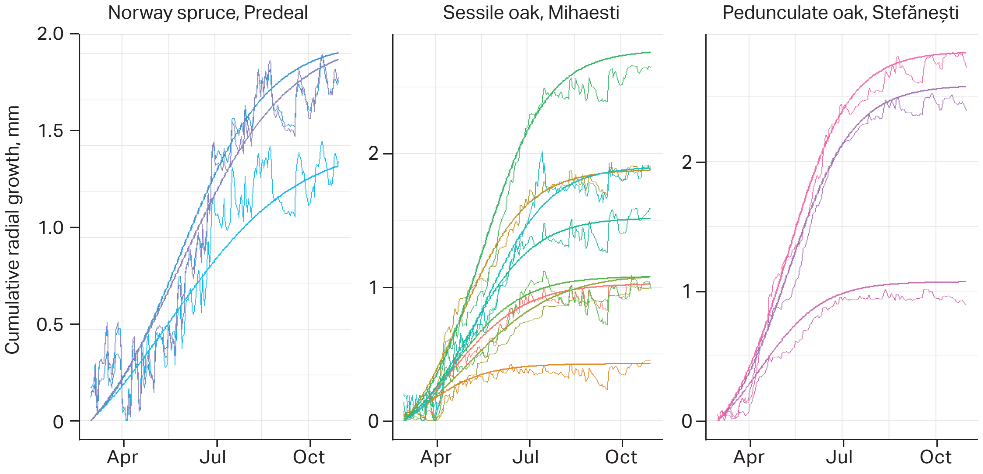

Figure 3-6: Cumulative stem radial growth for different specimens of Norway spruce (*Picea abies*), sessile oak (*Quercus petraea*) and pedunculate oak (*Q. robur*). Two curves are shown per specimen: a smoothed curve and a curve showing average daily values.

in common beech starts and ends comparatively late, but ceases relatively quickly in autumn. The growth cycle for Norway spruce is similar, but growth culminates earlier and shows more activity in spring. Growth of both oak species starts much earlier in spring, however pedunculate oak culminates earlier and shows little activity in late summer to autumn, while sessile oak remains active for longer.

For a number of individual trees, Figure 3-6 compares broad changes in stem growth over a single growing season against daily fluctuations caused by changes in weather. Such data are only available from point dendrometers. The three curves for daily variability in spruce, for example, show simultaneous drops in stem diameter during late summer, presumably caused by a prolonged period of drought.

A similar comparative analysis of variability in stem diameter based on data from permanent girth bands and continuous point dendrometers, was undertaken at two Romanian ICP Forests Level II (intensive) monitoring plots containing sessile oak and Norway spruce. In both plots the resulting growth patterns are similar for permanent girth bands and point dendrometers. Although there is criticism regarding the use of permanent girth bands (due to errors induced by swelling/hydration and shrinkage/dehydration), the results confirm the usefulness of both growth assessment methods. The differences in duration of tree ring formation and in accumulated biomass at inter- and intra-species level can be explained by variation in weather conditions, forest stand health, stand productivity and environmental conditions (altitude, soil, water availability etc.).

Further reading

Badea O, Neagu S, Leca S, Silaghi D, Iacob C, Guiman GH, Teodosiu M, 2011: Trees and stands growth in the forest monitoring system. Revista Pădurilor 126 (3-4): 28-34.

Closing comments

This Executive Report summarises some of the results from basic and advanced monitoring and research activities at ICP Forests plots, especially the ~600 Level II (intensive) monitoring sites. Together with the extensive Level I monitoring network of almost 6000 active plots across large parts of Europe and Turkey, this programme provides a good basis for monitoring and forest research. Results from scientific collaborations or similar programmes at the national or international level are not only welcome at the annual scientific conferences, but may also be included in studies such as that reported in Section 3.1. Monitoring and forest research are both important elements of measures to maintain the productive functions of forests (e.g. timber supply) and to ensure that forests continue to provide shelter and refuge for various organisms, as well as to afford further societal functions such as drinking water provision, substrate stabilisation, recreation, and even spiritual values.

Two examples illustrate the extraordinary potential of the multilateral monitoring and research system of ICP Forests. First, the revised EU National Emission Ceiling Directive (NECD) which entered into force in 2016 and which includes requirements for ecosystem monitoring, is a good example of the legislative integration of forest monitoring activities. Hopefully, monitoring undertaken in accordance with the revised NECD will make use of the methods and experience gained over the past 30 years within ICP Forests. Second, repeated calls for the development of a broad-scale research infrastructure on forest ecosystems have been issued under the EU research programme Horizon 2020. Supporting consortia with ICP Forests in the future will be vital in the further development of wider forest research infrastructures at the European level.

Credits

As editor, Walter Seidling would like to thank all those who have actively contributed to this Executive Report and all those who helped in the planning and realisation of the 6th Scientific Conference at Bucharest, Romania. Thanks are also extended to all those keeping the basic monitoring and research infrastructure of ICP Forests running in the field as well as virtually by feeding and controlling its data infrastructure.

The work in Section 2.2 was funded by the EU within the MSCA individual fellowship (NITRIPHYLL n. 705432) awarded to Rossella Guerrieri and European Research Council Synergy grant ERC-2013-SyG610028-IMBALANCE-P awarded to Josep Peñuelas. Rossella Guerrieri acknowledges the follow-on support from the Royal Society within the Newton International Fellowship for the work at the UK sites.

Participating countries and contacts

Albania: Ministry of the Environment, Forests and Water Administration (*info@moe.gov.al*)

Andorra: Ministeri de Turisme I Medi Ambient, Ms Silvia Ferrer, Ms Anna Moles (*silvia_ferrer_lopez@govern.ad*, *anna_moles@govern.ad*)

Austria: Austrian Research Centre for Forests (BFW), Mr Ferdinand Kristöfel (*ferdinand.kristoefel@bfw.gv.at*)

Belarus: Forest inventory republican unitary company “Belgosles”, Mr Valentin Krasouski (*belgosles@open.minsk.by*)

Belgium, Flanders: Research Institute for Nature and Forest (INBO), Mr Peter Roskams (*peter.roskams@inbo.be*)

Belgium, Wallonia: Service public de Wallonie (SPW), Mr Christian Laurent, Mr Etienne Gérard (*christian.laurent@spw.wallonie.be*, *etienne.gerard@spw.wallonie.be*)

Bulgaria: Executive Environment Agency at the Ministry of Environment and Water Monitoring of Lands, Ms Genoveva Popova (*forest@eea.government.bg*)

Canada: Natural Resources Canada, Mr Pal Bhogal (*pal.bhogal@nrcan.gc.ca*), Ministère des Ressources naturelles, Mr Rock Ouimet (*rock.ouimet@mrnf.gouv.qc.ca*)

Croatia: Croatian Forest Research Institute, Mr Nenad Potočić (*nenadp@sumins.hr*)

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

Czechia: Forestry and Game Management Research Institute (FGMRI), Mr Bohumír Lomský (*lomsky@vulhm.cz*)

Denmark: University of Copenhagen, Department of Geosciences and Natural Resource Management, Mr Morten Ingerslev (*moi@life.ku.dk*)

Estonia: Estonian Environment Agency (EEIC), Ms Endla Asi (*endla.asi@envir.ee*)

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

France: Level I: Ministère de l’Agriculture, de l’Agroalimentaire et de la Forêt, Mr Frédéric Delport, Mr Fabien Caroulle (*frederic.delport@agriculture.gouv.fr*, *fabien.caroulle@agriculture.gouv.fr*), Level II : Office National des Forêts, Mr Manuel Nicolas (*manuel.nicolas@onf.fr*)

Germany: Bundesministerium für Ernährung und Landwirtschaft (BMEL), Ms Sigrid Strich (*sigrid.strich@bmel.bund.de*)

Greece: Hellenic Agricultural Organization “DEMETER”, Mr Panagiotis Michopoulos (*mipa@fria.gr*)

Hungary: National Food Chain Safety Office, Mr László Kolozs (*kolozsl@nebih.gov.hu*)

Ireland: University College Dublin (UCD), Mr Jim Johnson (*jim.johnson@ucd.ie*)

Italy: Ministry for Agriculture and Forestry Policies, Corpo Forestale dello Stato, Ms Angela Farina, Ms Laura Canini (*a.farina@corpoforestale.it*, *l.canini@corpoforestale.it*)

Latvia: Latvian State Forest Research Institute “Silava”, Mr Urdis Zvirbulis (*urdis.zvirbulis@silava.lv*)

Liechtenstein: Amt für Umwelt (AU), Mr Olivier Nägele (*olivier.naegele@llv.li*)

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Lithuania: State Forest Survey Service, Mr Albertas Kasperavicius (*alber_k@lvmi.lt*)

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

Former Yugoslav Republic of Macedonia: Ss. Cyril and Methodius University, Faculty of Forestry, Mr Nikola Nikolov, Mr Srdjan Kasic (*nnikolov@sf.ukim.edu.mk*, *irpc@sumers.org*)

Republic of Moldova: Agency Moldsilva, Mr Stefan Chitoroaga (*icaspiu@starnet.md*)

Montenegro: Ministry of Agriculture, Forestry and Water Management, Mr Ranko Kankaras, Mr Milosavom Anđelićem (*ranko.kankaras@mpr.gov.me*, *milosav.andjelic@mpr.gov.me*)

The Netherlands: Ministry for Health, Welfare and Sport, Ms Esther J.W. Wattel-Koekkoek (*esther.wattel@rivm.nl*)

Norway: Norwegian Institute of Bioeconomy Research (NIBIO), Mr Volkmar Timmermann (*volkmar.timmermann@nibio.no*)

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

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

Romania: National Institute for Research and Development in Forestry (INCDS), Mr Ovidiu Badea, Mr Romica Tomescu (*biometrie@icas.ro*, *obadea@icas.ro*)

Russian Federation: Centre for Forest Ecology and Productivity of the Russian Academy of Sciences, Ms Natalia Lukina (*lukina@cepl.rssi.ru*)

Serbia: Institute of Forestry, Mr Radovan Nevenic (*nevenic@eunet.rs*)

Slovakia: National Forest Centre - Forest Research Institute, Mr Pavel Pavlenda (*pavlenda@nlcsk.org*)

Slovenia: Slovenian Forestry Institute (SFI), Mr Marko Kovač, Mr Primož Simončič (*marko.kovac@gozdis.si*, *primoz.simoncic@gozdis.si*)

Spain: Área de Inventario y Estadísticas Forestales (AIEF), Dirección General de Desarrollo Rural y Política Forestal, Mr Roberto Vallejo, Ms Belén Torres Martinez, Ms Ana Isabel González Abadías (*rvallejo@magrama.es*, *btorres@magrama.es*, *aigonzalez@magrama.es*)

Sweden: Swedish Forest Agency, Mr Sture Wijk (*sture.wijk@skogsstyrelsen.se*)

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

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

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

United Kingdom: Forest Research Station, Alice Holt Lodge, Ms Sue Benham (*sue.benham@forestry.gsi.gov.uk*)

United States of America: USDA Forest Service, Pacific Southwest Research Station, Mr Andrzej Bytnerowicz (*abytnerowicz@fs.fed.us*)

For further information, visit:

www.icp-forests.net

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