ICP Forests

LRTAP
Long-range Transboundary Air Pollution

THE CONDITION OF FORESTS IN EUROPE

2013 EXECUTIVE REPORT

2013

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2013 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)

www.icp-forests.net

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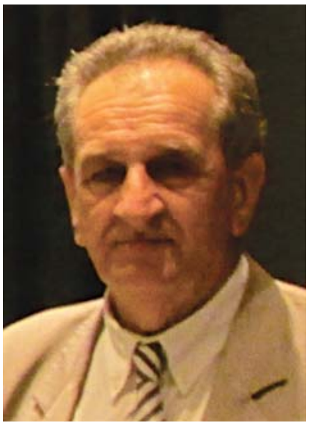
PREFACE



Perica Grbic
Eng. Director – Directorate of Forests

The need to protect and improve the management and monitoring of forest resources across Europe has become increasingly clear in recent years. Forests and their associated resources are immensely valuable to the economies and welfare of both developing and developed nations and there is worldwide concern over the impacts of global climate change on forests as well as the rate at which this change is taking place. Forests are one of the most important terrestrial ecosystems, of vital significance for sustaining the balance between oxygen and carbon in the atmosphere and they are under threat.

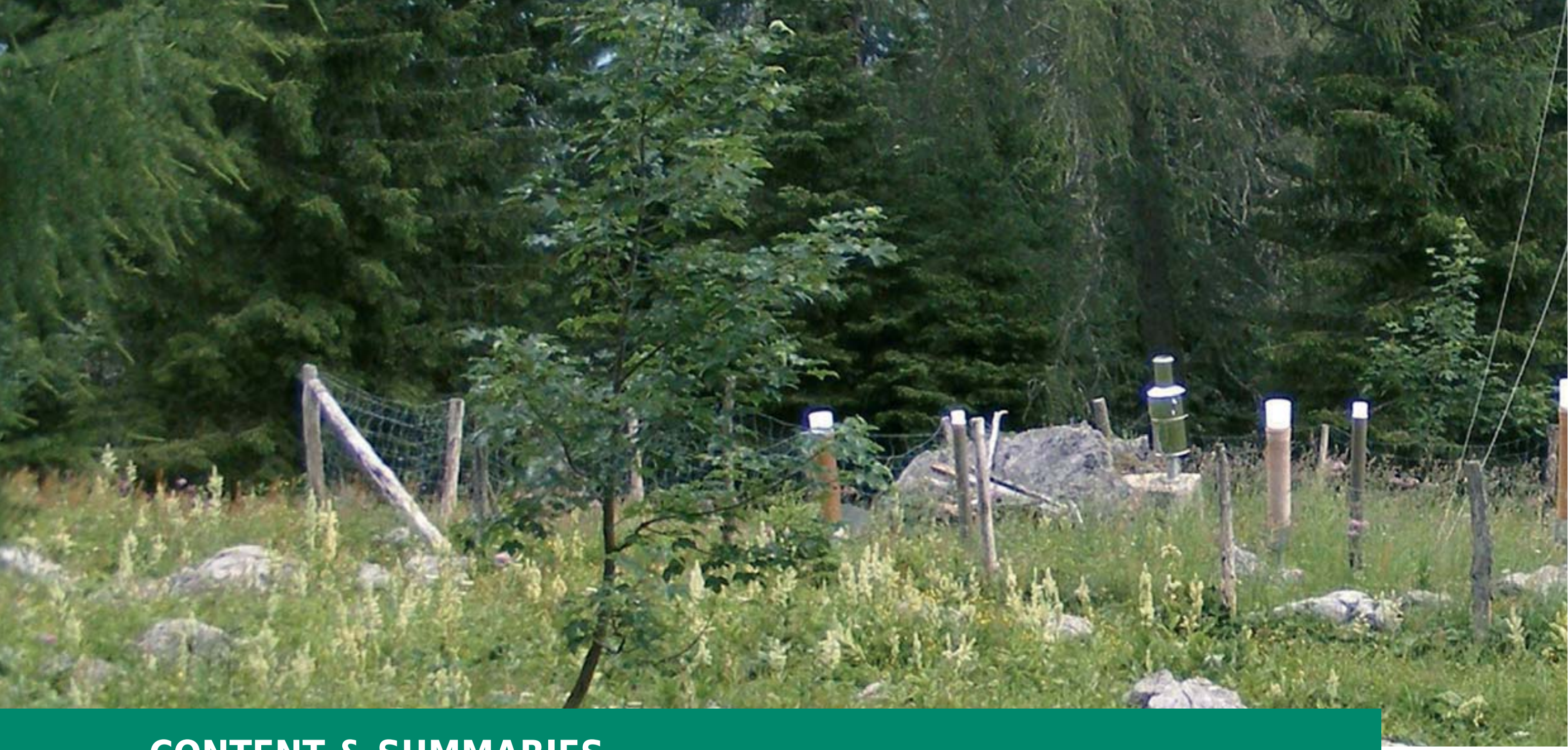
Forests provide key ecosystem services – they regulate climate, sequester carbon, protect watersheds, and help conserve biodiversity. Many of our decisions are made without a full understanding of the value of these ecosystem services, or of the rate at which forests are being lost in the pursuit of more immediate economic gains. Sophisticated forest observation systems and methodologies are now available and the need for accurate information on change within forests is increasing. Thus, our common understanding of forest change and air pollution effects on forests will improve dramatically.

Good and effective communication between scientists and forestry experts within the context of monitoring forest condition is a prerequisite for establishing the values, issues, risks, and challenges related to global change. Proposing measures for integrated sustainable land use of the key ecosystems on the planet is now possible and will help to limit the adverse impacts of air pollution and other anthropogenic impacts on forest condition.

Ministry of Agriculture, Forestry and
Water Management

Republic of Serbia

Perica Grbic
Director – Directorate of Forests



CONTENT & SUMMARIES

Just over three-quarters (78%) of the atmosphere comprises inert nitrogen which has very limited availability for biological use.

All terrestrial ecosystems need reactive nitrogen and historically this has been in short supply. Artificial nitrogenous fertilizers and fossil fuel combustion are both sources of reactive nitrogen and their use has dramatically altered the global nitrogen cycle.

1. ATMOSPHERIC DEPOSITION

Nitrogen deposition largely originates from fossil fuel combustion and animal husbandry. Deposition is highest in central Europe. Only a minor decrease in deposition has been measured on intensive monitoring plots over the past decade (see p. 6).

2. LICHENS

Lichens are very sensitive indicators of nitrogen deposition. Deposition is high on 75% of the European forest plots and this is reflected in the change in lichen species composition over time (see p. 8).

3. MOSSES

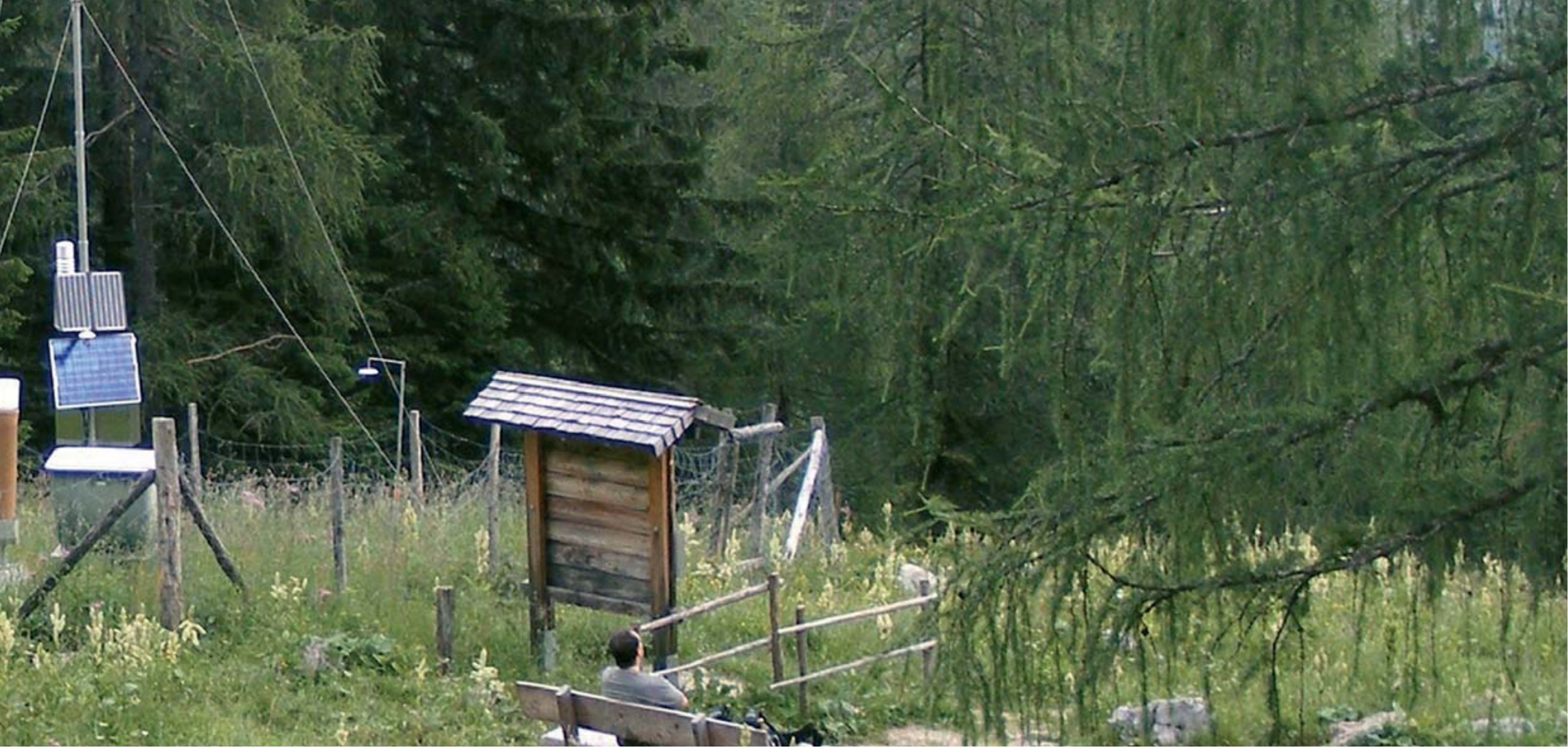
Mosses absorb most of their nutrients and water across their surface. As a result, they are directly affected by atmospheric deposition. In a study carried out in Austria, Croatia, Italy, and Slovenia the nitrogen content in mosses significantly increased with increasing nitrogen deposition (see p. 10).

4. FUNGI

Fungal species diversity and structure significantly decrease with increasing nitrogen deposition. On a European transect through nine countries, 393 mycorrhizal species were determined. These fungal types live in symbiosis with tree roots and play a major role in nutrient uptake by trees (see p. 12).

5. SOIL SOLUTION

An analysis of trends on the Level II plots showed exceedances of critical limits for nitrogen in the subsoil on 50% of the plots. Leaching is mainly dependent on nitrogen deposition with other factors playing a relatively minor role (see p. 14).



Open field site with meteorological equipment and deposition samplers in Berchtesgaden (Germany), complementing the Level II plot within the forest.

6. LITTERFALL

Litterfall and its decomposition are critical processes for transferring nutrients from above-ground forest biomass to soils. Tree species composition (and thus foliar litter chemistry) affects nitrogen cycling rates at the scale of entire forest stands; for example, the scale of the nitrogen transfer in litterfall determines the amount of nitrogen available for tree growth (see p. 16).

7. SOIL SOLID PHASE

Soils play a key role in nitrogen cycling and storage within ecosystems. They host nitrogen-fixing microorganisms, as well as those that release nitrogen back into the air. Mineralization of organically-bound nitrogen takes place within soils and converts nitrogen to a form available for tree growth. Loss of nitrogen from the soil is mainly through harvesting and leaching. One of the key questions concerns the saturation status of European forest soils (see p. 18).

8. GROUNDWATER QUALITY

Rain water containing dissolved nitrogen is pulled downwards through the soil by gravity, this is known as leaching. Leaching may affect the quality of drinking water pumped up from groundwater. In forests on sandy soils in the Netherlands nitrogen-leaching has decreased by 55% over the past 20 years, showing the success of emission reduction policies (see p. 22).

9. EFFECTS ON TREES

9A FOLIAGE NUTRIENT BALANCE

Soil nitrogen generally stimulates plant growth. However, excess nitrogen can cause other nutrients such as magnesium to become deficient. This can affect forest health and enhance the effects of additional stress factors. Nutrient imbalances were detected in leaves and needles on 10% of the nitrogen-saturated plots (see p. 24).

9B CROWN CONDITION (TREE HEALTH)

Effects of nitrogen deposition on leaf and needle loss can be detected at a local level for some tree species. These impacts are compounded by the effects of weather, insects and diseases, and soil condition (see p. 26).

9C STEM GROWTH

Nitrogen acts as fertilizer for trees. At sites with low nitrogen soil levels, atmospheric nitrogen inputs increase growth. But on nitrogen-saturated plots, even high atmospheric nitrogen inputs have no impact on tree growth (see p. 30).

10. CONCLUSIONS

Assessing the input of nitrogen to forests and the direct and indirect responses of forest trees are core activities of the large-scale and intensive monitoring of forest ecosystems in Europe. ICP Forests provides policy makers with key information for forest management, especially under the projected future climatic changes (see p. 33).

1. ATMOSPHERIC DEPOSITION

LARGE REGIONAL VARIATION IN NITROGEN DEPOSITION

Nitrogen deposition was measured on 219 ICP Forests Intensive ICP Forests Intensive Monitoring (Level II) plots in 24 countries across Europe in 2011.

High deposition levels were recorded in the forests of central Europe, from Denmark to the Swiss Plain. For ammonia the regions of high deposition also extend further westward, to northern France, the central UK and Ireland. In the Mediterranean area, relatively high values were only recorded at sites in Spain and southern France.

SLIGHT DECREASE IN NITROGEN DEPOSITION ACROSS EUROPE

Trends in nitrogen deposition across Europe are based on data from 83 plots with continuous measurements between 2002 and 2011 (Fig. 1-1).

The mean combined throughfall deposition of nitrate (NO_3) and ammonia (NH_4) decreased from ~13 to ~9 kg N ha^{-1} a^{-1} between 2002 and 2011 and the mean combined bulk deposition from ~10 to ~7 kg N ha^{-1} a^{-1} (Fig. 1-2). This is a decline of around 30% and corresponds to a mean decrease of about 3% per year. However, the situation on individual plots may differ from the mean trend.

HIGH REGIONAL NITROGEN LOADS STILL LIKELY IN THE FUTURE

Model results (not depicted) suggest that by 2020 critical deposition loads for nutrient nitrogen will still be exceeded on up to 50% of the land surface of the EU depending on the scenario used.

Critical nitrogen deposition loads in Europe are generally widely exceeded.

Collection of stem flow is important on trees with a smooth bark like European beech (*Fagus sylvatica*) (Freising, Germany).

To minimise errors due to contamination, several deposition samplers are run in parallel at the open field site in Gronik, Slovakia.

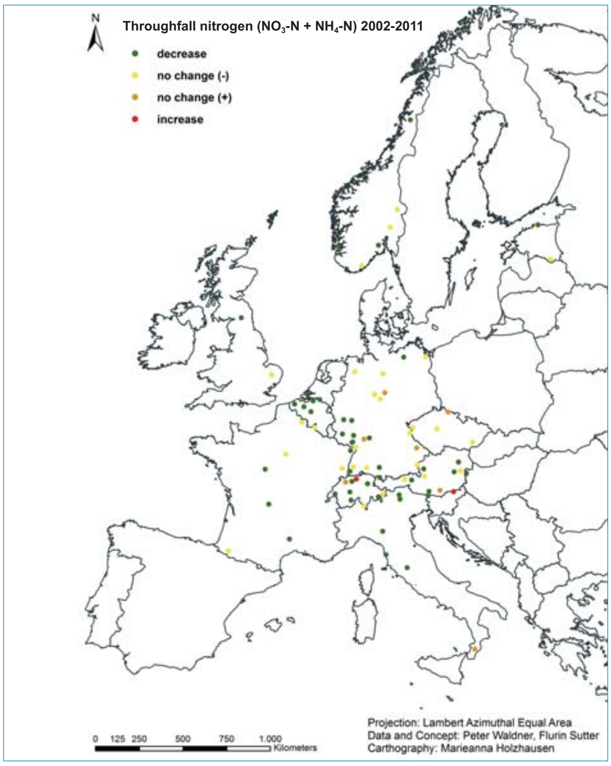


Figure 1-1: Temporal trends of nitrogen throughfall deposition (nitrate and ammonia) at 83 Level II plots in 10 countries across Europe with continuous measurements between 2002 and 2011.

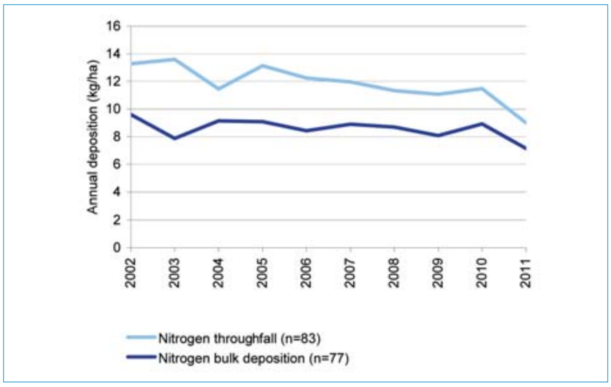


Figure 1-2: Trends in throughfall and bulk nitrogen deposition in European forests over the past decade. Bulk deposition measurements are carried out on an open field close to the forest stand, whereas throughfall deposition is measured below the forest canopy. Throughfall deposition is generally higher than bulk deposition as tree canopies filter deposition from the air and are therefore enriched. Also, total deposition of nitrogen to forests is generally even higher than throughfall of ammonia and nitrate, because (i) nitrogen is partly taken up in the canopy by the leaves or needles and (ii) because nitrogen transformed to organic nitrogen is not included here.

2. LICHENS

IDEAL BIOMONITORS FOR AIR POLLUTANTS

Lichens depend on the atmosphere for nutrition. They take up water, nutrients and gases over their entire surface and so respond directly to changes in atmospheric pollution. This is particularly the case for lichens growing on other plants such as trees (epiphytic lichens).

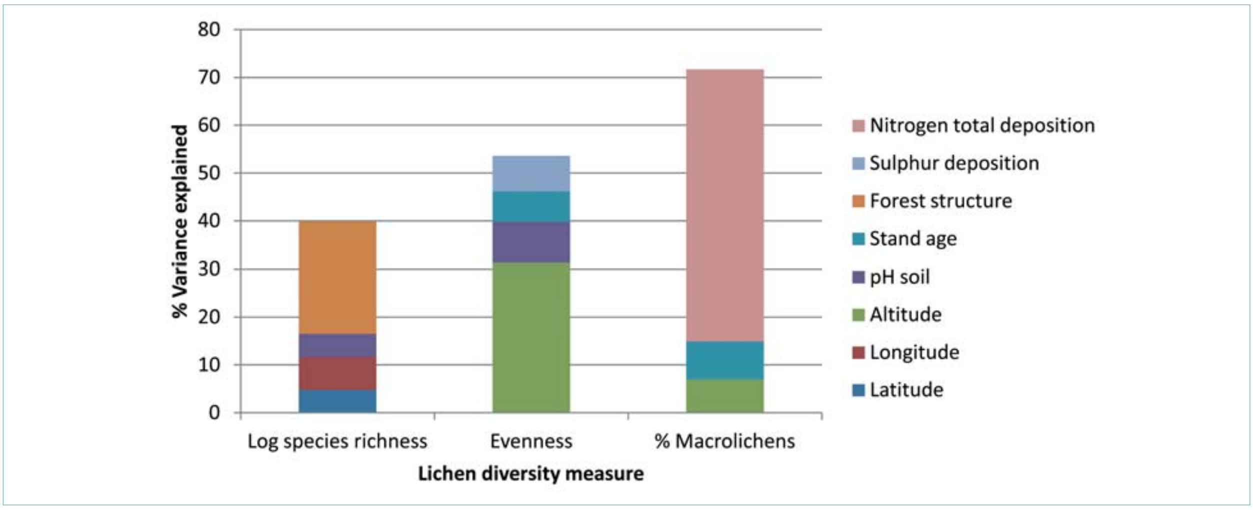
NITROGEN IMPACTS GREATEST ON MACROLICHENS

Epiphytic lichen species were determined on 83 Level II plots. In total, 292 species were found on the 1155 trees assessed. Results show that in addition to climatic factors such as rainfall, regional variation in temperature, and site factors such as soil acidity (pH), stand age, and forest structure, lichen diversity was clearly influenced by nitrogen and sulphur deposition (Fig. 2-1).

While total species richness mainly reflects the typical climatic and site factors, recent sulphur deposition appears to have some impact on the quantitative composition of lichen cover on tree bark. What is particularly striking though is the strong influence of total nitrogen deposition on the abundance of macrolichens and this probably reflects the high surface area to volume ratio of these species.

The correspondence between nitrogen deposition and the percentage of macrolichens recorded, allows the derivation of a critical load (CLO) value of 2.4 kg ha^{-1} a^{-1} (Fig. 2-2).

Figure 2-1: Environmental factors explaining (R^2) different aspects of epiphytic lichen species diversity.



Lichens are highly sensitive to atmospheric pollutants and can therefore be used as indicators of air quality. Lichens and aerial algae on cork oak (*Quercus suber*) near Rome, Italy (left) and *Hypogymnia physodes* associated with crustose and leprose lichens on oak in Berlin, Germany (right).

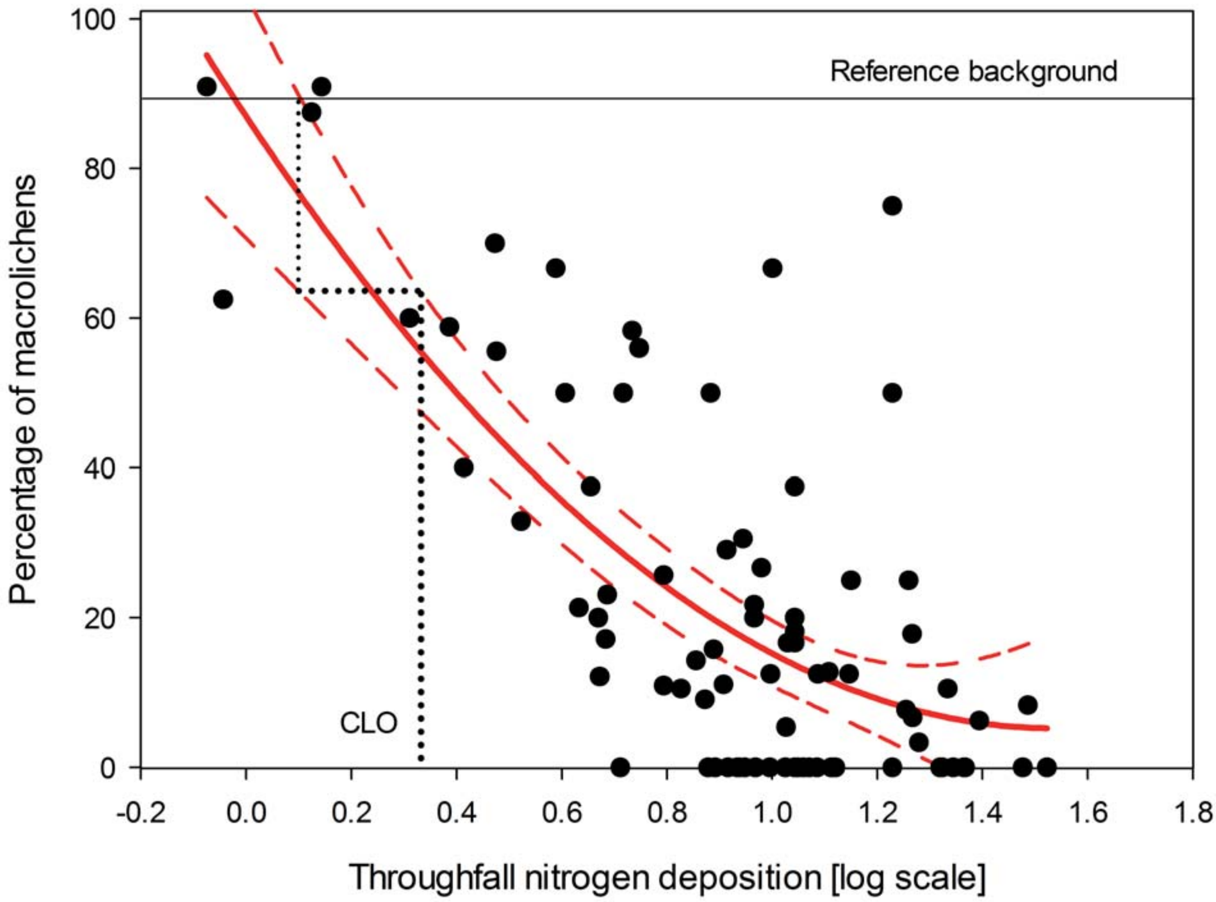


Figure 2-2: Percentage of lichen species adapted to nutrient-poor conditions as a function of nitrogen deposition on the Level II monitoring plots.

3. MOSSES

MOSSES AS MONITOR ORGANISMS

Most mosses are ectohydric; they absorb water and nutrients across their surface directly from rain, fog, mist, and dew. Their rooting system is poorly developed and they lack an outer protective layer on aboveground plant sections (cuticle).

In this, mosses differ from most flowering plants which absorb water and nutrients over roots in the soil. The idea of using mosses for monitoring air pollution first appeared in the late 1960s.

MOSSES READILY AVAILABLE ALMOST EVERYWHERE

Monitoring atmospheric nitrogen levels using mosses is easier and cheaper than conventional analyses of precipitation or air and so a much higher sampling density can be achieved.

Using a combination of the two, makes it possible to obtain detailed local air pollution data (conventional monitoring) as well as more detailed spatial patterns of pollutants (biomonitoring).

MOSSES ACCUMULATE NITROGEN

Many studies have used mosses to assess the ongoing increase in nitrogen pollution. The relationship between the nitrogen content of the moss *Hypnum cupressiforme* (Fig. 3-1) and the nitrogen content of wet deposition (NH_4-N + NO_3-N) was examined on 14 ICP Forests Level II plots in Slovenia (8), Austria (3), Italy (2), and Croatia (1).

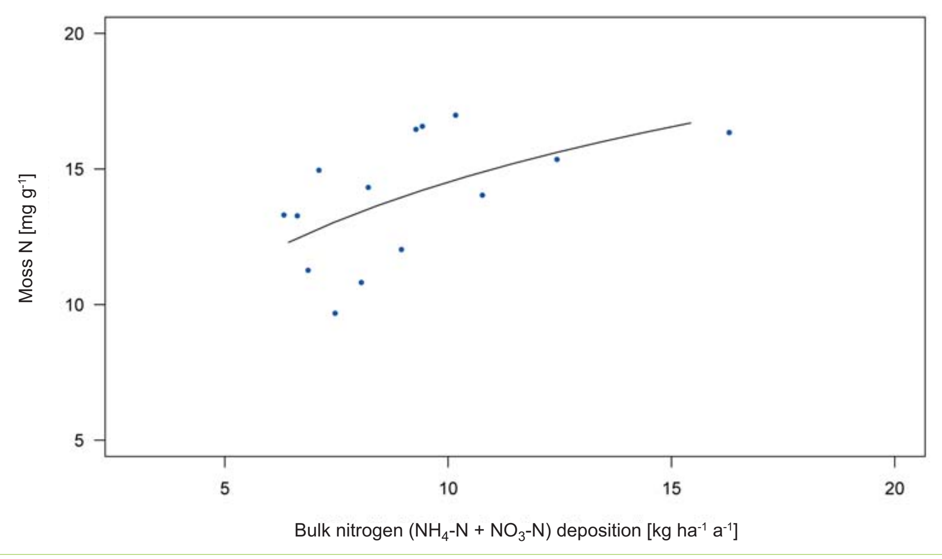
The results revealed a weak but significant correlation between nitrogen content in moss and nitrogen content in deposition. This indicates the usefulness of this type of monitoring (Fig. 3-2).

Figure 3-1: Moss (*Hypnum cupressiforme* Hedw.).

Extensive moss cover in the Nefcerka valley in the High Tatras, Slovakia.

Common hair moss (*Polytrichum commune*) in the Leningrad region, Russia.

Figure 3-2: Non-linear relationship between the nitrogen content of moss and the annual total wet open-field (bulk) nitrogen deposition (NH_4-N + NO_3-N) at Level II plots in southern Europe.



4. FUNGI

Cep (*Boletus edulis*) in a spruce (*Picea abies*) dominated stand in Polána, Slovakia.

FUNGI AT THE INTERFACE BETWEEN SOIL AND TREES

Ectomycorrhizal (ECM) fungi cover nearly all the fine roots of trees in boreal and temperate forests, thus effectively functioning as the interface between trees and soil. These fungi provide trees with most of their water and soil nutrients in exchange for sugar. An ectomycorrhiza is the symbiotic produced structure formed between a fine root of a tree and a fungus (Fig. 4-1).

So far, mycorrhizal assessments have been carried out in 12 Scots pine (*Pinus sylvestris*) plots in England and Germany and 22 oak plots (*Quercus robur* and/or *Q. petraea*) across nine countries from Spain to Romania (Fig. 4-2). Over 3000 soil cores have been examined and over 10 000 mycorrhizas analyzed using DNA-based techniques that identified 112 fungi in pine and 393 in oak forests. An ongoing project will include over 100 plots of spruce, pine and beech.

FUNGI RESPOND TO NITROGEN DEPOSITION

At the continental scale, nitrogen pollution and acidification drive ECM communities through their impacts on tree roots, fungi and soil conditions. The critical nitrogen load for ECM communities in European oak forests is estimated at 9.5–13 kg N ha^{-1} a^{-1}; above 17 N ha^{-1} a^{-1} communities suffer a more drastic change. Nitrogen deposition decreases species richness of ECM communities, and shifts dominance towards nitrophilic fungi resulting in a decrease or even loss of nitrogen-sensitive fungi. For instance, species of *Tricholoma*, *Cortinarius* and *Piloderma* show a consistently negative response to increasing nitrogen inputs and are not detected in plots receiving over 20 kg N ha^{-1} a^{-1}.

Although soil pH variation is mainly driven by soil characteristics, it tends to decrease with increasing levels of nitrogen deposition. Fungal richness and evenness both decline when soil pH decreases, leading to dominance by acidophilic fungi. For instance, the generalist fungi *Scleroderma citrinum* and *Russula parazurea* appear and increase in oak plots as nitrogen deposition increases and pH decreases.

Root density is an important factor related to ECM community composition. Plots with higher nitrogen deposition have lower root density and less even communities – probably because trees need fewer fine roots when abundant inorganic nitrogen is available and this leads to increased fungal competition for roots.

EACH FUNGAL SPECIES HAS ITS OWN NICHE

Different ECM fungi play different functional roles in forests, for example accessing different nitrogen pools and conferring drought tolerance or resistance to pathogens. Fungi with different exploration types (such as specialised for long-, medium- or short-distance transport) respond strongly to eutrophication and acidification in European oak forests. The effects of changes in the presence and proportions of different ECM functional groups across Europe merit investigation because they are likely to affect tree growth and determine the resilience of forests to environmental change.

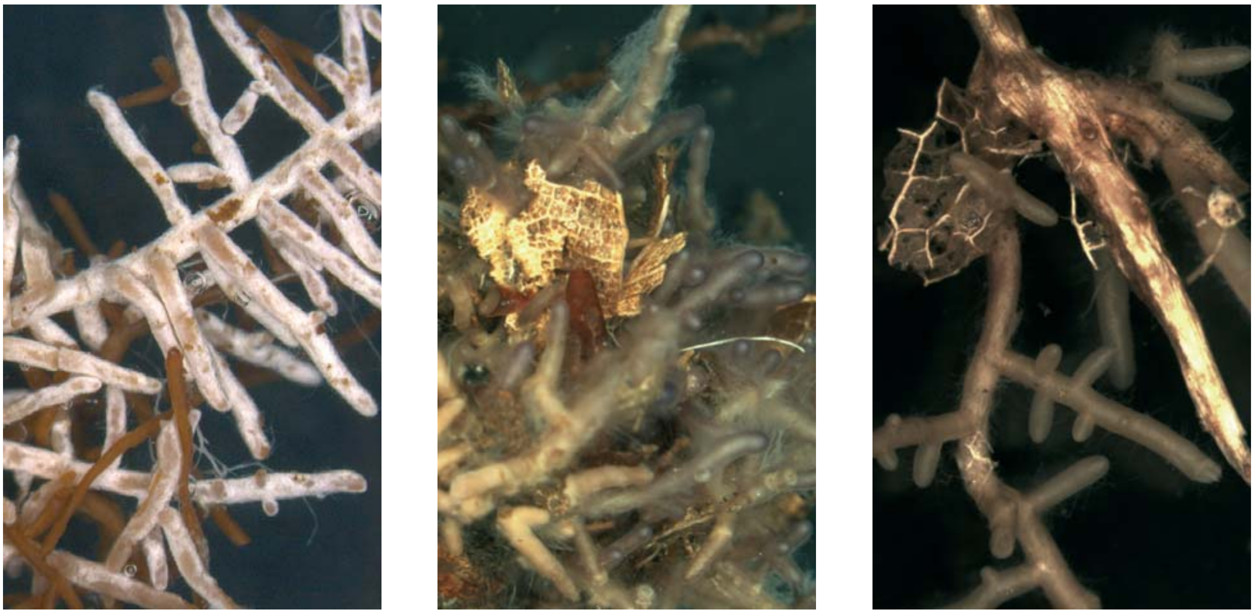


Figure 4-1: Roots of oak trees forming mycorrhizas with different fungi. Left: the puffball *Scleroderma citrinum*, middle: the mushroom *Laccaria amethystina*; right: the truffle *Elaphomyces muricatus*.

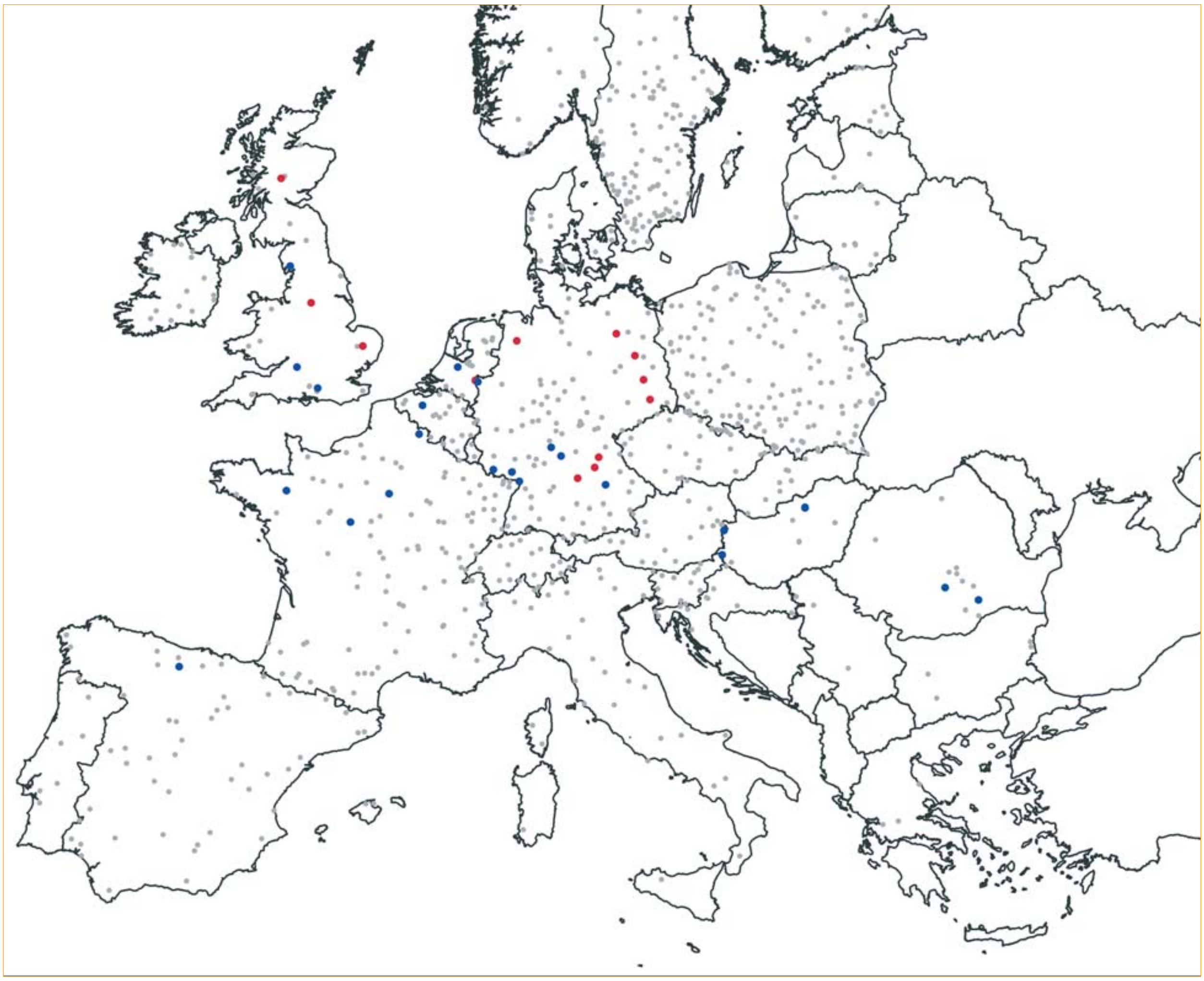
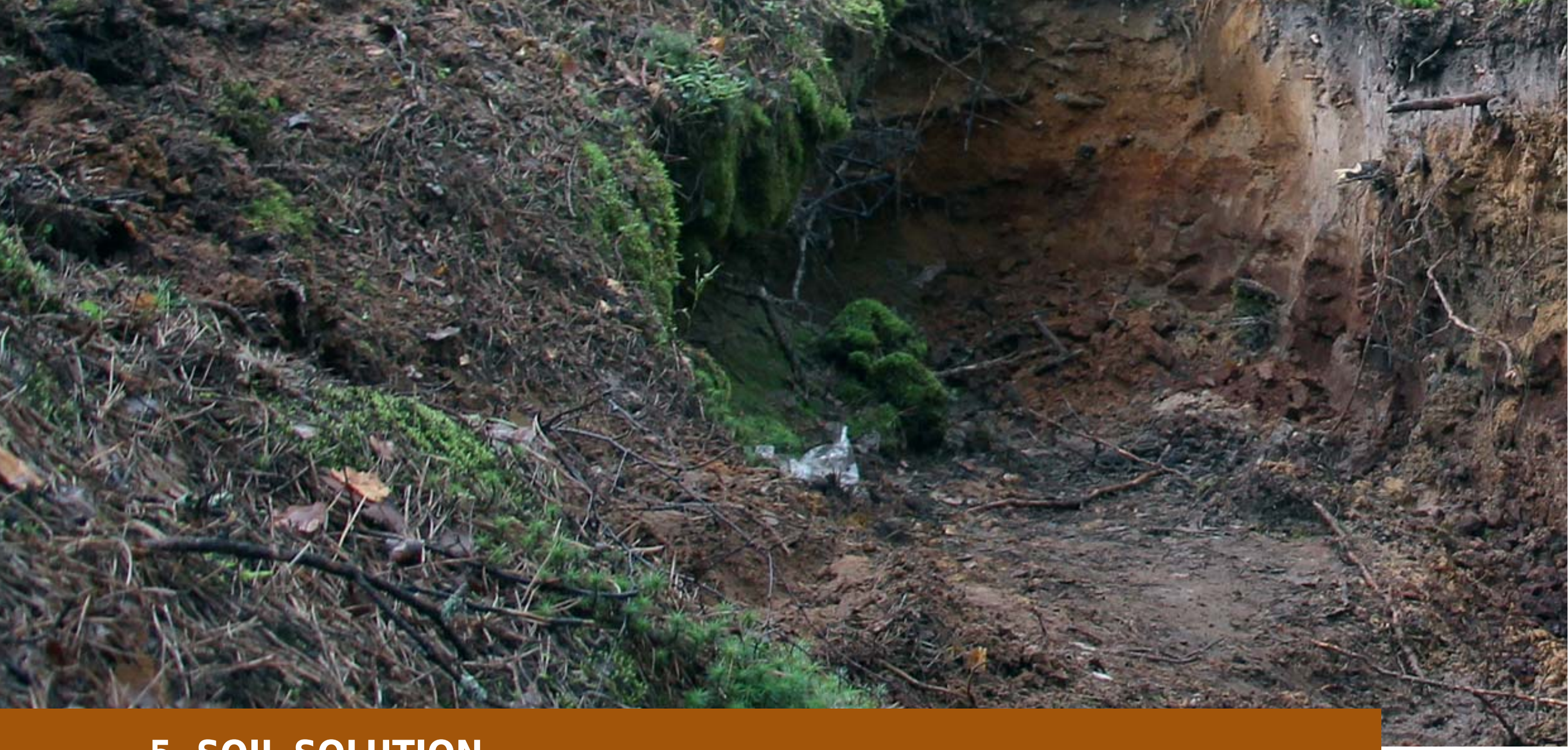


Figure 4-2: Plots sampled for the mycorrhizal assessments. Grey dots: Level II sites; blue dots: oak plots; red dots: Scots pine plots.



5. SOIL SOLUTION

SOIL SOLUTION: EXCHANGE MEDIUM IN SOILS

Over the past ten years, many studies have identified the factors influencing nitrate leaching from European forest ecosystems. The 'Indicators of Forest Ecosystem Functioning' (IFEF) database is a compilation of nitrogen input/output flux studies including 248 sites mainly distributed throughout northern, eastern and central Europe and the database for ICP Forests Intensive Monitoring (Level II) plots containing validated original data submitted by the participating countries.

There are 254 Level II plots with continuous chemical analysis of the soil solution. The studies at the European scale have shown that nitrate leaching depends on nitrogen deposition.

Many studies have also highlighted the role of soil conditions (such as temperature, moisture, acidity) in controlling nitrogen concentrations in the soil solution. For most of these relationships, differences were observed between coniferous and deciduous forests. The critical limit of 1 mg N l^{-1} leading to nitrate leaching was exceeded in the mineral subsoil in 50% of the 173 selected Level II plots, in particular those in the Netherlands and Belgium.

Multiple influences can therefore be determined leading to different overall trends.

DISSOLVED NITROGEN: MANY CAUSES – ONE EFFECT

Temporal trends of nitrogen in soil solution have been analysed in several countries participating in the ICP Forests programme. Decreasing trends in nitrate fluxes reflecting declining nitrogen deposition were observed at individual sites (Tab. 5-1).

In many studies, changes in concentration or leaching were mainly attributed to disruption of the nitrogen cycle caused by cuttings, storm felling (Fig. 5-1), tree decline, or pest attacks (Fig. 5-2). Stand age and soil water regime also caused annual variation in nitrate leaching from the root zone.

A large number of studies indicated that most of the nitrogen received from atmospheric deposition was retained in the soil, particularly in northern Europe, where forest ecosystems are still nitrogen-limited.

Sampling of soil solution on a Belgian Level II plot.

Soil profile with moss cover in the southern Taiga, Russia.

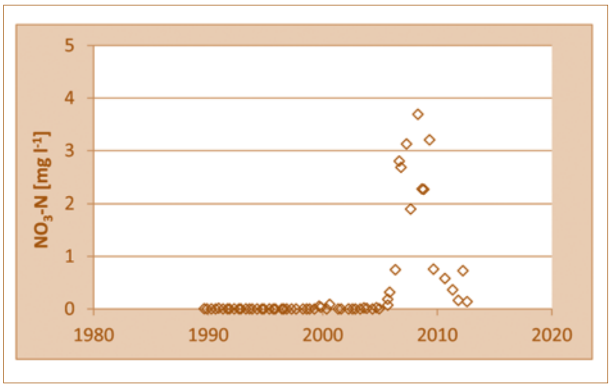


Figure 5-1: Change in nitrate-nitrogen concentration in soil solution after storm felling of trees (data from the SWETHRO network).

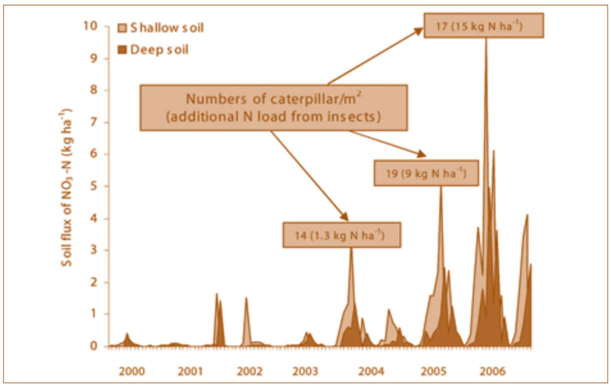


Figure 5-2: Change in nitrate-nitrogen fluxes from soils after periodic insect attack.

Table 5-1: Explanatory factors for changes in nitrate concentrations or fluxes in solutions collected from the subsoil of Level II plots across Europe (10 years of monitoring at least); orange: reported frequently, blue: reported occasionally.

Pluri-annual changes in mineral nitrate in subsoil solutions	**Explanatory factors**
Increase	Cuttings, storm fellings, tree decline, pest attacks
Decrease	Declining nitrogen deposition
No trend	Immobilisation in the soil

6. LITTERFALL

PERFECT RECYCLING

In forested ecosystems, litterfall is the largest source of organic material and nutrients in the soil humus layer. It represents a major pathway through which soils, depleted through nutrient uptake and leaching, are replenished. In addition, litterfall represents one of the primary links between producer and decomposer organisms. Thus the amount and quality of litterfall provide considerable information about the dynamics of nutrient cycling within forest ecosystems.

The amount of annual litterfall can vary considerably, and is related to the weather conditions that differ from year to year. Nutrient concentrations in litter are affected by several factors, such as tree species, soil properties, climatic factors, and tree growth rates. Furthermore, concentrations vary between the different components of litterfall and are usually highest in flowers, followed by leaves, then bud scales, and lowest in branch litter.

NITROGEN IN LITTERFALL VARIES CONSIDERABLY

The most common tree species on ICP Forests plots are beech (*Fagus sylvatica*), Norway spruce (*Picea abies*), and Scots pine (*Pinus sylvestris*). Nitrogen concentrations in total litterfall vary from 5.6 to 17.3 mg g^{-1} and from 8.1 to 12.9 mg g^{-1} in foliar litter, decreasing in the order beech > spruce > pine. Long-term trends of nitrogen in foliar litter were studied at some German and Finnish ICP Forests plots. Although results from selected plots appear to show a slight increase, there is no overall trend over time (Fig. 6-1). However, there is a clear spatial trend in nitrogen concentration in litterfall needles of Norway spruce and Scots pine, with concentrations decreasing northwards.

NITROGEN TURNOVER RATES WITH LITTERFALL ARE LOWER THAN FOR CALCIUM

A study at ICP Forests plots in Finland showed that about 2% of the above-ground tree biomass was returned annually to the forest floor as litterfall (= turnover rate); with this 2% of tree biomass accounting for about 6% of the soil nitrogen pool in spruce and pine stands. More needles ended up on the forest floor as senescent needles (foliar litter) on the spruce plots (1793 kg ha^{-1}) than on the pine plots (1251 kg ha^{-1}), although the proportion of senescent needles in relation to living needle mass of the trees was higher in the pine stands (38%) than the spruce stands (15%).

For example, an average of 15 kg ha^{-1} a^{-1} of needle nitrogen was recycled back to the soil on the spruce plots, but only 7 kg ha^{-1} a^{-1} on the pine plots, which is clearly affecting the nutrient status of the soil.

The nitrogen turnover rate for pine needles (14%) was higher than for spruce (10%), indicating that over 85% of nitrogen had been translocated back into the trunk or living needles. In contrast, the turnover rate in needles of the least mobile nutrient calcium (Ca) was over 60%.

Litterfall collectors and deposition samplers in a Scots pine (*Pinus sylvestris*) stand at Schorfheide, Germany.

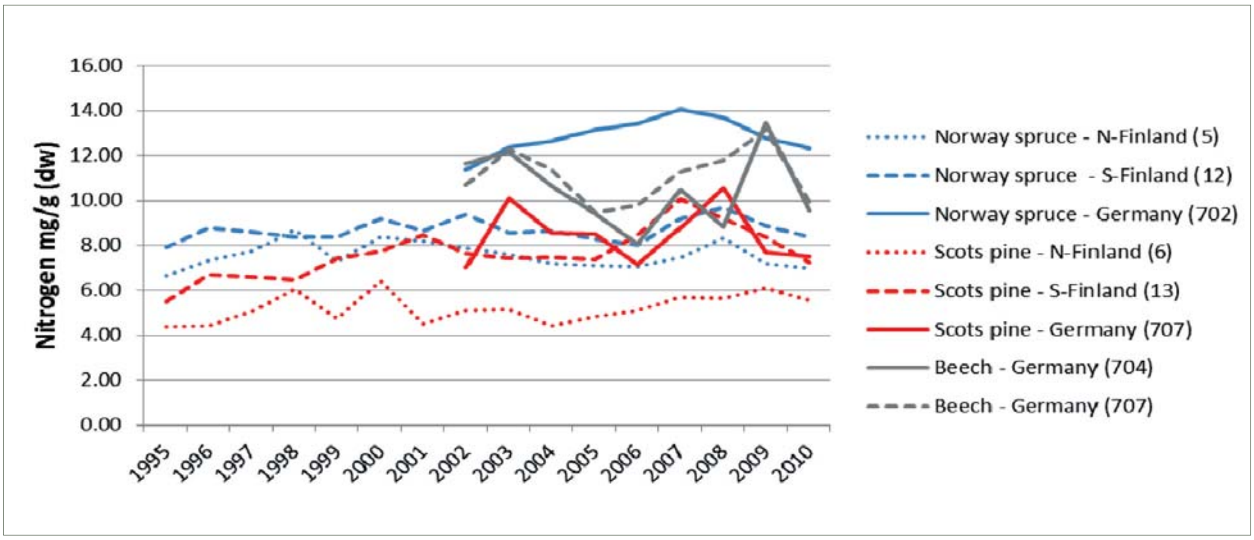


Figure 6-1: Nitrogen concentration in foliar litter at some Finnish (1995-2010) and German (2002-2010) ICP Forests Level II plots.

Litterfall collectors in a Scots pine (*Pinus sylvestris*) stand as part of the British Level II network.

7. SOIL SOLID PHASE

SOLID SOIL AND THE NITROGEN CYCLE

The forest soil nitrogen cycle is connected to the global nitrogen cycle via several pathways, including biological N_2 fixation and denitrification (release of N_2, NO and N_2O to the atmosphere), as well as NO_3^- leaching, and the deposition of nitrogen compounds (NH_x and NO_y). Inputs of nitrogen to forest soils originate from the decomposition of plant matter, nitrogen-fixation by microbes, atmospheric deposition, and from fertilizers.

Losses of nitrogen from soils occur mainly through tree harvesting, direct emissions from soil, and leaching. Within the soil, nitrogen cycles between plant roots, decomposing organic matter, and soil microorganisms (Fig. 7-1).

Soil profile in the southern Taiga in Russia.

FOREST ECOSYSTEM SERVICES: REGULATION OF GLOBAL CLIMATE AND SOIL QUALITY

Most studies conclude that forests will become increasingly nitrogen-saturated in the future. Higher NO_3^- leaching rates across Europe are expected on the basis that the overall rate of nitrogen deposition is not likely to decrease significantly.

On the one hand, nitrogen-leaching is likely to increase at nitrogen-saturated sites due to higher mineralization rates in response to climate change. Although the combined effects of warming and increased atmospheric levels of carbon dioxide (CO_2) may, however, increase nitrogen demand in the more nitrogen-limited systems. On the other hand, once forests are nitrogen-saturated, they become more responsive to changes in nitrogen deposition; there is only a very short lag between reductions in nitrogen deposition and a proportional decrease in nitrogen-leaching.

Forests play an important role in the regulation of global climate by sequestering carbon, both in the soil and in biomass. Increased atmospheric CO_2 concentrations stimulate forest growth and the storage of above-ground carbon, provided that other nutrients such as nitrogen are not growth limiting. So the CO_2 fertilizer effect on tree growth is unlikely to occur in nitrogen-limited systems.

Soil profiles sampled during the British BioSoil campaign featuring a brown earth (left) and a gley soil (right).

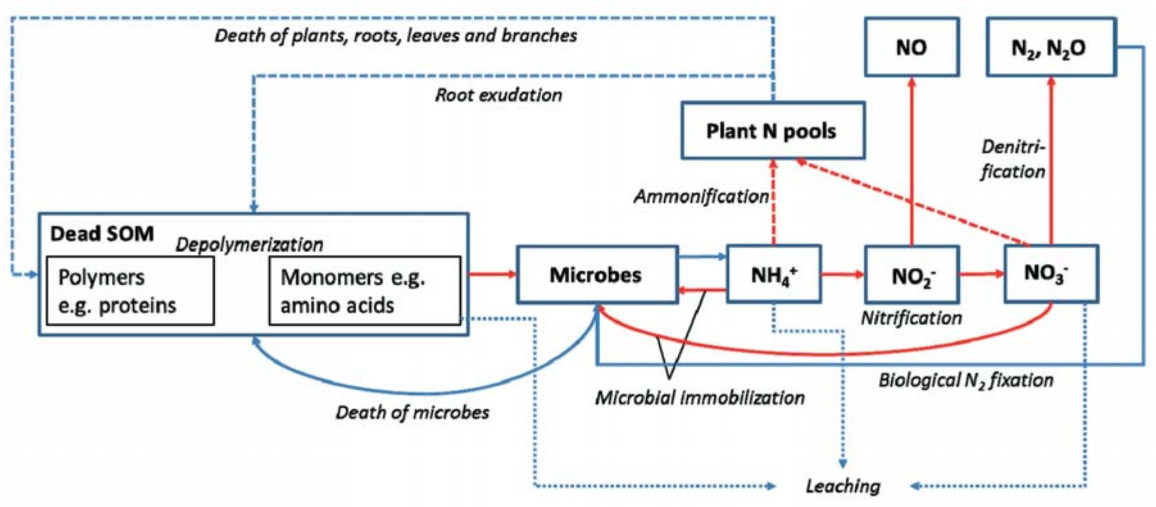


Figure 7-1: Nitrogen cycling between plants, organic matter and microbes in forest soils (after Rennenberg et al. 2009); black dashed lines: plant processes; solid lines: microbial processes; red dashed and solid lines: competitive processes between plants and microbes; blue lines: hydrological transport pathways; SOM: soil organic matter.

MAJOR ROLES OF SOLID SOIL IN THE FOREST NITROGEN CYCLE

- Within temperate forest ecosystems, soils represent the largest nitrogen pools (8.0 ± 6.7 t N ha^{-1}, see Fig. 7-2). On average, 85% of the total ecosystem nitrogen capital is stored in the soil. Within the soil, nitrogen is bound to organic matter and rarely accumulates to any signifcant extent on mineral soil exchange complexes (for example, NH_4^+ fixation at soil exchange sites).
- Excess nitrogen is lost from soils in the form of nitrate into groundwater and streams or is emitted as a gas.
- The C:N ratio of the soil is of great importance in the balance between nitrogen mineralisation and nitrogen immobilisation. Soil microbes use carbon as an energy source. High C:N ratios favour immobilisation and incorporation of nitrogen into the microbial biomass. Low C:N ratios may result in a rapid conversion of microbial nitrogen into nitrate.
- While soil texture directly affects the size of the C and N pools, it is mediating the C and N dynamics through its influence on the soil climate (soil moisture and temperature).
- The pH of the soil plays a role in the release of NO and NO_2, the latter especially when C:N ratios are low. The reduction in soil pH resulting from nitrification and/or directly from deposition may affect the nitrogen cycle in many ways.

NITROGEN SATURATION IN EUROPEAN FOREST SOILS

Input–output budgets for European forests show that above a threshold of about 10 kg ha^{-1} a^{-1} of nitrogen in throughfall, many sites appear nitrogen-saturated and have nitrate-leaching rates of over 5 kg ha^{-1} a^{-1}. Emissions of NO and N_2O from European forest soils may indicate nitrogen-saturation.

In terms of regulating soil quality, continued nitrogen deposition and NO_3^- leaching will continue to result in soil acidification.

Rendzina sampled during the British BioSoil campaign.

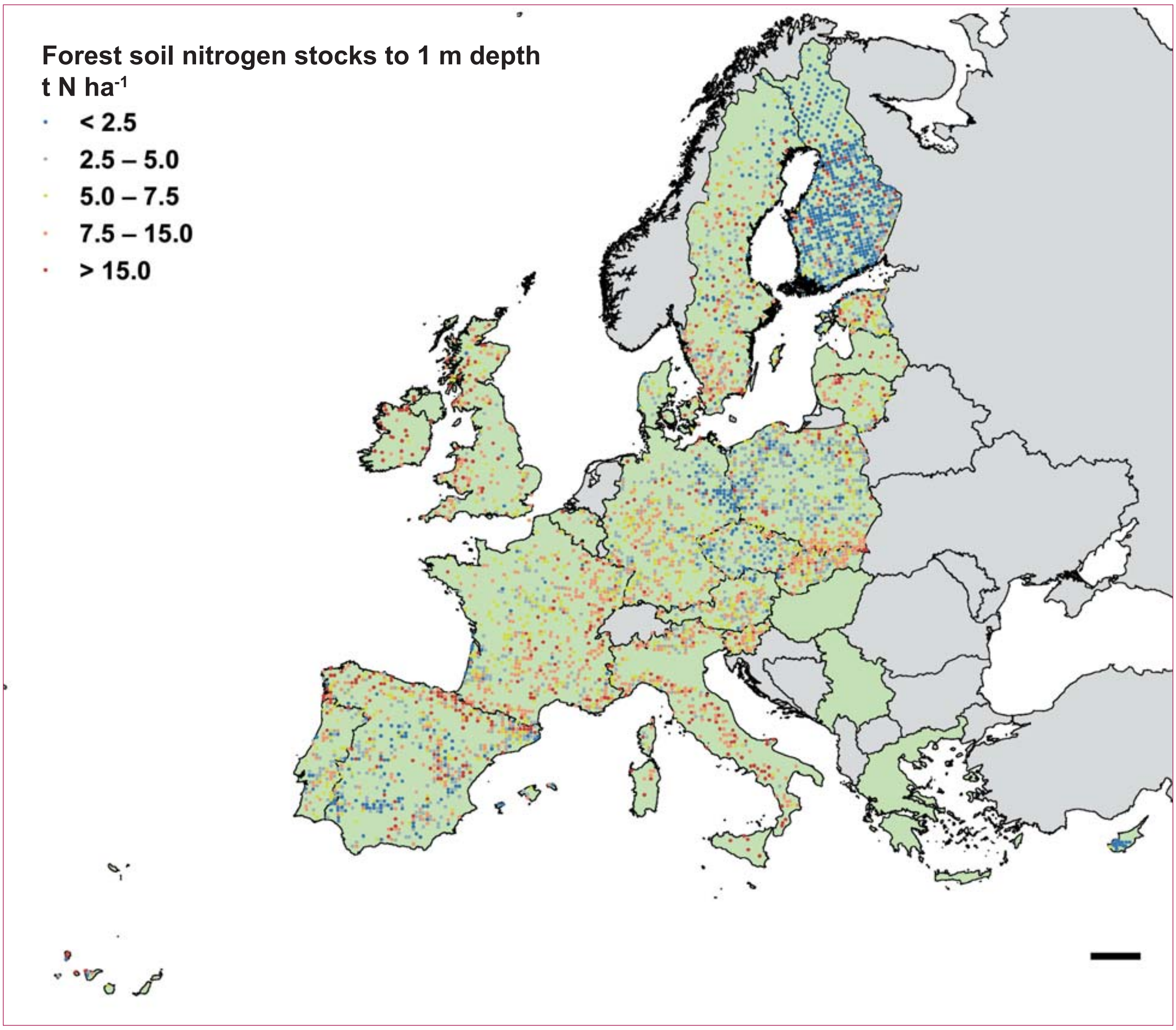
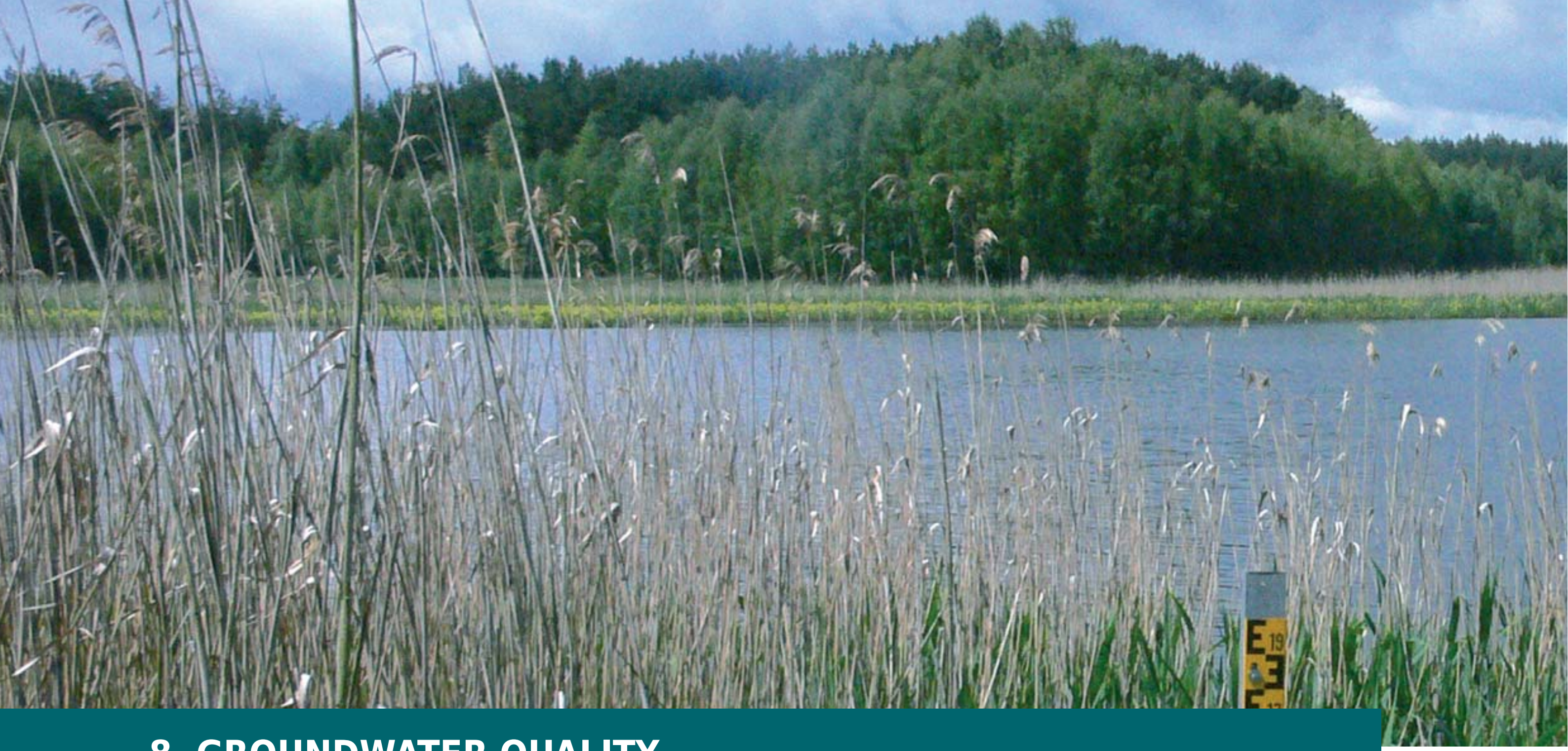


Figure 7-2: Forest soil nitrogen stock to 1m depth.



8. GROUNDWATER QUALITY

SOIL: A BOTTOMLESS PIT

When it rains, the spaces between soil particles fill with water. Gravity pulls the water down through the soil. Nitrates dissolve in the water and are carried downward. This movement is called leaching. It affects among other things the quality of drinking water which is pumped up from groundwater. In forests on sandy soils in the Netherlands, the nitrogen concentration in groundwater at 1 m depth (i.e. leaching water) has decreased by 55% in the past 20 years (Fig. 8-1). Concentrations of sulphur and aluminium in the upper groundwater have also decreased.

DECLINING NITROGEN IN SOIL WATER

The primary input of nitrogen is via precipitation onto the forest stand. As a result of emission reduction policies, nitrogen concentrations in rain water have decreased by 40% over the past 20 years in the eastern part of the Netherlands.

However, the positive effect of the reduction in nitrogen emissions on groundwater in nature areas may be stronger in the Netherlands than in other EU countries, because the study areas are close to areas with intensive agricultural land use and so it might be that measures reducing emissions from agriculture might also be impacting the neighbouring nature areas.

Groundwater gauge located in the Biosphere reserve Schorfheide-Chorin, Germany.

Measurement of lake levels as part of a complete monitoring of the hydrological system in Schorfheide-Chorin, Germany.

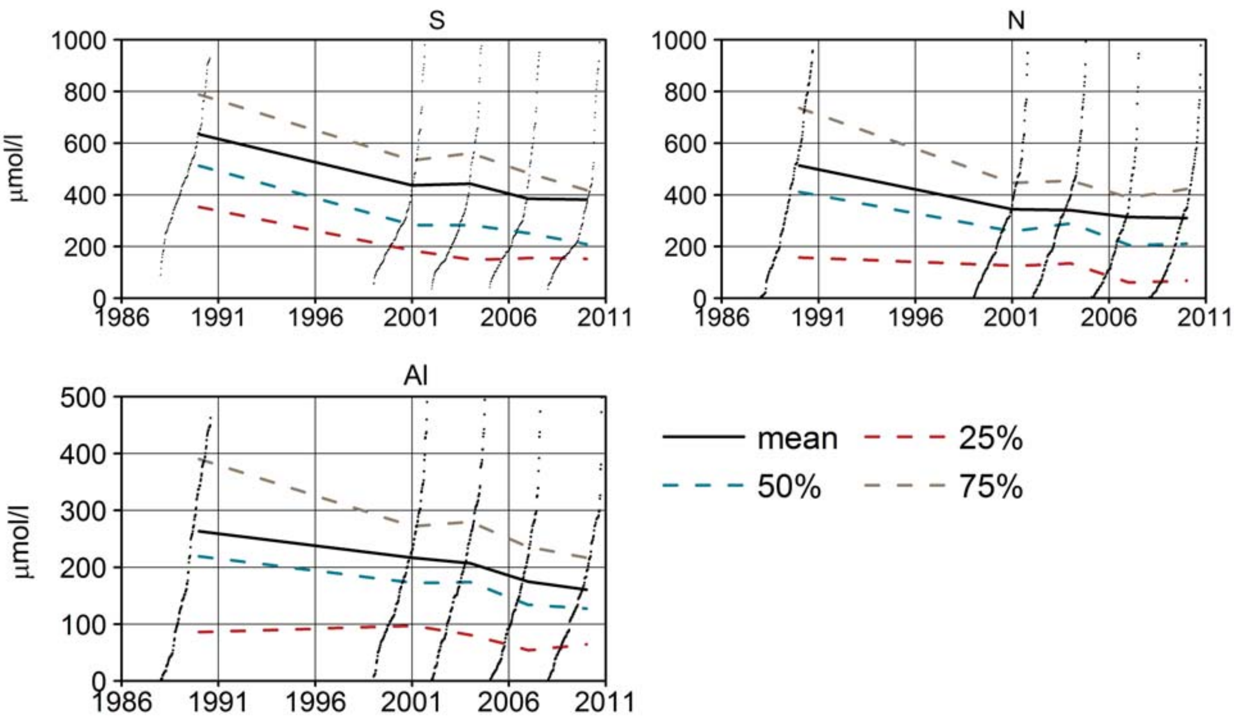
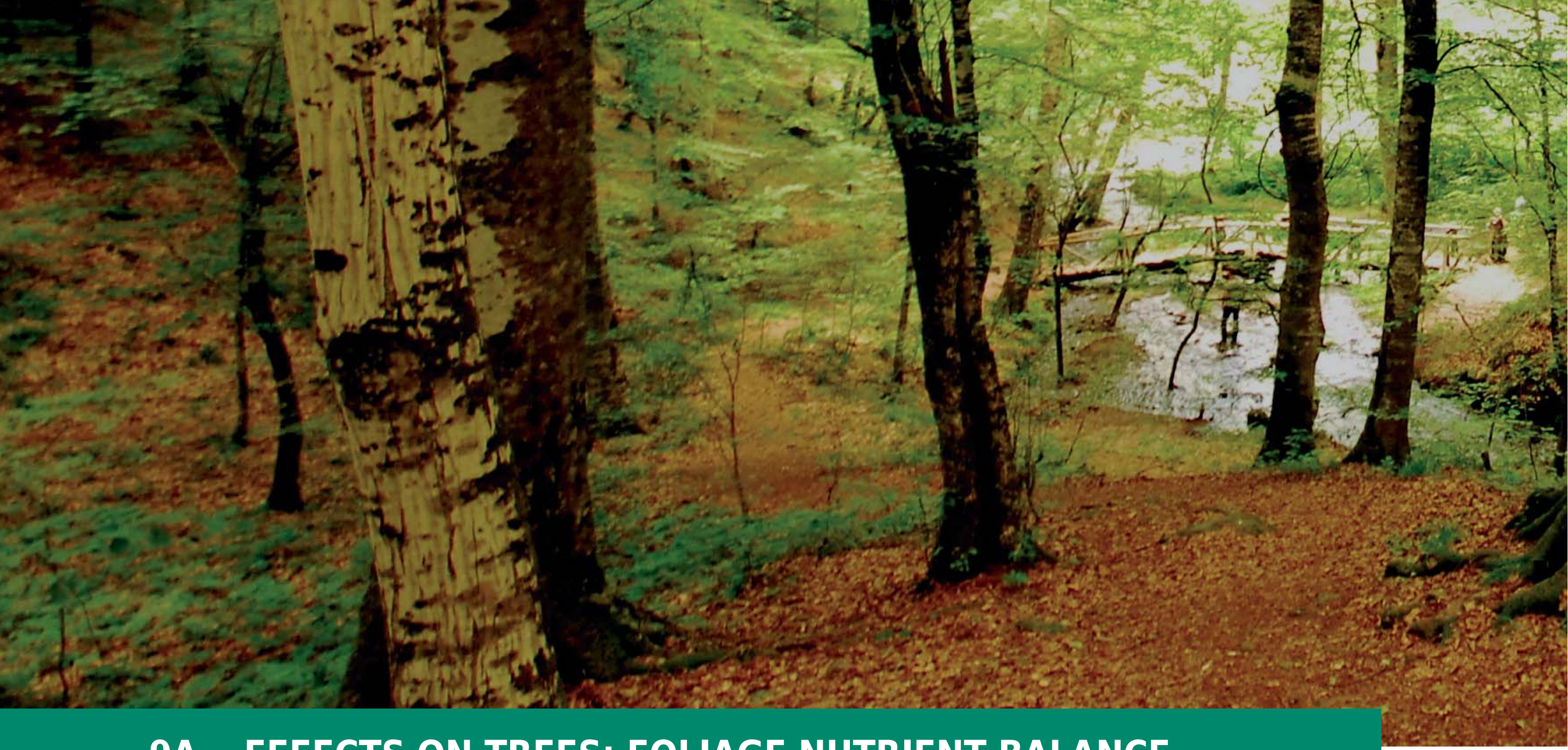


Figure 8-1: Serial measurements of groundwater concentrations of sulphur (S), nitrogen (N) and aluminium (Al). The overall development is indicated by percentiles (25%, 50%, and 75%) and the mean values.



9A EFFECTS ON TREES: FOLIAGE NUTRIENT BALANCE

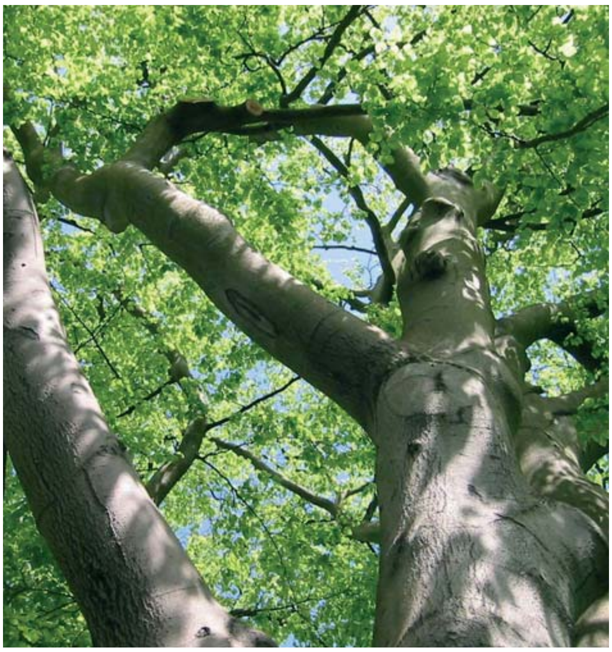
HIGH NITROGEN INPUT INCREASING NUTRIENT INBALANCES

Nitrogen is a primary nutrient that plants obtain mainly with their roots from the soil. Nitrogen inputs to the soil generally act as a fertilizer and stimulate plant growth. Excess nitrogen availability, however, can result in nutrient imbalances such that other elements like magnesium become deficient. Chemical analyses of tree needles and leaves provide information on tree nutrition. They are carried out every other year on around 500 ICP Forests Level II plots.

Results indicate balanced tree nutrition on the majority of the Level II plots. However, where the forests are nitrogen-saturated, nutrient deficiency becomes more frequent. Low magnesium availability was detected on 10% of those plots for which nitrogen concentrations in the soil solution indicated saturation.

As a result, nutrient imbalances are not widespread in the monitored forests and occur specifically in central European forests. With continuing high nitrogen deposition loads and increasing nitrogen saturation, the importance of such deficiencies will increase, particularly in forests that are naturally poor in nutrients.

Male flowering of maritime pine (*Pinus pinaster*) near Rome, Italy.



European beech (*Fagus sylvatica*) in covert wood, Great Britain.

Oriental beech (*Fagus orientalis*) stand in Turkey.

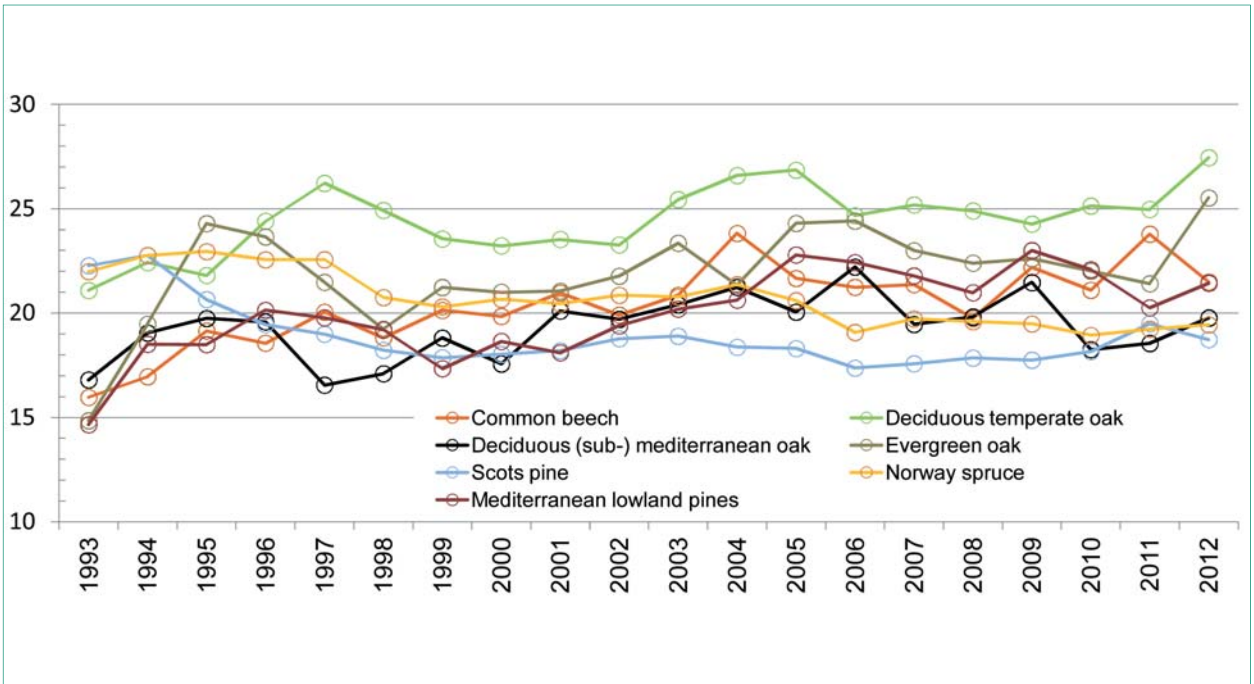
Magnesium deficiency in Norway spruce (*Picea abies*) in south-west Germany (Stefan Meining, Büro für Umweltbeobachtung).

9B EFFECTS ON TREES: CROWN CONDITION (TREE HEALTH)

FOLIAGE AS AN INDICATOR OF TREE HEALTH

Foliage density of trees (often referred to as defoliation) has been assessed as a proxy for forest health in Europe since the 1980s. Although the 2012 results (115,737 trees on 6217 plots) show long-term overall stability in defoliation values (Fig. 9b-1), there are some species-specific short-term fluctuations, such as for oak species in 2012. Factors responsible for the short-term fluctuations must be differentiated from those responsible for the long-term trends and both must be understood in order to identify the range of factors driving the complex temporal and spatial patterns (Fig. 9b-2) observed in crown condition.

Figure 9b-1: Mean defoliation (%) of the most common tree species in Europe from 1993 to 2012.



Cork oak (*Quercus suber*) and maritime pine (*Pinus pinaster*) near Rome, Italy.

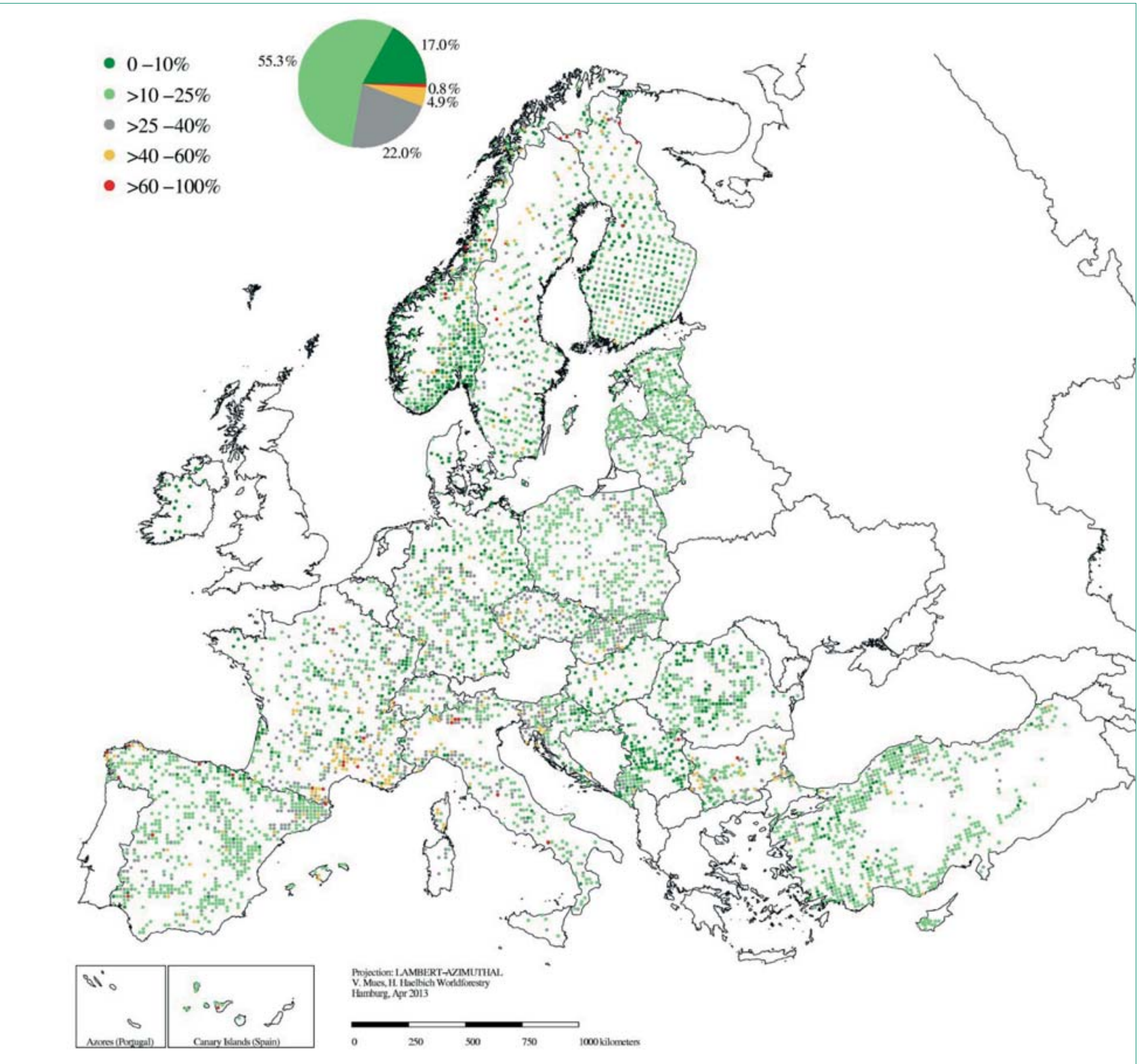


Figure 9b-2: Defoliation classes (crown condition) of all species on the ICP Forests Level I plots in 2012.

NITROGEN – JUST ONE PIECE OF THE PUZZLE

Nitrogen deposition is an important driver of processes within forest ecosystems and much work has been done to identify its impact on tree performance, especially growth. Three recent studies were carried out at the European level to investigate the possible role of nitrogen deposition on forest health as indicated by tree defoliation.

NITROGEN AND PHOSPHORUS – TWO ESSENTIAL PARTNERS

The first study considered Level I plots (n=876) and defoliation data (year 2009), with N:P foliar ratios (years 1987-1999) as a proxy for nitrogen availability. Data were summarized to a single average value per species and plot. Sites demonstrating severe nitrogen-limitation were excluded following a segmented regression. The dependency of defoliation from N:P ratios was tested by means of a Bayesian approach.

A positive relationship between N:P ratios and crown defoliation (n=876; p=0.013) was found for N:P ratios above a certain limit (breakpoint) and a negative relationship below that limit. This can be interpreted as saying that at a generally higher level of nitrogen, defoliation is enhanced by high nitrogen (or low phosphorus) content in leaves.

COMPLEX APPROACHES WITH DISTINCT OUTCOMES

A further study exploring crown defoliation used modeled climate data, damage symptons, deposition, and critical load data for nutrient nitrogen.

The study considered Level I plots (n=2,405) for the years 2001, 2006 and 2011. After removing noise due to geographical variation, the random forest analysis revealed that nitrogen deposition (either NH_4-N or NO_3-N) was an important predictor of defoliation for species such as Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and beech (*Fagus sylvatica*), while meteorological variables were more important for other species (e.g. *Quercus petraea, Q. robur*).

NITROGEN CONTRIBUTING SIGNIFICANTLY

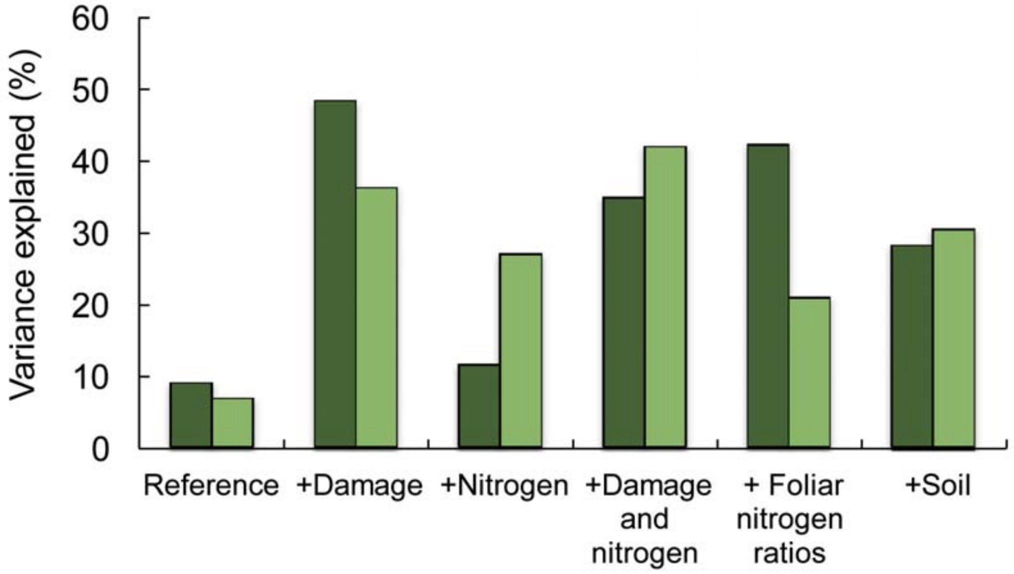
The third study included defoliation status, site- and stand parameters, meteorology, biotic and abiotic damage symptoms, soil, foliar chemistry and nitrogen deposition.

Data were collected on 131 ICP Forests Level II plots for four main species: beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and pendunculate oak (*Quercus robur*) over the period 2006 to 2009. A Partial Least Square (PLS) regression was used for evaluation.

Preliminary results show that the reference defoliation model (based on site, stand and precipitation) was always improved by the addition of damage symptoms (all species), total nitrogen in throughfall and foliar ration of nitrogen and phosphorus (European beech), and foliar and soil nutrition (European beech, Norway spruce) (Fig. 9b-3).

The combined addition of damage symptoms and nitrogen flux resulted in the best model performance in beech and Scots pine.

Figure 9b-3: Relative importance in terms of explained variance of the factors responsible for defoliation in Norway spruce (*Picea abies* - dark green) and beech (*Fagus sylvatica* - light green).



9C EFFECTS ON TREES: STEM GROWTH

INFLUENCE OF CLIMATE AND DEPOSITION ON STEM INCREMENT

Within the ECLAIRE project an integrated analysis of about 15 years (1994 to 2010) of growth and deposition data was undertaken to establish widely applicable quantitative relationships between nitrogen, sulphur and ozone exposure (POD) and ecosystem carbon balance, that allows for differences in climatic condition.

In a first step, growth data of 349 even-aged ICP Forests Level II plots across Europe dominated by beech, oak, spruce, and pine trees were jointly analysed with meteorological and deposition data derived from the Climatic Research Unit dataset and EMEP database, respectively. The expected increment value before major anthropogenic influences was assessed for all plots based on site productivity curves, stand age, and stand density index.

In addition, an evaluation with relative growth expressed as percentage ratio of actual growth against expected growth was applied.

NITROGEN ENHANCING GROWTH AT POORER SITES, BUT NO EFFECT AT RICHER SITES

In general, absolute forest increment was non-linearly related to nitrogen deposition (Fig. 9c-1). A fertilising effect is found at low levels of nitrogen deposition. At higher levels of nitrogen deposition, saturation with no further acceleration of the general growth level can be seen.

The broad scattering of plots around the smoothing line indicates the influence of other variables such as soil characteristic, local climatic condition as well as uncertainties in the modelling approach of nitrogen deposition. Calculations with relative growth revealed similar results.

Annual growth pattern of a mature Scots pine (*Pinus sylvestris*) in north-east Germany.

Mature Scots pine (*Pinus sylvestris*) on a Level II plot with permanent numbers at Schorfheide, Germany.

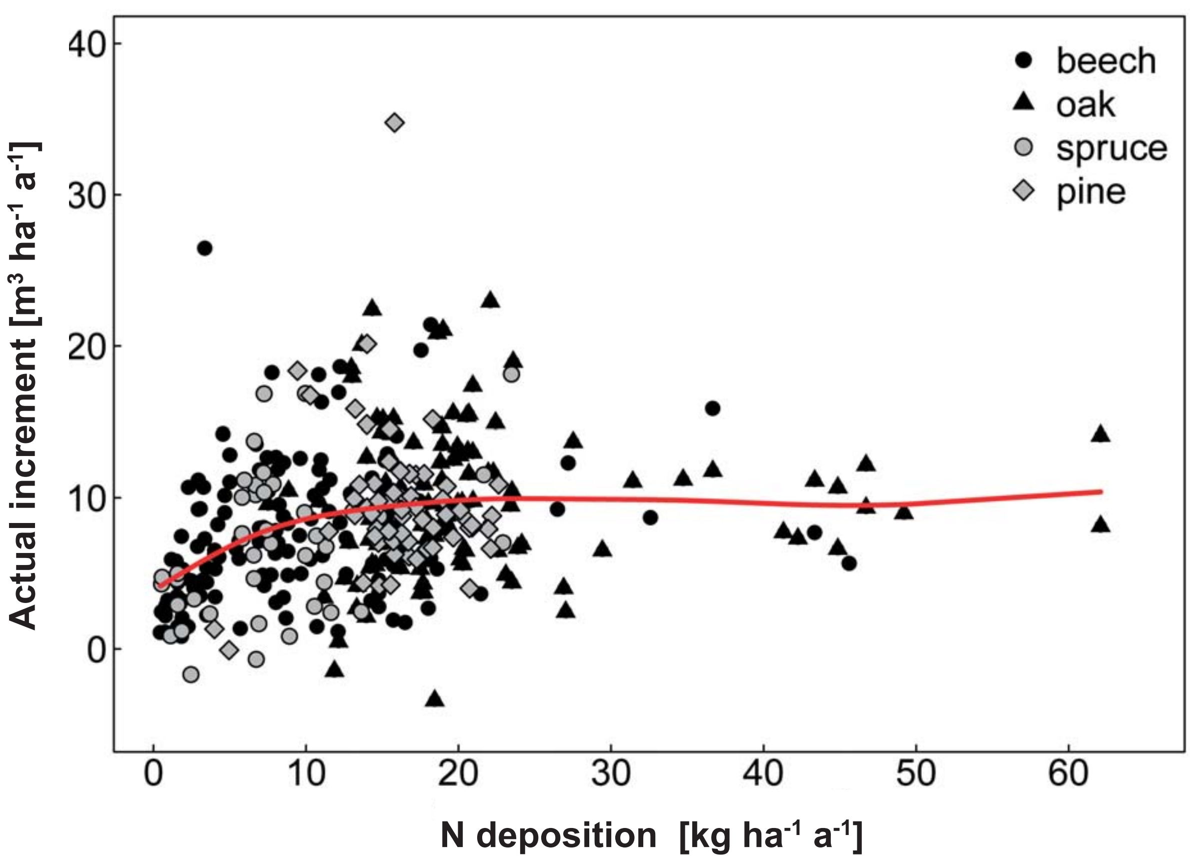


Figure 9c-1: Scatter plot of actual forest increment at ICP Forests Level II sites against mean nitrogen deposition. Dots indicate the dominant tree species of the sites. The red spline describes the relationship, while the considerable scatter of the dots calls for additional parameters to be included.

View over the river Tikhaya Sosna in the Woronesch Oblast, Russia.

10. CONCLUSIONS

Activities under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) focus 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 compounds in the atmosphere and the nitrogen loads deposited onto forest ecosystems are still high.

Measuring inputs of nitrogen compounds to the environment, with particular respect to forests, is one of the core activities of ICP Forests. The monitoring is undertaken in accordance with the agreed methodology documented in the ICP Forests Manual. The measurements provide site-specific deposition estimates for all relevant atmospheric inputs. The monitoring data are of considerable value to modellers. As well as providing policy makers with key information on topical environmental issues, the work of ICP Forests also fulfils the reporting requirements under the LRTAP Convention.

Organisms within forest ecosystems show wide-ranging responses to nitrogen. Some of these organisms, such as mosses and lichens, may appear initially as having little relevance in economic terms. However, as bioindicators these organisms have considerable value. The response of key organisms like mycorrhizal fungi towards nitrogen inputs is particularly important. Mycorrhizal fungi represent the interface between forest tree species – most of which are of considerable economic value – and the soil. Changes shown by these intermediary organisms may have considerable influence on the ecosystem services human society depends on. Findings documented here are thus of high relevance not only for conservation reasons (for example, in the case of conserving rare lichen or moss species), but in a much broader societal context.

Assessing the direct and indirect responses of forest trees is another core activity of ICP Forests. Trees are long-lived organisms and possess the ability to both accept and adapt to changing environmental conditions. So understanding their often indistinct responses and symptoms is not straightforward. A further complication is that trees interact with both the soil and the atmosphere. Thus, there are many questions to be answered in order to fully understand responses – from the individual tree to the entire forest ecosystem. Rarely linear and generally involving multiple drivers, this challenge is increasingly being taken up by scientists and their findings are of great importance, if not always simple to interpret. It is here that the interest in nitrogen has arisen: a macronutrient below certain concentrations, yet toxic at high levels.

The fate of nitrogen as it moves from the atmosphere through the soil and down to the groundwater has become much better known over the past couple of decades. Many different biologically-driven or chemically-driven processes occur during this passage and nitrogen is a key element for all types of soil organisms. Together with acidification, nitrogen-saturation of soils has been one of the strongly debated elements in the search for factors driving forest decline. As ICP Forests continues with its intensive system of measurements in forest soils, more details will become known. This work is of major importance for future decisions concerning silviculture, particularly in combination with some of the changes projected for our future climate. Together with findings from national forest inventories, the large-scale and intensive monitoring of forest ecosystems in Europe undertaken by ICP Forests will provide a sound basis for future planning. Both in terms of forestry continuing to be one the main economic activities in many rural areas, as well as efforts to conserve one of the most biodiverse habitats known.

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Undercut slope at the Dubna river in the southern Taiga, Russia.

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