Long-term monitoring of forest ecosystem compartments

2

Long-term observations are crucial for ecosystem monitoring in general and for forest ecosystems in particular, because such systems have high capacities to store atmospheric inputs and feedback loops may be slow. Changes in carbon storage in forest soils are one such example, and can only be directly measured within the multi-annual monitoring activities of ICP Forests. Measurements on various topics have now been performed over a relatively long period – in the case of crown condition, foliar analysis and soil analysis for more than 30 years (Level I monitoring) and for more intensive monitoring activities for more than 20 years (Level II monitoring).

Soil solution chemistry should reflect such long-term changes. However, in the case of carbon, long-term developments are overlaid by cyclic and episodic annual variations, governed by seasonal weather conditions. These complex dynamics make it a challenge to separate the various components: a seasonal short-term component, a long-term development, and variability ('noise') due to undefined influences such as small-scale disturbances or measurement errors. Based on work undertaken at a Swiss monitoring site, Section 2.1 provides an example of how the different components can be analysed. Together with large-scale statistical approaches, this may help to explain the increasing presence of dissolved organic carbon in freshwater bodies in Europe and North America.

Deposition of airborne substances is a process central to the study of air pollution effects on forest ecosystems. To follow these processes at a sufficient level of detail and accuracy is one of the main activities of the monitoring at Level II sites. Examples from six sites in Romania document the amounts of substances being deposited in forest ecosystems and through the declines observed, the success of air pollution abatement policies. The contribution presented in Section 2.2 concerns atmospheric deposition and soil solution measurements.

Nutritional supply of tree foliage is the combined result of many processes, governed by annual weather conditions (especially during spring) with mobilisation from soil, transport within the xylem and finally by becoming part of the foliage where its metabolic role takes place. Collecting samples of leaves or needles provides the opportunity to assess the supply of trees with a wide range of nutrients. To avoid variation due to position effects within crowns, it is important to follow the methodology outlined in the extensive ICP Forests manual. This guarantees a stable signal for the average nutritional status of trees in forests. Section 2.3 demonstrates how subtle changes over time can accumulate to relevant amounts.

2.1 Is dissolved organic carbon in soil solution increasing?

Several studies have shown that dissolved organic carbon (DOC) levels in surface waters across Europe and North America have increased in response to the decline in acidic atmospheric deposition. The response in the soil solution within forest soils across Europe has been less unequivocal due to factors acting at the local (soil and vegetation) and regional (atmospheric deposition of nitrogen and sulphur) scale. The objective of this study was to understand DOC trends in soil solution from 2000 to 2016 at six Swiss Level II plots by analysing the influence of throughfall DOC over this same period and by measuring the distribution of DOC between the hydrophobic and hydrophilic fractions (for the period 2005 to 2012) by means of UV spectroscopy (see 'Terminology' box).

Soil solution DOC time series at the six Swiss sites exhibit both upward and downward monotonic trends (Seasonal Mann-Kendall test) and as such confirm the ambiguous findings of soil solution DOC trends at the European scale. Interestingly, decomposition of the DOC time series shows that the long-term component of both throughfall and soil solution is not monotonic. Instead, irregular patterns with DOC

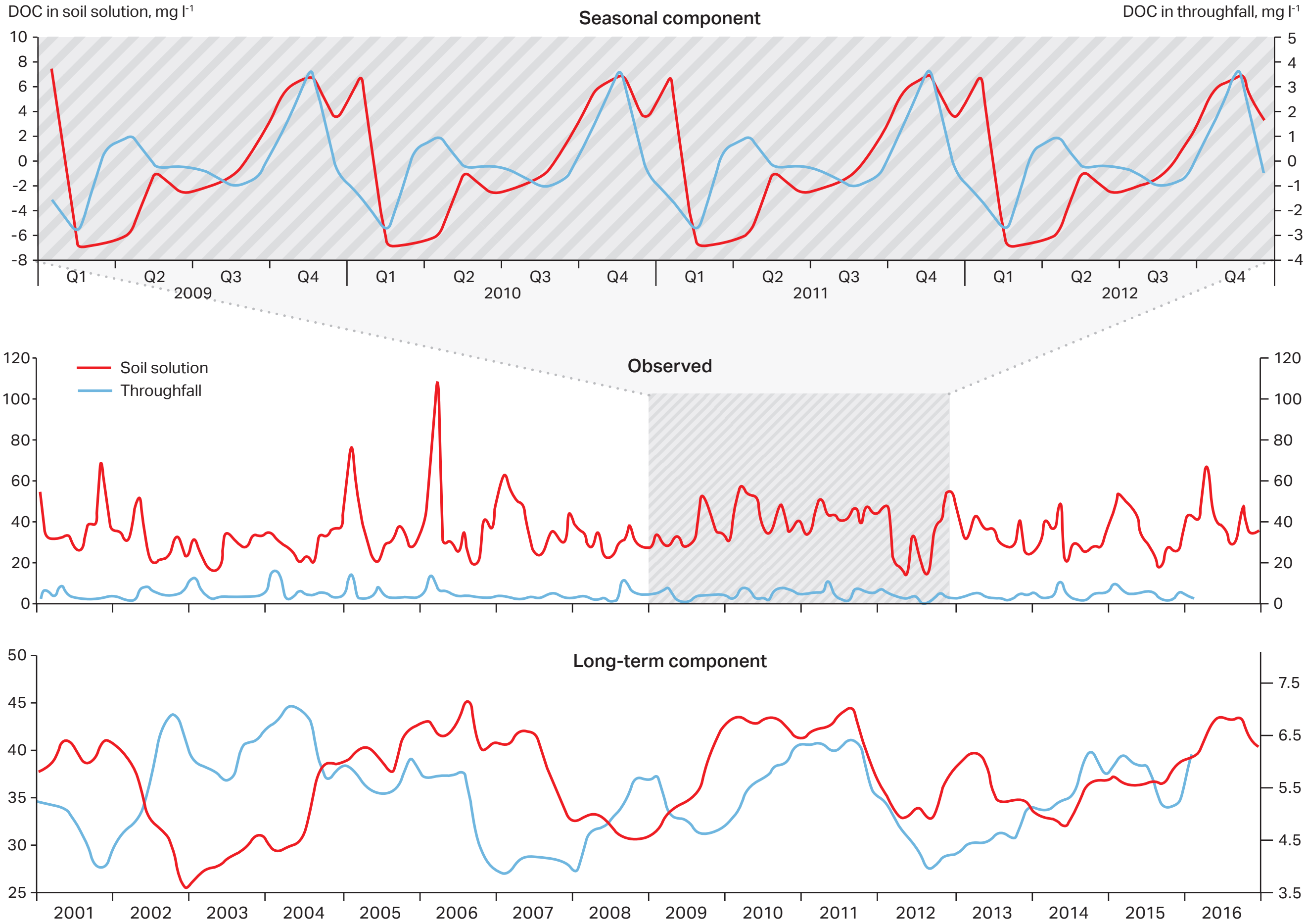

Figure 2-1: Additive time series decomposition of the dissolved organic carbon (DOC) concentration measured in throughfall and soil solution (0 cm depth) at the Swiss Level II plot 'Beatenberg'. The seasonal component is centred at the mean value. The long-term component is extracted by a moving average filter. The remaining random component (not shown) is derived by subtracting the trend and seasonal components from the observed data.

peaks in certain years are observed (Figure 2-1). There is little resemblance of the long-term component in throughfall and soil solution. In contrast, except for a small time lag, the seasonal pattern of throughfall and soil solution DOC is very similar with a minor peak in spring and a major peak in October. The spring peak may be related to the start of the growing season with its massive bud burst and the simultaneous snow melt that may lead to a release of DOC. The autumn peak is related to the litterfall and the related increase in canopy leaching. Associating the long-term component peaks with litterfall, mast years and climatic data may help to pinpoint causal relationships in future.

In soil solution the hydrophobic fraction and total DOC are strongly related (both $R^2_{adj.} > 0.79$) with hydrophobic DOC constituting the major share of total DOC (74%), but much less for throughfall (47%; Figure 2-2).

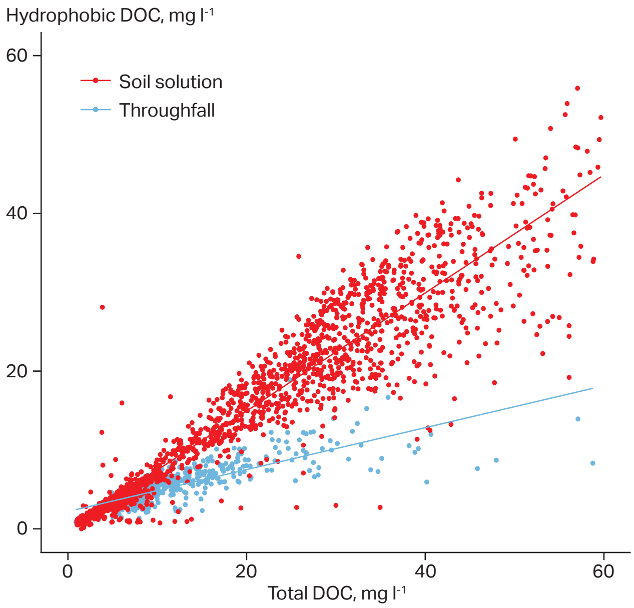

Figure 2-2: Hydrophobic DOC versus total DOC in soil solution and throughfall samples at six Swiss Level II plots.

In contrast to the ambiguous monotonic trends observed for total DOC, the hydrophobic DOC fraction showed consistently decreasing trends at five of the six sites at a significance level of 5% (Seasonal Mann-Kendall test). This is all the more surprising given the large variability in DOC levels and the short time series considered. The trends observed imply that the counterpart, the hydrophilic DOC fraction, is increasing in the soil solution. The low-molecular hydrophilic fraction is more enriched in nutrients, but at the same time more susceptible to microbial degradation and leaching and may eventually contribute to the observed increase in stream water DOC concentrations mentioned at the start of Section 2.1.

Terminology

UV spectroscopy: When a substance absorbs radiation the energy of the photons is transferred to the substance. The amount of radiation absorbed at different wavelengths is characteristic of a particular substance and thus allows its identification. This technique is routinely used in analytical chemistry. UV spectroscopy measures the absorption of ultraviolet radiation (10–400 nm) by different analytes. Absorption at 260 nm was used in this application because absorption is significantly higher for the hydrophobic DOC fraction at this wavelength. By measuring absorption at 260 nm it is therefore possible to distinguish hydrophobic DOC from hydrophilic DOC at different concentrations.

Further reading

Camino-Serrano M et al., 2016: Trends in soil solution dissolved organic carbon (DOC) concentrations across European forests. Biogeosciences 13: 5567-5585.

2.2 Air pollutants in deposition and soil solution

Atmospheric deposition and soil solution are both monitored within the ICP Forests programme in order to investigate trends and correlations with other factors that can affect forest ecosystems. This section reports on concentrations of a range of substances measured at four intensive monitoring (Level II) plots in Romania. Between 1998 and 2016, bulk deposition and throughfall of sulphate decreased significantly

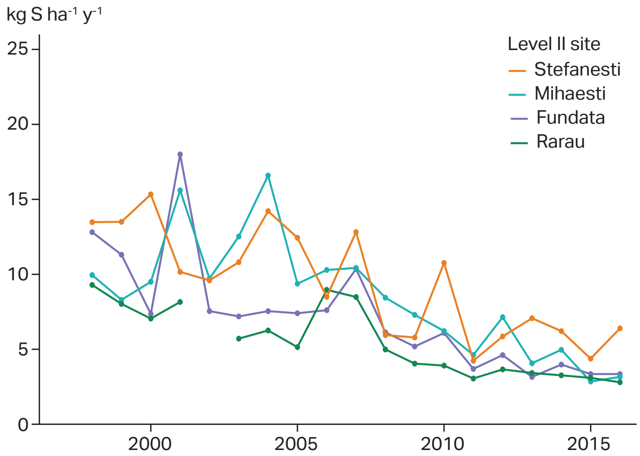

Figure 2-3: Annual deposition of sulphate sulphur with open field total deposition at four Romanian Level II sites.

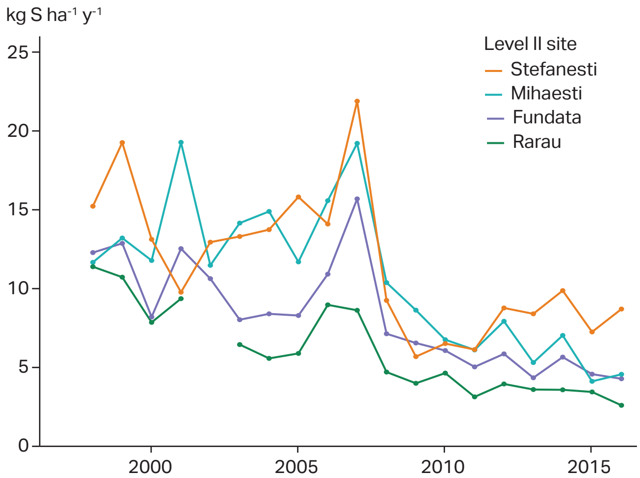

Figure 2-4: Annual deposition of sulphate sulphur with throughfall precipitation at four Romanian Level II sites.

at all plots (Figures 2-3 and 2-4). The same trends were observed for ammonium, except at 'Stefanesti', located near the capital Bucharest, where ammonium fluxes in throughfall still exceeded 8 kg ha^{-1} y^{-1} in 2013 and 2015 (Figure 2-5), values to be considered high in a European context. For the other three plots, throughfall fluxes at least since 2013 have been below or close to 4 kg ha^{-1} y^{-1}, which can be considered low.

A decline in ammonium nitrogen was also measured in the soil solution. A significant decrease of its concentration was observed at 'Fundata' at all four depths of the soil profile. Although nitrate nitrogen concentrations and fluxes also decreased, the trends were not significant at any of the plots.

The level of throughfall deposition of nitrate was below 4 kg N ha^{-1} y^{-1} in 2015 at all four plots, which is considered low.

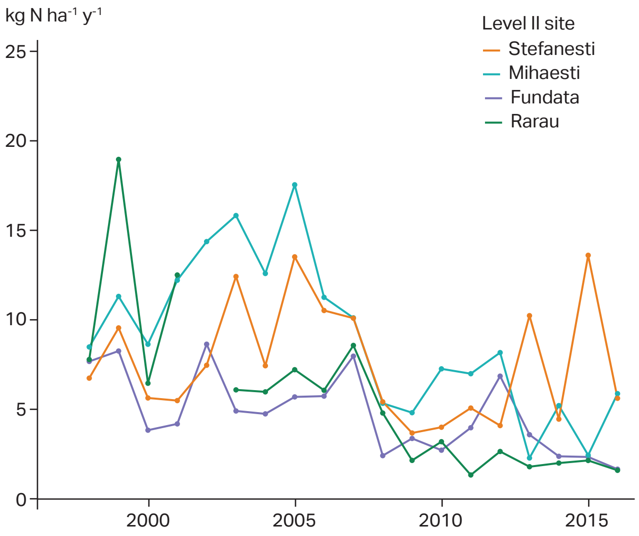

Figure 2-5: Annual deposition of ammonium nitrogen with throughfall precipitation at four Romanian Level II sites.

Fluxes of chloride decreased at three plots, but increased significantly at 'Stefanesti', up to about 50 kg Cl ha^{-1} y^{-1} in the past three years, which is 2.5-fold higher than for 1998.

For calcium, throughfall and open field deposition showed no trend. In 2015, throughfall deposition was high (over 10 kg Ca ha^{-1} y^{-1}) at the three plots in central and southern Romania, possibly due to the influence of Saharan dust transported over these regions. At 'Rarau', in northern Romania, throughfall deposition was below 10 kg Ca ha^{-1} y^{-1}.

Annual mean concentrations and fluxes of magnesium decreased at three plots, but the trend was not significant. In contrast, the mean magnesium concentration increased at 'Rarau', a plot on calcareous soil.

Further reading

Barbu I et al., 2011: Monitoring of atmospheric deposition in the research grid of forest ecosystems selected in the framework of FutMon. Revista Pădurilor 126: 70-84. (In Romanian)

2.3 Tree nutrition trends

Evaluating changes and trends in tree nutrition reflects environmental forces acting at the tree level. The longest uninterrupted time series for ICP Forests Level II plots in Czechia are from two Norway spruce (*Picea abies*) plots (e.g. Figure 2-6), for the

Figure 2-6: Monitoring needle chemistry for a Norway spruce tree; samples are first collected in the forest and then subject to chemical analysis in the laboratory.

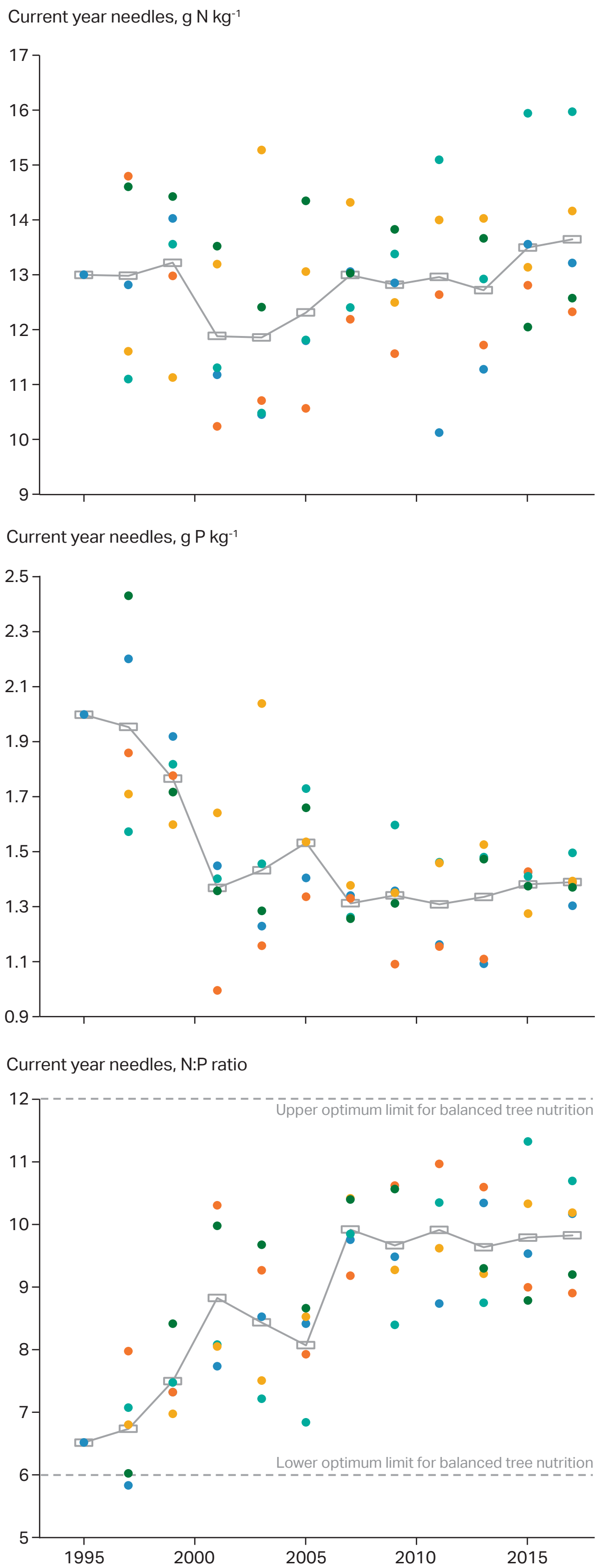

Figure 2-7: Development of total nitrogen, phosphorus, and the nitogen:phosphorus ratio for current-year needles of five specimens of Norway spruce (represented by five different colours) at Plot 2161 in Czechia. Grey lines show average values of all sampled trees. Plot 2161 is located in central Bohemia, 440 m above sea level.

period 1995 to 2017. Other sampled plots differ in the length of sampling period, continuity of data sets and the array of elements analysed. Sampling and analysis are generally performed every two years and in accordance with the designated methodology.

Monitoring data for plot 2161, one of the two long-term monitoring plots in Czechia show a large amount of variability but since around 2005 there appears to be both a slight increase in nitrogen concentration and a slow decrease in phosphorus concentration. This created an imbalance between the two important nutrients, with N:P ratios approaching (Figure 2-7) or even exceeding a value of 12, which is seen as an upper optimum limit for balanced tree nutrition.

Potassium behaves differently in mountainous areas: decreasing at altitudes over 800 m above sea level, especially in one-year old needles, while at lower altitudes concentrations fluctuate or even increase slightly.

The annual average magnesium concentration at two plots of European beech (*Fagus sylvatica*) decreased between 2001 and 2015; one from 2.3 to 1.5 g Mg kg^{-1} dry matter and the other from 1.4 to 0.9 g Mg kg^{-1} dry matter. A decrease in magnesium of about 25% was found on a Scots pine plot between 2005 and 2015.

Sulphur concentrations were higher in the 1990s, with present-day levels around 1.0–1.3 g S kg^{-1} dry matter within coniferous plots and about 1.6 g S kg^{-1} dry matter for broadleaved plots. This suggests that in Czechia sulphur should no longer be considered a contaminant, but rather a nutrient.

Overall, it seems that nutrition levels are changing slightly, with an imbalance often observed in the ratio between nitrogen and other important nutrients, especially between nitrogen and phosphorus. This indicates the importance of controlling emissions and monitoring immissions of nitrogen.

Further reading

Jonard M et al., 2015: Tree mineral nutrition is deteriorating in Europe. Global Change Biology 21: 418-430.