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Time trends in nitrogen and sulfur throughfall fluxes and soil solution concentrations

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Background and aim

Increasing air pollution have affected element fluxes and balances and soil pH in the forest ecosystem in Europe notably in the last century. These effects lead to damaged and impaired forests, most pronounced in central Europe. However, measures were taken to reduce the air pollution with the aim to reduce the damages and restore more vital forests. The main elements in focus were S and N.

The aim of this study was to analyze the Danish long-term ICP Forests monitoring data to examine if the N and S fluxes in throughfall and the concentrations of N and S in soil solution have decreased within the last 30 years.

Materials and methods

The fluxes of nitrogen (N) in form of nitrate (NO_3^--N) and ammonium (NH_4^+-N) as well as sulfur (SO_4^{2-}-S) were measured in throughfall at four Level II sites in Denmark during periods of 15-31 years. These data were compared with the corresponding concentrations of NO_3^--N and SO_4^{2-}-S in the soil solution sampled in 90 cm depth in the mineral soil by PTFE suction cups (Prenart, Copenhagen).

The four Level II sites (see Figure 1):

- **Ulborg:** Norway spruce stand planted in 1964 on former heathland; nutrient poor sandy soil; surroundings: forest and heathland, but nearby high-intensive cattle and pig farming may influence the N deposition. Monitoring 1985-2013 (ended due to windthrow damage).
- **Frederiksborg:** Beech stand planted in 1964 on former cropland; nutrient rich loamy soil, surroundings: mainly old forest. Monitoring since 1985.
- **Vestskoven:** Oak afforestation on former cropland in 1970; soil: nutrient rich loam; surroundings: relatively close to several highways and Copenhagen. Monitoring since 2001.
- **Suserup:** Beech-dominated semi-natural forest with ash and oak; soil: nutrient-rich loam; surroundings: mainly forest and cropland with few farm animals. Monitoring since 2002.

Results

Sulphur

The throughfall flux of SO_4^{2-}-S decreased over time in all four sites, most notably in the beginning of the period from 1985 into the 1990's. The latest observations show fluxes of SO_4^{2-}-S close to or below 5 kg ha^{-1} $year^{-1}$.

A parallel decrease was observed in the concentration of SO_4^{2-}-S in the soil solution at all four sites. There was a five-fold decrease in both the flux of SO_4^{2-}-S in throughfall as well as in the soil solution SO_4^{2-}-S concentration over the 31 years of monitoring at the Frederiksborg site.

Nitrogen

The time trends for NO_3^--N and NH_4^+-N are not as clear as for SO_4^{2-}S and the variation over time is much more pronounced.

In general, there is a tendency that the NH_4^+-N flux in throughfall is decreasing over time, most pronounced at Ulborg, the site that is most influenced by cattle farming and emissions from farm manure.

The ratio of NO_3^--N to NH_4^+-N in throughfall changes over time. In the first half of the examined period, the NH_4^+-N flux was higher that the NO_3^--N flux in throughfall, but this ratio shifted over time and was inverted in the last half of the period at all four sites.

Even though the time trends for N in the throughfall are not that clear, the concentrations of NO_3—N in the soil solution appear to decrease notably over time at Ulborg, Vestskoven and Suserup, but not at Frederiksberg, where there appear to be an increase in the NO_3^--N flux in throughfall.

The temporal variations in throughfall fluxes of NO_3^--N and NH_4^+-N tend to follow the same pattern at the different sites, e.g. increases from 2005 to 2006 at all sites.

Conclusions

The efforts to decrease the input and effect of S from air pollution in the forest ecosystems have had a marked effect on both the flux of SO_4^{2-}-S in the throughfall and the corresponding concentration in the soil solution.

For N the picture is less clear, but a decrease in the throughfall NH_4^+-N flux at three of the sites corresponds to a decrease in the concentration of NO_3—N in the soil solution.

Figure 1. Location of the four level II sites: Ulborg, Frederiksborg, Vestskoven and Suserup

Figure 2. Photos from Ulborg (A), Frederiksborg (B) and Suserup (C).

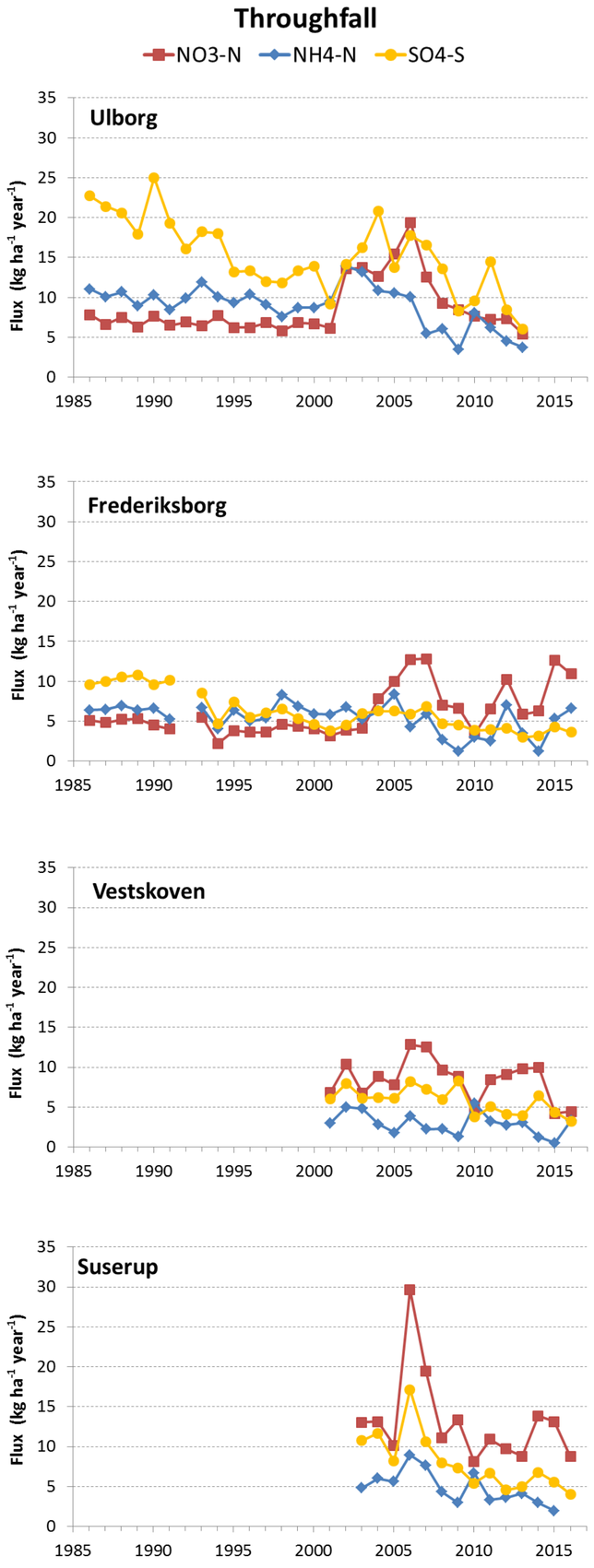

Figure 3. The yearly flux of NO3-N, NH4-N and SO4-S in throughfall.

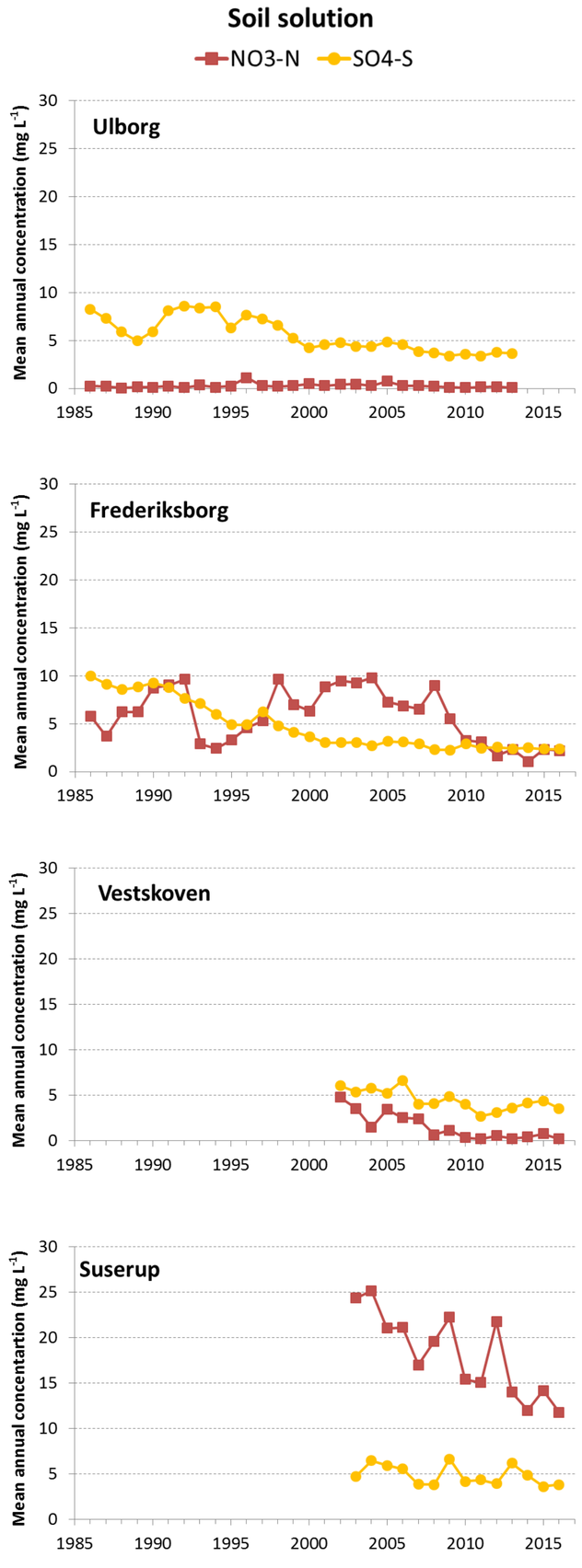

Figure 4. The mean annual concentrations of NO_3-N and SO_4-S in soil solution, sampled in 90 cm depth in the mineral soil.