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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 has affected element fluxes and balances, and soil pH in the forest ecosystems 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 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 36 years.

Materials and methods

The fluxes of nitrogen (N) in form of nitrate (NO_3^--N) and ammonium (NH_4^+-N) and sulfur in the form of sulfate (SO_4^{2-}-S) were measured in throughfall at five Level II sites in Denmark during periods of 7-36 years. These data were compared with the corresponding concentrations of NO_3^--N and SO_4^{2-}-S in soil solution sampled in 90 cm depth in the mineral soil by PTFE suction cups (Prenart, Copenhagen).

The five 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).
- **Tyvkær:** Norway spruce stand planted in 1968, second generation spruce on former heathland; nutrient poor sandy soil; surroundings: forest and heathland. Monitoring 2016-2022 (established when Ulborg was windthrown).
- **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 sites, most notably in the beginning of the period from 1985 into the 1990's at Ulborg, but the decrease is also observed in the last decade. The latest observations show fluxes that is notably below 5 kg S ha^{-1} $year^{-1}$.

A parallel decrease was observed in the concentration of SO_4^{2-}-S in the soil solution at all 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 36 years of monitoring at the Frederiksborg site. In the concentration of SO4^{2-}-S in the soil solution appear to be more stable.

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. At Frederiksborg this tendency is also observed, but to a less degree.

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 than 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, most pronounced at Frederiksborg, Vestskoven and Suserup.

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 two of the sites corresponds to a decrease in the concentration of NO_3—N in the soil solution. And at four of the five sites, the initial five year periods show higher throughfall fluxes than the last five year periods.

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).

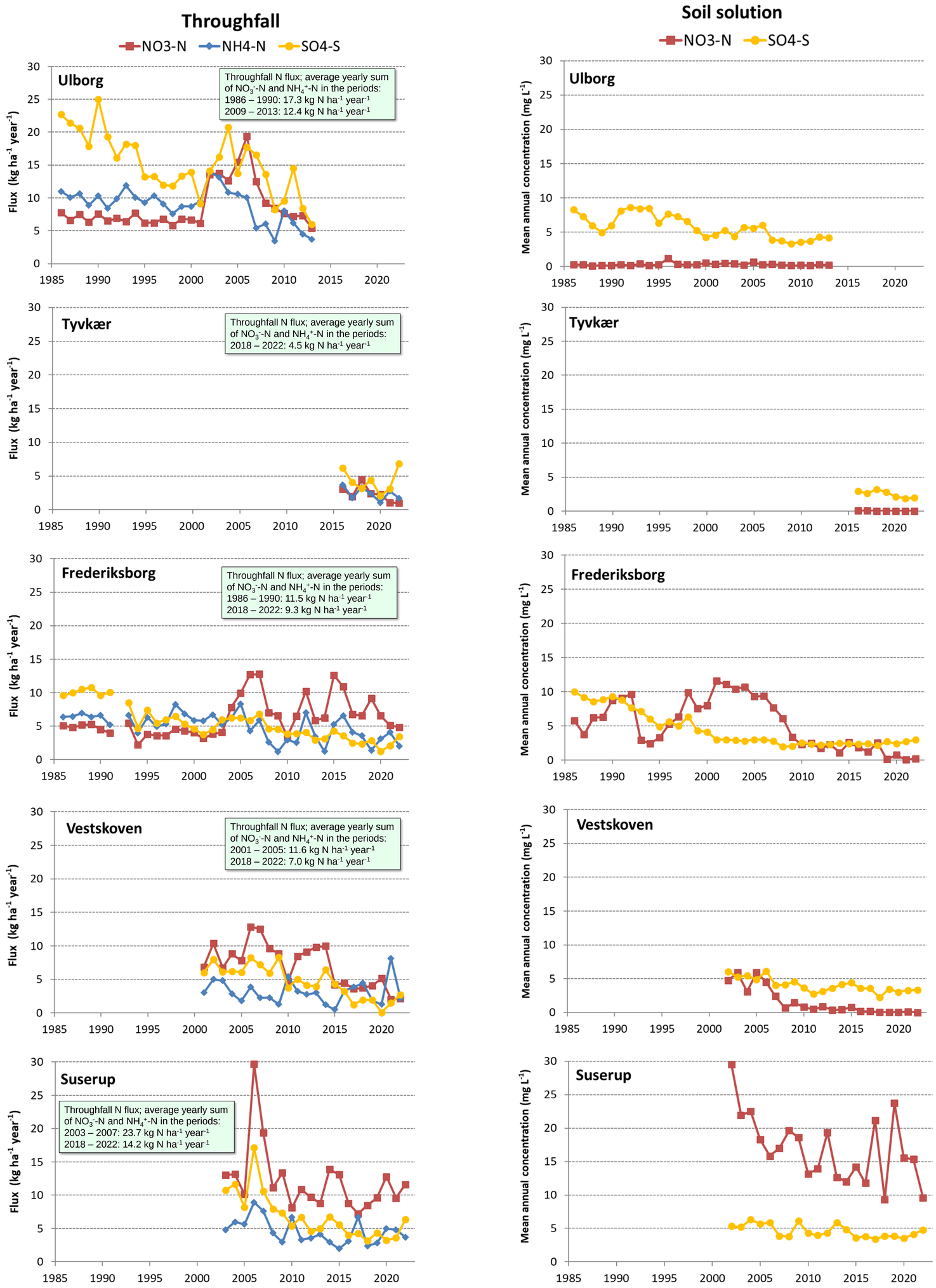

Figure 3. The yearly flux of NO3-N, NH4-N and SO4-S in throughfall.

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.