Trends in EU Nitrogen Deposition and Impacts on Ecosystems

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An overview of the achievements and the current state of knowledge on reactive nitrogen in Europe, focusing on deposition, critical load exceedances, and modeled and measured trends.

Close to where the Neretva river merges with the Neretvan channel of the Adriatic sea, the Croatian river forms many armlets and creates a delta of a great area with particularly fertile lands, where fruits and vegetables are grown.

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Agriculture is the main nitrogen user in Europe.

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Reactive nitrogen (Nr) is all the nitrogen (N) found on Earth fixed in compounds other than gaseous N_2. The amount of Nr in the biosphere is currently one of the biggest problems faced and results in a cascade of environmental effects. The largest cause of the N problem is the fixation of atmospheric N during combustion processes and fertilizer production. Another significant factor is the transport of large quantities of nutrients from one side of the world, where there is a general shortage of Nr, to areas with an excess of Nr. Nitrogen deposition is one of the most important environmental pressures in Europe affecting our ecosystem services, health, and economy.

The required environmental quality of semi-natural ecosystems with regards to Nr deposition can be given using so-called critical deposition levels. The amount of deposition that can be supported by an ecosystem without any damage is called the critical load.[1] A critical load is defined as the deposition level below which no change in species composition takes place or, sometimes, below which certain processes do not take place, such as N leaching or the accumulation of N.[2,3]

Nitrogen in Europe: Major Sources and Effects

In Europe, Nr is used for food production. Any Nr that does not make its way into the products remains in the environment. Europe is food self-sufficient apart from the heavy import of soya, which is used largely as feed for animals. Agriculture is the main N user in Europe and has different losses to the atmosphere (e.g., ammonia [NH_3] and nitrous oxide [N_2O]) and to surface and ground water (e.g., nitrate [NO_3^-]). Less than 50% of the N input in agriculture is utilized in products. The main sources of N losses are:

- NH_3 to air: ~90% of total NH_3 emission;
- N_2O to air: ~60% of total N_2O emissions; and
- N in surface waters: ~40–60% of total N emissions.

The release of nitrogen oxides (NO_x) to the atmosphere is the other component disrupting the N-cycle and a direct result of the high temperature combustion of fossil fuels or biomass.

Anthropogenic disruption of the N-cycle at various levels results in a number of human health, ecosystem, and climate effects.[4-6] NO_x and NH_3 contribute to acid deposition and eutrophication, which, in turn, can lead to potential changes in soil and water quality. NO_x and NH_3 also contribute to the formation of secondary particulate aerosols and NO_x plays a key role in the formation of tropospheric ozone (O_3)—both important air pollutants due to their adverse impacts on human health. Van Grinsven et al.[7] listed Nr-related effects in Europe and estimated the societal costs associated with them based on the so-called "willingness to pay" method (see Table 1). Nitrogen contributes to a range of human health and environmental

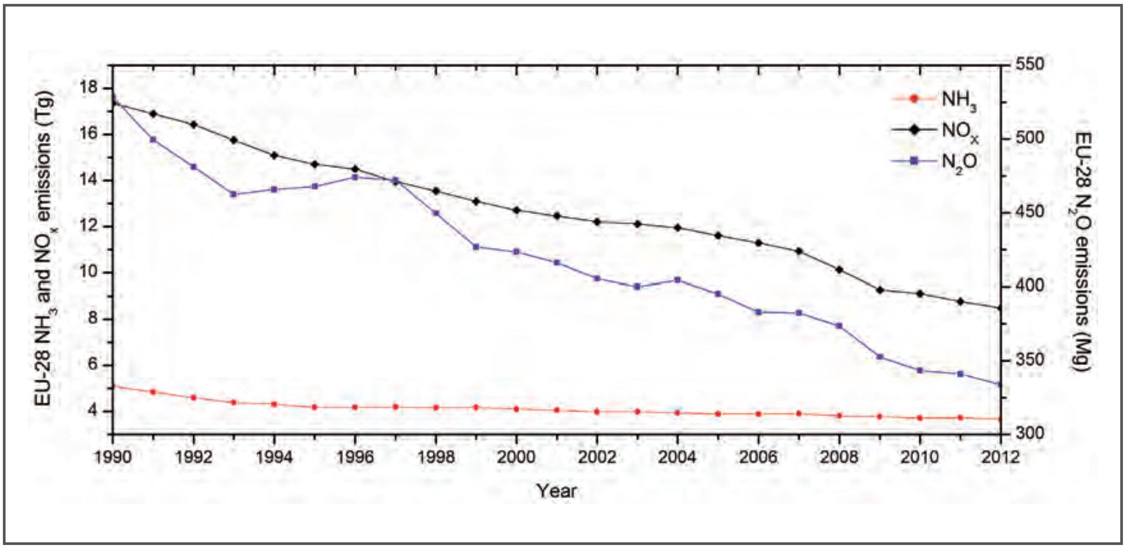


Figure 1. Emissions of NH_3, NO_x (Tg), and N_2O (Mg CO_2eq) in Europe between 1990 and 2012.[3,23]

EFFECT	EXTENT IN EUROPE	N-SHARE (%)
Cardiovascular and respiratory diseases and lung cancer	9 month loss of life expectancy 255,000 premature deaths (2000)	0–20
Cardiovascular and respiratory diseases due to NO_x-induced ozone	Premature deaths 26,000 (2000)	70
Terrestrial eutrophication from N-deposition	1196 km^2 (74%) ecosystems with exceeding critical loads (2000)	100
Terrestrial acidification from N-deposition	302 km^2 (24%) forest areas with exceeding critical loads (2000)	40
Crop damage due to ozone	4–9 billion euro/yr (2000)	70
Fresh water eutrophication	42% of 27,000 samples exceeds 10 mg/l NO_3 (2004–2007)	100
Groundwater nitrate pollution	15% of 31,000 samples exceeds 50 mg/l NO_3 (2004–2007)	100
Colon cancer related to nitrate in drinking water from groundwater	18,000 lost life years (3.4% of total incidence)	100
Global warming and cooling from N_2O, NO_x, N-deposition, PM, and ozone	Offset GWP by 17 to -16 mW/m^2	100

Table 1. The contribution of N to human health and environmental effects in Europe.[6,7]

impacts, which are amplified through the Nr cascade.[8] Nitrogen management policies are mainly focused on air quality, surface and ground water pollution, and ecosystem health.[3,9]

Between 1980 and 2011, NO_x and NH_3 emissions in Europe declined by 49% and 18%, respectively (see Figure 1).[3] These decreases are mainly due to policies that enforced measures in transport and fuel switching, plant improvement (e.g., flue-gas abatement techniques) in the energy and production industries, and the Nitrate Directive in agriculture reducing the use of fertilizer.[3] The emissions of N_2O decreased by 38% mainly due to the measures from the Nitrate Directive, the Common Agriculture Policy (CAP), and the Landfill Waste Directive.[3]

Concentration and Deposition Observations in Europe

A systematic network was designed under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) to monitor air quality and deposition.[10,11] Furthermore, there are national monitoring networks on environmental quality, especially in central Europe. For example, results from the European Monitoring and Evaluation Programme (EMEP) showed that the reduction in NO_x is reflected in the measurements, with an average decrease of NO_x and NO_3^- in precipitation by 23% and 25%, respectively, since 1990.[10] A majority of the EMEP sites show a decreasing trend in reduced N both in air and precipitation on the order of 25% since 1990.[10]

Atmospheric deposition to forests has been monitored with sampling and analyses of bulk precipitation and throughfall at several hundred plots for more than 15 years. The overall decreasing trends for inorganic N in the decade 2000–2010 was about 2% with the strongest decreasing trends observed in western central Europe in regions where deposition fluxes are highest.[12]

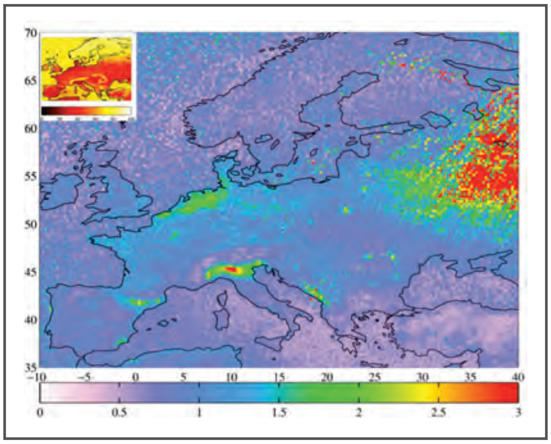


Figure 2. NH_3 column satellite observations by IASI averaged between November 2007 and April 2015 (molecules cm^{-2}).

More recently, satellite images became available for NO_2[13] and NH_3[14] concentrations in the atmosphere that will play an important role in future Nr monitoring. For NO_2, more than 10 years of observations are available and for NH_3, Infrared Atmospheric Sounding Interferometer (IASI) data have been available since November 2007. Figure 2 shows the novel average NH_3 columns across Europe observed by IASI.[14] Evaluation of satellite-based NH_3 concentrations is ongoing and first comparisons show reasonable results.[15]

Modeled Trends in Deposition and Concentration

Figure 3 presents the modeled total N deposition for 2009 and the relative change to the situation modeled for 1990. Banzhaf et al.[16] have demonstrated the ability of the LOTOS–EUROS model to reproduce observed nonlinear responses in concentrations to emission changes between 1990 and 2009. Modeled N deposition is highest across regions with intensive agricultural activities in Northwestern Europe.

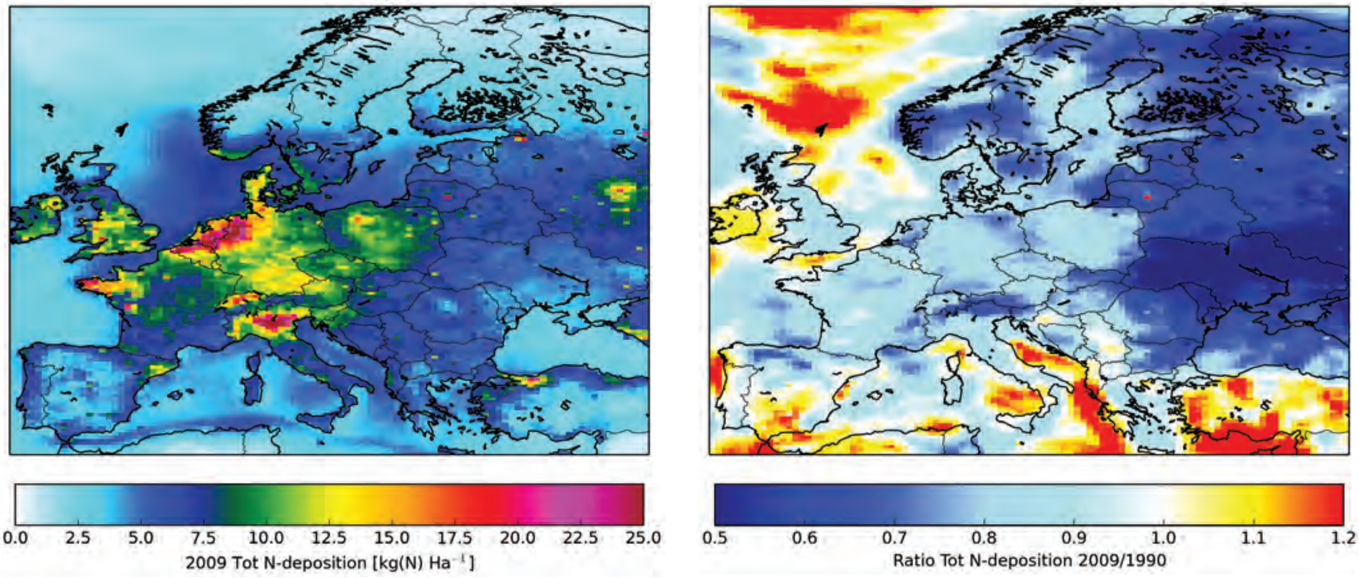
It was shown that the model was able to capture the declining trends observed for all considered sulfur and nitrogen components. However, for NO_x a mismatch between modeled and observed trends was found in central and western Europe indicating that the NO_x emissions have not declined as fast as reported. This study has also shown that the atmospheric concentrations of nitrogen components do not respond one-to-one to emission changes.

Critical Loads and Trends in Exceedances

The European Environment Agency (EEA) applied the concept of critical loads exceedances to assess air quality scenarios using the most recent critical load database.[17] In Europe, exceedances of the critical loads for eutrophication peaked at 79% in 1990. This percentage is projected to decrease to 54% in 2020 under the amended Gothenburg Protocol (see Figure 4). The report concludes that if all technically feasible reduction measures are implemented, the area at risk of eutrophication will still be 51% in 2030.

Evidence is mounting that elevated Nr deposition exerts a proportionally stronger impact on nutrient-poor habitats and can reduce the abundance of individual species at Nr inputs below the critical load. It is important to realize that the critical loads are calculated based on direct responses of plant communities to N fertilization. However, critical loads for soil fauna and microbes can be lower than those used in the current plant-centered assessments.[18,19] These organisms constitute an important part of biodiversity and affect plant diversity via their impact on nutrient turnover.[20]

Figure 3. Modeled total deposition (Kg N ha^{-1}) for 2009 (left) and the changes in deposition between 1990 and 2009 (ratio deposition 2009/1990) (right).



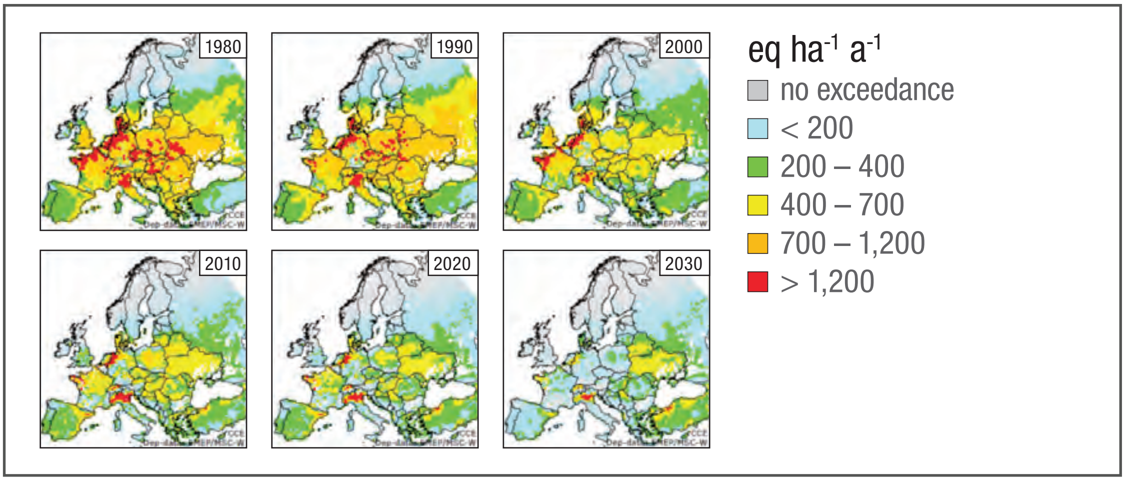


Figure 4. Areas where critical loads for eutrophication are exceeded by N deposition between 1980 (top left) to 2030 (bottom right).

The impact of changes in soil biota on plant communities might take longer to detect and is not likely to be grasped by current investigations on direct responses of plant community diversity to N additions. Hence, critical load thresholds may need to be lowered.[2,21,22] **em**

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