The impacts of nitrogen deposition on:

Acid and Calcareous Grasslands

Grasslands are the most extensive semi-natural plant communities in the UK countryside, with over 20% of our native species associated with these habitats (Preston *et al*., 2002). Unfertilised acidic and calcareous grasslands contain over 300 of the 540 grassland-associated native plant species. These two types of grassland have exceptional conservation and amenity value as a result of their floristic diversity. Unprecedented decreases occurred in the area of semi-natural grassland communities in the UK from 1930-1988, largely associated with agricultural expansion and intensification.

Of the 179 native species whose UK distribution declined in this period, nearly 40% are species of calcareous, unimproved or acidic grassland/heathland (Rich & Woodruff, 1996). Recent evidence indicates that the rapid increase in nitrogen (N) deposition that occurred in the latter half of the 20th century has been a major contributor to UK grassland biodiversity loss (Stevens *et al.*, 2004).

The long-term cumulative nitrogen deposition on UK grasslands

Energy production through the combustion of fossil fuels results in the emission of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) into the atmosphere. Food production also causes pollutant emissions: ammonia (NH_3) from farm animal units and both ammonia (NH_3) and nitrous oxide (N_2O) from intensive fertiliser use. These pollutants are transported in the atmosphere affecting air quality and rainfall chemistry across the UK. This has resulted in acidification of soils and waters in acid-sensitive areas such as many upland habitats and has also contributed to N enrichment of semi-natural areas. Reductions in emissions due to policy control measures have resulted in lower quantities of sulphur and nitrogen oxides falling on different habitats but, due to increases in emissions from shipping, recovery has not been as fast as hoped for. Ammonia emissions increased sharply from the 1950s to 2000 and currently remain at these peak levels.

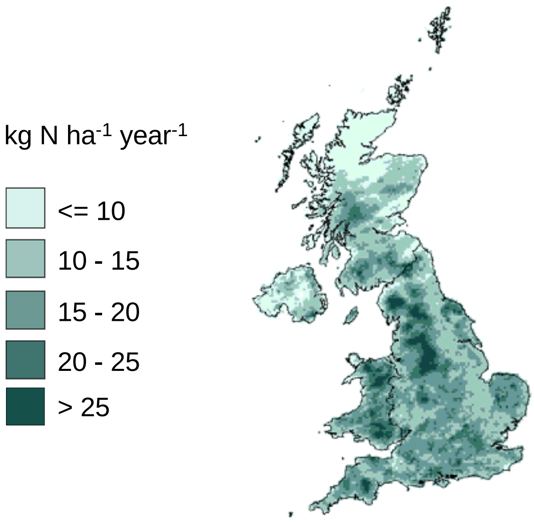

Fig 1a. Nitrogen (NOx + NHx) deposition measured 2003-2005

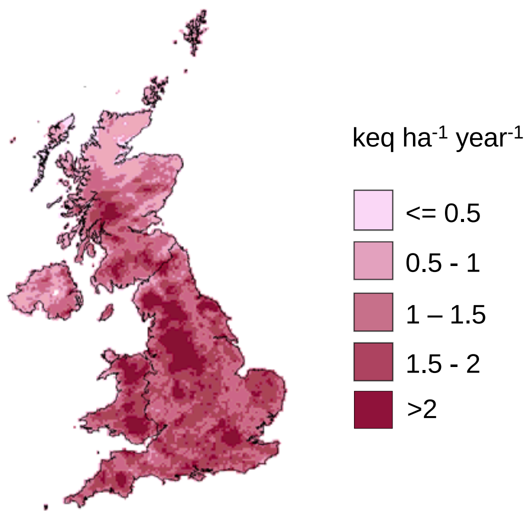

Fig 1b. Total acid deposition (S + NOx + NHx) measured 2003-2005

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Evidence of acidification and N-enrichment effects at the national scale

There are various sources of information which indicate vegetation, soils and waters have been affected by acidic and N deposition. A review of the evidence for the UK was brought together by the National Expert Group on Transboundary Air Pollution (NEGTAP) (http://www.nbu.ac.uk/negtap/home.html). The evidence for N enrichment of vegetation includes two national monitoring programmes – the Countryside Survey and the New Plant Atlas for the UK – which identified shifts in species composition towards more nutrient-demanding species in the latter half of the 20th century (Preston *et al*. 2002, Haines-Young *et al*. 2003) (e.g. Figure 2).

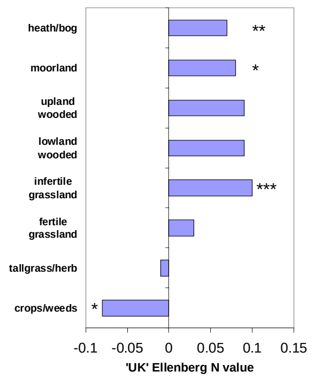

*Figure 2. The change in UK fertility score for different habitats between 1990 and 1998 taken from the most recent UK Countryside Survey (redrawn from Haines-Young et al., 2003). A low value is associated with low fertility and a high value with high fertility. Statistically significant changes are marked as * P<0.05, ** P<0.01, *** P<0.001.*

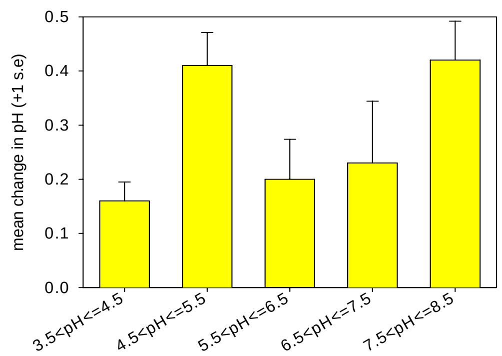

Figure 3. The increase in soil pH (0-15cm) from 1978-1998/9 at 767 sites across Great Britain (NEGTAP 2001)

Acidification of soils and waters recorded in some areas during the 20th century are now being reversed, reflecting the success of emission policies to reduce levels of acid deposition in the environment (e.g. Figure 3). There are still areas at risk, however, due to increases in sulphur emissions from shipping.

Why does air pollution affect our grassland, soil and waters?

The richness and diversity of species in unfertilised grasslands is dependent upon the large numbers of plants coexisting, without any single species being so dominant as to exclude others. Species-rich grasslands are typically associated with low productivity, generally as a result of nutrient limitation. Deposition of N can upset the delicate balance of competition between species, with increased nutrient availability causing eutrophication. These effects can be both direct - where some species such as mosses and lichens are damaged by acid rain, or indirect - where some species are out-competed by others (Carroll *et al.*, 2003). In addition, excessive N supply relative to plant demand causes N to be washed out of soil rather than taken up into plants, and this can lead to pollution of rivers and lakes. The acidifying components of N deposition also change soil chemistry and can have adverse effects on soil microbial activities and upon many plant species. The major changes in soil chemistry caused by N deposition include loss of calcium and other base cations in association with nitrate leaching, and increased solubility of aluminium. In the uplands, where the soils are often already highly leached due to the high annual rainfall, further base cation depletion and soil acidification are likely to have serious long-term impacts on the plant communities.

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Current evidence for nitrogen pollution effects on grasslands

Direct impacts of N enrichment on grassland biodiversity have been established from long-term N addition experiments in the Derbyshire Dales (Carroll *et al.*, 2003), confirming loss of species richness typically through the increase of grasses at the expense of forbs and mosses. These changes are progressive with time and are greater with higher rates of N deposition. One of the most sensitive indicators of N pollution impacts is the flowering of forbs in both calcareous and acid grasslands to which simulated pollutant N deposition has been applied in monthly spray additions for over a decade (Figure 4).

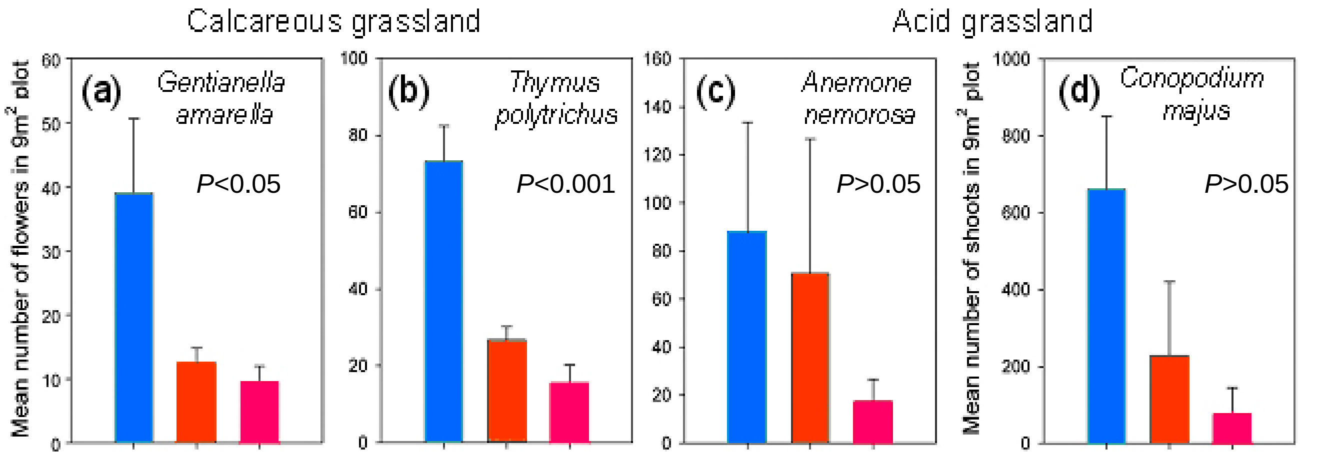

Figure 4. Numbers of flowers (a-c) and numbers of shoots (d) of plants in control plots (blue) and plots receiving simulated pollutant N deposition at 35 (red) and 140 (pink) Kg N ha^{-1} year^{-1} for 10-11 years. (O'Sullivan & Leake, UKREATE).

Loss of flowering seriously compromises the amenity value of these grasslands, and is likely to have long-term effects on the sustainability of those species that depend upon seed production for regeneration, such as the biennial *Gentianella amarella*. Our findings that some species are particularly sensitive to N deposition is supported by the national monitoring that has also found declines in the extent of the important calcareous grassland species *Thymus polytrichus*, and *Gentianella campestris*. However, some of the change and loss of species may have already occurred during the early part of the 20th century (Emmett, 2007), or be hidden by the long term nature of the changes and variability inherent in grasslands.

In another UKREATE acid grassland experiment in Mid Wales, an increase in cover of grass species at the expense of bilberry was found following regular additions of N where grazing pressure was reduced to encourage the return of a more diverse flora. In more heavily grazed paddocks, the effect of N addition was not apparent, indicating the dominant effect grazing has in some systems. In both experiments, acidification and loss of base cations was observed in soil water draining from the experimental plots. These effects will be long lasting without human intervention since replacement of bases from rainfall and weathering contribute small inputs compared to the losses. The extent to which upland grasslands can naturally recover from the long-term inputs of acidic pollution remains uncertain, and may require addition of bases such as ground limestone or dolomite to facilitate recovery of damaged sites.

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How will climate change and management affect the impacts of air pollution?

Air pollution interacts with both management and climate change to affect the sustainability of our fragile and nationally important grassland habitats. Drought and frost exacerbate physiological stress on plants caused by N pollution. Warming and drought mobilises N, increasing the risk of N enrichment of the plant community and leaching of N and acidity to linked streams and rivers. Some grassland plants receiving high rates of N deposition have increased susceptibility to frost and drought damage and may suffer increased attack from pathogens and insect herbivores. Drought increases the risk of grassland fires with potentially devastating effects on the species-rich communities that are dominated by slow-growing plants, many of which spread clonally. Where N deposition inhibits flowering and seed production this may compromise grassland recovery from seed-banks after extreme events such as fire or drought that damage or kill the turf. Appropriate grazing management is of absolutely vital importance for the maintenance of grassland communities and to prevent invasion by scrub and trees. However, overgrazing by sheep has been a particular problem in much of the upland grasslands causing the sward to break down and leading to increased erosion and oxidation of soil organic matter. Where grazing is reduced to encourage the return of heathland species we have found evidence that N deposition can slow their return. The use of specific management tools such as mowing with removal of clippings to deplete N enriched grasslands may help to reduce the effects of N pollution but further work is needed to validate this approach.

UK actions being taken to help reduce air pollution

Protocols under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP), have already led to substantial emissions reductions for sulphur dioxide and nitrogen oxides. As a result, acid deposition in the UK has declined by approximately 50% over the past 12 years, mainly due to reductions in sulphur emissions. Under the latest CLRTAP agreement (the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone) UNECE parties have agreed more stringent emission ceilings for SO_2 and NO_x as well as the first emission ceilings for NH_3, to be met from 2010. A major driver for agreement of these ceilings was the aim to reduce exceedance of critical loads for acidification and eutrophication across Europe. Critical loads are defined as the amount of acidity or nutrient N deposited on an ecosystem that, if exceeded, could lead to damage of that ecosystem. Critical loads are improved and refined as new data on ecosystem impacts become available. A recent update of UK critical loads has been undertaken and the report is available at: www.critloads.ceh.ac.uk .

Further Information

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