The impacts of sulphur and nitrogen deposition on: woodlands

Woodlands are valued for their high conservation status, contribution to the landscape, ability to store carbon and provision of public access and recreation opportunities. Recent surveys have shown no evidence of widespread damage from air pollution to forest trees, but excess nitrogen (N) deposition has been implicated in observed changes in the composition of woodland plant communities. Plant surveys indicate that N-demanding species such as bramble are becoming more abundant while others, such as bilberry, are declining. It is also thought that a lack of regeneration due to under-management in recent decades and browsing by deer has contributed to a degradation of ecological condition in some woodlands.

The distribution of inputs of acidity and nitrogen across the UK

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.

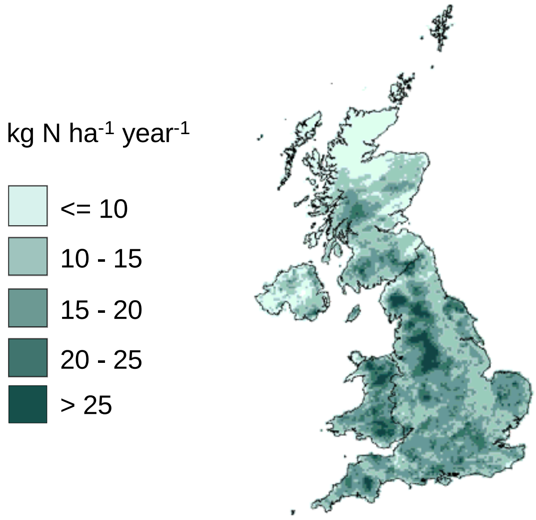

Fig 1a. Nitrogen (NOx + NHx) deposition measured 2003-2005

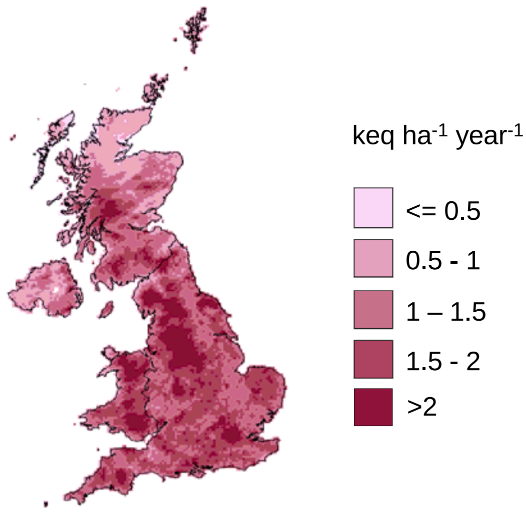

Fig 1b. Total acid deposition (S + NOx + NHx) measured 2003-2005

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Evidence of acidification and N-enrichment effects on semi-natural habitats

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).

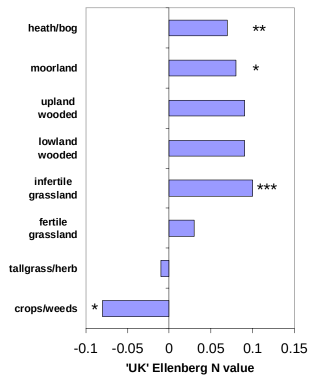

*Figure 2. The change in UK fertility score for different habitats between 1990 and 1998 taken from the most recent UK Countryside Survey (redrawn from Haines-Young et al., 2003). A low value is associated with low fertility and a high value with high fertility. Statistically significant changes are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

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.

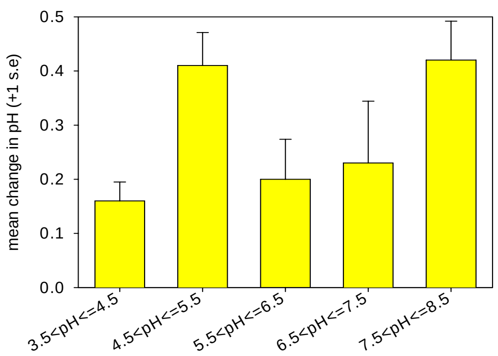

Figure 3. The increase in soil pH (0-15cm) from 1978-1998/9 at 767 sites across Great Britain (NEGTAP 2001)

How does air pollution affect our waters, soils and vegetation?

Although rainfall is naturally acidic, additional acidity either introduced directly by sulphur dioxide and nitrogen oxides or formed during the breakdown and uptake of ammonia has affected waters, soils and vegetation in the UK. The pH of lakes and rivers fell during the last century, in turn affecting populations of fish, invertebrates and water plant communities. Soils also became more acidic, affecting organic matter breakdown and soil nutrient balance. Soil acidification increases the solubility of some elements such as aluminium in the soil solution, which can be toxic to plant roots at high concentrations. Pollutants are also deposited to vegetation directly as gases, aerosols and in fogs and mists, and can cause direct damage to plants at high concentrations.

Emissions of nitrogen oxides and ammonia can lead to N enrichment (eutrophication). These problems can result in a loss of biodiversity in sensitive ecosystems because N-loving species benefit at the expense of other species of conservation interest that contribute so much to the character of semi-natural habitats. This happens due to nutrient imbalances, increased susceptibility to climatic stress and higher levels of insect or fungal damage which all affect the balance of competition between species.

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Current evidence for air pollution effects in British woodland

Long-term monitoring indicates that there is no widespread damage to forests and trees in the UK as a result of atmospheric pollution. The network of 350 Forest Condition Survey Plots, on which diameter increment and crown condition have been measured since 1987, shows no link between soil acidification and tree vitality. However, soil function may be affected leading to more subtle effects. For example, the Forest Condition Survey has identified a link between N deposition and the level of insect damage to Scots pine (Figure 4). An in-depth analysis of the ground flora associated with beech woodlands across the network has also revealed a relationship between the distribution of N-demanding species and distance to woodland edge (Figure 5) - a clear signal of the effects of N deposition. This observation is supported by recent surveys of plant communities, including Countryside Survey 2000, the New Plant Atlas and a re-analysis of ecological condition of over 100 semi-natural woodlands first surveyed in1971 (Kirby *et al.*, 2005), as well as by studies of the effects of point sources of N pollution (Pitcairn *et al.*, 2002). However, there are caveats that should be applied when interpreting observed trends as a clear signal of the effects of N deposition. First, the level of woodland management has declined over the past two to three decades as a result of the poor economic climate of the forestry sector, reducing light levels on the forest floor thus favouring shade-tolerant species. Second, the woodlands have aged, which similarly affects the composition of the ground flora (Figure 6).

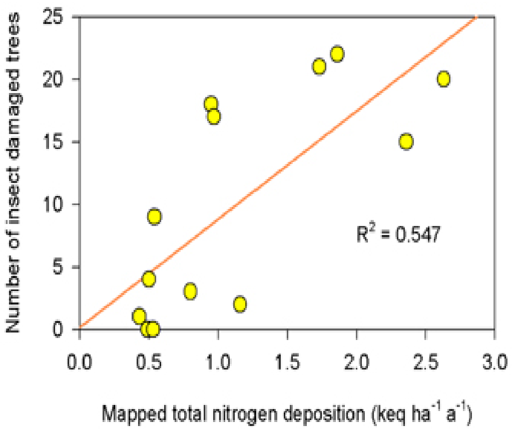
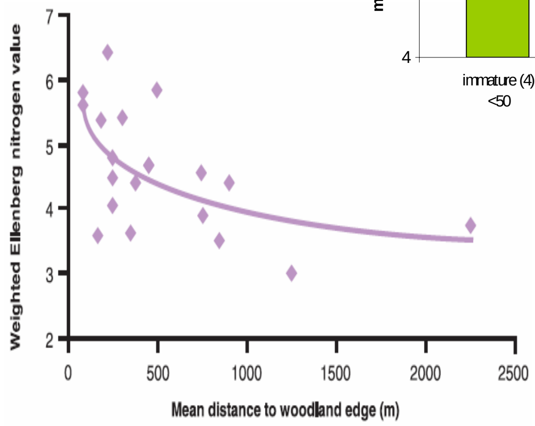


Figure 4 (above). Relationship between observed number of insect damaged trees and mapped total nitrogen deposition for Forest Condition Survey Scots pine plots (NEGTAP, 2001).

Figure 5 (below). Changes in the nitrogen demand of beech woodland ground flora with proximity to the woodland edge (Kennedy, 2003).



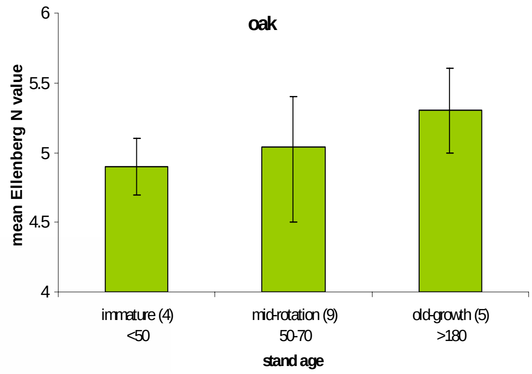


Figure 6 (above). Variation in nitrogen demand of ground flora of oak woodland with stand age.

Soil solution chemistry from the Intensive Forest Monitoring Network has indicated some recovery over the past ten years from high historical pollution loading, as a result of emission control policies. The most dramatic observation is the downward trend in tree foliar sulphur concentrations, corresponding to a reduction in soil solution sulphate concentrations across the network. Indeed, it is likely that sulphur deficiency may become an issue in the near future in some regions. There is little evidence to indicate a reduction in N deposition or its impacts; on the contrary, there is continuing evidence of the effects of high N deposition, particularly in areas dominated by intensive agriculture, such as East Anglia. At one site in Thetford forest, where N deposition in throughfall has been measured as 25 kg ha^{-1} yr^{-1}, soil solution pH has fallen by 2 units since monitoring began in 1995 and nitrate concentrations in soil solution as high as 150 mg l^{-1} have been measured. Nettle, a species with high N demand, has also increased its dominance of the ground flora over this period (Vanguelova *et al.*, 2007).

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

The predicted changes to the climate of the UK are likely to have significant impacts on woodland plant communities. Limited evidence suggests that rising CO_2 levels may favour weedy species, at the expense of slower growing species, possibly compounding the impacts of N deposition. Where water is not limiting, the combined effects of N deposition and rising CO_2 levels are likely to lead to significant increases in forest growth. There is already some evidence for this in old-growth oak in southern England (Broadmeadow, 2004). Climate change will also affect soil processes, leading to interactions between growth, nutrient cycling and pollutant inputs. For example, mineralisation rates will increase thus affecting nutrient availability, while nutrient uptake and leaching may be affected by changing rainfall patterns and a longer growing season (Bradley *et al.*, 2005).

Conventional forest management increases the input of N that a forest ecosystem can withstand, by removing a proportion in timber. At the same time, base cations are removed reducing the ability of the ecosystem to withstand acid deposition, particularly woodlands established on soils low in base cations. The future level of woodland management, particularly in response to an increased utilisation of woodfuel for climate change mitigation objectives, will affect how woodlands respond to the continuing effects of air pollution and it will be important to ensure that this interaction is accommodated in developing new climate change policy and forest management practices.

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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