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We need to talk about nitrogen

The impact of atmospheric nitrogen deposition on the UK's wild flora and fungi

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Amid the clamour about climate change and carbon emissions, another alarm bell, largely unheard, has been sounding for some time. Global pools of reactive nitrogen have been building in the atmosphere, soils and waters from the burning of fossil fuels and intensive farming. This excess of reactive nitrogen is now being deposited throughout the biosphere, significantly impacting our most precious semi-natural habitats, changing their plant communities and the very functions these ecosystems provide.

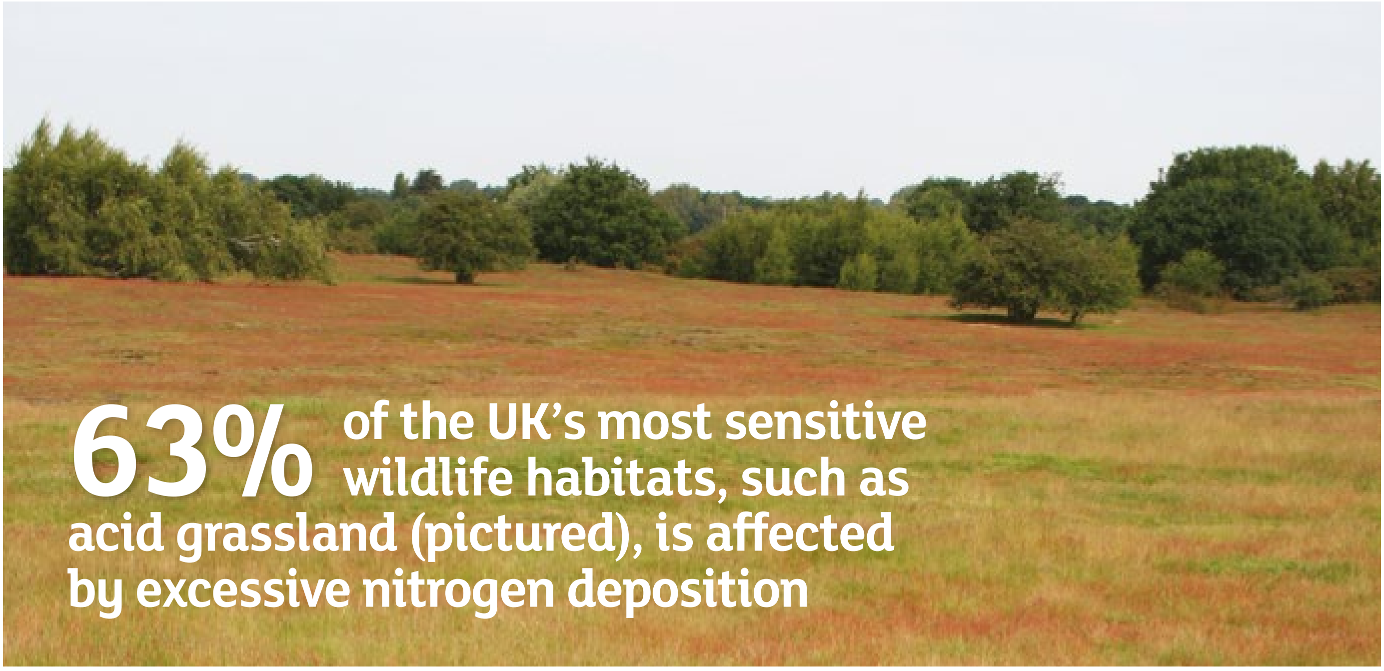
We need to talk about nitrogen deposition, to raise awareness of its causes and consequences, to agree on solutions, and to work together to integrate these solutions into policy and practice now.

This short publication summarises current evidence and provides background information to raise awareness of atmospheric nitrogen deposition, where it is coming from, where it is affecting semi-natural habitats, the impacts on habitats, plants and fungi, and how it is recorded.

The paper provides further information sources that set out what can be done to address this issue – be that by a member of the public, a land owner or manager, or by governments.

It has been written with significant help from Carly Stevens at the University of Lancaster, Mike Ashmore at the Stockholm Environment Institute and colleagues at the Centre for Ecology & Hydrology (CEH). In addition, special thanks are needed for Clare Brewster, a postgraduate student of Lancaster University, who produced an updated, revised version of the original paper.

Botanical Society of Britain & Ireland
British Bryological Society
British Lichen Society
Chester Zoo
flora locale
rspb giving nature a home
National Trust
SEI
Woodland Trust



The impact of atmospheric nitrogen deposition on the UK's wild flora and fungi: a summary

In the UK, rates of atmospheric nitrogen deposition increased substantially between 1950 and the 1990s, with a small decline over the last decade. This has led to environmental changes, chiefly due to eutrophication and acidification of habitats. Accumulation of extra nutrients, as well as reduction in soil pH, is negatively affecting natural and semi-natural habitats whose important biodiversity developed in direct response to low nutrient levels.

Species richness in many semi-natural habitats declines with increasing nitrogen deposition across the UK. These habitats are highly valued natural capital, integral to UK ecosystems, key components of protected landscapes, and host to inter-dependent communities of plants, lichens, fungi, insects, birds and other animals; yet 63% of all nitrogen-sensitive habitats across the UK receive nitrogen deposition higher than they can tolerate.[1]

Even if there were to be substantially reduced rates of nitrogen deposition in future, recovery of habitats will be a slow process and the impacts of nitrogen may be a far more immediate threat to these habitats than climate change.

What's happening globally...

Over the past 50 years, human activity has caused significant changes to the world's ecosystems. Our dependency on fossil fuels, which is well recognised, has been paralleled by our dependency on manufactured nitrogen-based fertiliser to increase crop yields significantly and produce feed for livestock. Both have enabled rapid population growth and economic development, but both also contribute significantly to the causes of climate change and changes to the global nitrogen cycle. The UN's Millennium Ecosystem Assessment documents that the costs of this growth and development will increasingly diminish the benefits for future generations unless more sustainable practices are adopted.[2]

Levels of reactive nitrogen have tripled in Europe and doubled globally in the last century. This is causing unprecedented changes to nutrient cycles and is driving widespread eutrophication of ecosystems and biodiversity loss, exacerbating climate change and causing significant human health impacts.[3]

Global emissions of nitrogen oxides and ammonia in the atmosphere have increased sharply in the second half of the 20th century.[4] Between 1960 and 2000, global emissions more than doubled and this trend is expected to continue for ammonia emissions until 2050 with continued use of artificial fertilisers and increasing meat consumption (Figures 1 and 2). Nitrogen oxides emissions are projected to stabilise due to technological improvements from the 2030s.[5]

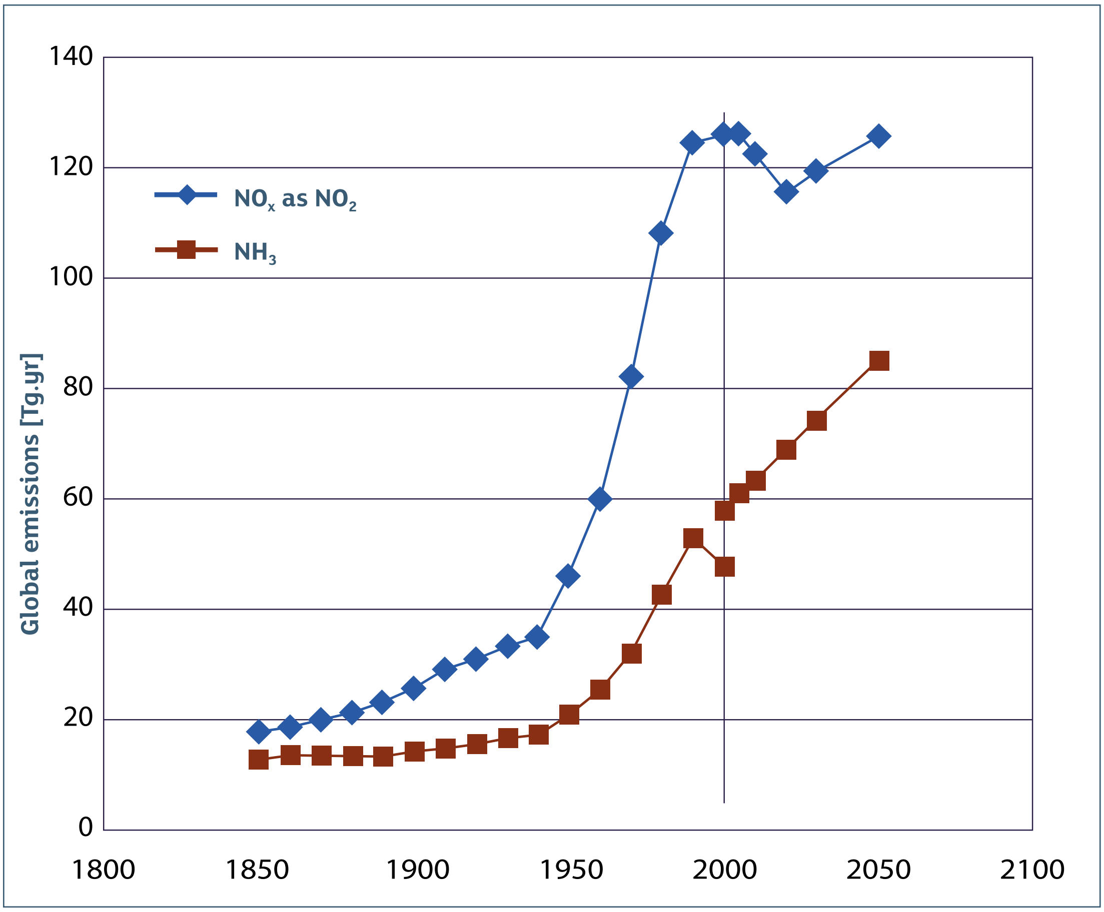


Figure 1: Trends and future projections of global emissions of nitrogen oxides and ammonia[5]

... and in the UK?

Over the last two decades, UK emissions of nitrogen oxides have fallen by about 70% due to measures to control air pollution, although there have only been small decreases in ammonia emissions. Despite these welcome reductions, deposition of both reduced and oxidised nitrogen to the UK has not declined as rapidly because of changes in atmospheric processing. RoTAP (2012) estimated that over the 20-year period 1988-2008, nitrogen oxides emissions fell by about 50%, but total deposition to the UK only fell by about 25%; for ammonia, over the period 1997-2008, UK emissions fell by about 15%, but UK deposition only fell by 2%.[7]

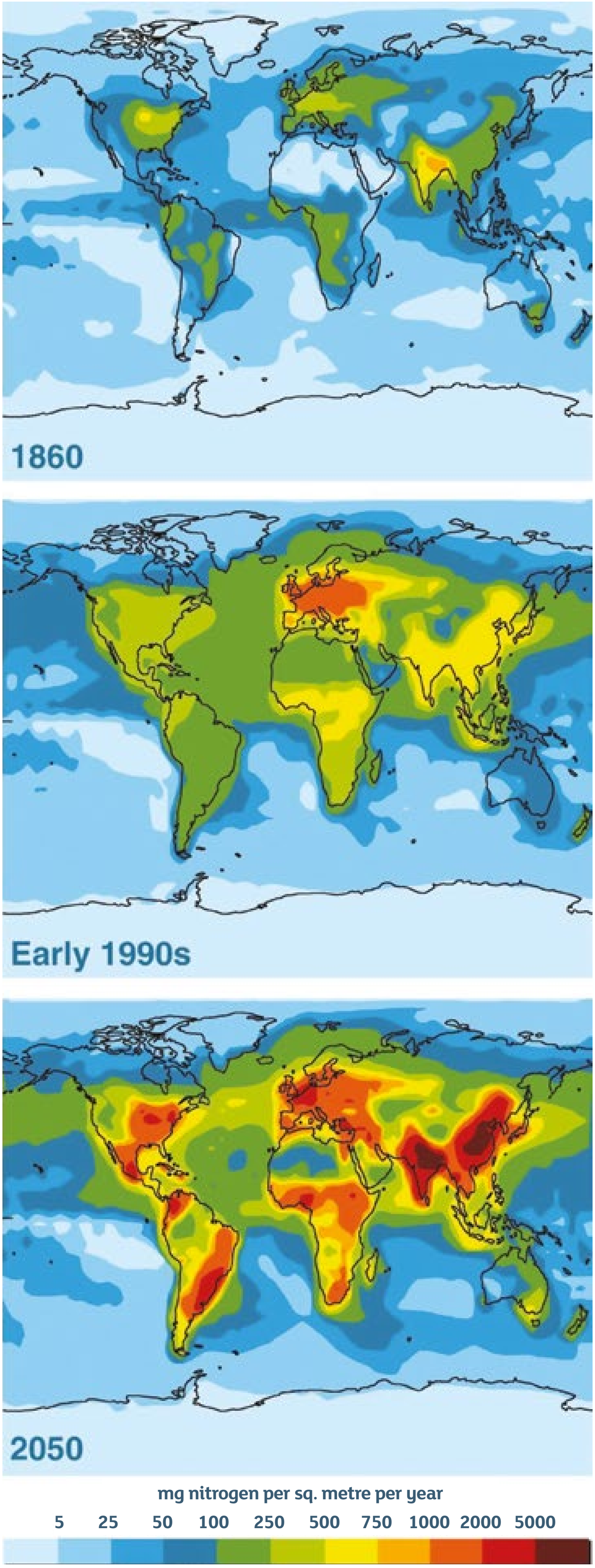


Figure 2: Global nitrogen deposition in 1860, early 1990s and projected for 2050[6]

What is atmospheric nitrogen deposition and where is it coming from?

Nitrogen deposition is the term given when reactive nitrogen pollutants emitted to the atmosphere are transferred to land and water bodies, either in gaseous form (dry deposition) or in precipitation (wet deposition).

In the UK, the two main forms of atmospheric nitrogen pollutants are nitrogen oxides (NO_x) and ammonia (NH_3). Nitrogen oxides are emitted from the burning of fossil fuels mainly from power stations, factories and transport emissions, whereas the main source of ammonia is from agriculture. In 2014, agriculture accounted for 83% of all UK ammonia emissions, with the largest contributor being livestock manures, especially from cattle, as well as emissions from organic and inorganic fertilisers that are spread onto fields.[8]

These gases undergo chemical and physical transformation as they disperse from their source, leading to different forms of deposition (Figure 3). For oxidised nitrogen, these comprise dry deposition of nitrogen oxide gases and wet deposition of nitrate; while for reduced nitrogen, these comprise dry deposition of ammonia gas and wet deposition of ammonium. Dry deposition of particulate and aerosol nitrate and ammonium can also contribute.

Reactive nitrogen

Although 78% of the atmosphere is made up of nitrogen gas, most of it is inert. In nature, it takes specialist soil bacteria, a volcanic eruption or a lightning strike to turn it into reactive nitrogen – a form usable by, and essential to, plants, lichens and fungi.

Reactive nitrogen describes all forms of oxidised nitrogen (e.g. nitrogen dioxide) or reduced nitrogen (e.g. ammonia). In many wild or semi-wild habitats, naturally occurring forms of reactive nitrogen are usually scarce and limit growth.

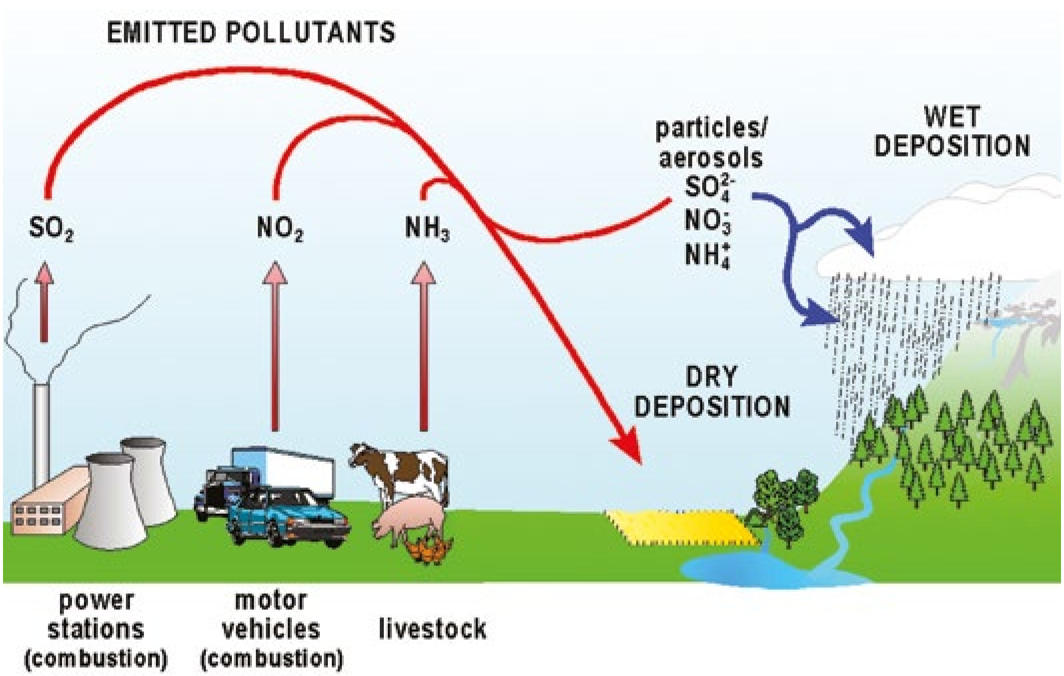
> *"More reactive nitrogen is now created each year by human activities than all natural sources combined"*
>
> European Nitrogen Assessment, 2011[3]

Once emitted to the atmosphere, primarily from human activities, reactive nitrogen may be deposited to soils and vegetation, where it can acidify soil and over-fertilise sensitive ecosystems.

In addition to these impacts on ecosystems, reactive nitrogen is a significant contributor to the human health impacts of poor air quality that costs £16 billion a year; it can also be re-emitted as nitrous oxide, which contributes to climate change and stratospheric ozone depletion.[5]

Rates of nitrogen deposition vary across the country. At a given location, it will comprise varying proportions of dry and wet deposition of 'oxidised' and 'reduced' forms. These can be from local, regional, national or international sources. In urban areas and along major transport routes, for example, nitrogen oxides tend to dominate, reflecting the impact of local combustion and vehicle emissions. In more rural areas, ammonia from local sources of agriculture tends to dominate. At a site immediately downwind of a large livestock farm, for example, concentrations of ammonia are likely to be high. This will lead to high rates of dry deposition since ammonia is highly reactive and deposits relatively quickly. By contrast, in our more remote upland areas away from industrial processes and intensive agriculture, nitrogen loading can still be excessive but is more likely to have been transported from sources further afield and be deposited as wet deposition.

Experimental evidence suggests that the different chemical and physical forms of nitrogen deposition and accumulation can influence the rate and extent of impacts in different ecosystems.[9] For example, a long-term controlled field experiment showed that, for the same overall nitrogen dose, 'dry' ammonia gas was more damaging to bog vegetation than 'wet' deposition of 'reduced' nitrogen (ammonia compounds), which was more damaging than 'wet' deposition of 'oxidised' nitrogen.[10] However, responses to the form of nitrogen are complex and habitat dependent, with conversion between nitrogen compounds resulting from the activities of soil microbes.



Key to chemical formulas

SO_2 = Sulphur dioxide
NO_2 = Nitrogen dioxide
NH_3 = Ammonia
SO_4^{2-} = Sulphate
NO_3^- = Nitrate
NH_4^+ = Ammonium

Figure 3: Pollutant emission and deposition processes.[11] Power stations and industry sources also emit nitrogen oxides

Which areas of the UK are affected?

Figure 4 shows the total deposition of nitrogen across the UK. Sensitive habitats in areas with intensive agriculture, such as East Anglia, receive high levels of dry deposition from local sources of ammonia. In contrast, the contribution of high rates of wet deposition from long-range transport can be seen in the areas of the Scottish/English border, the Pennines and the Welsh mountains, where there are few substantial local emission sources but where rainfall is high. As Figure 4 shows, the deposition rate is above 15kg N ha^{-1} $year^{-1}$ for much of the UK. This compares with levels of nitrogen deposition generally of 3-5kg N ha^{-1} $year^{-1}$ found in remote areas, such as parts of north-west Scotland, with few local emission sources and away from large trans-boundary inputs.

Figure 5 shows the concentration of ammonia in the atmosphere, emphasising the effect of agricultural sources, and in particular livestock. These can be compared with critical levels, the concentrations of pollutants in the atmosphere above which negative effects on sensitive species may occur. They are not habitat specific. Critical levels of ammonia for lichens and bryophytes are set at 1µg m^{-3} while the critical level of ammonia for herbaceous species is 3µg m^{-3}.[13]

Sixty-four per cent of the UK land area has ammonia concentrations above the critical level for lichen and bryophyte species for which the UK has internationally important communities, compared with only 3.9% of the UK land area where the critical level is exceeded for herbaceous plants.[14] Critical levels for nitrogen oxides are generally only exceeded in large urban areas or close to major roads, while critical levels of ammonia are more often exceeded in agricultural areas.[11]

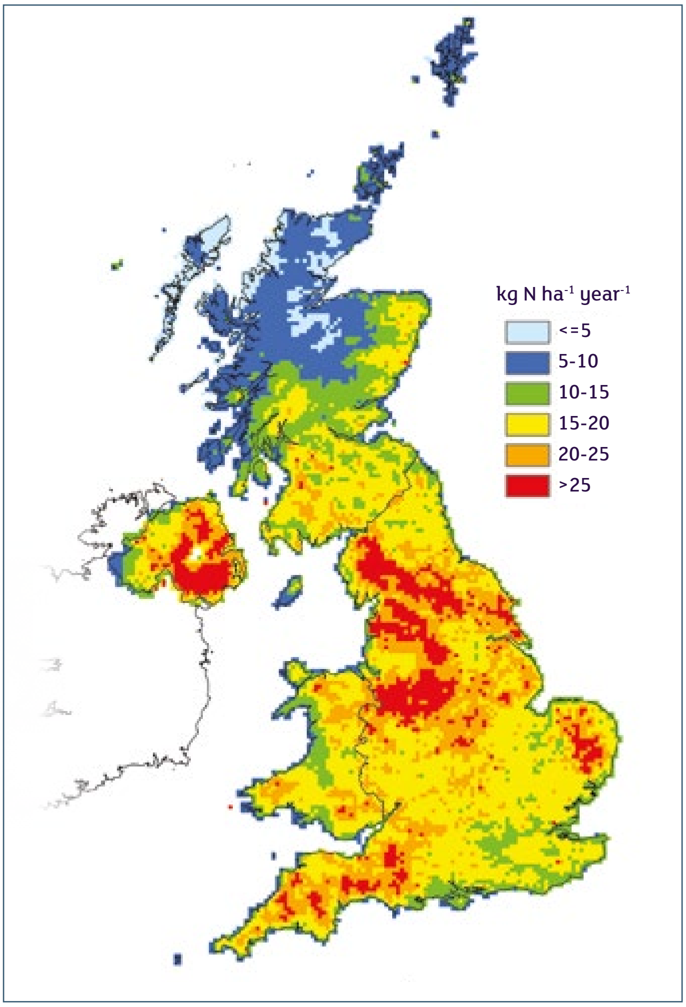


Figure 4: Nitrogen deposition (2011-2013). Map assumes moorland (i.e. low-growing vegetation) everywhere

Source: Centre for Ecology and Hydrology[12]

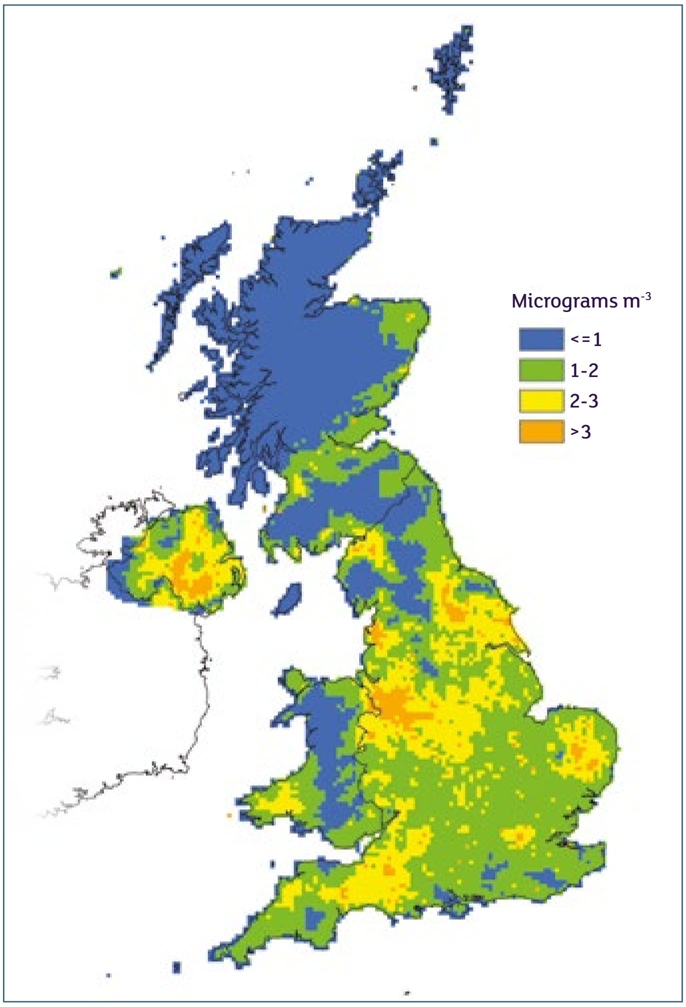


Figure 5: Ammonia concentrations (2010-2012)

Source: Centre for Ecology and Hydrology[12]

How do nitrogen deposition and high atmospheric concentrations affect plants and other living organisms?

Evidence clearly demonstrates the impact of high nitrogen deposition on ecosystems, observed over a range of spatial and temporal scales. The effects are significant, with observable species loss, changes in soil chemistry and habitat degradation resulting from nutrient enrichment (eutrophication), acidification (lower pH), or direct damage (toxicity). Government-funded research demonstrates these impacts are widespread and affect many threatened vascular plant, bryophyte and lichen species.[15]

Species loss and nutrient enrichment

Although some vascular plants, bryophytes and lichens are nitrophilic and respond positively to increased nitrogen levels, studies show that species associated with nutrient-poor habitats are increasingly under threat.[15,16] Clear correlations have been demonstrated between rates of nitrogen deposition and species richness in a range of habitats, both in the UK (see Figure 6) and Western Europe. These studies typically find low species richness at high levels of nitrogen deposition while some, such as those habitats that are naturally rich in nutrients, do not show correlations. In a characteristically nutrient-poor semi-natural plant community, enrichment with nitrogen provides a competitive advantage to those species most able to use the additional nutrients. This promotes competitive species, such as grasses, over slower growing species adapted to low nutrient conditions, so reducing overall species richness within habitat types and contributing towards the homogenisation of plant communities.[17]

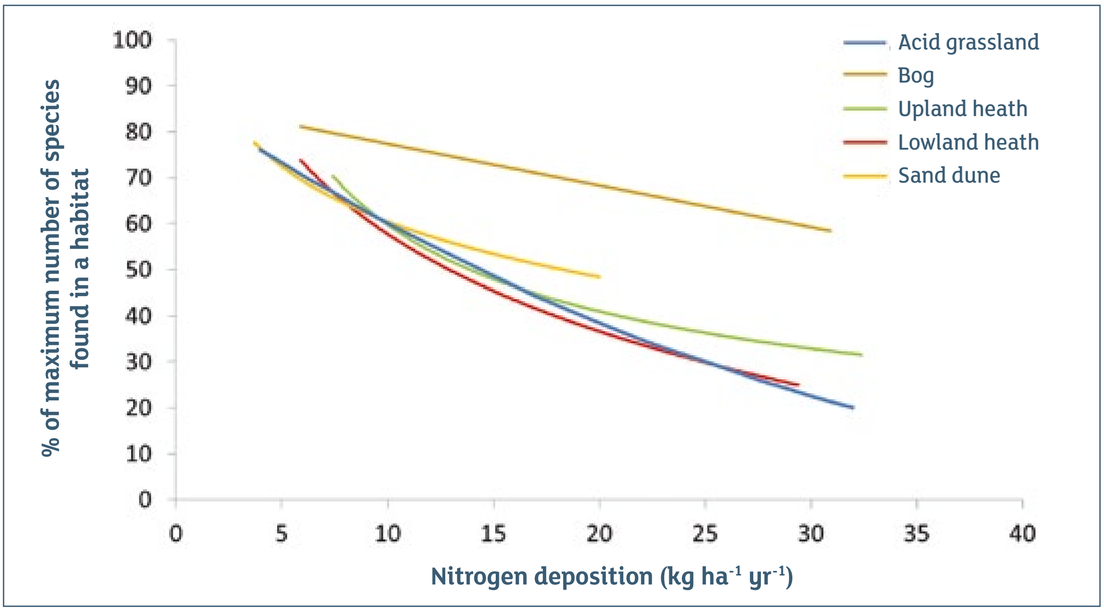


Figure 6: The role of nitrogen deposition on widespread plant community change across semi-natural habitats

Source: Field et al (2014)[18]

It is possible to identify species associated with either high or low levels of nitrogen deposition by correlating species presence and abundance with levels of nitrogen deposition. Some examples of vascular plants identified as sensitive include harebell (*Campanula rotundifolia*), fairy flax (*Linum catharticum*) and bird's-foot trefoil (*Lotus corniculatus*).[19,20]

Certain fungal groups may also be very sensitive to increased nitrogen deposition. Declines of grassland fungi in north-west Europe and major changes in the ectomycorrhizal fungi in forests in central Europe have been attributed, among other causes, to nitrogen deposition.[21] Flowering plants, such as orchids, which are heavily dependent on ectomycorrhizal fungal associations, may be particularly affected by such declines.

Effects of nitrogen deposition and high atmospheric ammonia concentrations can often be seen around poultry units. As one study shows (Figure 7), a more nitrogen-tolerant grass, Yorkshire fog (*Holcus lanatus*), increases in abundance closer to the poultry farm whereas less nitrogen-tolerant species, such as broad buckler fern (*Dryopteris dilatata*), decrease in abundance.

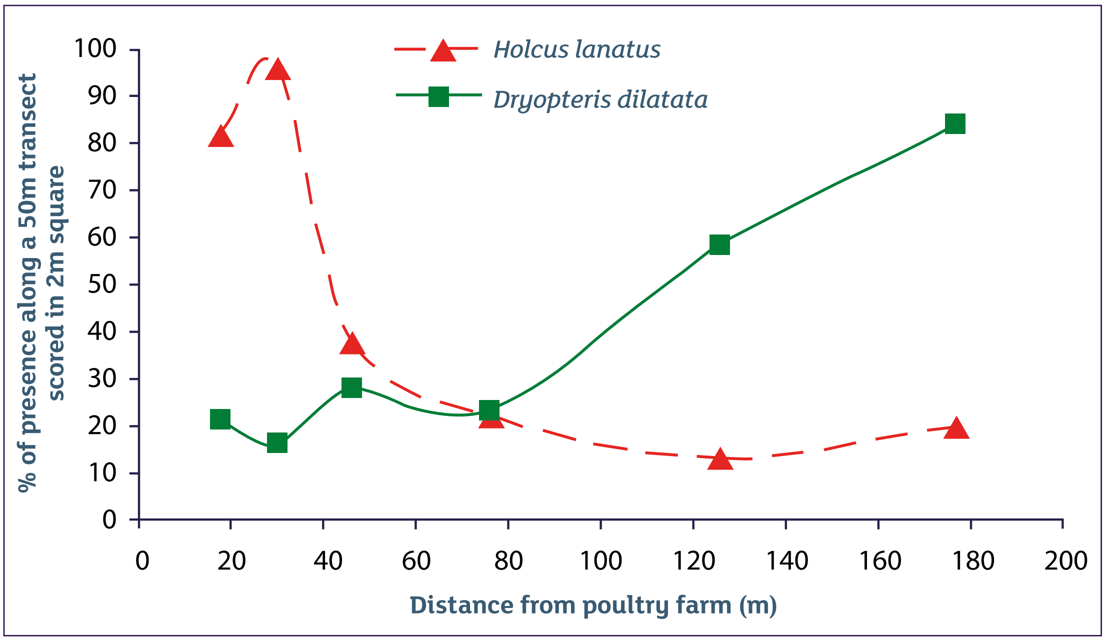


Figure 7: The response of two species, Yorkshire fog (*Holcus lanatus*) and broad buckler fern (*Dryopteris dilatata*) to ammonia[22]

Acidification

Nitrogen deposition also causes acidification. For example, reduced nitrogen compounds such as ammonium acidify soil via microbial transformations but also assimilation in plants leading to acidification of the rhizosphere.[23] As pH decreases, it changes the broader chemistry of the soil, including the cycling of other nutrients, and increases the availability of metals such as aluminium. Plants can be adapted to specific pH ranges, and acidification means that they are less able to compete with less specialised plant species for resources, or they may be negatively affected by other changes in the soil.

Direct damage

Direct damage occurs most commonly at high gaseous concentrations of ammonia or nitrogen oxides. Impacts on plants include bleaching, leaf discoloration and increased susceptibility to damage from drought, frost and diseases.[24] These direct impacts reduce plant health and can cause them to be less vigorous and die, with associated impacts at the community and habitat level.

Acute effects are often observed close to nitrogen sources. In one experiment ammonia was released to simulate the effects of a pig or poultry farm on a bog habitat. Direct damage was caused to sphagnum moss and to *Cladonia* lichen which became bleached, overgrown with algae and significantly damaged due to high ammonia concentrations.[22]

Figure 8: Bleaching damage to *Cladonia* lichen from ammonia

Figure 9 (far left) shows a healthy community of ephyphitic lichens on an alder tree in Wales. **Figure 10** (left) shows excess algal growth on a tree at Moninea bog in Northern Ireland as a result of acute atmospheric ammonia pollution from nearby poultry farms

Sensitive bryophyte and lichen species

The UK supports internationally important epiphytic communities of mosses, lichens and liverwort species. These species can be highly sensitive to nitrogen pollutants, especially dry deposition of ammonia and nitrogen oxides, causing changes such as those illustrated in Figures 9 and 10.[25,26] Investigations have identified bryophytes and lichens that are particularly sensitive[26,27], for example, the endangered eyelashes treebeard lichen (*Usnea florida*, Figure 11).

Figure 11: Eyelashes treebeard (*Usnea florida*)

Impact on wider ecosystems

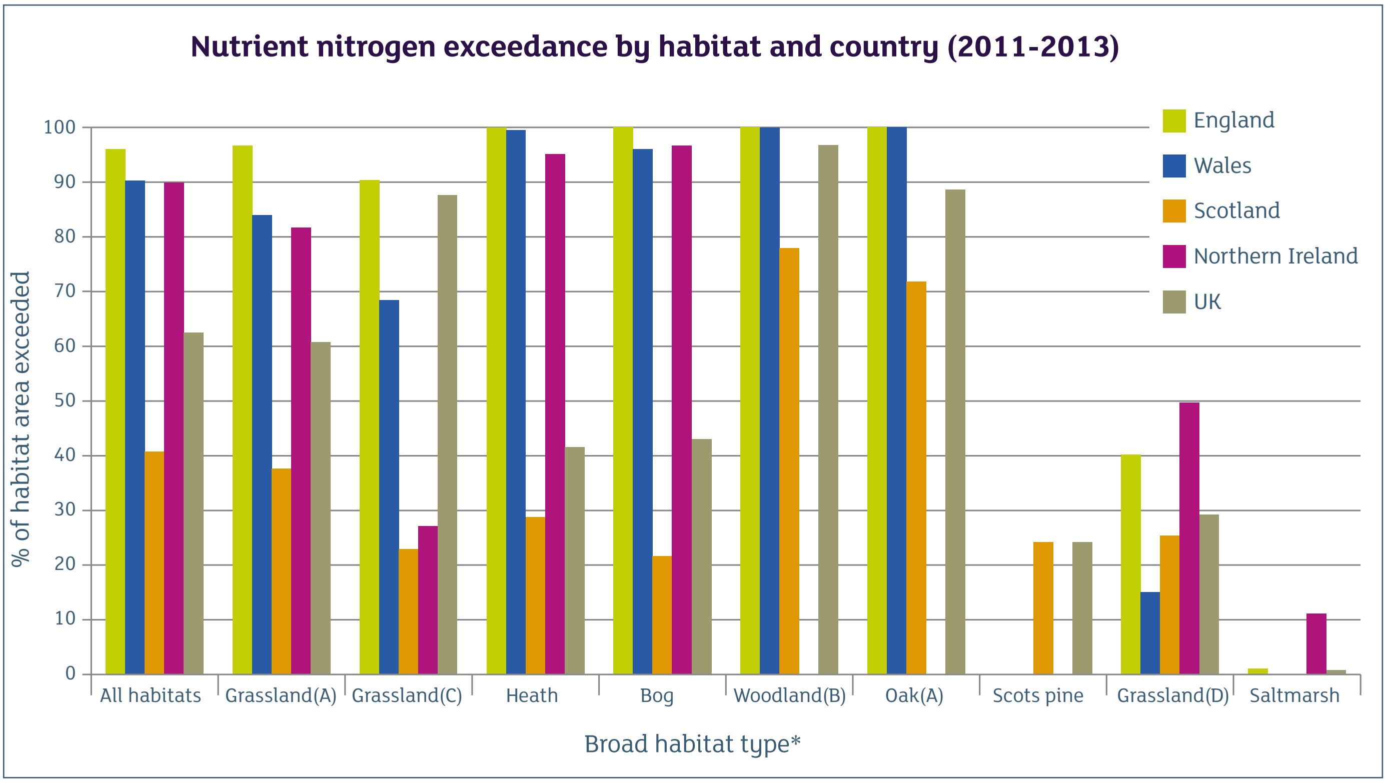
In addition to impacts on specific species, early evidence also suggests that habitat changes resulting from nitrogen deposition may also affect other taxonomic groups such as insects and birds, although further research is required.[28,29] For example, changes in plant species composition may affect invertebrate herbivores whose larvae feed on only one plant species. One Swedish study demonstrated declines of butterfly species from grassland sites was greater for species whose larval host plants were more adapted to low nutrient conditions; while colonisations were reported for butterfly species whose larval host plants were adapted to nutrient-rich conditions.[30] A survey of British moths also suggested that species with larval stages feeding on plants adapted to low-nutrient conditions declined between 1970 and 2010.[31] Although neither of these studies specifically included nitrogen deposition as a factor, they demonstrate how changes in host plant frequency that are caused by nitrogen deposition can lead to effects on invertebrates.

How much is too much?

The measure of sensitivity of a habitat to nutrient deposition is called a 'critical load'. This represents a threshold for that habitat, above which species loss or habitat degradation is expected either immediately or in the long term. Some habitats are much more sensitive than others – i.e. they have a lower critical load (see Table 2, opposite). Experimentally derived critical loads are important in providing an indication of the long-term threat from nitrogen deposition.

Many very sensitive habitats occur in areas of the UK where their critical loads are exceeded, even though they may be in areas of relatively low nitrogen deposition. As Figure 12 shows, the percentage area of UK habitats (2011-2013) with nitrogen deposition exceeding critical loads varies by habitat type and by country.[32] Although there is an overall decreasing trend in the percentage of UK habitats affected by nitrogen deposition, with levels exceeding critical loads dropping from 75% of UK-sensitive habitats in 1996, to 62.5% in 2011-2013 (see Table 1, opposite), rates of exceedance remain particularly high in England, Wales and Northern Ireland.[32]

Figure 12: Exceedance of nutrient nitrogen critical loads by habitat and country, based on Concentration Based Estimated Deposition (CBED) nitrogen deposition for 2011-2013[34]



* Grassland (A) – Acid grassland; Grassland (C) – Calcareous grassland; Heath – Dwarf shrub heath; Woodland (B) – Broadleaved woodland (managed); Oak (A) – Acidophilous oak (unmanaged); Scots pine – Scots pine (unmanaged); Grassland (D) – Dune grassland

Table 3 gives the UK and country breakdown of the percentage of internationally important sites where the critical loads for nitrogen deposition are exceeded for one or more habitat features. Other habitats within the sites may be less sensitive to nitrogen and have higher critical loads and lower, or no, exceedance.

With continuing high levels of nitrogen deposition, continued impacts are likely to be high. These may well increase in frequency and occur over wider areas due to the cumulative effects of nitrogen deposition over time.[17]

Table 1: Shows the percentage of UK sensitive habitats exceeding critical loads for eutrophication in 2011-2013.[32]

Country	Percentage of UK sensitive habitats exceeding critical loads based on deposition data for 2011-2013
England	96.0
Wales	90.3
Scotland	40.7
Northern Ireland	89.9
United Kingdom	62.5

Table 2: Critical loads and exceedance in UK

Source: Hall et al., 2015[33]

Critical loads of nitrogen used to assess and map exceedance in UK habitat	kg N ha^{-1} $year^{-1}$
Molinia caerulea meadows	**15-25**
Alpine & subalpine calcareous grassland	**5-10**
Low & medium altitude hay meadows	**20-30**
Heathland	**5-15**
Mire, bog & fen habitats	**5-10**
Coastal dune heaths	**10-20**

Critical loads are expressed in ranges because they are assigned for habitat throughout Europe (assigned by UN Economic Commission for Europe) and account for sensitivities to nitrogen deposition through soil type, groundwater level and precipitation.[33]

Table 3: Summary of exceedance of nutrient nitrogen (eutrophication) critical loads for UK SACs and SPAs, based on CBED nitrogen deposition for 2011-2013[33,34]

Country	% Special Areas of Conservation (SACs) (with critical loads) with exceedance of one or more features based on CBED nitrogen deposition for 2011-13	% Special Protection Areas (SPAs) (with critical loads) with exceedance of one or more features based on CBED nitrogen deposition for 2011-13
England	93.9	90.3
Wales	93.7	92.9
Scotland	82.6	64.5
Northern Ireland	98	83.3
United Kingdom	89.9	76

Total number of sites by country is based on the 'Site Relevant Critical Load' database held for work under Defra contract AQ0826. Percentages are calculated as the percentage of sites (for which nitrogen critical loads could be assigned to at least one habitat feature) where nitrogen deposition exceeds one or more habitat features. Analysis is done separately for SACs and SPAs, so the results above do not take account of where these sites may overlap with one another.

Reducing nitrogen deposition – policy and practice

The nitrogen deposition problem is complex and requires co-ordinated and multi-faceted approaches to address both its causes and consequences. Links need to be strengthened between related policy areas such as agriculture, water quality, energy, transport, climate change and public health. The reactive nitrogen problem is a global, regional, country and local issue, and effective solutions will need to be sufficiently integrated to drive a reduction in overall emissions.

The UN's Millennium Ecosystem Assessment (2005) and the UK's National Ecosystem Assessment (2011) identify atmospheric nitrogen deposition as one of the top two drivers of change in plant diversity, along with climate change. Policy commitments for biodiversity also provide a driver for addressing nitrogen deposition. For example:

- Convention on Biological Diversity's Strategic Plan for Biodiversity (2011-2020) includes Target 8: *By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity;*
- European Biodiversity Strategy and the various UK country biodiversity strategies;
- EU Habitats Directive and UK legislation protecting designated areas (including Areas/Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation).

The policy framework for reducing air pollution across the UK is currently set at global, European, UK and national levels. The UK is a party to the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) and its 2012 Gothenburg Protocol. Many of the UK's legal standards on pollutant emissions and air quality derive from European Directives, including the Air Quality Directive 2008 and the European National Emissions Ceilings Directive (NECD), which sets national emissions ceilings for nitrogen oxides and ammonia (and other pollutants). Industrial installations, including large intensive pig and poultry units, are regulated under the Industrial Emissions Directive and the Environmental Permitting Regulations 2010. There are currently no regulatory mechanisms in place in the UK for other agricultural ammonia emission sources. Voluntary mechanisms are being introduced, for example, some ammonia mitigation measures are included in Common Agricultural Policy (CAP) schemes in England.

Action now needed

Protecting habitats from atmospheric nitrogen deposition will need action on three levels:

- International and national action to reduce long-range deposition;
- Local action that reduces or intercepts emissions close to sensitive designated nature conservation sites;
- On-site restoration to mitigate the impact of past or present deposition.

"Substantial policy intervention on oxidised nitrogen compounds, and little policy intervention on reduced nitrogen compounds [ammonia], has produced very limited success in reducing the effects of eutrophication within the UK"

Review of Transboundary Air Pollution, 2012[7]

The UK's planned exit from the European Union (EU) could lead to significant changes in this regulatory framework, depending on the agreed terms of departure, the transposition of European law into domestic law, and the UK's subsequent relationship with the EU and other European bodies. However, the UK's international commitments will continue to apply. New agricultural or land management policy to replace the Common Agricultural Policy (CAP) will also impact on policy and practice relating to nitrogen emissions.

Recovery and management of habitats

In the UK, substantial reductions in emissions of nitrogen have been achieved over the past 20 years or more, mainly for nitrogen oxides from combustion sources, with some further reductions likely through new policy commitments.

By contrast, there is significant potential for tackling ammonia emissions, where mitigation measures are largely based on voluntary codes of practice.[35] Overall, emission reductions have not resulted in similar levels of decrease in nitrogen deposition, with non-linearities due to changing atmospheric chemistry.[7] For sensitive habitats close to emission sources, e.g. in lowland agricultural areas, spatially targeted measures to reduce local emissions have the potential to be a cost-effective means for local reductions in nitrogen deposition. For other sites, in particular those in remote areas away from sources and dominated by long-range nitrogen inputs, national and international measures are key.

A reduction in nitrogen deposition is necessary if habitats are to be protected but, even once this has been achieved, reversing the effects can be very slow. A number of studies have investigated recovery and shown that over time impacted habitats can sometimes, although not always, return to a state close to similar areas where no nitrogen has been added.[36] However, this may take decades and lowering nitrogen deposition is often not enough; measures such as physically removing the accumulated nitrogen may also be required.[37]

A review published in 2013 found that there is some potential for mitigating the impacts of nitrogen deposition through on-site management and effective management techniques were found for a range of habitats. However, this potential varies greatly between habitat and management practice, and should not be seen as a substitute for action to reduce emissions.[38]

Conclusion

This paper highlights the damaging impacts of atmospheric nitrogen deposition on habitats and their botanical and fungal communities.

PLINK members will continue to work together and with the academic and evidence-gathering communities to raise awareness of the problems caused by atmospheric nitrogen deposition. We will raise awareness with the general public and highlight actions that can be taken to tackle the sources of nitrogen deposition, showcasing action at the site level to reduce the impacts of atmospheric nitrogen deposition.

In turn, we call on our elected governments to match our action with the necessary measures at international, regional and country level to ensure good words are turned into practical action, with better co-ordination between regulatory, advisory and voluntary measures.

Others have an important role to play too. We need to build on the improving technologies, allowing better targeting of nitrogen and measures to ensure that impacts of nitrogen deposition are properly recognised and restorative management is implemented to ensure our ecosystems are restored.

Sources of online information

The Air Pollution Information System (APIS), developed in partnership by the UK conservation agencies, regulatory agencies and the Centre for Ecology and Hydrology (CEH), has an excellent website: http://www.apis.ac.uk provides information on whether critical loads are being exceeded on any habitat within any protected site (SAC, SPA or SSSI) in the UK, and also gives the source of the atmospheric nitrogen.

The Review of Transboundary Air Pollution (RoTAP) report (see http://www.rotap.ceh.ac.uk/home) reviews the current state of rural air pollution issues in the UK, evaluates the extensive measurements of atmospheric pollutants and their effects, and produces a synthesis of current understanding which will be used to inform air quality policies. A summary of the main report for policy makers is available on their website.

There are several websites which provide additional information on key issues:

- Defra has published a range of research reports: http://uk-air.defra.gov.uk/library/. Those in the section 'Effects of Air Pollution on Natural Ecosystems' are particularly relevant.
- Data and maps of UK air pollutant deposition: http://www.pollutantdeposition.ceh.ac.uk/
- Information on critical loads and dynamic modelling for acidification and eutrophication: http://www.cldm.ceh.ac.uk/
- OPAL Air Survey – a citizen science project aimed at surveying lichens that are indicators of nitrogen deposition: https://www.opalexplorenature.org/airsurvey
- Nitrogen Footprint – for personal and organisational action: http://www.n-print.org
- WWF Netherlands have published an excellent overview of the global nitrogen problem: 'Nitrogen: too much of a vital resource'
- The International Nitrogen Initiative (INI) promotes action on the nitrogen problem worldwide and has useful information from around the world: http://www.initrogen.org
- The European Nitrogen Assessment has evaluated all aspects of the nitrogen problem in Europe: http://nine-esf.org/ena
- Task Force on Reactive Nitrogen (TFRN) of the UNECE Convention on Long-range Transboundary Air Pollution: http://www.clrtap-tfrn.org/

Additional references

A comprehensive listing of issues and evidence can be found within these reports:

- JNCC (2011) Evidence of nitrogen deposition impacts on vegetation: implications for county strategies and UK biodiversity commitments. *A summary of JNCC reports no. 447 and 44:* http://jncc.defra.gov.uk/pdf/Project%20summary%20v4_final.pdf
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- European Commission – Recovery strategies for nitrogen-sensitive habitats: http://ec.europa.eu/environment/nature/natura2000/platform/action_results/recovery-strategies-for-nitrogen-sensitive-habitats_en.htm
- Global Overview on Nutrient Management in collaboration with the International Nitrogen Initiative wrote the publication, Our Nutrient World: The challenge to produce more food and energy with less pollution (2013). Published by the Centre for Ecology and Hydrology (CEH), Edinburgh UK. http://nutrientchallenge.org/document/our-nutrient-world

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Plant Link

Plant Link (PLINK) is a forum of nearly 40 organisations who work together to advance the conservation of wild plants and fungi. The network supports delivery of the Global Strategy for Plant Conservation (GSPC), which was adopted as part of the Convention on Biological Diversity (CBD) in April 2002.

Working towards the GSPC requires action at both the UK and country level, taken forward by the PLINK UK group as well as PLINK Scotland, PLINK Cymru and PLINK England groups.