Plantlife

Cleaner air for Scotland's wildlife

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

Contents

Context

The 2019 Independent Review of the Scottish Government's *Cleaner Air for Scotland* strategy[1] concluded that more work is needed to address ammonia emissions from agriculture and to protect sensitive wildlife habitats from air pollution.[2] In November 2019, Plantlife Scotland, with funding from the Scottish Government, hosted a workshop with stakeholders from academia, farming and the environment sectors, to explore policy options to help deliver these aims.

This report summarises the conclusions of that workshop and presents the available evidence on atmospheric nitrogen deposition and its impacts on Scotland's plants and fungi and the wildlife that depend on them. It sets out recommendations for those who own and manage our land, for the Scottish Government and other public bodies, and for the public.

This is the latest in a series of reports by Plantlife and partners calling for action to tackle the impacts of air pollution on wildlife. For further information, see **https://www.plantlife.org.uk/uk/our-work/policy/nitrogen**

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British Bryological Society
Botanical Society of Britain & Ireland
The James Hutton Institute
Woodland Trust Scotland
British Lichen Society
buglife
Soil Association Scotland
WWF

Executive summary

Through the climate and biodiversity emergencies runs an invisible thread: air pollution. Intensive farming and the burning of fossil fuels have disrupted the global nitrogen cycle; levels of reactive nitrogen in the atmosphere have tripled in the last century.

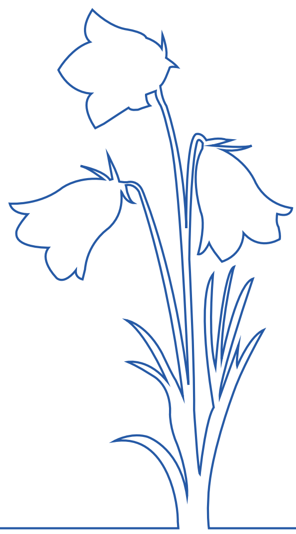
Excess nitrogen (N) in the air is causing significant harm to Scotland's unique diversity of wild plants and fungi, and to our most important natural habitats, so weakening the ecosystem services that they provide. Atmospheric nitrogen emissions are also a significant contributor to climate change and can directly harm people's health, livelihoods and well-being.

Scotland's internationally important habitats include temperate rainforests, vast peatlands and species-rich grasslands. The latest data shows that more than a third of these nitrogen-sensitive habitats – and more than three-quarters of land within Special Areas of Conservation (SACs) – have higher levels of atmospheric nitrogen than they can tolerate. This is leading to species loss, lowered resilience to climate change, pests and disease and, in the worst cases, toxic damage to plants, lichens and fungi. This, in turn, is affecting pollinators and other animals that depend on them.

It is now estimated that more reactive nitrogen is created each year by human activities than through all natural sources combined. Yet globally, only about 20% of nitrogen compounds that we put into the environment reach their intended target, with 80% lost to the environment.

This picture is unlikely to change without concerted action by Government, the farming industry and others to reduce emissions of nitrogen oxides (NO_x) and ammonia (NH_3), a compound of nitrogen and hydrogen. Scotland's NO_x emissions, mainly from transport and energy generation, have declined but are still a significant source of pollution. Ammonia emissions have declined by only 16% since 1970, with agriculture now accounting for 92% of emissions.

The evidence is clear and the solutions are available. The revision of the *Cleaner Air for Scotland* strategy offers the Government a golden opportunity to lead the way in tackling atmospheric nitrogen pollution for the benefit of people, nature and the climate.



Summary of recommendations

Recommendations to protect wild flora and fungi:

- Introduce a targeted programme to reduce emissions close to the most sensitive and vulnerable SACs, Sites of Special Scientific Interest (SSSIs) and Important Plant Areas (IPAs)
- Strengthen environmental monitoring and development control for pollution sources
- Integrate available data on atmospheric nitrogen concentration, deposition levels and impacts into the monitoring, assessment and management of sensitive habitats in SACs and SSSIs, as well as into the development of wider biodiversity measures and policies
- Manage sensitive habitats to decrease nitrogen concentrations and deposition rates and their impacts on biodiversity e.g. planting tree shelterbelts where appropriate

Recommendations to cut airborne nitrogen pollution from agriculture:

- Reduce the nitrogen content of livestock feed and match it to animal requirements
- Target the use of manufactured fertilisers efficiently, matched to specific crop requirements, tailored to each field and applied at the right time and under the right conditions
- Improve the design and management of animal housing
- Cover slurry and solid manure stores
- Improve the efficiency of manure and slurry-spreading techniques and technology

Recommendations for policy makers to reduce ammonia emissions from agriculture:

- Provide integrated, tailored advice to farmers on reducing ammonia emissions
- Develop an integrated strategy to reduce air pollution, water pollution and greenhouse gas emissions from farming
- Strengthen regulation to require the use of low-emissions infrastructure, equipment and techniques in the management of livestock manures and other fertilisers
- Extend the environmental permitting system to include large intensive beef and dairy units, and lower the emissions thresholds for pig and poultry units
- Provide financial support for farm businesses to meet the capital costs of complying with regulation
- Strengthen the local and national planning systems to prevent cumulative impacts from new development and in particular, intensive livestock units and energy from waste processing systems
- Provide additional support for government agencies to ensure compliance with farm regulation
- Commission an analysis of options for a differential tax on different types of mineral nitrogen fertilisers, based on their emission potential

Recommendations for wider Scottish Government policy initiatives:

- Introduce legally-binding national targets for reducing NO_x and ammonia emissions, concentrations and total nitrogen deposition to the environment
- Publish the Scottish Nitrogen Balance Sheet to improve nitrogen use efficiency nationally across sectors
- Include information on ammonia and the impacts of atmospheric nitrogen pollution in public information about air quality
- Support further research into the impacts of atmospheric nitrogen on biodiversity and ecosystem services
- Develop a post-Brexit land management scheme to pay farmers and other land managers for delivering public goods such as clean air, clean water and biodiversity

The nitrogen cycle

Inert nitrogen (N_2) makes up 78% of the Earth's atmosphere. Only **reactive** nitrogen is available to plants, lichens and fungi.

In nature, it takes a volcanic eruption, a lightning strike or specialist soil bacteria to turn inert N_2 into reactive nitrogen. While reactive nitrogen acts as a fertiliser, it is not commonly found in abundance in nature. As a result, many wild plants are adapted to limited nutrient availability and, when nitrogen pollution occurs, they cannot compete with species that are adapted to higher levels of fertility.

Reactive nitrogen takes many forms including nitrates (NO_3-), ammonia (NH_3), ammonium (NH_4), nitrogen oxides (NO_X) and nitrous oxide (N_2O), as well as many other organic and inorganic chemicals. It is constantly cycling through the environment, being fixed from the atmosphere, deposited into the landscape, leaching through soils and into waters, being taken up by plants and animals, and accumulating in soils, water, and emitted into the atmosphere (see Figure 1).

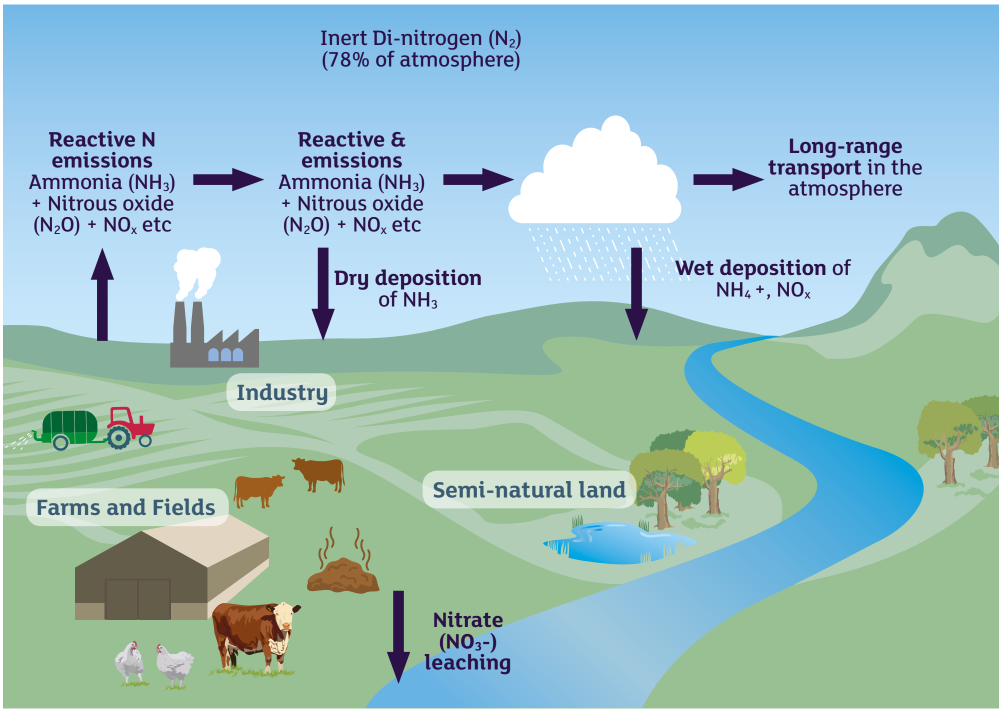


Figure 1: Reactive nitrogen in the atmosphere passes through different chemical forms and can be deposited locally or transported over long distances. Ultimately, excess reactive nitrogen is deposited to soils, water and vegetation, either as gas (dry deposition) or dissolved in rain, mist or snow (wet deposition). Over the past 50 years, human activity has caused significant changes to the world's ecosystems; our impact on the nitrogen cycle may have been one of the greatest.

Humans have increasingly disrupted the natural nitrogen cycle by burning fossil fuels, so releasing large amounts of nitrogen that have been locked away for millions of years, and by burning biomass while clearing land and in the form of firewood, peat and other products. But the most significant impact has been the invention of the Haber-Bosch industrial process. This allows us to convert inert nitrogen drawn from the atmosphere into mineral fertiliser (80%) with the remaining 20% used for other industrial processes, including the manufacture of explosives.[3] This process produces some 150 million tonnes of ammonia a year.[4,5,6]

It is estimated that more reactive nitrogen is created each year by human activities than through all the natural sources combined. Globally, only about 20% of nitrogen compounds we put into the environment reach their intended target, with 80% lost to the environment.

This wasted nitrogen includes all the main reactive nitrogen chemicals which threaten our:

Water quality – nitrogen pollution of rivers, lochs and seas leads to eutrophication and oxygen depletion. Nitrates, mainly from wastewater and agricultural sources, continue to threaten drinking-water quality and ecosystem functioning.

Air quality and public health – nitrogen accounts for up to 50% of fine particulate matter and 60% of ground level ozone pollution, mainly from transport, industry, energy and agricultural sources.

Climate – nitrous oxide (N_20) has a warming potential 300 times that of carbon dioxide with an atmospheric lifetime of 200 years. Around 70% arises from agricultural sources, in addition to wastewater, industry and traffic.

Ozone layer – nitrous oxide is now the dominant cause of stratospheric ozone depletion.

Ecosystems and biodiversity – atmospheric nitrogen deposition, resulting from NO_x and ammonia emissions is threatening biodiversity, through eutrophication and acidification.[7]

Soils – nitrogen fertilisers have a beneficial effect on agricultural and forest yields, but excess nitrogen can result in soil acidification, changes in soil organic matter content, loss of soil biodiversity and increased leaching of nitrogen into water.[8]

Global trends in atmospheric nitrogen pollution[9]

Globally, around 413 million tonnes of reactive nitrogen are added to the natural environment each year. Half of this comes from natural nitrogen fixation but 210 million tonnes are added by the use of mineral fertilisers and burning of fossil fuels. In Europe, levels of reactive nitrogen have tripled over the last 100 years.

Global nitrogen emissions associated with nitrogen oxides are projected to continue at around 40 million tonnes a year until 2040 and then decline to 15 million tonnes a year by 2100, depending on how fast and far measures to cut emissions are implemented.

In contrast, most predictions are that ammonia emissions to the atmosphere will increase from 60 million tonnes a year in 2000 to between 70 and 80 million tonnes by 2100, mainly because of the increased demand for food and the nitrogen fertiliser required to produce it. Climate change itself introduces greater uncertainty to these predictions since ammonia emissions are coupled to temperature. Some estimates are that ammonia-derived emissions might reach as much as 130 million tonnes a year by 2100 in a warming climate.

Nitrogen emissions in Scotland

Significant progress has been made in improving air quality in Scotland since 1990 (see Figure 2); however, levels of nitrogen pollution have not dropped as quickly as other pollutants and continue to damage people's health and the natural environment.

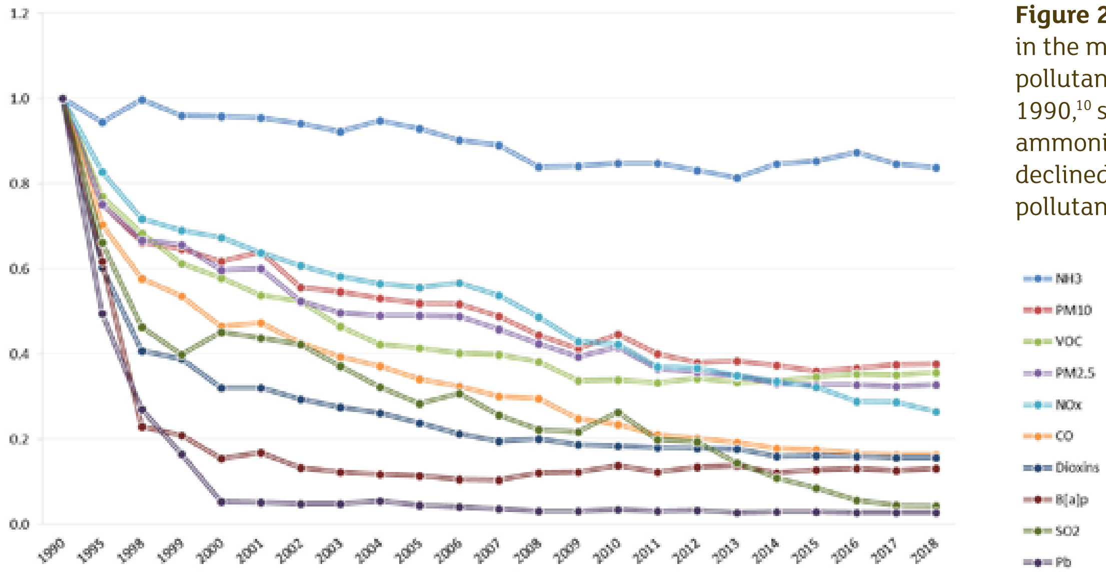


Figure 2: Normalised trends in the main atmospheric pollutants in Scotland since 1990,[10] showing how little ammonia (NH_3) emissions have declined compared to all other pollutants.

NO_x emissions have declined due to tougher regulations, which have driven changes in energy generation, particularly technological advances such as catalytic converters. By 2018 this had achieved a 73% decline in NO_x emissions since 1990. **Transport** still has some way to go and now accounts for 48% of Scotland's NO_x emissions, with 89% of passenger car emissions from diesel engines.

Ammonia emissions have declined by only 16%.[11] Most ammonia derives from agriculture. Emissions have dropped since 1990 due to declines in livestock numbers as well as more targeted mineral fertiliser use, but the decline has been almost completely offset by the increased use of urea-based fertilisers and emissions from spreading anaerobic digestate products. In 2018, 92% of Scotland's ammonia emissions came from **agriculture**.

Forecasts by the UK Government[12] show that, with current approaches to tackling atmospheric pollution, further reductions will be slow. The measures and policies in place are likely to achieve only a 4% reduction in ammonia emissions against the 2005 baseline, compared with the 16% it is committed to deliver by 2030. Unless further action is taken, the UK is also likely to miss its 2030 target of a 73% reduction in NO_x emissions compared to 2005.

Unfortunately, even the reductions that have been achieved to date have not substantially reduced the atmospheric deposition of nitrogen because of how nitrogen cycling is changing over time. It is thought that NO_x emissions in the atmosphere are increasingly being converted into nitric acid and aerosol nitrates, which are deposited locally rather than carried over long distances. So, despite drops in emissions of up to 70% within the UK, deposition fell by only 23%. Over the same period, the more modest 21% decrease in ammonia emissions across the UK has not resulted in any significant change in either atmospheric concentrations or deposition to the environment.[13]

UK	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030 projected	2030 targets
Ammonia ('000 t)	325.7	301.1	302.8	283.4	263.4	275.7	276.4	279	276	277	238
Nitrogen oxides ('000 t)	3026	2473	1918	1676	1182	949	823	735	628	558	453

** Projected UK-wide emissions for 2020, 2025 and 2030 under current policies and measures

Figure 3: UK actual, projected and target emissions of ammonia and nitrogen oxides, 1990 to 2030

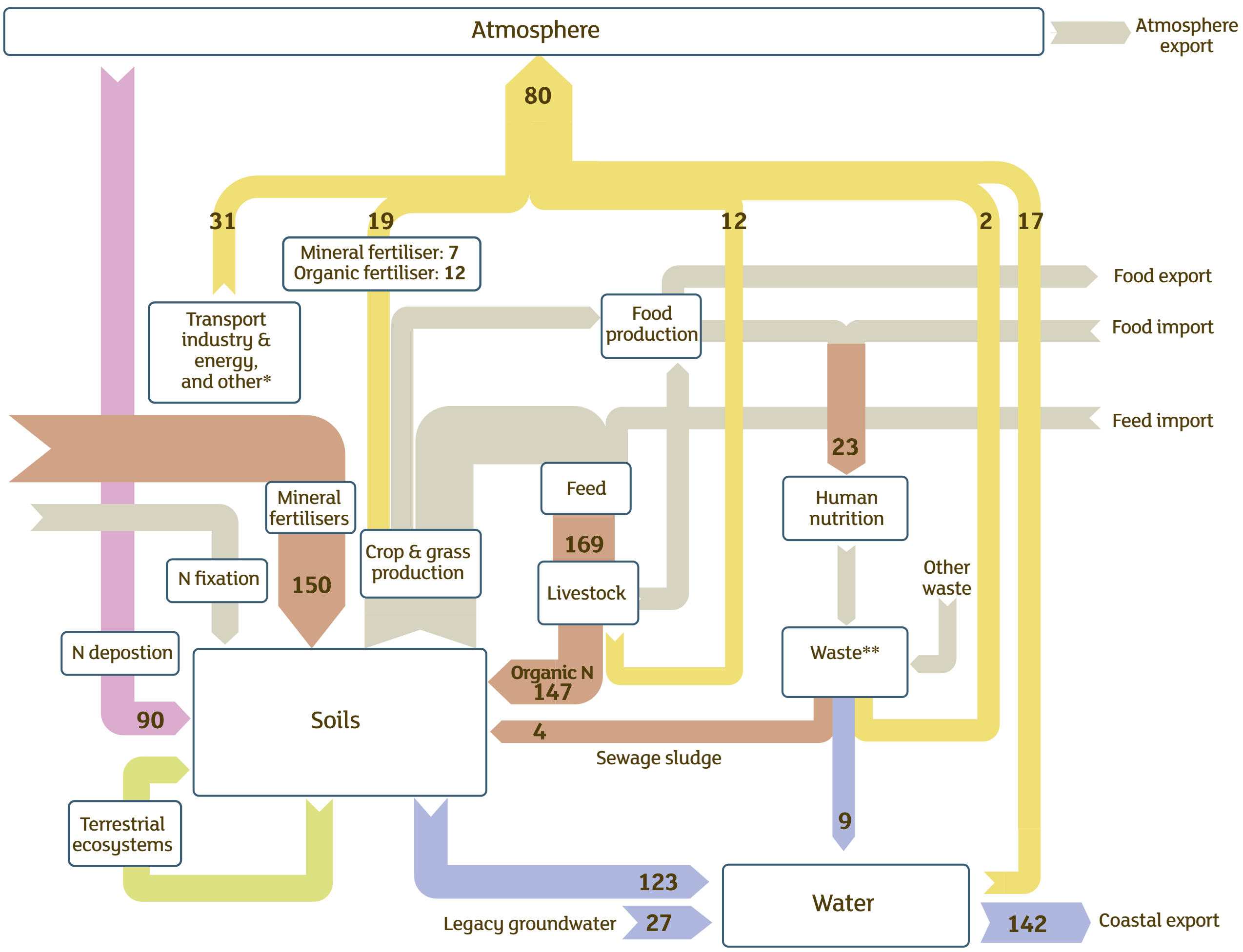
If Scotland is to reduce the environmental and health impacts of nitrogen pollution, a more rapid and ambitious programme of action is required

Nitrogen flows in Scotland

An initial nitrogen balance sheet for Scotland (Figure 4) shows significant inputs of nitrogen into agriculture from the use of mineral and organic fertilisers, slurries and manures as well as high inefficiencies in its use within food production, with much of the nitrogen applied ending up in our natural environment.

Alongside burning fossil fuels for transport and energy generation, our food system results in substantial flows of nitrogen to water of 132,000 tonnes of nitrogen (ktN); to the atmosphere (80 ktN), and atmospheric nitrogen deposition back into terrestrial systems at the rate of 90 ktN each year. There is also deposition directly to water bodies which is not quantified in the diagram.

Figure 4: Nitrogen flows for Scotland (kt N yr[1]), combining inputs and outputs between the atmosphere, hydrosphere/soil, human/consumption and import/ export (using latest available data, dates ca. 2010-2018). N.B. values may not add up due to rounding.[14]



*"other" includes small contributions on N emissions from off-road vechicles, fishing, and fugitive emissions mainly in the form on NO_x and land use change mainly in the form on N_2O.
** "Waste" includes N flows form landfill, compost, sewage and anaerobic digestion. "Other waste" is shown in a very simplified way here, to avoid large numbers of arrow from food production, industry etc.

Impacts on Scotland's wild flora and fungi

Where the impacts of nitrogen are felt[15]

Different habitats have different levels of sensitivity to nitrogen deposition and are therefore assigned different critical loads. The **critical load** is the rate of nitrogen deposition above which significant harmful effects on habitats and species are expected to occur.

35% of all nitrogen-sensitive habitats and 76% of all SACs across Scotland received nitrogen deposition higher than their critical loads between 2016 and 2018.[16]

Critical loads are exceeded in Scotland in the south and east of the country where most livestock and agricultural production occurs, as well as where urban populations, industry and transport links are concentrated.

Levels are lower in the north and west of the country where internationally rare nitrogen-sensitive semi-natural habitats and species, such as temperate rainforest, persist.

The critical load for nitrogen is regularly exceeded in a range of different habitats in Scotland that are known to be nitrogen-sensitive, in particular woodlands and montane habitats (see Figure 6). Many other areas of habitat in the north and west are close to exceeding critical loads due to long-range transport of air pollution, and cannot tolerate any further increases in nitrogen deposition.

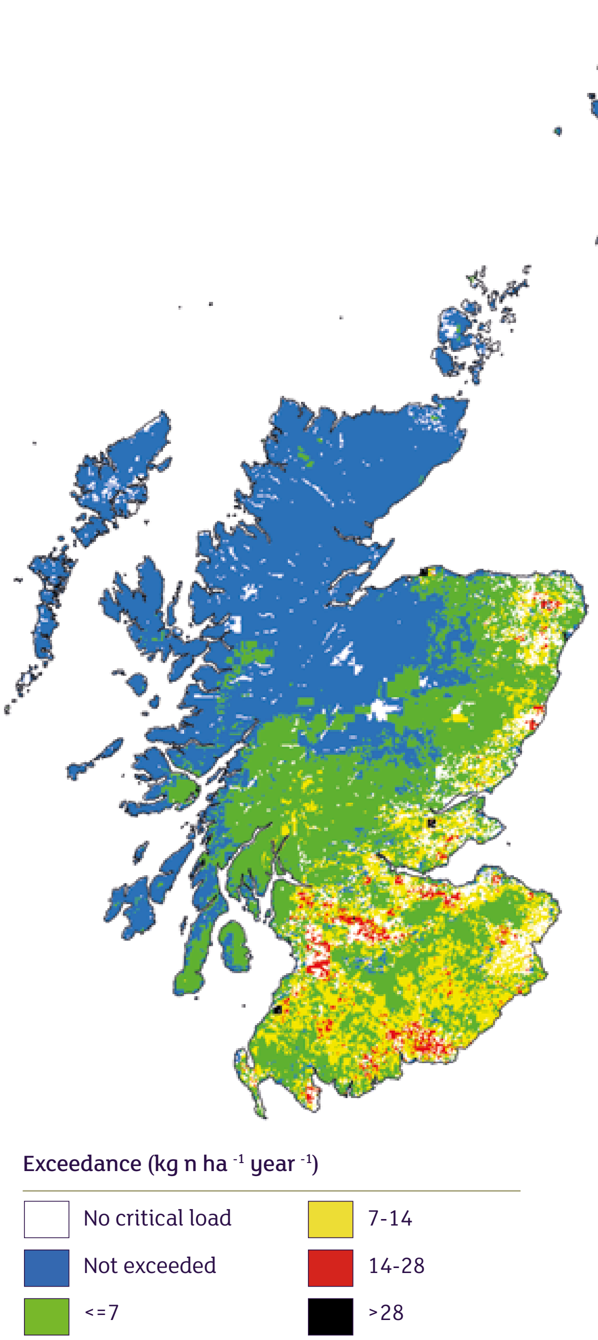
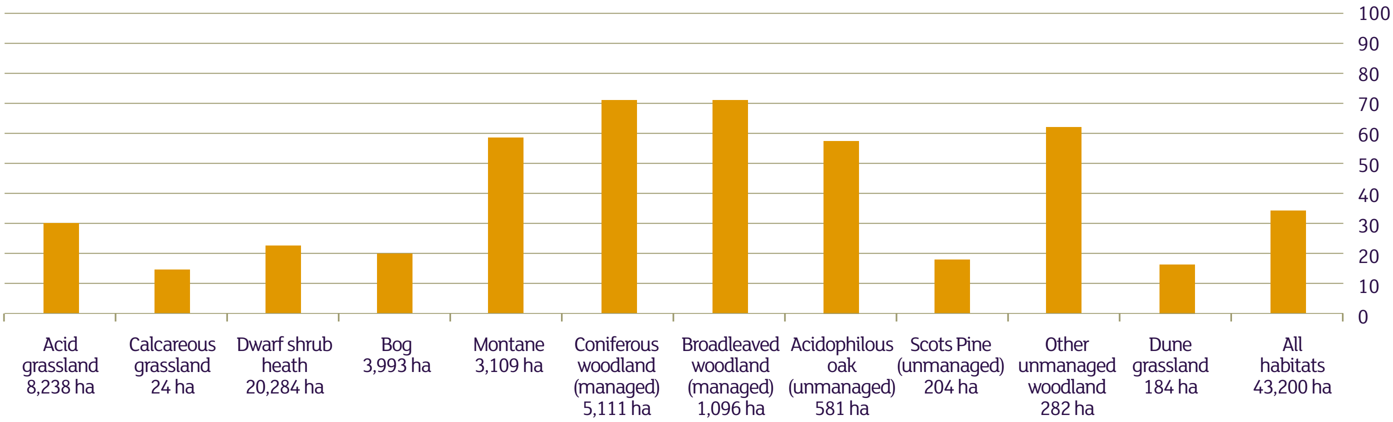


Figure 5: Average Accumulated Exceedance (AAE) of nutrient nitrogen critical loads in 2016-18

Figure 6: The percentage of the total area of different nutrient-sensitive habitats in Scotland where nutrient nitrogen critical loads were exceeded between 2016 and 2018.[17]



Atmospheric nitrogen is deposited into the landscape in different ways and at different rates. For example, the low-growing vegetation of heathland and grassland intercepts less pollution than taller vegetation of native woodlands. This is due in part to smaller total leaf areas intercepting the air flow and lower air speeds close to the ground. The level of pollution also changes over time and depends on particular pollution episodes and weather events.

Different species have different tolerances to atmospheric nitrogen; lichens and bryophytes are more susceptible to damage than grasses and other plants. Just over 0.1% of Scotland's land area is exposed to ammonia above the **critical level** for flowering plants, but the same level of atmospheric pollution means that 18% of Scotland is exposed to levels that may harm more susceptible lichens and mosses.[18]

The most significant impacts of nitrogen pollution on the natural environment:

Eutrophication occurs when added nitrogen 'fertilises' soils and water. Common, fast-growing species, such as nettle and hemlock, thrive and out-compete more sensitive species, such as harebell and devil's-bit scabious, which are often smaller and most scarce. This reduces species richness and contributes to the homogenisation of plant communities. At its most serious, eutrophication can lead to the degradation of vulnerable habitats, such as peatland, grassland, sand dunes, heathland and native woodland and in some cases to local extinctions of sensitive plant and lichen species.[19]

Soil acidification occurs as the result of the deposition of nitrogen and sulphur compounds from the atmosphere.

Soils are complex systems consisting of water, minerals, organic matter, micro-organisms and soil fauna. Healthy soils are essential for the functioning of the wider ecosystem. The relative balance of nitrogen and other elements can affect the soil as well as the growth and development of plants.

All soils can deal with a certain amount of additional acidity before the pH drops. However, over time, soil chemistry changes in response to acidity, soils become less able to deal with further acidification and eventually the pH falls.

Toxicity – at high levels, ammonia concentrations in the air can damage plants, including necrosis to leaves, growth reduction, growth stimulation and by altering the susceptibility of plants to frost, drought and pathogens such as insect pests and invasive species. Excess nitrogen in rivers, lochs and other freshwater bodies can also have toxic effects on aquatic animals with thin and permeable skin surfaces.

While it may take large pollution events to cause immediate damage to plants and animals, ecosystems are impacted by nitrogen which accumulates over decades.[20] Past atmospheric nitrogen deposition has already built up in the landscape and caused environmental change in Scotland. Even if we were able to reduce future deposition rates, recovery would not be immediate, particularly in the most sensitive ecosystems.

Recommendations for action to protect wild flora and fungi

Reducing nitrogen emissions at source is more effective than attempting to intercept nitrogen in the atmosphere or mitigate its impacts once it has been deposited into the environment. Recommendations to strengthen policy and action to reduce emissions, as outlined elsewhere in this report, should take priority.

- **Strengthen the local planning system to prevent impacts from new developments** such as intensive livestock units. The strategic siting of new cattle, pig and poultry units will reduce impacts on nearby sensitive habitats and species. The cumulative impact of new farm developments in relation to existing sources of ammonia emissions should be taken into account.
- **Improve monitoring of pollution sources around sensitive habitats** to identify immediate and wider impacts on biodiversity. For example, there is currently no information about where, when or how much slurry, manure or litter is stored or spread on land near sensitive habitats.
- **Incorporate nitrogen deposition into condition assessment** of protected sites. This should then inform site management plans to:
  - Identify and monitor the sources and impacts of atmospheric nitrogen input to the site;
  - Engage local land managers to help reduce nitrogen pollution through siting of livestock housing and more efficient nutrient/waste management;
  - On-site mitigation measures (as set out right).
- **Reduce the impacts of nitrogen deposition on nature conservation sites** by i) controlling dominant species that are adapted to higher nitrogen levels, and/or ii) removing excess nitrogen from the system. Techniques for achieving this include: grazing, cutting, burning, fertilisation, liming, hydrological management, scrub and tree management, and disturbance used to improve habitat suitability for vulnerable species. However, many management techniques involve trade-offs with other conservation priorities (e.g. carbon emissions from burning), reinforcing the point that there is no substitute for emissions reduction at source.
- **Plan tree-planting schemes to help intercept nitrogen emissions** before they reach species-rich habitats. This can be done at a farm level (e.g. tree belts around livestock housing), on the borders of nature conservation sites or at a wider strategic level. Trees can help to disperse, dilute and recapture atmospheric ammonia.
- **Control emissions from heavily-stocked grazing of cattle** and evaluate the impact of grazing ruminants on land close to sensitive habitats including SSSIs.

The impacts of nitrogen on some of Scotland's most important habitats

Important Plant Areas (IPAs) have been identified by Plantlife and partners to help focus effort on internationally important species and areas. There are 47 IPAs in Scotland, ranging from the vast landscapes of the Cairngorms to individual lochs and woods. Plantlife's analysis shows that more than half of IPAs have exceeded the critical load, receiving more nitrogen than they can tolerate.

By land area, just under half of wood habitats and a quarter of open habitats within IPAs have exceeded the critical load. Almost all IPAs south of the Great Glen (from Inverness to Fort William) have exceeded their critical load.

Scotland's temperate rainforest[22]

Scotland is one of Europe's last significant strongholds of this globally important habitat. It persists on the West Coast due to the mild, wet climate and low levels of air pollution but most of the woodlands are in poor and declining condition facing threats from invasive rhododendron, inappropriate grazing and browsing, tree disease and atmospheric pollution.[23]

Lichens provide shelter, food and microhabitats for invertebrates and contribute to carbon cycling and water retention. Many are sensitive to changes in the level of atmospheric nitrogen; classic rainforest species such the lungwort lichens (*Lobaria* spp) can quickly be lost with acidifying rainfall.

Nitrogen pollution[24,25] also affects other woodland plants and fungi, changing the way the ecosystem functions and reducing its resilience to climate change and diseases. Trees may show increased growth because of the extra nitrogen but in the longer term, growth will be curtailed as soils become nitrogen-saturated, resulting in nutrient imbalances and acidification. At high nitrogen deposition levels, trees suffer bleaching, discolouration and increased susceptibility to damage from drought, frost and disease such as acute oak decline.

High levels of nitrogen lead to a greater abundance of nitrogen-tolerant plant species, which out-compete and impact on characteristic ancient woodland plants and mosses. The knock-on effects on animals are likely to be significant if, for instance, food plants for woodland butterflies and other insect larval stages are impacted.

Many woodland fungi have also been shown to be sensitive to nitrogen deposition. There is particular concern about impacts on ectomycorrhizal species associated with tree roots,[26] and the subsequent impacts on tree health. The loss of these woodland fungi can also result in soil carbon release to the atmosphere, with climate change implications.

©Stan Philips

Temperate rainforest is found within the **West Coast of Scotland IPA,** a large area that includes all the best examples of oceanic woodland and oceanic montane heath on the mainland of Scotland, stretching from Ben Hope in the north down to Knapdale and Loch Lomond in the south. It is noted for lichens, bryophytes, stoneworts and vascular plants interest, some found nowhere else in the world. While the whole of the IPA is sensitive to atmospheric pollution and is close to exceeding the critical load, the south and east of the site are currently experiencing the highest deposition rates, largely due to long-range pollution from NO_x emissions.

Peat bogs[27]

Peatlands are damaged by the deposition of both sulphur and nitrogen from the atmosphere, or 'acid rain', particularly in high rainfall areas. Excess sulphur and nitrogen directly affect peatland chemistry and vegetation, causing acidification. Even exposure to relatively modest deposition of ammonia can lead to dramatic reductions in species cover, with almost total loss of heather, bog mosses and lichen. These effects appear to result from direct uptake into the plant rather than via the soil and have been observed in Northern Ireland near to intensive poultry units.

Flanders moss ©Alistair Whyte

Nitrogen is a fertiliser and moderate levels of deposition may actually boost Sphagnum growth. However, at higher deposition rates the capacity of Sphagnum to use the extra nitrogen is exceeded.[28] Nitrogen may inhibit moss growth while faster-growing vascular plants, such as grasses, may be able to exploit the excess, out-competing and ultimately displacing peat-forming species.

It also appears that nitrogen can increase the rate of decomposition at the bottom of the moss shoot, which will result in a thinner moss layer and decreased peat accumulation.

At very high exposure, for example close to livestock units, gaseous ammonia can have a direct toxic effect on the growth of a range of plant species, leading to die-back of Sphagnum, lichens and dwarf shrubs such as heather.

In most of the UK, the deposition of atmospheric sulphur pollutants has now fallen below the critical load for otherwise healthy peat bogs and Sphagnum is recovering. However, the deposition of nitrogen still lies above the 'critical load' for much of the UK's peat bog area, a problem that is exacerbated because some 70-80% of these bogs are degraded, and hence probably more sensitive to pollution.

The long-term effect of nitrogen deposition on the balance between peat-forming species and other plants in bogs, and the impact this may have on carbon sequestration, is not well documented or understood.

Rannoch Moor IPA, in Highland Perthshire, is an extensive, previously glaciated plateau surrounded by hills. The vegetation that developed here represents the most extensive complex of western blanket and valley mire in Britain. The blanket bog, sustained by high levels of rainfall, is home to plants such as ling, bog myrtle, bearberry, great sundew, least water lily, a variety of grasses and Sphagnum mosses. The site is particularly famous as the main British location for the Rannoch-rush. Nitrogen deposition maps suggest it is experiencing an increased level of deposition.

Grasslands

Grasslands cover more than 2 million hectares or almost 30% of Scotland's land area[29] but as little as 0.6% of this area is made up of high biodiversity value semi-natural grasslands. Lowland semi-natural grasslands are home to over 200 UK Biodiversity Action Plan priority species, while upland semi-natural grasslands are home to 41.[30] These grasslands have suffered from agricultural improvement and conversion to arable production, afforestation and built development. Today they continue to face pressure from inappropriate grazing and browsing, climate change and atmospheric pollution.

Nitrogen deposition is a threat to grasslands across Europe.[31] Most studies have focused on acid grasslands where excess nitrogen has been shown to lead to a loss in species richness and diversity; an increase in the cover of grasses and other competitive and nitrogen-demanding species, and a decrease in the cover of rarer diminutive forbs.

A statistical analysis of data from long-term studies of a range of Scottish grassland sites between 1958 and 2014[32] indicates that while some are starting to recover from the high levels of sulphur deposition in the 1970s, there was no evidence for a comparable reversal of the impacts of nitrogen pollution. While calcareous, neutral and wet grassland habitats such as hay meadows, water meadows and grazing pastures showed signs of recovery, acid grasslands did not.

Frog orchid ©Alistair Whyte

Another study of sand dune and machair sites[33] between 1975 and 2011 showed that while nitrogen pollution had little impact on overall species diversity, it had shifted species composition to vegetation more characteristic of nutrient-rich sites. The impacts of this were particularly severe in south-east Scotland. This study also concluded that while declining levels of atmospheric pollution might be beneficial, habitat recovery may take many decades.

Merrick Kells IPA, in Galloway, contains a high diversity of upland habitats, including blanket bog, wet heath, and arctic-alpine grasslands. This includes a rare hawkweed *Hieracium holosericeum*, alpine saw-wort, purple saxifrage and the localised liverwort *Pleurozia purpurea* and moss *Campylopus setifolius*.

The IPA experiences a relatively high level of nitrogen deposition, and there is anecdotal evidence of a reduction in montane species, and an increase in generalists. It is likely that climate change, and less winter snow, is also driving these changes.

Ammonia and farming

Agriculture accounted for 92% of Scotland's ammonia emissions in 2018.[34] The majority of emissions was the result of manure management and use, with the rest from inorganic fertilisers.

Ammonia and other nitrogen emissions from farming can be significantly reduced by improving the efficiency of how livestock, their manure and other fertilisers are managed.[36] Using only the amount of nitrogen needed will decrease pollution while cutting costs and maintaining productivity.

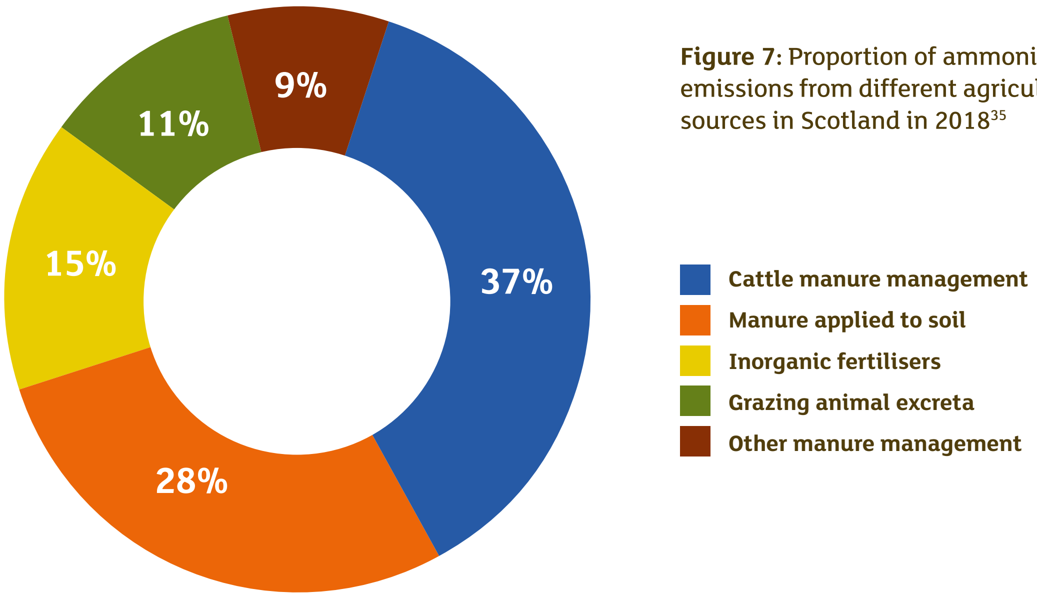


Figure 7: Proportion of ammonia emissions from different agricultural sources in Scotland in 2018[35]

Recommendations to cut nitrogen pollution from agriculture:

The range of options for on-farm actions to reduce ammonia emissions is already well documented. It is important to note that the potential of each measure to reduce emissions only applies to that particular stage of the management process. For example, taking measures to keep nitrogen in livestock manures while it is being stored needs to be complemented by measures that it is not lost while spreading it on the land, otherwise much of the emissions saved early in the management process will be lost at the latter stages.

The following actions must be taken collectively to reduce emissions effectively:

Reduce the nitrogen content of animal feed – potential for 10-15% emission reduction.

Up to 85% of nitrogen consumed by farm animals is excreted in their faeces and urine, leading to ammonia emissions. Nitrogen and protein content of feed, including grass, silage, hay and grains, should be matched to the needs of the livestock. Each 1% drop in protein content in animal feed can lead to up to a 15% drop in ammonia emissions.

Tailored use of manufactured (mineral) fertilisers – potential for 40-90% emissions reduction

As with animal feed, match fertiliser to crop and pasture requirements to maximise efficiency, minimise pollution and save money. Using precision technology in terms of better timing, amounts and using precision application technology could cut emissions by 40-90%.

Ammonia emissions can be reduced by: adding urease inhibitors to urea-based fertilisers; mixing fertiliser swiftly and directly into the soil to maximise absorption; avoiding application of urea-based fertilisers in warm, dry or windy conditions.

Spreading techniques and technology – up to 100% emissions reduction

Manure and slurry are useful sources of on-farm organic fertiliser but the traditional 'broadcast application' involves greater exposure to the air, causing higher ammonia emissions. Placing the slurry directly on the surface and direct application into soil reduce ammonia emissions and ensure even distribution, as well as preventing pollution of rivers and streams. Timing fertiliser application to coincide with cool, humid and windless conditions is another important factor in reducing emissions. Some of the required equipment needed for low-emission slurry spreading is expensive, so efforts should focus on supporting contractors to invest in new kit and better skills rather than individual farmers.

Improve the design and management of animal housing – up to 90% emissions reduction

- Use grooved or slatted floors to move manure and urine quickly into collection areas with sloped walls that reduce the exposed surface area of the slurry
- Separate urine from manure as much as possible and regularly clean soiled areas
- Increase the amount of bedding used per animal to create a barrier between the urine and the air and allow the collection of solid rather than liquid waste, which is easier to store and emits less ammonia
- Keep the temperature and airflow low around manure; if the facility is artificially ventilated, keep fans and acid scrubbers clean
- Increase the time livestock is grazed outside. Urine will be absorbed into the ground, reducing the opportunity for ammonia emissions, as well as nitrogen being recaptured by the vegetation, reducing the need for additional fertiliser.

Changing the existing stock of animal housing will take time and money, however there should be an immediate requirement to implement best existing designs for new-builds using the optional Schedule 2 EIA for livestock housing above a threshold size, and retrofitting where possible.

Covering slurry and solid manure stores – 30-100% emissions reduction

The surface area of manure exposed during storage influences the ammonia loss. Lagoons, which have a high surface area, have particularly high levels of ammonia losses, whereas taller and narrower 'tanks' reduce emissions. Fully enclosed storage (e.g. covered stores and bags) have the lowest ammonia emissions and prevent rain from diluting the slurry. Reducing the airflow across a slurry store's surface also decreases ammonia emissions.

Recommendations for policy makers to reduce nitrogen pollution from agriculture

Raise awareness of ammonia and its impacts among farmers and their advisors through direct training and advice, as well as farming media, agricultural colleges and training providers. Industry leaders and organisations need to talk about nitrogen use efficiency in terms of farm productivity and the impacts on nature, climate change and public health.

The farming sector will benefit from accessible and evidence-based messaging. This should be tailored to different types or groups of farmers as part of whole farm approaches that link actions on water, soils, air, greenhouse gases, efficiency and profitability, wildlife and habitats. Showcase success stories that demonstrate achievements and the savings that can be met in terms of costs and impacts.

Voluntary measures and codes of good practice, as recommended by the 2019 Independent Review of the Cleaner Air for Scotland strategy, are suitable for interventions that are already considered acceptable to the agricultural sector and that can deliver short-term benefits at a low cost.

However, despite long-standing advice to farmers regarding voluntary measures, there has been little progress in reducing nitrogen emissions from agriculture. There is a need for new policy, regulation and incentives from the Scottish Government to ensure action is taken and emissions are reduced, in particular for measures with higher capital costs or a lower level of acceptability or knowledge among farmers.

Further recommendations to the Scottish Government:

- Actively support programmes to raise awareness and give advice to the farming sector to increase nitrogen use efficiency and to reduce ammonia emissions;
- Provide targeted financial support for farm businesses to meet the capital cost of reducing ammonia emissions on the basis of ‘public money for public goods’.
- Urgently review options to regulate those sectors that are currently under-regulated, in particular dairy and beef farming. This could include steps to:
  - Require nutrient management planning and use of low-emission techniques by all farm businesses to improve nitrogen use efficiency;
  - Require the use of low-emission livestock housing, slurry stores and other infrastructure on all new farm developments and (phased in over time) for existing farm operations;
  - Extend environmental permitting to large and/or intensive dairy and beef units, as well as lowering the threshold for intensive pig and poultry units;
  - In addition to supporting them with new technologies and skills, also introduce a licensing or permitting regime for slurry contractors (following the precedent from transport providers and emissions standards);
- Provide political support and resources for compliance and enforcement of existing and new regulation;
- Commission analysis of options for a differential tax on high-emission mineral nitrogen fertiliser such as urea-based fertilisers with high nitrogen emissions, based on the risk to humans, climate and ecosystems.

Photograph by Gabriel Jimenez on Unsplash

Time for action

Recommendations for the Scottish Government in its *Cleaner Air for Scotland* strategy and other policy initiatives

The 2019 Independent Review of the *Cleaner Air for Scotland* strategy made two specific recommendations to the Scottish Government on ammonia emissions and atmospheric nitrogen deposition:

- Urgently develop a voluntary code of practice for agriculture and engage the sector to achieve best practice in controlling ammonia emissions, before considering regulatory intervention if this does not have an adequate impact; and
- Set appropriate targets for atmospheric emissions and their impact on wildlife habitats, and consider improvements to monitoring of both protected areas and wider ecosystems for the impacts of air pollution.

The scientific evidence and the conclusions of Plantlife Scotland's stakeholder workshop support these recommendations and point to the need for additional action as a matter of urgency.

Recommendations in relation to impacts on nature and reducing ammonia emissions from farming are given in earlier sections. However, action is needed across government on the cross-cutting issue of atmospheric nitrogen affecting sensitive ecosystems, human health, and our climate and soils. This includes:

- Introduce legally-binding national targets for reducing NO_x and ammonia emissions, as well as atmospheric nitrogen deposition and concentrations in the environment. Targets should be set according to the reductions required to minimise damage to human health and the natural environment;
- Integrate measures on ammonia emissions and atmospheric deposition with the Scottish Nitrogen Balance Sheet, carbon budget, biodiversity strategy and other environmental and agricultural policy across government;
- Incorporate information on ammonia and NO_x emissions and their public health impacts, as well as the environmental impacts of nitrogen deposition, into public information about air quality, for example via the Scottish Government Air Quality website;
- Incorporate nitrogen into existing food standards and labels to harness the power of consumers and the supply chain to drive change at the farm level;
- Support further scientific research into atmospheric nitrogen and its impacts on biodiversity and human health, and the potential mitigation of these, through our universities and research institutes such as Scotland's Rural College, the UK Centre for Ecology & Hydrology, and the James Hutton Institute.
- Initiate further research and programmes of action on awareness-raising and stakeholder engagement, an area which the Independent Review of the *Cleaner Air for Scotland* strategy did not have the opportunity to consider but which highlighted the urgent need for further work. In particular, this will help build understanding of the importance of ammonia emission reduction within the food manufacturing and retail sectors, to help share the costs of action throughout the food supply chain and across public and private sectors;
- Support international initiatives such as the UN Global Campaign on Sustainable Nitrogen Management,[37] which aims to raise public and policy makers' awareness of the wider challenge of nitrogen and the need to take action.

As the UK leaves the European Union and its Common Agricultural Policy, there is an opportunity to redesign food and farming systems to be more efficient and sustainable, supporting healthy diets and a circular economy. Consumer choices are key to bringing about the changes needed, putting nitrogen on a par with carbon, and demonstrating to the Government and food industry that there is a demand for change.

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We are Plantlife

For 30 years, Plantlife has had a single ideal – to save and celebrate wild flowers, plants and fungi. They are the life support for all our wildlife and their colour and character light up our landscapes. But without our help, this priceless natural heritage is in danger of being lost.

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