IUCN UK Committee Peatland Programme
*Briefing Note Nº**13***

Atmospheric pollution

History of atmospheric pollution

Peatlands can be damaged by deposition of pollutants from the atmosphere – often termed 'acid rain'. This results from the release of sulphur and nitrogen pollutants into the atmosphere. Originally associated with the Industrial Revolution, 'acid rain' was first described by Robert Angus Smith, a Manchester chemist of the 1800s, whose observations were made in close proximity to the peatlands of the South Pennines. Sulphur dioxide (SO_2) pollution, which is mainly emitted from coal burning power stations, peaked in the 1970s and has since decreased by over 90% due to emission controls and changes in energy supply. Nitrogenous air pollutants have decreased less. Nitrogen oxide (NO_x) emissions, which are mainly from vehicles, have decreased by two thirds since their peak in 1990, but the decrease in ammonia (NH_3) emissions, which are mainly from intensive livestock farming, is much less certain and may be only about 20%.

'Acid rain'

Sulphur now reduced by 90%

Nitrogen oxides reduced by 66% but ammonia perhaps only by 20%

Particulates bring other pollutants

Other associated atmospheric pollutants include particulates, some of which contain heavy metal compounds. While extreme levels of such pollution were recognised as harmful to human health and historic buildings in urban areas even in the late 1800s, the suggestion that atmospheric pollution could seriously affect extensive natural ecosystems across distances which transcended national boundaries was recognised later, becoming a highly controversial issue in Europe during the 1970s and 1980s.

Industrialising countries see similar problems

Today, the same problems are now being seen in countries undergoing rapid industrialisation such as China and India. Ironically, the burning of tropical peatlands (peat is essentially the precursor to coal) has been the major cause of the 'brown cloud' air pollution events that have afflicted Southeast Asia in recent years, notably during the severe El Niño drought of 2015. The threat posed by atmospheric pollution both to human society and to natural ecosystems is now recognised, and in most parts of the world measures are being actively taken to reduce emissions.

Wet and dry deposition

Weak organic acids, strong pollutant acids

Atmospheric pollutants are deposited onto peatlands as gases and particles (dry deposition), in rain (wet deposition) and in cloud droplets (occult deposition). The importance of wet and occult deposition increases to the west of the UK and with increasing altitude. The sulphur and nitrogen compounds have direct effects on peatland vegetation and on peat chemistry. They also cause acidification. Peatlands are well known to be naturally acidic. This is because the decomposing plant material which forms peat produces organic acids, which are "weak" acids and a natural part of the system; hence peatland vegetation is made up of acid loving species. In contrast, sulphur and nitrogen pollutants form inorganic "strong" acids, which cause an unnatural increase in acidity (i.e. drop in pH).

Impacts of atmospheric pollution

Extensive areas devoid of Sphagnum

Sulphur and nitrogen have different effects on the peat bog surface, but in the past the combination of these pollutants has been sufficient to kill much of the *Sphagnum* in the Southern Pennines, reducing or halting peat accumulation, exposing the peat surface and contributing to the severe erosion which characterises this region. Similar loss of *Sphagnum* and onset of erosion is evident in the Brecon Beacons, which lie downwind of the South Wales coalfield, and in peatland areas adjacent to industrial Central Belt of Scotland. In many cases, the proximity of these blanket bogs to large population centres has also exposed them to land-use pressures, including managed burning and wildfire (see ***Briefing Note 8: Burning***) and trampling by livestock (see ***Briefing Note 7: Grazing and Trampling***), making it difficult to ascribe peat degradation to a single cause. It is now generally accepted, however, that atmospheric pollution has had a direct detrimental impact on many bogs, and that it may also increase their vulnerability to other pressures.

Sulphur acidifies to extremes

Sulphur deposition causes sulphate leaching from the bog, which increases acidity (i.e. reduces the pH) of both the peat itself and the waters that drain from it. This acidification process is exacerbated by dry conditions, for example as a result of drainage, gully erosion or drought, which reduce the capacity of the bog to store sulphur in less harmful organic forms. In addition, sulphur compounds are directly toxic to *Sphagnum* and are believed to have caused its loss from the South Pennines from the Industrial Revolution onwards. Despite the huge reduction in sulphur deposition, *Sphagnum* is only recovering very slowly in areas such as the South Pennines and Brecon Beacons. This is most likely due to the accumulated pollutants within peat and thus its continuing acidity and to the continuing deposition of nitrogenous pollutants, along with other land-use pressures such as burning.

Elevated nitrogen levels inhibit mosses but fertilize vascular plants.

Ammonia is toxic.

Nitrogen is an essential plant nutrient. In remote areas such as Northern Scandinavia and Canada, modest nitrogen deposition may actually boost *Sphagnum* growth. However, at the higher deposition rates characteristic of the UK and continental Europe, the capacity of *Sphagnum* to utilise the pollutant nitrogen is exceeded. There may be direct inhibitory effects of the nitrogen on the moss, and faster-growing vascular plants such as grasses can also exploit this excess, outcompeting 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, nitrogen pollution in the form of gaseous ammonia can have a direct toxic effects on growth of a range of plant species, leading to die-back of *Sphagnum,* lichens and dwarf shrubs.

Areas at risk	Atmospheric pollutant deposition rates are now collated and available through the APIS website (http://www.apis.ac.uk/), and 'critical loads' are given for a variety of atmospheric pollutants. 'Critical loads' are ecosystem- specific deposition rates of sulphur and nitrogen below which significant ecological effects are not detectable (http://www.cldm.ceh.ac.uk/uk-national-focal-centre).
Sulphur now perhaps below 'critical load' ***Nitrogen still exceeds 'critical load'*** ***DOC rise may be due to fall in sulphur levels so management may now be key***	 From these data the evidence suggests that deposition of atmospheric sulphur pollutants may have now fallen below what is regarded as the 'critical load' for virtually all areas of UK peat bog, provided that bog is in otherwise good condition. This decline has permitted an apparent recovery of *Sphagnum* cover over areas which have had no trace of *Sphagnum* in living memory. Current deposition of nitrogen pollutants, on the other hand, although slowly diminishing, still generally lie above what is regarded as the 'critical load' for much of the UK peat bog resource. However, for both nitrogen and acidity, current deposition rates are above the critical load for healthy bog across approximately half of the UK peat bog resource. Given that 70-80 % of the bog in the UK is degraded, and hence probably more sensitive to pollution, it is likely that there are adverse effects of deposition of nitrogen and/or acidity over a significantly greater area than the critical loads for healthy bog suggest. An observed rise in dissolved organic carbon (DOC) in drainage waters from peat-dominated catchments has been attributed to the reduction in sulphur deposition because more acidic conditions during the years of intense atmospheric pollution effectively suppressed the solubility of organic matter. As sulphur deposition continues to fall towards pre-industrial background levels, some further increase may be expected to continue in future, although this is unlikely to be as great as the changes observed during the last 30 years. On the other hand, the reduction in the suppressing effect of acidity means that peatlands may now be more susceptible to other factors causing increased DOC leaching, for example linked to management or climatic extremes. The resulting pulses of very high DOC runoff may present significant challenges for water treatment but also points to the need for careful consideration of peatland management practices.
Other benefits from addressing this issue	Reductions in atmospheric pollution levels which permit the re-establishment of typical peat-forming species such as *Sphagnum* across peatbog-dominated catchments then also permit the re-establishment of ecosystem services associated with healthy peat bog systems, including flood management, water quality control, carbon storage and support for a distinctive biodiversity.
Gaps in Knowledge	Identified gaps: • The extent to which the reduction in sulphur-deposition levels is now enabling re-colonisation of peat bog landscapes by *Sphagnum*, and the extent to which persistence of acidification in degraded peatlands is acting as a barrier to the re-establishment of *Sphagnum* and the subsequent re-initiation of peat formation.

- The effect of continued nitrogen deposition on the growth and decomposition of *Sphagnum* and on the long-term competitive balance between typical peat-forming species and other vascular plants, and the impact this may have on carbon sequestration, is not well documented or understood.
- A history of nitrogen deposition may have pushed peatlands into phosphorus limitation. On severely-impacted sites where *Sphagnum* re-introduction or re-establishment is being considered, it may be worth *investigating* whether initial small additions of phosphorus might increase moss growth, decrease moss decomposition rate, and thereby increase carbon sequestration.
- The mechanisms behind the relationship between observed rises in DOC and reductions in sulphur pollution have not been fully determined, but are important in establishing whether a rise in DOC can be expected to continue or whether it will stabilise or even fall over time.

Practical Actions

Practical actions:

- Establish a formal UK-wide *Sphagnum* monitoring programme as a simple 'keystone species' metric of ecosystem health (and encourage additional citizen science projects such as the MoorLIFE 'Big Moss Map' project).
- Develop a method for UK critical load mapping that takes account of the interacting impacts of air pollution and land-management on the condition of blanket bog ecosystems.
- Investigate the mechanisms which determine the interactions between atmospheric pollution, vegetation condition, water quality and long-term carbon storage.
- Adoption of good land management practice to avoid or reverse the effects of activities such as drainage, over-grazing or burning which exacerbate the effects of nitrogen deposition, thereby increasing resilience to current impacts of nitrogen deposition and also enhancing the potential for recovery from past pollution.
- Routinely incorporate measures of possible air-pollution impacts, such as peat acidity, sulphur and nitrogen content, in the assessment and monitoring of blanket bog condition.
- When planning restoration actions, take account of the potential extent to which the current rather poor general condition of blanket bogs (e.g. lack of key species, invasion by grasses) may, in addition to more obvious land-management influences, be a legacy of historic or current air pollution.
- In extreme cases where *Sphagnum* cover has been entirely lost due to historic pollution, vegetation restoration including reintroduction of *Sphagnum* may be required.

More Information

UNECE Review of critical loads of nitrogen
http://wge-cce.org/Publications/Other_CCE_Reports/Review_and_revision_of_empirical_critical_loads_and_dose_response_relationships_2011
DEFRA review of Acidification, Eutrophication, Heavy Metals and Ground-Level Ozone in the UK
http://www.rotap.ceh.ac.uk/

IUCN UK Peatland Programme:

http://www.iucn-uk-peatlandprogramme.org/
Natural England Uplands Evidence Review:
http://www.naturalengland.org.uk/ourwork/uplands/uplandsevidencereviewfeature.aspx
Scottish Natural Heritage Report on peat definitions:
http://www.snh.org.uk/pdfs/publications/commissioned_reports/701.pdf
Peatland Action:
http://www.snh.gov.uk/climate-change/what-snh-is-doing/peatland-action/

This briefing note is part of a series aimed at policy makers, practitioners and academics to help explain the ecological processes that underpin peatland function. Understanding the ecology of peatlands is essential when investigating the impacts of human activity on peatlands, interpreting research findings and planning the recovery of damaged peatlands.

These briefs have been produced following a major process of review and comment building on an original document: Lindsay, R. 2010 'Peatbogs and Carbon: a Critical Synthesis' University of East London. published by RSPB, Sandy. http://www.rspb.org.uk/Images/Peatbogs_and_carbon_tcm9-255200.pdf, this report also being available at high resolution and in sections from: http://www.uel.ac.uk/erg/PeatandCarbonReport.htm

The full set of briefs can be downloaded from:www.iucn-uk-peatlandprogramme.org.uk

The International Union for the Conservation of Nature (IUCN) is a global organisation, providing an influential and authoritative voice for nature conservation. The IUCN UK Peatland Programme promotes peatland restoration in the UK and advocates the multiple benefits of peatlands through partnerships, strong science, sound policy and effective practice.

We are grateful to Scottish Natural Heritage, Natural England, Natural Resources Wales, the Forestry Commission RSPB Scotland and the Peter de Haan Charitable Trust for funding support.

Authors
Date

Chris Evans, Sarah Woodin, Richard Lindsay
Version Date: 8th August 2016