Evidence of nitrogen deposition impacts on vegetation: implications for country strategies and UK biodiversity commitments

Project Summary

This is a summary of JNCC reports no. 447 and no. 449

ISSN 0963 8091

Project summary

Key messages

- Risk assessment, based on exceedence of critical loads, suggests that nitrogen (N) deposition poses a significant threat to sensitive semi-natural habitats in the UK. It is predicted that this will still be the case in 2020, despite reductions in emissions of reactive nitrogen gases.
- A new analysis of eight national scale vegetation datasets (Stevens *et al* 2011) shows that this risk is translating into actual change in the wider countryside in the habitats studied; acidic and calcareous grassland, heathland and bogs. The results indicate significant responses in the cover and presence of 91 plant and lichen species in relation to N deposition, indicating a change in habitat structure. These included two BAP priority species, four species (or species groups) mentioned in Annexes of the Habitats Directive and 24 positive indicator species used in Common Standard Monitoring. The results also revealed significant impacts on habitat function, shown by changes in both species and ecosystem function indices (such as Ellenberg N).
- Changes in both species occurrence and ecosystem function indices often occur at low levels of N deposition (<10kgN/ha/yr). This is sometimes lower than established critical loads indicating that they are not set at a level which prevents an impact to all species or ecosystem functions.
- Changes in species occurrence and indices of ecosystem function also progressively continue as N deposition levels continue rising above the current critical load values. This indicates that ongoing damage occurs above the critical load and there are some benefits from reductions in deposition even if it remains above the critical load.
- Nitrogen deposition is compromising our ability to deliver current conservation commitments such as the objective to achieve Favourable Conservation Status under the Habitats Directive, and the targets of country biodiversity strategies.
- Looking to the future, predictions of deposition in 2020 indicate risk levels will remain high, and impacts observed on the ground may well increase in frequency and occur over a wider area than at present due to the cumulative effects of N deposition over time.
- Recovery is only likely in local areas where emission control measures have been put in place, as options for mitigation through habitat management are limited.
- At a site level, N deposition impacts are very unlikely to be detected using Common Standards Monitoring (CSM). Case studies demonstrate that there are sites assessed as in favourable condition where evidence of nutrient enrichment attributed to N deposition can be detected. Refinements to CSM protocols to record changes in vegetation species composition, species richness and Ellenberg N scores at permanent locations over time will detect more subtle changes at individual sites.
- An analysis of current vegetation surveillance schemes was undertaken to identify data and analysis gaps. Vegetation data exist for most Broad Habitats in the wider countryside, and have the potential for further analyses to show the effects of N deposition. However, some habitats require targeted survey or research.
- Key recommendations for improving broad scale vegetation surveillance schemes include improving bryophyte and lichen species recording where possible, recording the Broad Habitat type and including structural measures such as vegetation height.

1 Introduction

Nitrogen pollution deposited from the atmosphere in a reactive form increased during the 20th century due to the large-scale combustion of fossil fuels and intensification of agriculture. The N released into the atmosphere is in two forms, oxidised nitrogen gases primarily from transport and power generation, and ammonia primarily from livestock production. Despite reduction in emissions of reactive nitrogen gases, as required under international policy obligations, a relatively small reduction in deposition is forecast for 2020 (ROTAP, in prep).

This unintended deposition of N from anthropogenic sources is equivalent to ca.17kgN/ha/yr on average across the UK (NEGTAP, 2001), but in many areas close to point sources it is considerably higher. To put this in context, 50-100kgN/ha/yr is typically applied to maintain high-productivity hill pasture. Critical loads for nutrient N are exceeded over large parts of the UK (Figure 1). The consequences for UK semi-natural habitats have been wide-ranging and widespread. They include a loss of species, the homogenisation of vegetation types, a change in flowering behaviour and an increased sensitivity to climatic factors. Changes in soil chemistry and the leaching of N into streams and lakes have also been observed. These changes potentially put at risk current conservation commitments and biodiversity targets.

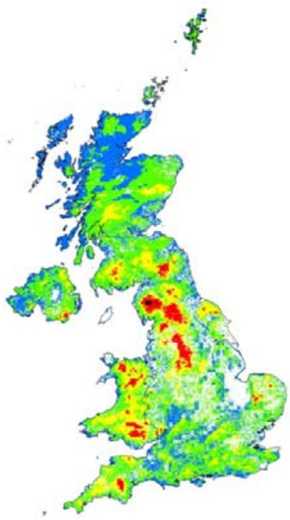

Figure 1. Exceedence of 5th percentile nutrient nitrogen critical loads for average nitrogen deposition in 2006-2008 (CBED model). All terrestrial habitats combined, freshwaters not included. Exceedence (keq/ha/yr) not exceeded; 0.0-0.5; 0.5-1.0; 1.0-2.0; >2.0. Source: CEH 2011: http://cldm.defra.gov.uk/.

There have been a considerable number of reviews of the impacts of N deposition (notably NEGTAP, 2001; ROTAP, in prep). However, not all vegetation surveillance data have been exploited in these reviews; some have never been analysed with respect to N deposition, and/or different statistical approaches have complicated comparisons. This project (Stevens *et al* 2011 and Emmett *et al* 2011) analysed broad-scale vegetation surveillance datasets, and interpreted the results together with other evidence to show the implications for biodiversity, specifically UK conservation commitments and targets, and briefly the provision of ecosystem services. Finally, existing vegetation surveillance schemes, including Common Standards Monitoring, were considered and an analysis undertaken to identify gaps in evidence and hence make recommendations for modification to existing surveillance, or recommendations for additional surveillance or data analysis.

2 Approach

The new project used data from eight different national vegetation datasets to look at relationships with N deposition. The datasets used were the Vascular Plant Database (1930-1969 and 1987-1999), Botanical Society of the British Isles (BSBI) Local Change Survey (1987-1988 and 2003-2004), British Bryological Society (BBS) Database, British Lichen Society (BLS) Database, Plantlife Common Plant Survey, Countryside Council for Wales Grassland Database, Scottish Natural Heritage National Vegetation Classification (NVC) survey, and Natural England Grassland Database. These datasets fall into two categories: large-scale tetrad (2 x 2km grid squares) and hectad data (10 x 10km grid squares), and smaller scale quadrat data. Four semi-natural habitats were selected for analysis: acid grasslands, calcareous grasslands, heathlands, and bogs. All four were analysed separately for uplands and lowlands. Spatial analysis of species presence across N deposition gradients was conducted, once the impact of other factors had been controlled for. The absence of a significant effect in a particular habitat should not be over interpreted as evidence that the species is not N-sensitive. Furthermore, N relationships are likely to have been underestimated due to having to control for other factors that might be co-localised with areas of high N deposition.

For the Vascular Plant Database and BSBI Local Change data, a temporal analysis was also conducted to examine whether changes in distribution over time can be related to the N deposition gradient. Basic outputs include individual species response functions to N deposition and more generic ecosystem properties, such as vegetation canopy height and specific leaf area (both related to presence of more competitive species with greater productivity), a generalised vegetation fertility index (Ellenberg N) and a generalised vegetation acidity index (Ellenberg R). Examples of the relationships observed are illustrated in Figures 2a – f.

3 Key findings

The results indicate a significant response in the cover and presence of 91 plant and lichen species and other ecosystem properties indicating changes in ecosystem structure and function at a national scale. Inhibition of species in response to N were observed for species such as autumn lady's-tresses *Spiranthes spiralis*, clustered bellflower *Campanula glomerata;* greater knapweed *Centaurea scabiosa;* long-stalked crane's-bill *Geranium columbinum*; slender trefoil *Trifolium micranthum*, bog-sedge *Carex limosa;* spiked sedge *Carex spicata;* and carline thistle *Carlina vulgaris.* Stimulation was observed for ca. 30% of species analysed including lesser butterfly-orchid *Platanthera bifolia* and betony *Stachys officinalis*.

The probability of presence of some species gradually increases or decreases with N deposition, whilst others have very clear break points or thresholds. To standardise these relationships the N deposition load was calculated when a species prevalence fell by 20% (i.e. was inhibited by N deposition) or fell by 50% (was strongly inhibited by N deposition) relative to occurrence at the lowest N deposition levels. Results for acid grassland, calcareous grassland, heathland and bog are shown in Annex 1. For broader ecological consequences, loads of N deposition were also identified for Ellenberg N, canopy height and specific leaf area indices when there is a 20% and 50% change in the index relative to values observed in lowest deposition areas. The results confirm that the number of species at risk increases at N deposition rates of above 5-10kgN/ha/yr as do broader ecological impacts. For acid and calcareous grasslands, and heathland, these levels are below current critical load values. The tables also indicate that reductions in deposition rates above the critical load will nevertheless be beneficial, as some species could benefit if rates were to fall for example from 40 to 30kgN/ha/yr.

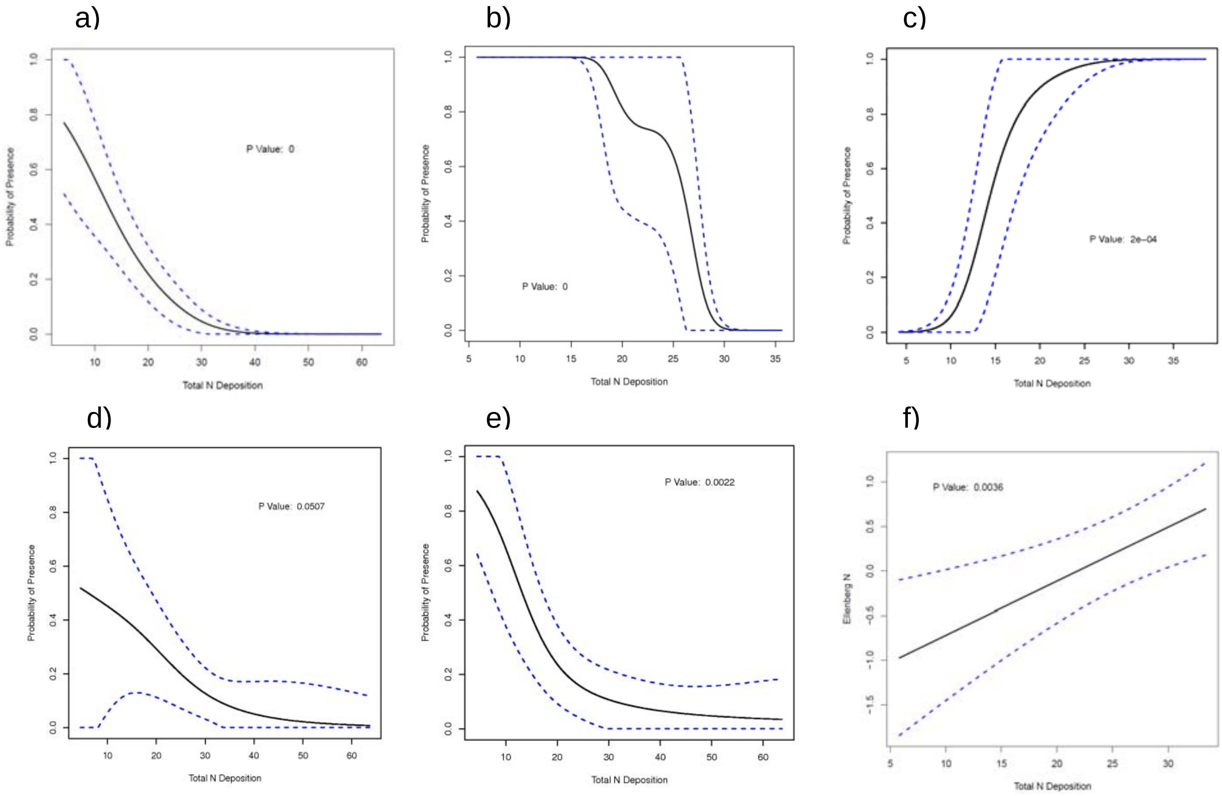

Figure 2. Examples of species responses (probability of presence) and an ecosystem function index, with increasing total inorganic N deposition (kg N ha^{-1} yr^{-1}). (a) reindeer lichen *Cladonia subulata* in heathland. Data from BLS; (b) clustered bellflower *Campanula glomerata* in lowland calcareous grassland. Data from BSBI local change; (c) floating hook-moss *Warnstorfia fluitans* in upland bog. Data from BBS database; (d) pyramidal orchid *Anacamptis pyramidalis* in upland calcareous grassland. Data from vascular plant database; (e) little mouse-ear *Cerastium semidecandrum* in lowland acid grassland. Data from vascular plant database; (f) Temporal analysis of mean change in Ellenberg N score (between 1987/88 and 2003/04) against total inorganic N deposition (kg N ha^{-1} yr^{-1}) for upland calcareous grassland. Data from BSBI local change.

4 Implications for conservation commitments

Evidence from the present analysis, together with other published studies (e.g. RoTAP, in prep), was assessed to determine implications for UK conservation commitments, including the Habitats Directive and UK Biodiversity Action Plan. The four habitats investigated in this study correspond with 12 habitats on Annex I of the Habitats Directive. For all four habitats there was evidence of impacts on structure and function, through impacts on species prevalence and ecosystem function. The study also reported an inhibition in presence of three species/species groups listed in the Annexes of the Habitats Directive. Surprisingly, a positive association was observed in a fourth species/group, *Sphagnum* spp, in heathlands. The study provides support for using the critical loads approach to identify N deposition as a pressure for the purposes of Habitats Directive Article 17 reporting.

For Biodiversity Action Plans the aim is to maintain or improve the status of wild flora and fauna and their ecosystems and habitats. The analysis by Stevens *et al* 2011 and Emmett *et al* 2011 provided clear evidence of many negative effects of N deposition for four broad habitats with relevance for seven BAP priority habitats and significant responses to N deposition for two BAP priority species Lesser Butterfly-orchid *Platanthera bifolia* and Annual

Knawel *Scleranthus annuus* in lowland heath, as well as other species of conservation value.

The response of other species of ‘conservation concern’ (e.g. included under various conservation instruments as well as species used to assess condition in CSM), are also reported. More species of conservation concern were negatively affected than were positively affected. Positive responses to N have been reported before and may represent increases in more competitive species under enhanced nutrient availability, or temporary increases during initial stages of N enrichment followed by increased sensitivity to secondary stresses and with subsequent decline in cover.

Progress towards national biodiversity strategies is currently compromised through continued N deposition. Habitat quality is reduced with changes in the prevalence of priority species and other species of conservation value, together with changes in indices of ecological function. Ecosystem services that rely on the structure and functioning of habitats, including supporting, regulating, provisioning and cultural services, are being/likely to continue to be impacted by N deposition. As there is evidence that N deposition effects can be cumulative over time and N deposition is not expected to decline significantly over the next decade, current aims to maintain and improve status seem unlikely to be met. Opportunities to improve this situation through management options are unfortunately limited. This means the Strategic Plan agreed by the Convention on Biological Diversity for 2011-2020, which included “Target 8: by 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity,” will be very challenging to deliver.

5 Recommendations for surveillance

This study demonstrated that it was possible to show N deposition effects in the four habitats studied (Acid and Calcareous Grasslands, Heathlands and Bogs), using existing broad-scale vegetation surveillance datasets. However, the completion of this analysis, along with a review of surveillance schemes, the different metrics used in recording and assessment, and the evidence available for different Broad Habitats, yielded some useful conclusions, and resulted in recommendations to improve surveillance.

The results presented clearly indicate that CSM is not sufficiently sensitive for detecting or attributing N deposition impacts on individual sites. Consequently sites may currently be recorded as in favourable/recovering condition and yet show signs of adverse N deposition impact. As many CSM indicator species were found not to be sensitive to N deposition, this study has proposed species which are sensitive to N and may be employed to detect future change. However, the ideal site based surveillance for N deposition impacts would incorporate complete floristic monitoring of replicate permanent quadrats located at random within fixed areas (e.g. a habitat area as initially mapped) over a number of years. Species richness, grass:forb ratio and changes in Ellenburg N are particularly useful metrics to use in assessment. Incorporating cover estimates, and a measure of biomass productivity, would enable an even more sensitive indication of N deposition impacts, and taking simple soil measurements (eg. pH and total C/N ratio) would be useful to produce niche models to generate site-specific lists of species at risk. Where in-depth site based surveillance is not possible, N deposition impact assessments should take account of critical load exceedence. This study provides support for the use of critical loads, by demonstrating changes in species occurrence and ecosystem function indices in the wider countryside at these levels of N deposition.

At the level of the wider countryside, many of the existing datasets used in this study were very useful in demonstrating N deposition impact. However, simple recommendations that would increase their usefulness have been given. These include always making sure the record has a Broad Habitat assigned to it, including structural measures such as vegetation height, and improving bryophyte and lichen species recording where possible. The three country grassland databases based on National Vegetation Classification (NVC) quadrat data, were less useful in detecting N deposition impacts. The study concludes that the NVC protocol is inherently biased against detecting change, since quadrats are placed within typical stands rather than in the same places on each visit.

The analysis of the evidence available for different Broad Habitats concluded that there is now probably sufficient evidence of the impact of N deposition on acid and calcareous grasslands and heathland habitats. There is also likely to be sufficient existing data to analyse to be able to show any N deposition impacts on a number of other Broad Habitats in the wider countryside (e.g. broadleaf and coniferous woodland habitats and fen, marsh and swamp). However, there is less evidence for some other Broad Habitats (arable and horticultural habitats; neutral grassland; montane habitats; inland rock; supralittoral rock; and supralittoral sediment), as well as for some components of Broad Habitats which are less well represented in the current study and the Countryside Survey (e.g. raised bogs and wet heathland priority habitats). In these cases the report recommends either analysis of existing surveillance datasets or targeted survey to demonstrate any N deposition impact.

6 Further Information

The full study is published in two JNCC research reports. The first, Stevens *et al* 2011 covers the methods and results of the analysis of the eight surveillance datasets. The second report, Emmett *et al* 2011 considers the implications of the results of the new analysis, together with other sources of evidence, for UK biodiversity commitments. The reports can be found at www.jncc.defra.gov.uk/page-2132.

7 References

EMMETT, B.A., ROWE, E.C., STEVENS, C.J., GOWING, D.J., HENRYS, P.A., MASKELL, L.C. & SMART, S.M. 2011. Interpretation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. *JNCC Report*, No. 449.

NEGTAP. 2001. Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK. Prepared by the National Expert Group on Transboundary Air Pollution on behalf of the UK Department for Environment, Food and Rural Affairs (DEFRA) and the Devolved Administrations. 314 pp.

ROTAP (in prep). Review of Transboundary Air Pollution, Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Defra. http://www.rotap.ceh.ac.uk

STEVENS, C.J., SMART, S.M., HENRYS, P.A., MASKELL, L.C., WALKER, K.J., PRESTON, C.D., CROWE, A., ROWE, E.C., GOWING, D.J. & EMMETT, B.A. 2011. Collation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. *JNCC Report*, No. 447.

Annex 1. Summary of responses in acid grassland, calcareous grassland, heathland and bogs.

Acid Grassland

Table 1. Percentage of acid grassland in the UK receiving different amounts of N deposition (2006-2008, CBED model) and forecast for 2020 (FRAME model), the species inhibited or strongly inhibited by different levels of N deposition according to Stevens *et al* (2011), and an overall summary of all evidence of species and functional change. Inhibition is defined as where species occurrence fell by 20% relative to occurrence at the lowest N deposition levels, and strongly inhibited where occurrence fell by 50% relative to occurrence at the lowest N deposition levels. Critical load ranges are presented (Bobbink and Hettelingh, 2011).

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N deposition as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N deposition as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
0-5	0.4	4.2			
5-10	20.4	22.7	• field mouse-ear *(Cerastium arvense);* • spring vetch *(Vicia lathyroides);* • hare's-foot clover *(Trifolium arvense);* • a lichen *(Peltigera didactyla);* • a lichen *(Cetraria aculeate);* • little mouse-ear *(Cerastium semidecandrum).*		20% increase in Ellenberg N at 5-10kgN/ha/yr and 50% increase at 10-15kgN/ha/yr in analysis of one dataset suggests a major change in N availability and nutrient cycling rates (Stevens *et al* 2011). Plant canopy height found to be positively related to N deposition in one dataset at 5-10kgN/ha/yr and negatively in another in

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N deposition as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N deposition as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
10-15	21.3	32.8	**Species above plus:** • heath dog-violet *(Viola canina);* • Western Earwort *(a liverwort) (Scapania gracilis);* • woolly fringe-moss (*Racomitrium lanuginosum).*	• field mouse-ear *(Cerastium arvense);* • spring vetch *(Vicia lathyroides);* • hare's-foot clover *(Trifolium arvense);* • a lichen *(Cetraria aculeate);* • little mouse-ear *(Cerastium semidecandrum).*	new analyses suggesting high sensitivity to N deposition but inconsistent response (Stevens *et al* 2011). Decline of *Cerastium arvense* identified in new analyses (Stevens *et al* 2011) unlikely to have major functional implications but together with evidence from Stevens *et al* (2004) indicates species change starts to occur below current mapping value in dry acidic grasslands.
2010/11 Critical Load range: Dry acid grassland = 10-15kgN/ha/yr; Wet acid grassland = 10-20kgN/ha/yr					
15-20	31.6	29.9	**Species above plus:** • a liverwort *(Frullania tamarisci).*	**Species above plus:** • a lichen *(Peltigera didactyla);* • heath dog-violet *(Viola canina);* • Western Earwort (a liverwort) *(Scapania gracilis).*	Reduced retention of deposited N in soils with increased nitrate leaching to freshwaters (RoTAP In Prep). Altered species composition both in Stevens *et al* (2011) and RoTAP (In Prep). Risk of increased fungal pathogen damage to sensitive species such as *Vaccinium myrtilus* (Strengbom *et al* 2002). Increased Ellenberg N value with N deposition indicating shift to more nutrient-loving species in Stevens *et al* (2011) but no change in Ellenberg R (acidity) value. Evidence species are differentially sensitive to forms of N deposited (UKREATE 2010).

N dep (kg/ha/yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N deposition as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N deposition as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
20-25	17.7	8.8			
25-30	6.0	1.4			Evidence of further increases in nitrate leaching and acidification of soils in acid-sensitive areas, ongoing shifts in species composition and increased N_2O production (RoTAP In Prep). Overall increase in competitive species and plant productivity indicated by new analyses: Canopy height increases by 20% at 30-35kgN/ha/yr and 50% at 45-50kgN/ha/yr in one dataset (Stevens *et al* 2011).
30-40	2.3	0.3		**Species above plus:** • a liverwort *(Frullania tamarisci).*	
40-50	0.4				
>50	0.01	0.005			

A 20% increase in Ellenberg N at 5-10kgN/ha/yr and 50% change at 10-15kgN/ha/yr in analysis of one dataset also suggests a major change in N availability and nutrient cycling rates resulting in shifts in vegetation composition. Results of research-scale surveys (Maskell *et al* 2010; Stevens 2004; Stevens, Duprè *et al* 2010) have previously shown clear declines in species richness of acid grasslands associated with N deposition. The majority of this loss in species richness in caused by a reduction in the cover and occurrence of forb species (Dupré *et al* 2010; Maskell *et al* 2010; Stevens *et al* 2006) leading to a higher grass:forb ratio (Maskell *et al* 2010; Stevens *et al* 2009).

Calcareous grasslands

Table 2. Percentage of calcareous grassland in the UK receiving different amounts of N deposition (2006-2008, CBED model) and forecast for 2020 (FRAME model), the species inhibited or strongly inhibited by different levels of N deposition according to Steven *et al* (2011), and an overall summary of all evidence of species and functional change. Inhibition is defined as where species occurrence fell by 20% relative to occurrence at the lowest N deposition levels, and strongly inhibited where occurrence fell by 50% relative to occurrence at the lowest N deposition levels. Critical load ranges are presented (Bobbink and Hettelingh, 2011).

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
0-5		0.01			
5-10	0.6	1.9	• *Spiranthes spiralis* • *Bromopsis erecta* • *Allium vineale* • *Geranium columbinum* • *Centaurea scabiosa* • *Daucus carota*	• Spiranthes spiralis • Bromopsis erecta • Centaurea scabiosa	Reduced presence of *Bromopsis erecta* below current mapped critical load value identified in Stevens *et al* (2011) may have important ecological implications as it is usually a dominant species when present. Changes in productivity and nutrient cycling may then follow.
10-15	7.4	17.5	**Species above plus:** • Carex spicata • Ononis repens • Carlina vulgaris	**Species above plus:** • *Daucus carota* • *Ononis repens* • *Carex spicata*	A 20% increase in Ellenberg N at 10-15kgN/ha/yr identified in new analyses (Stevens *et al* 2011). Canopy height increases by 20% at 5-10kgN/ha/yr and 50% at 15-20kgN/ha/yr identified in new analysis of one dataset (Stevens *et al* 2011).

N dep (kg/ha/yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
15-20	41.8	60.9	**Species above plus:** • *Echium vulgare* • *Rosa micrantha* • *Cynoglossum officinale* • *Cladonia foliacea* • *Melica nutans*	**Species above plus:** • *Allium vineale* • *Geranium columbinum*	
2010/11 Critical Load range = 15-25kgN/ha/yr					
20-25	31.4	12.9	**Species above plus:** • *Campanula glomerata*	**Species above plus:** • *Carlina vulgaris* • *Echium vulgare* • *Rosa micrantha* • *Cynoglossum officinale* • *Cladonia foliacea* • *Melica nutans*	Altered species composition previously reported both in Stevens *et al* (2011) and RoTAP (In Prep). Increase in competitive species and plant productivity as indicated by increased canopy height and specific leaf area by Stevens *et al* (2011). Increased Ellenberg N value with N deposition indicating shift to more nutrient-loving species in Stevens *et al* (2011). A 20% change at 10-15kgN/ha/yr and a 50% change at 35-40kgN/ha/yr in one dataset. Evidence of further increases in nitrate leaching, loss of forb species and overall plant species richness (RoTAP In Prep).
25-30	9.7	5.4		**Species above plus:** • *Campanula glomerata*	
30-40	8.9	1.4			
40-50	0.3				
>50		0.02			

Reduced presence of upright brome *Bromopsis erecta* identified in the new analyses by Stevens *et al* (2011) may have important ecological implications as it is usually a dominant species when present. Changes in productivity and nutrient cycling may then follow. Indeed a 20% increase in Ellenberg N at 10-15kgN/ha/yr was also identified in new analyses together with an increase in canopy height by 20% at 5-10kgN/ha/yr and 50% at 15-20kgN/ha/yr. Other evidence from N manipulation experiments and research-scale surveys indicates that at high levels of N deposition species richness declines (RoTAP In Prep) with reductions in forb and bryophyte cover and increases in grass cover with increasing N deposition (RoTAP In Prep).

Heathland

Table 3. Percentage of heathland in the UK receiving different amounts of N deposition (2006-2008, CBED model) and forecast for 2020 (FRAME model), the species inhibited or strongly inhibited by different levels of N deposition according to Steven *et al* (2011), and an overall summary of all evidence of species and functional change. Inhibition is defined as where species occurrence fell by 20% relative to occurrence at the lowest N deposition levels, and strongly inhibited where occurrence fell by 50% relative to occurrence at the lowest N deposition levels. Critical load ranges are presented (Bobbink and Hettelingh, 2011).

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
0-5	0.9	9.4			
5-10	45.1	47.7	• acid frillwort (a liverwort) (*Fossombronia wondraczekii);* • a reindeer moss *(Cladonia cervicornis verticillata);* • a reindeer moss *(Cladonia strepsilis);* • bearberry *(Arctostaphylos uva-ursi);* • comb notchwort (a liverwort) *(Anastrophyllum minutum);* • Pearson's finerwort (a liverwort) *(Lepidozia pearsonii);* • a lichen *(Cetraria aculeate);* • a lichen *(Cetraria muricata);* • a reindeer moss *(Cladonia*	• acid frillwort (a liverwort) (*Fossombronia wondraczekii);* • a reindeer moss *(Cladonia strepsilis);* • bearberry *(Arctostaphylos uva-ursi).*	A 20% increase in Ellenberg N at 5-10kgN/ha/yr relative to lowest levels of N deposition according to one dataset (BSBI LCS) (Stevens *et al* 2011)

N dep (kg/ha/yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
			uncialis biuncialis); • Heath Navel (*Lichenomphalia umbellifera);* • fairy beads (a liverwort) *(Microlejeunea ulicina);* • a reindeer moss *(Cladonia cervicornis cervicornis);* • a reindeer moss *(Cladonia subulata);* • large white-moss (*Leucobryum glaucum).*		
10-15	26.8	25.2	**Species above plus:** • a reindeer moss *(Cladonia portentosa);* • cowberry *(Vaccinium vitis-idaea).*	**Species above plus:** • a reindeer moss *(Cladonia cervicornis verticillata);* • comb notchwort (a liverwort) *(Anastrophyllum minutum);* • Pearson's finerwort *(a liverwort) (Lepidozia pearsonii);* • a lichen *(Cetraria aculeate);* • a lichen *(Cetraria muricata);* • a reindeer moss *(Cladonia uncialis biuncialis);* • fairy beads (a liverwort) *(Microlejeunea ulicina).*	

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
2010/11 Critical Load range = 10-20kgN/ha/yr					
15-20	15.5	13.6	**Species above plus:** • heath dog-violet *(Viola canina);* • *pink earth lichen (Dibaeis baeomyces);* • a reindeer moss *(Cladonia glauca).*	**Species above plus:** • Heath Navel *(Lichenomphalia umbellifera);* • a reindeer moss *(Cladonia cervicornis cervicornis);* • a reindeer moss *(Cladonia subulata);* • large white-moss (*Leucobryum glaucum);* • a reindeer moss *(Cladonia portentosa);* • cowberry *(Vaccinium vitis-idaea);* • heath dog-violet *(Viola canina).*	Altered species composition both in Stevens *et al* (2011) and RoTAP (In Prep). A 20% increase in Ellenberg N value at 5-20kgN/ha/yr) relative to lowest levels of N deposition for both upland and lowland heathland indicating shift to more nutrient-loving species in Stevens *et al* (2011). A 20% reduction in Ellenberg R value at 15-20kgN/ha/yr relative to lowest levels of N deposition (Stevens *et al* 2011). Conflicting evidence of change in canopy height with both positive and negative relationships described. Suggests sensitivity of habitat to change with direction of change dependent on site factors (Stevens *et al* 2011).
20-25	7.7	3.7	**Species above plus:** • a lichen *(Peltigera hymenina).*	**Species above plus:** • pink earth lichen *(Dibaeis baeomyces);* • a reindeer moss *(Cladonia glauca).*	A maximum change in canopy height of 1500% at 20-25kgN/ha/yr) relative to lowest levels of N deposition observed in one dataset (VPD) (Stevens *et al* 2011).

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
25-30	2.9	0.5		**Species above plus:** • a lichen *(Peltigera hymenina).*	
30-40	0.9				
40-50					
>50					

Evidence from research-scale surveys and experiments in the UK heathlands shows a reduction in species richness at high N deposition although positive responses by some species are also reported (Edmondson 2007; Maskell *et al* 2010; RoTAP In Preparation). An increase in grass cover and a reduction in the cover and richness of forbs, bryophytes and lichens have also been reported (RoTAP In Preparation). The results of Stevens *et al* (2011) investigation support these findings with a reduction in the occurrence of several stress-tolerant forb and shrub species with increasing N deposition (e.g. heath dog-violet *Viola canina,* cowberry *Vaccinium vitis-idaea*) as well as reductions in the probability of presence of some bryohyte and a number of lichen species (e.g. the bryophyte *Lepidozia pearsonii*, and lichen *Cetraria aculeata* (Stevens *et al* 2011). In addition, and a 20% change in Ellenberg N at 5-10kgN/ha/yr according to the BSBI Local Change Survey.

Bogs

Table 4. Percentage of Bogs in the UK receiving different amounts of N deposition (2006-2008, CBED model) and forecast for 2020 (FRAME model), the species inhibited or strongly inhibited by different levels of N deposition according to Steven *et al* (2011), and an overall summary of all evidence of species and functional change. Inhibition is defined as where species occurrence fell by 20% relative to occurrence at the lowest N deposition levels, and strongly inhibited where occurrence fell by 50% relative to occurrence at the lowest N deposition levels. Critical load ranges are presented (Bobbink and Hettelingh, 2011).

N dep (kg/ha/yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
	2006-08	**Pre-dicted 2020**			
0-5	1.0	15.5			No evidence of impact on indices of ecological function below 10kgN/ha/yr identified in new analyses (Stevens *et al* 2011).
5-10	47.3	44.3	• matchstick flapwort (a liverwort) *(Odontoschisma denudatum)*; • comb notchwort (a liverwort) *(Anastrophyllum minutum)*.		
2010/11 Critical Load range = 5-10kgN/ha/yr					
10-15	19.2	20.7	**Species above plus:** • Shady earwort (a liverwort) *(Scapania umbrosa);* • Bog pouchwort (a liverwort) *(Calypogeia sphagnicola).*	• matchstick flapwort (a liverwort) *(Odontoschisma denudatum);* • comb notchwort (a liverwort) *(Anastrophyllum minutum);* • Shady earwort (a liverwort) *(Scapania umbrosa).*	Altered species composition both in Stevens *et al* (2011) and RoTAP (in Prep). Increased Ellenberg N value with N deposition indicating shift to more nutrient-loving species in Stevens *et al* (2011): 20% increase at 15-20kgN/ha/yr, but no change in Ellenberg R (acidity) value. No evidence of increase in competitive plants and productivity found by Stevens *et al* (2011).
15-20	14.7	11.5	**Species above plus:** • a reindeer moss *(Cladonia portentosa).*	**Species above plus:** • Bog pouchwort (a liverwort) *(Calypogeia sphagnicola).*	

N dep (kg/ha/ yr)	**UK % of habitat with this deposition level**		**Species distribution inhibited by N dep as determined by Stevens *et al* (2011)**	**Species distribution strongly inhibited by N dep as determined by Stevens *et al* (2011)**	**Evidence of change including impacts on functions and soil processes**
					Risk to climate regulation depending on balance in change in productivity, decomposition rates and nitrous oxide production. Uncertainty in evidence to date.
20-25	9.7	7.0		**Species above plus:** • a reindeer moss *(Cladonia portentosa).*	
25-30	6.2	0.9			

There is a paucity of data on bogs, both from previous research scale studies and from the national-scale surveys used in Stevens *et al* (2011) and Emmett *et al* (2011). Results from previous research suggest a reduction in bryophyte and lichen cover, changes in the growth and cover of heather *Calluna vulgaris,* and changes in species composition (Sheppard *et al* 2008; RoTAP In Preparation). This report supports this evidence demonstrating changes in the probability of presence for individual species, including bryophytes and lichens (e.g. declines in the bryophyte *Anastrophyllum minutum* and the lichen *Cladonia portentosa*) with increasing N deposition. No evidence of impact on indices of ecological function below 10kgN/ha/yr identified in new analyses.

References

BOBBINK, R. & HETTELINGH, J.P., eds. 2011. *Review and revision of empirical critical loads and dose-response relationships*, Coordination Centre for Effects, National Institute for Public Health and the Environment (RIVM). www.rivm.nl/cce

DUPRÉ, C., STEVENS, C.J., RANKE, T., BLEEKER, A., PEPPLER-LISBACH, C., GOWING, D.J.G., DISE, N.B., DORLAND, E., BOBBINK, R. & DIEKMANN, M. 2010. Changes in species richness and composition in European acidic grasslands over the past 70 years: the contribution of cumulative atmospheric nitrogen deposition. *Global Change Biology,* **16 (1)**, 344-357.

EDMONDSON, J.L. 2007. Nitrogen pollution and the ecology of heather moorland, Manchester Metropolitan University, Manchester.

EMMETT, B.A., ROWE, E.C., STEVENS, C.J., GOWING, D.J., HENRYS, P.A., MASKELL, L.C. & SMART, S.M. 2011. Interpretation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. *JNCC Report*, No. 449.

MASKELL, L.C., SMART, S.M., BULLOCK, J.M., THOMPSON, K. & STEVENS, C.J. 2010. Nitrogen deposition causes widespread loss of species richness in British habitats. *Global Change Biology,* **16**, 671-679.

NEGTAP. 2001. Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK. Prepared by the National Expert Group on Transboundary Air Pollution on behalf of the UK Department for Environment, Food and Rural Affairs (DEFRA) and the Devolved Administrations. 314 pp.

ROTAP (in prep). Review of Transboundary Air Pollution, Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Defra. http://www.rotap.ceh.ac.uk

SHEPPARD, L.J., LEITH, I.D., CROSSLEY, A., VAN DIJK, N., FOWLER, D., SUTTON, M.A. & WOODS, C. 2008. Stress responses of Calluna vulgaris to reduced and oxidised N applied under 'real world conditions'. *Environmental Pollution,* **154**, 404-413.

STEVENS, C.J., DISE, N.B., MOUNTFORD, J.O. & GOWING, D.J. 2004. Impact of nitrogen deposition on the species richness of grasslands. *Science,* **303 (5665)**, 1876-1879.

STEVENS, C.J., DUPRÈ, C., DORLAND, E., GAUDNIK, C., GOWING, D.J.G., BLEEKER, A., DIEKMANN, M., ALARD, D., BOBBINK, R., FOWLER, D., CORCKET, E., MOUNTFORD, J.O., VANDVIK, V., AARRESTAD, P.A., MULLER, S. & DISE, N.B. 2010. Nitrogen deposition threatens species richness of grasslands across Europe. *Environmental Pollution,* **158**, 2940-2945.

STEVENS, C.J., SMART, S.M., HENRYS, P.A., MASKELL, L.C., WALKER, K.J., PRESTON, C.D., CROWE, A., ROWE, E.C., GOWING, D.J. & EMMETT, B.A. 2011. Collation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. *JNCC Report*, No. 447.