JNCC Report
No. 449

Interpretation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives

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June 2011

ISSN 0963 8091

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This report should be cited as:

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

This project was jointly funded by Defra, Joint Nature Conservation Committee, Natural England, Countryside Council for Wales and Scottish Natural Heritage.

Executive Summary

1. According to current analysis large areas of the country exceed the critical load and level for reactive nitrogen (N) pollutants, and are predicted to continue to do so in 2020 despite reductions in emissions of reactive N gases. (The definition of a N critical load is “the amount of N deposition below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge”.) This project addressed the need to test if this risk is translating to visible change in the wider countryside resulting in broad scale ecological damage which impacts on both conservation commitments and biodiversity targets, and ecosystem service provision.

2. Here, the largest analysis of national vegetation data sets in relation to N deposition to date carried out by Stevens *et al* (2011), together with other sources of independent evidence, are interpreted within this context. The Stevens *et al* (2011) study statistically analysed eight independent national vegetation surveillance datasets using a consistent approach, to identify evidence of N deposition impacts in four habitat types; acidic and calcareous grassland, heathland and bogs.

3. The results indicate a significant response in the cover and presence of 91 plant and lichen species indicating a change in ecosystem structure. These included two BAP priority species, four species mentioned in Annexes of the Habitats Directive and 24 positive Common Standard Monitoring indicator species. Inhibition in response to N was observed for species such as *Spiranthes spiralis* (Autumn Lady's-tresses); *Campanula glomerata* (Clustered Bellflower); *Centaurea scabiosa* (Greater Knapweed); *Geranium columbinum* (Long-stalked Crane's-bill); *Trifolium micranthum* (Slender Trefoil); *Carex limosa* (Bog sedge); *Carex spicata* (Spiked sedge)*;* and *Carlina vulgaris* (Carline thistle). Stimulation was observed for ca. 30% of species including *Platanthera bifolia* (Lesser Butterfly-orchid) and *Stachys officinalis* (Betony). Experimental data suggests that stimulation responses can be short-lived resulting in later increased susceptibility to secondary stress and reduced cover.

4. N deposition thresholds are identified where species prevalence falls by 20% of that observed in low N deposition areas, and where species prevalence falls by 50% of that observed in low deposition areas. Thresholds for three indices of functional change; canopy height, specific leaf area and Ellenberg N, are also calculated where there is a 20% and 50% change in the index relative to values observed in lowest deposition areas. These three functional indices provide information on the level of nutrient availability and productivity levels due to species change and are calculated from typical values for species recorded rather than direct measurements. N deposition has a variable effect on ecosystem service provision and a short review on the evidence of effects on supporting, regulating, provisioning and cultural services is presented.

5. The results reveal that changes in both species and ecosystem function indices occur at low thresholds of N deposition (5-10 kgN/ha/yr). In some cases these are below critical loads for N indicating that critical loads are not protecting all species or ecosystem functions, and current conservation commitments and biodiversity targets are at risk. These include the aim to maintain or improve the status of wild flora and fauna and their ecosystems and habitats in response to the Convention for Biological Diversity (CBD) Articles 8 and 9. Clearly these targets are at risk of not being delivered with the level of inhibition of species and changes to ecosystem function reported here, and new critical load mapping values (i.e. the value within the critical

load range that is identified for national mapping of critical loads in the UK) are adopted which take account of this new evidence.

6. Changes in species and ecosystem function indices continue above critical load values indicating that ongoing damage occurs above the critical load threshold and there may be benefits from reductions in deposition even if the threshold is not reached.

7. Looking to the future, although the UK government is currently investigating actions necessary to meet the National Emission Ceilings Directive and Gothenburg Protocol 2010 emissions targets and new lower targets for 2020 are being negotiated, total reactive N emissions and hence deposition, seem unlikely to show a major decline in the period 2010-2020 (ROTAP, in prep). This indicates that 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 management options are limited. This means that the Strategic Plan agreed in October 2010 by the Convention on Biological Diversity (CBD) 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 challenging to deliver.

8. Case studies of Common Standards Monitoring (CSM) condition assessment of individual sites showed that changes as a consequence of N deposition are very unlikely to be detected using CSM. Monitoring of changes in vegetation species composition, species richness and Ellenberg N scores over time was able to detect more subtle changes at individual sites, suggesting that damage is occurring even in sites judged to be in favourable condition.

9. An assessment of current vegetation monitoring schemes is presented and concludes that National Vegetation Classification (NVC) quadrat data, held for many sites, are inherently biased against detecting subtle impacts, e.g. of air pollution, since quadrats are placed within typical stands rather than being placed randomly, and if the NVC surveys are repeated, quadrats will be placed in a new typical stand rather than the same location as previously. In the future, any surveillance schemes for detecting N impacts at site levels would ideally 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. This would allow the presence of individual species, mean Ellenberg N score and species richness, all sensitive indicators of N deposition impacts, to be determined. Incorporating cover estimates would enable the use of still more sensitive indicators of N deposition impacts. Where simple soil measurements (pH and total C/N ratio) are available, niche models could be used to generate site-specific lists of species at risk. 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. 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.

Acknowledgements

Funding for this project was provided by Defra, the Countryside Council for Wales, the Joint Nature Conservation Committee, Natural England and Scottish Natural Heritage. We are very grateful to all of the organisations that provided data for this project: Botanical Society of the British Isles, British Bryological Society, British Lichen Society, Plantlife, Scottish Natural Heritage, Countryside Council for Wales and Natural England. We are also grateful to all those who participated in the workshop associated with this project: Clare Whitfield, Chris Cheffings, Anna Robinson, Vicky Morgan, Mark Crick, Zoe Russell, Alastair Burn, Sue Rees, Isabel Alonso, Richard Jefferson, Mick Rebane, Iain Diack, Carrie Rimes, Simon Bareham, Peter Coleman, Colin Powlesland, Rob Kinnersley, Mark Hill and Mike Sutcliffe.

Contents

1 Introduction

Atmospheric nitrogen (N) deposition poses a serious threat to sensitive semi-natural habitats in the UK (Hall, Bealey, and Wadsworth 2006; NEGTAP 2001). Much of the effort to quantify areas of habitats that are threatened by N pollution has taken place in response to the 1979 Convention on Long-Range Transboundary Air Pollution (CLRTAP). Under this Convention, national emissions of atmospheric pollutants are restricted with the aim of reducing deposition rates, thus reducing exceedence of critical loads (CL). Critical loads are “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge”(Nilsson and Grennfelt 1988).Thus the risk from N deposition on semi-natural terrestrial and freshwater habitats is currently quantified using the critical load approach which identifies areas where N deposition is above the critical load threshold. According to current analysis by the UK National Focal Centre for Critical Loads Modelling and Mapping large areas of the country exceed the critical loads for nutrient N and critical levels for ammonia, and are predicted to continue to do so in 2020 despite reductions in emissions of reactive N gases (Hall *et al* 2006). To identify if this risk is translating to visible damage in the wider countryside resulting in broad scale ecological damage which impacts on both conservation targets and ecosystem service provision, analyses of national surveillance datasets are required. These datasets may focus on a range of targets including water bodies, vegetation data, soil quality and gaseous fluxes. Of primary interest in this report is the evidence of change in national vegetation datasets from analyses recently carried out by Stevens *et al* (2011), and the resulting consequences for broader ecological damage and ecosystem services. The need to translate critical load exceedence to definitions of habitat quality and damage in international biodiversity legislation in this way is increasingly recognised (WGE 2009).

The work by Stevens *et al* (2011) represents the largest analysis of national vegetation data sets in relation to N deposition to have been conducted to date. Eight independent national vegetation surveillance datasets were statistically analysed using a consistent approach to identify evidence of N deposition impacts. Here we interpret this new evidence, in combination with a range of existing evidence (notably the syntheses in NEGTAP 2001 and RoTAP (in prep)), in terms of the ecological implications of N deposition for the wider countryside and the ecosystem services and goods it provides. Implications for UK conservation commitments are also commented on in relation to both current state of biodiversity and likely future impacts on targets. Limitations and challenges of identifying N deposition impacts at both site level and national scale are discussed together with an analysis of current surveillance schemes and recommendations for improvements to identify future responses to N deposition.

2 Implications for the wider countryside

A wide range of evidence is now available regarding of the effects of N deposition on ecosystem structure and function for a range of habitats (Carey *et al* 2008, Maskell *et al* 2010, UKREATE 2010, RoTAP (in prep), Stevens *et al* (2011). This covers evidence from experiments, research-scale surveys, national monitoring programmes such as Countryside Survey and analysis of national vegetation data sets. These results suggest that consequences of N deposition in semi-natural habitats are wide ranging including; overall reduction in species richness; homogenisation of vegetation; increased productivity which is often damaging in nutrient-poor systems; the onset of nitrate leaching resulting in eutrophication of water bodies; and acidification of waters in acid-sensitive areas.

2.1 Challenges in detecting change

Whilst the magnitude of species compositional change associated with atmospheric N deposition is relatively small in comparison to the impact of agricultural improvement (e.g. Firbank *et al* 2008; Vickery, Tallowin, and Feber 2001; Robinson and Sutherland 2002), conversion (drainage, re-seeding, NPK fertiliser application) of larger areas of semi-natural habitats in Britain is now much less common under current policies. Therefore atmospheric N deposition has been a subtle yet pervasive driver whose signal is clearest when other impacts are held constant or factored out, and where existing areas of semi-natural habitat are sampled in an unbiased fashion (Maskell *et al* 2010; Stevens *et al* 2004). Because atmospheric N deposition is impossible to ‘see’ and the consequences are relatively subtle it remains challenging to link cause with effect by appealing to visible evidence. However, as Hill & Carey (1997) commented “Britain is a grassy country”. While this is in large part due to long-term agricultural exploitation and grazing of large tracts of our landscape, we now have clear evidence that the loss of wild flowers and increase in nutrient-demanding grasses has also been driven by the cumulative effects of at least 150 years of N deposition. In areas of high deposition, this has made the countryside, and especially our larger tracts of semi-natural habitats, less colourful and lower in plant biodiversity (Rotap in prep; Stevens *et al* 2011). Since many invertebrates and pollinating insects also preferentially depend upon nectar-producing flowers, N deposition is also likely to have contributed to a reduction in the potential for delivery of the pollination ecosystem service (Carvell *et al* 2006; Biesmeijer *et al* 2006).

Superimposed on these responses to diffuse atmospheric N deposition, in many parts of Britain, plant species assemblages are likely to have been modified by point source emissions such as intensive animal houses. These impacts constitute an additional tier of ecosystem changes that are only partially quantified by the spatial relationships found in large-scale analyses. Detection of N deposition impacts relies heavily on matching ecological responses with modelled or interpolated estimates of deposition at reasonably coarse scales. Since we know that N deposition can drive ecological change it is probable that a large number of more localised impacts have occurred but are not easy to attribute because measured deposition from significant point sources is unavailable (Stevens *et al* 2011; Pitcairn *et al* 1998; Truscott *et al* 2005). Since point source impacts are more likely in lowland Britain, attribution is even more challenging because local N point sources operate alongside other drivers such as excess P and aquatic sources of N loading in enriched run-off, vehicular NOx, and land-use related disturbance and succession. Nevertheless the evidence from Stevens *et al* (2011) together with other sources provides powerful evidence of the impacts of diffuse N deposition on vegetation species composition and ecosystem function.

2.2 Linking to ecological consequences

In some cases, making the link between change in vegetation composition and ecological consequences is challenging as only correlative relationships are possible from surveillance schemes. It is experimental data which can identify causal links. In some cases there are no broad-scale ecosystem functional changes as, for example, a loss of rare species may have little consequence for overall ecosystem functions such as primary productivity or water quality regulation, although they could be of importance for specialists in the pollination or food chain. The loss to the conservation value, however, may be large particularly if the species in question is a target or priority species for the habitat. It is the loss or gain of a keystone species which will make fundamental changes in the structure and function of the habitat, thus fundamentally changing the overall value of a site for both conservation purposes **and** ecosystem function. One approach to assess the evidence of these wider ecological changes due to N deposition is to assess changes in critical ecosystem functions such as primary production and nutrient cycling - in ecosystem services language these are ‘supporting services’. Linking these directly to changes in species composition may not always be possible but a combination of species level changes together with changes in indices of ecosystem structure and / or function indices and application of expert knowledge provides an evidence base, albeit correlative and in some instances expert based, between biodiversity change and ecosystem function. For example, in Stevens *et al* (2011) individual species responses were examined in addition to three indices of ecosystem structure and function based on typical values for individual species. These were:

- Canopy height: an index of productivity levels. Habitats with greater numbers of more competitive species typical of nutrient rich situations would be expected to have higher canopy height (if management levels remain constant). N deposition would be expected to increase competitive species and thus increase the mean habitat canopy height.

- Specific Leaf Area (SLA): a measure of leaf area divided by dry mass. More competitive species typical of nutrient rich situations would be expected to have a higher SLA. N deposition would therefore be expected to increase the mean SLA for a habitat.

- Ellenberg N score: an index of N nutrient availability (1-9) as identified by the relative balance of species which favour or disfavour N nutrient availability i.e. a high score indicates a preference for high nutrient availability conditions. An increase in the overall Ellenberg value for a site can therefore indicate a shift in composition consistent with greater N availability due to N deposition. Small shifts in Ellenberg value can result from major species losses and gains e.g.:

	Ellenberg value for species present	
	Time 1	Time 2
Species a	4	4
Species b	5	5
Species c	3	absent
Species d	7	7
Species e	absent	4
Mean Ellenberg	**4.7**	**5**

Loss of species ‘c’ and gain of species ‘e’ results in shift in overall Ellenberg of 0.3. An apparently small change but one which indicates a major species shift

Here we calculate thresholds of N deposition levels at which changes occur for both species prevalence and these function indices, based on the statistical analyses carried out in Stevens *et al* (2011).

For functional indices, a 20% change in the variable relative to the lowest deposition was identified as “functional change” and a 50% change as “major functional change”. For relationships of the indicator against N deposition which were humpbacked or levelled-off, a maximum change is provided together with the N deposition rate that produced the change. For relationships which did not level off this is indicated as the upper end point (Table 2.1).

For species, the thresholds of N deposition were identified where species prevalence fell by 20% relative to prevalence found at the lowest levels of N deposition (‘inhibition’ of species) and where prevalence fell by 50% (‘strongly inhibited’) (Tables 2.2-2.5). Data are also presented in Appendix 3 (Tables 10.5-10.8) of the levels of deposition where species prevalence fell by 10% and 80% from that found at the lowest levels. These tables also illustrate the upper and lower (95%) confidence intervals for deposition levels causing a decline in species prevalence of 10%, 20% 50% and 80%.

It is interesting to note that many changes observed in both species and ecosystem indices were found to occur at low levels of deposition (5-10 kgN/ha/yr), some below critical loads. For example, Figure 2.1 shows spatial analysis of the probability of presence of the lichen *Cladonia subulata* in heathland which declines steadily in its probability of presence from the lowest levels of deposition found in the UK.

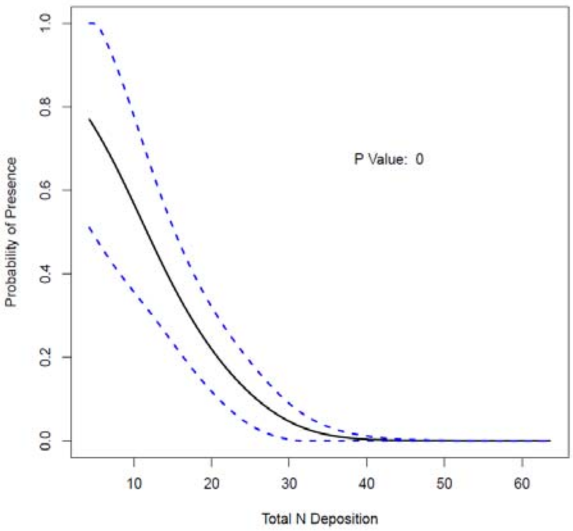

Figure 2.1. Spatial change in the probability of presence of *Cladonia subulata* in heathland with increasing total inorganic N deposition (kg N ha^{-1} yr^{-1}). Data from British Lichen Society. P<0.0001.

Table 2.1. N deposition thresholds (kg N ha^{-1} yr^{-1}) for changes in the functional indicators Canopy Height, Specific Leaf Area and Ellenberg N, as identified by Stevens *et al* (2011). Also indicated is the dataset from which a significant relationship to N deposition was derived, the habitat type, shape of relationship, and the maximum change observed and N deposition this occurred at if relationships were hump-backed or levelled off. 'Not Observed' indicates that a 20% or 50% change was not observed within the range of N deposition included in this study. VPD indicates Vascular Plant Database, LCS indicates Local Change Survey.

Habitat	Upland or Lowland	Dataset	Functional variable	Slope of relationship	N deposition where a functional change is observed (20% change)	N deposition where a major functional change is observed (50% change)	Max change observed (%)	N deposition where max % change observed
Calcareous Grassland	Upland	VPD	Canopy Height	Positive	5-10	15-20	58%	20-25
Calcareous Grassland	Upland	VPD	Ellenberg N	Positive	10-15	35-40	upper end point	
Calcareous Grassland	Lowland	VPD	Ellenberg N	Humpback	Not Observed	Not Observed	9%	25-30
Calcareous Grassland	Lowland	VPD	SLA	Humpback	Not Observed	Not Observed	4%	25-30
Calcareous Grassland	Lowland	LCS	Ellenberg N	Positive	10-15	Not Observed	upper end point	
Acid Grassland	Lowland	VPD	Canopy Height	Positive	30-35	45-50	upper end point	
Acid Grassland	Lowland	VPD	Ellenberg N	Positive	5-10	10-15	upper end point	
Acid Grassland	Upland	VPD	SLA	Humpback	Not Observed	Not Observed	5%	20-25
Acid Grassland	Lowland	LCS	Ellenberg N	Positive	30-35	Not Observed	upper end point	
Heathland	Lowland	VPD	Canopy Height	Positive	5-10	5-10	1500%	20-25
Heathland	Upland	VPD	Ellenberg N	Positive	15-20	Not Observed	upper end point	
Heathland	Lowland	VPD	Ellenberg N	Positive	15-20	Not Observed	upper end point	
Heathland	Lowland	LCS	Canopy Height	Negative	5-10	5-10	71%	10-15
Heathland	Lowland	LCS	Ellenberg N	Positive	5-10	10-15	upper end point	
Bog	Upland	VPD	Ellenberg N	Positive	15-20	Not Observed	upper end point	

In the following section, these analyses to identify thresholds are reported for the first time to provide a broad picture of N deposition impacts on the habitats investigated at different N deposition rates. The percentage of habitat above the critical load is indicated for the UK to identify the scale of potential risk using current thresholds, with data for devolved administrations provided in Annex 3. New critical load mapping values (i.e. the value within the critical load range that is identified for use for national mapping of critical loads in the UK) have been developed concurrently with this report and the analysis of Stevens *et al* 2011 is being used to inform this.

2.2.1 Acid grasslands

Results of research-scale surveys (Maskell *et al* 2010; Stevens 2004; Stevens *et al* 2010) show clear declines in species richness of acid grasslands associated with N deposition. The majority of this loss in species richness is 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). The results of this project (Stevens *et al* 2011) support these findings with a number of forb species showing negative relationships with N deposition (i.e. a reduced probability of presence with increasing N deposition) (e.g. *Cerastium arvense, Viola canina*) as well as negative relationships for sensitive bryophytes and lichens (e.g. *Racomitrium lanuginosum* (bryophyte), *Peltigera didactyla* (lichen)). Some of the species which have negative relationships with N deposition, such as *Vicia lathyroides* and *Viola canina*, are among the most attractive species found in this community. This gives them a high cultural value. The results also indicate that these grasslands are more eutrophic (higher Ellenberg N score) in areas of high deposition and have become more eutrophic over time. Research scale surveys have also demonstrated an increase in acid tolerant species with increasing N deposition (Maskell *et al* 2010; Stevens *et al* 2010). The consequence of these changes in response to N deposition in acid grasslands will be a loss of species richness and functional diversity resulting in grasslands becoming increasingly grass dominated and some sensitive species put at risk of decline in areas of high deposition. Many of these changes are occurring at low levels of deposition, below the critical load for this habitat. Ecological consequences include increased productivity as indicated by increased canopy height and SLA in Stevens *et al* (2011) due to greater dominance by competitive grass species, reduced water quality due to N in excess of plant uptake requirements and acidification transformations in soil, reduced climate regulation due to removal of N limitation of gentrification resulting in increased N_2O production but possibly partially offset by increased carbon sequestration by plants. Overall balance will be dependent on soil type (see summary in RoTAP in prep). A summary of changes in species prevalence and ecosystem structure and function at different deposition rates is presented in Table 2.2.

Table 2.2. Percentage of acid grassland in the UK receiving different amounts of N deposition as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model, the species inhibited or strongly inhibited by different levels of N deposition according to new analysis by 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. Further data for 10% and 80% relative decline and for upper and lower confidence intervals are presented in Appendix 3. The 2003 critical load range (UNECE, 2003) and 2003 UK mapping value (Hall *et al* 2003) is also indicated together with the revised critical loads (Bobbink and Hettelingh 2011) and the 2011 mapping value. The evidence from Stevens *et al* 2011 has informed the setting of the 2011 mapping value. Data on % areas for devolved administrations are presented in Appendix 3.

N deposition (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	**Predicted 2020**			
0-5	0.4	4.2			
5-10	20.4	22.7	*Cerastium arvense* *Vicia lathyroides* *Trifolium arvense* *Peltigera didactyla* *Cetraria aculeata* *Cerastium semidecandrum*		20% increase in Ellenberg N at 5-10 kgN/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 new analyses. Suggests sensitivity of habitat to change with direction of change dependent on site factors. (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
10-15	21.3	32.8	**Species above plus:** *Viola canina* *Scapania gracilis* *Racomitrium lanuginosum*	*Cerastium arvense* *Vicia lathyroides* *Trifolium arvense* *Cetraria aculeata* *Cerastium semidecandrum*	
2003 Critical load range = 10-20 kgN/ha/yr **2003 mapping value = 15kgN/ha/yr** **2010 Critical load range: Dry acid grassland = 10-15 kgN/ha/yr; Wet acid grassland = 10-20 kgN/ha/yr** **2011 New UK mapping value Dry acid grassland = 10 kgN/ha/yr; Wet acid grassland = No change (15kgN/ha/yr).**					
15-20	31.6	29.9	**Species above plus:** *Frullania tamarisci*	**Species above plus:** *Peltigera didactyla* *Viola canina* *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 myrtillus* (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.

N deposition (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	**Predicted 2020**			
					Evidence that species are differentially sensitive to forms of N deposited (UKREATE 2010).
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 30-35 kgN/ha/yr and 50% at 45-50 kgN/ha/yr in one dataset (Stevens *et al* 2011).
30-40	2.3	0.3		**Species above plus:** *Frullania tamarisci*	
40-50	0.4				
>50	0.01	0.005			
Total (%)	100	100			

2.2.2 Calcareous grasslands

Evidence from N manipulation experiments and research-scale surveys indicates that at high levels of N deposition species richness declines (RoTAP in prep; Wilson *et al* 1995) with reductions in forb and bryophyte cover and increases in grass cover as N deposition increases (RoTAP in prep; Morecroft *et al* 1994). The results of the analysis of national vegetation datasets supports these findings with a reduction in the occurrence of several stress-tolerant forb species with increasing N deposition (e.g. *Carlina vulgaris*) as well as changes in the probability of presence of bryophyte and lichen species (Stevens *et al* 2011). For example, *Campanula glomerata* and *Spiranthes spiralis* are both forb species of calcareous grassland which show significant negative responses to N deposition. The grass *Bromopsis erecta* showed a significant negative relationship with N deposition. This grass is a key species in several calcareous grasslands habitats and decline could have important habitat conservation implications. The results of this project (Stevens *et al* 2011) and research scale surveys (RoTAP in prep; Bennie *et al* 2006) show that calcareous grasslands are more eutrophic (higher Ellenberg N score) in areas of high deposition and have become more eutrophic over time. Competitive species (those with a high specific leaf area and canopy height) are also becoming more prevalent, increasing the habitat averages for these measures. The consequence of these changes in response to N deposition in calcareous grasslands are a loss of species richness and functional diversity with grasslands becoming increasingly grass-dominated and productive with reduced water quality due to onset of nitrate leaching. A summary of changes in species prevalence and ecosystem structure and function at different deposition rates is presented in Table 2.3.

Table 2.3. Percentage of calcareous grassland in the UK receiving different amounts of N deposition as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model, the species inhibited or strongly inhibited by different levels of N deposition according to new analysis by 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. Further data for 10% and 80% relative decline and for upper and lower confidence intervals are presented in Appendix 3. The 2003 critical load range (UNECE, 2003) and 2003 UK mapping value (Hall *et al* 2003) is also indicated together with the revised critical loads (Bobbink and Hettelingh 2011) and the 2011 mapping value. The evidence from Stevens *et al* 2011 has informed the setting of the 2011 mapping value. Data on % areas for devolved administrations are presented in Appendix 3.

N deposition (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	**predicted 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 10-15 kgN/ha/yr identified in new analyses (Stevens *et al* 2011). Canopy height increases by 20% at 5-10 KgN/ha/yr and 50% at 15-20 kgN/ha/yr identified in new analysis of one dataset (Stevens *et al* 2011).
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*	
2003 Critical load range= 15-25 kgN/ha/yr **2003 mapping value = 20kgN/ha/yr** **2010/11 Critical load range = 15-25 kgN/ha/yr** **2011 New UK mapping value = 15 kgN/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 10-15 kgN/ha/yr and a 50% change at 35-40 kgN/ha/yr in one dataset Evidence of further increases in nitrate leaching, loss of forb
25-30	9.7	5.4		**Species above plus:** *Campanula glomerata*	
30-40	8.9	1.4			
40-50	0.3				
>50		0.02			

N deposition (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	**predicted 2020**			
					species and overall plant species richness (RoTAP in prep).
Total (%)	100	100			

2.2.3 Heathlands

Heathlands have received a lot of research attention in relation to N deposition, especially in the Netherlands where N deposition, in combination with pest attacks, has been responsible for the degradation of large areas of heathland (Brunsting and Heil 1985; Heil and Diemont 1983). Evidence from research-scale surveys and experiments in the UK 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 prep). An increase in grass cover and a reduction in the cover and richness of forbs, bryophytes and lichens have been reported (RoTAP in prep). The results of this investigation support these findings with a reduction in the occurrence of several stress-tolerant forb and shrub species with increasing N deposition (e.g. *Viola canina, Vaccinium vitis-idaea*) as well as reductions in the probability of presence of some bryophyte and a number of lichen species (e.g. *Lepidozia pearsonii* (bryophyte), *Cetraria aculeata* (lichen), *Cladonia strepsilis* (lichen)) (Stevens *et al* 2011). Some *Cetraria* lichen species are of international conservation importance so N deposition could present a serious threat to surviving populations. The low-growing shrub *Arctostaphylos uva-ursi* also showed a strong negative relationship with N deposition. This species has a very restricted distribution in Great Britain. We also see declines in the cushion-forming bryophyte *Leucobryum glaucum* which is valued for its aesthetic appeal. The results of Stevens *et al* (2011) also show that heathland vegetation is more eutrophic (higher Ellenberg N score) in areas of high deposition and has become more eutrophic over time. The results of the new analysis in Stevens *et al* (2011) suggest a positive response of six *Sphagnum* species to N deposition in this habitat. Increased production rates have been reported before but this can result in a tipping point being reached which results in a breakdown of *Sphagnum* cover and invasion by grasses in the long term (Lamers *et al* 2000). The consequence of these changes in response to N deposition for heathlands is a loss of species-richness and functional diversity with some sensitive species put at risk in areas of high deposition.

Changes in the occurrence of some of these species may also occur in habitats we haven't considered. For example, a number of *Cladonia* species which showed negative responses to N deposition in heathland or calcareous grassland, are also found in other habitats. *Cladonia* species, such as *Cladonia foliacea*, which showed a negative response to N deposition in calcareous grasslands, form an important component of the Annex I grey dune habitat (NVC habitat SD11 *Carex arenaria - Cornicularia aculeata* dune community). *Cladonia* lichens are food plants for the scarce moth species *Parascotia fuliginaria* and *Eilema pygmaeola*. Consequently negative impacts of N deposition on Cladonia lichens could threaten scarce habitats and other species. A summary of changes in species prevalence and ecosystem structure and function at different deposition rates is presented in Table 2.4.

Table 2.4. Percentage of heathland in the UK receiving different amounts of N deposition as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model, the species inhibited or strongly inhibited by different levels of N deposition according to new analysis by 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. Further data for 10% and 80% relative decline and for upper and lower confidence intervals are presented in Appendix 3. The 2003 critical load range (UNECE, 2003) and 2003 UK mapping value (Hall *et al* 2003) is also indicated together with the revised critical loads (Bobbink and Hettelingh 2011) and the 2011 mapping value. The evidence from Stevens *et al* 2011 has informed the setting of the 2011 mapping value. Data on % areas for devolved administrations are presented in Appendix 3.

N deposition (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	**Predicted 2020**			
0-5	0.9	9.4			
5-10	45.1	47.7	*Fossombronia wondraczekii* *Cladonia cervicornis verticillata* *Cladonia strepsilis* *Arctostaphylos uva-ursi* *Anastrophyllum minutum* *Lepidozia pearsonii* *Cetraria aculeata* *Cetraria muricata* *Cladonia uncialis biuncialis* *Lichenomphalia umbellifera* *Microlejeunea ulicina* *Cladonia cervicornis cervicornis* *Cladonia subulata* *Leucobryum glaucum*	*Fossombronia wondraczekii* *Cladonia strepsilis* *Arctostaphylos uva-ursi*	A 20% increase in Ellenberg N at 5-10 kgN/ha/yr relative to lowest levels of N deposition according to one dataset (BSBI LCS) (Stevens *et al* 2011)
10-15	26.8	25.2	**Species above plus:** *Cladonia portentosa* *Vaccinium vitis-idaea*	**Species above plus:** *Cladonia cervicornis verticillata* *Anastrophyllum minutum* *Lepidozia pearsonii* *Cetraria aculeata* *Cetraria muricata* *Cladonia uncialis biuncialis* *Microlejeunea ulicina*	
2003 Critical load range= 10-25 kgN/ha/yr **2003 UK mapping value = 15 kgN/ha/yr** **2010/11 Critical load range = 10-20 kgN/ha/yr** **2011 New UK mapping value for Dry and Wet heathlands = 10 kgN/ha/yr**					
15-20	15.5	13.6	**Species above plus:** *Viola canina* *Dibaeis baeomyces* *Cladonia glauca*	**Species above plus:** *Lichenomphalia umbellifera* *Cladonia cervicornis cervicornis* *Cladonia subulata* *Leucobryum glaucum* *Cladonia portentosa* *Vaccinium vitis-idaea* *Viola canina*	Altered species composition both in Stevens *et al* (2011) and RoTAP (in prep). A 20% increase in Ellenberg N value at 5-20 kgN/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 15-20 kgN/ha/yr relative to lowest levels of N deposition

N deposition (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	**Predicted 2020**			
					(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:** *Peltigera hymenina*	**Species above plus:** *Dibaeis baeomyces* *Cladonia glauca*	A maximum change in canopy height of 1500% at 20-25 kgN/ha/yr) relative to lowest levels of N deposition observed in one dataset (VPD) (Stevens *et al* 2011).
25-30	2.9	0.5		**Species above plus:** *Peltigera hymenina*	
30-40	0.9				
40-50					
>50					
Total (%)	100	100			

2.2.4 Bogs

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). Results from previous research suggest a reduction in bryophyte and lichen cover, changes in the growth and cover of *Calluna vulgaris,* and changes in species composition (Sheppard *et al* 2008; RoTAP in prep). This report supports this evidence demonstrating changes in the probability of presence for individual species, including bryophytes and lichens (e.g. declines in *Anastrophyllum minutum* (bryophyte) and *Cladonia portentosa* (lichen)) with increasing N deposition. Species such as the *Odontoschisma* and *Calypogeia* bryophytes, some of which show negative relationships with N deposition, are of international conservation importance. The results of Stevens *et al* (2011) also suggest that bogs are becoming more eutrophic and less species rich in areas of high deposition. There is a need for a targeted survey of raised bogs to determine the impact of deposition on species composition. The consequence of these changes in response to N deposition in bogs will be a loss of species-richness and functional diversity with some sensitive species put at risk in areas of high deposition. A summary of changes in species prevalence and ecosystem structure and function at different deposition rates is presented in Table 2.5.

Table 2.5. Percentage of bog in the UK receiving different amounts of N deposition as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model, the species inhibited or strongly inhibited by different levels of N deposition according to new analysis by 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. Further data for 10% and 80% relative decline and for upper and lower confidence intervals are presented in Appendix 3. The 2003 critical load range (UNECE, 2003) and 2003 UK mapping value (Hall *et al* 2003) is also indicated together with the revised critical loads (Bobbink and Hettelingh 2011) and the 2011 mapping value. The evidence from Stevens *et al* 2011 has informed the setting of the 2011 mapping value. Data on % areas for devolved administrations are presented in Appendix 3.

N deposition (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	**Predicted 2020**			
0-5	1.0	15.5			No evidence of impact on indices of ecological function below 10 kgN/ha/yr identified in new analyses (Stevens *et al* 2011).
5-10	47.3	44.3	*Odontoschisma denudatum* *Anastrophyllum minutum*		
2003 Critical load range= 5-10 kgN/ha/yr **2003 UK mapping value = 10 kgN/ha/yr** **2010/11 Critical load range = 5-10 kgN/ha/yr** **2011 New UK mapping value = variable 8-10 kgN/ha/yr depending on rainfall class**					
10-15	19.2	20.7	**Species above plus:** *Scapania umbrosa* *Calypogeia sphagnicola*	*Odontoschisma denudatum* *Anastrophyllum minutum* *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 15-20 kgN/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). Risk to climate regulation depending on balance in change in productivity, decomposition rates and nitrous oxide production. Uncertainty in evidence to date.
15-20	14.7	11.5	**Species above plus:** *Cladonia portentosa*	**Species above plus:** *Calypogeia sphagnicola*	
20-25	9.7	7.0			
25-30	6.2	0.9			
30-40	1.7	0.1			
40-50	0.1				
>50					
Total (%)	100	100			

3 Ecosystem service provision

Ecosystem services are defined by the Millennium Ecosystem Assessment (MEA) as “the benefits people obtain from ecosystems”. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits (MEA 2003). A National Ecosystem Assessment is now underway for the UK using a modified framework from the MEA (Figure 5.1). The original four types of service, namely regulating, supporting, provisioning and cultural, are split between fundamental ecosystem processes which are called primary and intermediate services and final services which can be mapped directly onto goods from which we derive benefit.

N deposition will drive many changes in the final goods and benefits derived from our ecosystems or so called ‘natural capital’. The effects are on the primary and intermediate services which are a mix of the supporting and regulating services in the MEA language. These impacts then drive changes in the final ecosystem services such as provisioning services (crops, trees, wild species diversity), regulating services (climate and clean water) and cultural (meaningful places). This approach avoids possible double accounting when valuing services, which is a risk when using the MEA approach where a tiered approach is not used.

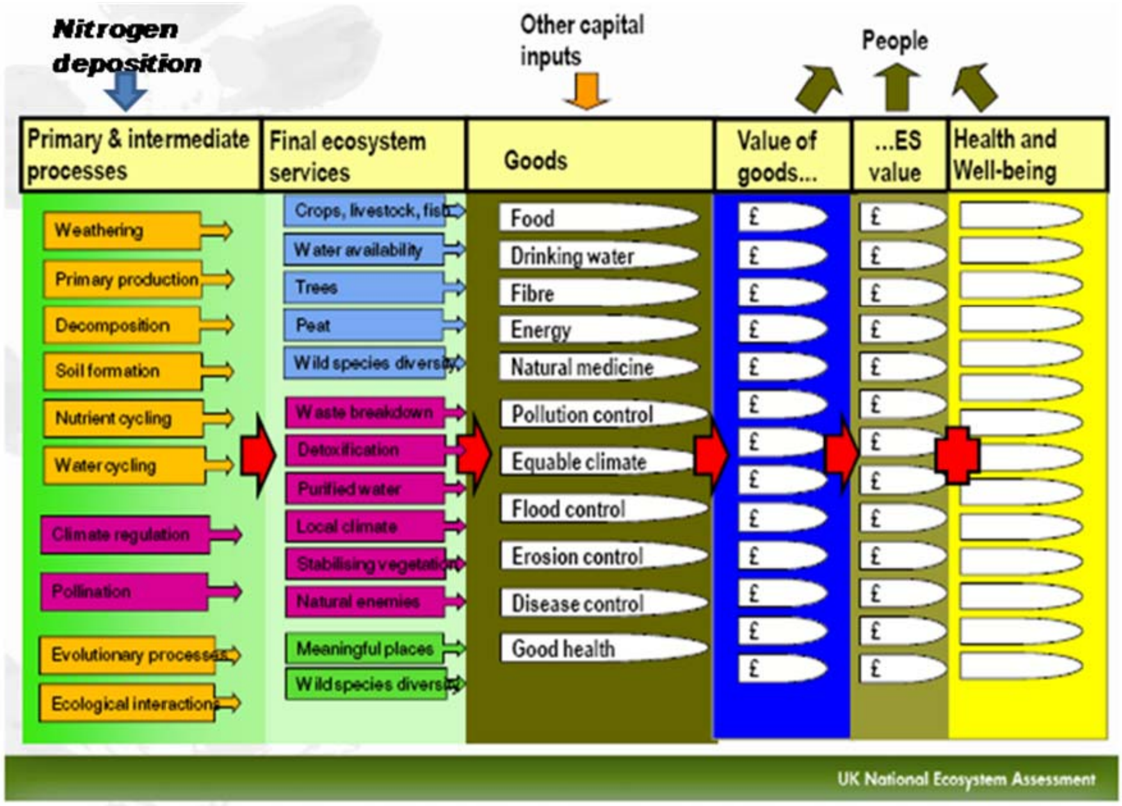

Figure 3.1. UK National Ecosystem Assessment approach to services adapted to show where N deposition has main effect. Primary, intermediate and final services are mapped onto Millennium Ecosystem Assessment services as: Regulating services (pink); Supporting services (yellow); Provisioning (blue); Cultural (green). Adapted from Watson and Albon (2010).

N deposition may have both positive and negative impacts on ecosystem service provision and impacts may be opposite for different habitats. A full assessment of the impacts of air quality on ecosystem services and their value is currently underway in a Defra funded project and it is not appropriate to anticipate the conclusions. However, several preliminary assessments have been carried out including a review of the evidence base for air quality impacts on ecosystem services in RoTAP (in prep), an assessment of impacts of NHy (Hicks *et al* 2008) and a case study of the impacts of N for coastal systems (Jones *et al* in prep). In brief, the findings indicate the following impacts on ecosystem services:

3.1 Supporting services

The two key aspects of supporting services likely to be changed by N deposition and for which there is most evidence are primary production and nutrient cycling. Where N is the nutrient limiting plant growth, N increases nutrient cycling rates and thus primary productivity. This will drive many of the changes observed in other ecosystem services which may be considered positive in some habitats (e.g. increased crop production in agricultural systems) but negative in others (e.g. increase in competitive species in semi-natural habitats). Negative impacts on soil quality will be observed in any acid-sensitive soil due to the acidifying effect of excess N. Soil formation may be accelerated due to increased plant production and thus the accelerated rate of organic matter accumulation. This may be considered positive in managed production based habitats but negative in others such as sand dunes where the increase in organic matter content reduces the competitive ability of some specialised species (Jones *et al* 2008). The new analysis in Stevens *et al* (2011) shows significant positive relationships between N deposition and canopy height and specific leaf area, which supports existing evidence of increased productivity in several habitats due to N deposition. Changes in nutrient cycling are also indicated through the positive relationships between N deposition and Ellenberg N values in Stevens *et al* (2011).

3.2 Regulating services

Excess N in the atmosphere has a range of negative effects on air quality and thus human health, both direct in terms of N deposition and indirect including increases in fine particulates and increases in ozone (Galloway *et al* 2003). It can also have negative impacts on climate; ammonia plays a role in the direct and indirect effects of aerosols on radiative forcing (Seinfeld and Pandis 1998). A full assessment of the effects of N pollution on climate is beyond the scope of this report as it includes the impacts on net ecosystem exchange of CO_2 and overall carbon storage, changes in N_2O, NO_2 and CH_4 fluxes, aerosol formation, albedo etc, but has been carried out for the European N Assessment (Sutton *et al* 2011). The overall contribution of N deposition to an increase in carbon sequestration is highly controversial. There is clearly a positive relationship, with increased forest growth positively related to N deposition across Europe, but some studies have probably over-stated the overall impacts (e.g. De Vries *et al* 2009), and in many areas production is no longer limited by N and another nutrient now limits productivity. The impact on carbon turnover and loss rates from the soil is also not well characterised; there are contrasting results for different habitats, with an increase indicated for forests (Janssens *et al* 2010) and a decrease for bogs (Bragazza *et al* 2006). Irrespective of this uncertainty, it is a highly inefficient and poorly regulated approach to increasing primary production by putting N into the atmosphere hoping it will increase C sequestration in some areas whilst risking biodiversity targets and water quality unintentionally in other areas. The new analyses carried out by Stevens *et al* (2011) illustrate the link to increased productivity but cannot offer any additional direct evidence of changes on the linked climate or air quality regulating services.

N deposition may affect the regulating role of ecosystems in water purification. N can increase productivity in waters at low levels, but eutrophication and links to acidification have frequently been described as levels increase further and pose real threats to fish supply, wild species diversity and human health (Dise *et al* 2001; MacDonald *et al* 2002). Links to changes in plant species composition are less well characterised and may be both direct and indirect. One clear example comes from *Sphagnum* bogs where the N-induced breakdown and loss of *Sphagnum* removed the 'filtering' effect of the moss on N entering the soil (Lamers *et al* 2000). The increase in N availability was identified as the primary driver for an increase in grass cover and nitrate leaching. Loss of bryophyte cover was also found to be the best predictor of nitrate leaching across a range of upland grassland and heathland sites, again suggesting an important filtering effect (Curtis *et al* 2005). The new analyses carried out by Stevens *et al* (2011) illustrate the clear potential of N to change species composition including bryophytes, but cannot provide any direct evidence of changes in the linked climate and water quality regulating services.

3.3 Provisioning services

Effects on provisioning services cascade from the fundamental impacts on the primary and intermediate supporting and regulating services as described above. Thus, N deposition can potentially increase the N available to plants, which could be seen as a positive factor in the growth of crops, grassland and productive forestry thus increasing food and fibre provisioning services. The impact on wild foods is less certain but it is likely that some species will be negatively impacted if they are less competitive species. In many semi-natural systems the change in growth of some competitive species resulting in e.g. an increased grass:forb ratio (RoTAP in prep), will change species composition, putting species of conservation value at risk, and thus affecting the wild species provisioning service. The new analysis by Stevens *et al* (2011) clearly demonstrates this is already occurring.

The effect of N on flowering species as demonstrated in Stevens *et al* (2011) and previous work e.g. in Countryside Survey (Maskell *et al* 2010) and increased grass:forb ratios (Stevens *et al 2009*) suggests there is clear evidence of declines in pollinator food plants which may cascade to reductions in pollination of crops although there is no direct evidence of pollination rates *per se*. The relevance of these changes will be very dependent on the spatial relationship between the pollinator food plants and crops. Changes in plant species composition may also affect habitats for pest predators. Although there is no direct evidence of N impacts on pests' damage to crops, there are several studies demonstrating N impacts on pest and pathogen outbreaks on species such as *Vaccinium myrtilus* and *Calluna vulgaris* (RoTAP in prep).

Whilst timber and wood fuel production may increase in production as described above (and potentially carbon sequestration - a regulating service), there will be a limit to this as limitation by other nutrients come into play and there are risks of long-term declines as a consequence of acidification and secondary factors such as susceptibility to frost damage (Aber *et al* 1989). There will be an impact on provisioning services in freshwaters, and marine may also be impacted. Nutrient input may increase productivity in the short term but fisheries and aquaculture are known to be sensitive to increased losses of N to freshwaters by leaching from soils which leads to acidification and eutrophication (e.g. Driscoll *et al* 2001; Smith and Schindler 2009; Emmett *et al* 1998).

Other provisioning services such as genetic resources and biochemicals, natural medicines and pharmaceuticals have not been directly investigated in relation to N deposition but the reductions in biodiversity and species richness generally observed with N deposition are likely to reduce the provisioning of these services at a local level.

3.4 Cultural services

Aesthetic values are likely to be impacted by N deposition, for example, as the species richness, and particularly the richness of flowers, is reduced and grass:forb ratios increase

(Fraser and Stevens 2008) and the new analysis by Stevens *et al* (2011) confirms this is occurring at a GB scale. However, it is difficult to assess the impact this has on recreation and ecotourism and this is likely to be small in reality. There are other potential impacts on recreation, for example, reduced water quality could reduce the suitability of areas for use for recreation e.g. fishing.

4 Relating evidence of N impacts to UK conservation commitments

In this section, evidence for N pollution impacts collated in Stevens *et al* (2011) are assessed in relation to UK conservation commitments, focussing on the Habitats Directive (HD) and the UK Biodiversity Action Plan (BAP).

4.1 Habitats Directive commitments

Article 17 of the Habitats Directive requires Member States to report every six years on the conservation status of the habitats and species listed in the directive. Article 1 of the HD provides definitions of conservation status:

- **conservation status of a natural habitat** means the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species […]

- **conservation status of a species** means the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations […]

The European Commission (2006) provides guidance on Article 17 reporting and the parameters to be assessed for conservation status assessments. For habitats these are:

- *Range*
- *Area*
- *Structure and functions (including typical species)*
- *Future prospects*

And for species:

- *Range*
- *Population*
- *Habitat for the species*
- *Future prospects.*

Of the habitats listed in Annex I of the HD, 77 occur in the UK, of which around 52 are terrestrial. Of the plant species listed in Annex II, IV or V of the directive, 21 occur in the UK (JNCC 2010).

The BAP broad habitats newly analysed by Stevens *et al* (2011) are indicated in Table 4.1 together with the relationship to Annex I habitats. It lists the typical species for the Annex I habitats defined in the UK 2007 Article 17 report (http://www.jncc.defra.gov.uk/page-4064). Table 4.2 lists the species listed in Annex II, IV or V of the Directive which occur in the UK and highlights the four of these which were analysed in Stevens *et al* (2011). Section 4.2 then provides a general description of how N deposition may affect conservation status parameters, followed by specific assessments for the habitats and species listed in the directive which were analysed by Stevens *et al* (2011).

Table 4.1. The BAP broad habitats newly analysed by Stevens *et al* (2011), their relationship to Annex I habitats and typical species (N.B. this is not restricted to plant species).

BAP broad habitat analysed by Stevens *et al* (2011)	**Annex I code**	**Annex I name**[1]	**Typical species**[2]
Calcareous grassland	6170	Alpine and subalpine calcareous grasslands	*Cerastium arcticum, Draba norvegica, Saxifraga nivalis, Dryas octopetala,Carex capillaris, Orthilia secunda, Galium boreale, Minuartia sedoides, Sagina saginoides, Botrychium lunaria, Cerastium alpinum, Potentilla crantzii*
	6210	Semi-natural dry grasslands and scrubland facies: on calcareous substrates (*Festuco-Brometalia*)	*Hippocrepis comosa*, *Gentianella amarella*, *Helianthemum nummularium*, *Orchis ustulata*, *Ophrys sphegodes*, *Thymelicus acteon*, *Hesperia comma*, *Polyommatus bellargus*, *P. coridon*
	6230	Species-rich *Nardus* grassland, on siliceous substrates in mountain areas (and submountain areas in continental Europe (note this is considered acidic grassland at EU level))	None
Acid grassland	2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands	None
	6230	Species-rich *Nardus* grassland, on siliceous substrates in mountain areas (and submountain areas in continental Europe (note this is considered calcareous grassland in the UK))	None
Dwarf shrub heath	4010	Northern Atlantic wet heaths with *Erica tetralix*	*Platanthera bifolia*
	4020	Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*	*Carex montana, Hammarbya paludosa*
	4030	European dry heaths	*Cuscuta epithymum, Carex montana, Lycopodium clavatum, Viola lactea, Ulex minor*
	4040	Dry Atlantic coastal heaths with *Erica vagans*	None
Bogs	7110	Active raised bogs	*Andromeda polifolia, Betula nana, Vaccinium microcarpum*
	7120	Degraded raised bogs still capable of natural	none

BAP broad habitat analysed by Stevens *et al* (2011)	**Annex I code**	**Annex I name**[1]	**Typical species**[2]
		regeneration	
	7130	Blanket bog	None
	7150	Depressions on peat substrates of the *Rhynchosporion* (overlaps with the Broad Habitat type)	*Hypericum elodes, Eleocharis multicaulis, Baldellia ranunculoides, Hammarbya paludosa, Drosera intermedia, Andromeda polifolia, Rhynchospora alba*

[1] **Descriptions at http://www.jncc.defra.gov.uk/ProtectedSites/SACselection/SAC_habitats.asp**
[2] **From audit trails at http://www.jncc.defra.gov.uk/page-4064**

Table 4.2. Plant species listed in Annexes II, IV or V of the Habitats Directive which occur in the UK (JNCC 2010). Species for which new analyses are available from Stevens *et al* (2011) are in shaded cells.

Vascular plants		**Non-vascular plants**	
Scientific Name	**English Name**	**Scientific Name**	**English Name**
Lycopodium sp.	Clubmosses	*Lithothamnium coralloides*	Maerl
Trichomanes speciosum	Killarney fern	*Phymatholithon calcareum*	Maerl
Rumex rupestris	Shore dock	*Buxbaumia viridis*	Green shield-moss
Saxifraga hirculus	Marsh saxifrage	*Marsupella profunda*	Western rustwort
Apium repens	Creeping marshwort	*Hamatocaulis (Drepanocladus) vernicosus*	Slender green feather-moss
Gentianella anglica	Early gentian	*Petalophyllum ralfsii*	Petalwort
Luronium natans	Floating water-plantain	*Leucobryum glaucum*	Large white-moss
Najas flexilis	Slender naiad	*Sphagnum sp.*	Bog-mosses
Ruscus aculeatus	Butcher's broom	*Cladonia subgenus Cladina*	subgenus of lichens
Cypripedium calceolus	Lady's-slipper orchid	Bruchia vogesiaca	Bruchia moss
Liparis loeselii	Fen orchid		

4.2 N effects on conservation status

Current evidence suggests the primary effect of N deposition on conservation status is through change in habitat quality resulting from changes in the habitat structure and function. Mechanisms by which N deposition influences oligotrophic and mesotrophic habitats have been summarised as "direct shoot toxicity, eutrophication, acidification, negative impacts of NHx, and increased susceptibility to secondary stress and disturbance factors" (Bobbink, Hicks *et al* 2010). Differences in the relative competitive ability of species result in changes in species composition and, ultimately, various functions including carbon sequestration, climate regulation and water purification due to a cascade of effects including change in plant production, soil microbial populations, decomposition rates and litter quality.

With respect to the parameters used in reporting conservation status of habitats, the surveillance data analysed by Stevens *et al* (2011) provides a valuable source of information on changes in ecosystem structure due to the large number of species studied. These same datasets have also been used to identify change in habitat function through use of indices such as canopy height, Ellenberg N and specific leaf area (Stevens *et al* 2011). This evidence has been collated for each Broad Habitat analysed in Stevens *et al* (2011), and these have been mapped across to Annex I habitats (Tables 6.3-6.6). It is clear that wide-ranging effects of N deposition on habitat quality, as indicated by structure and function has occurred, presumably through the mechanisms described above. There is also clear evidence from other sources of a link between N deposition and changes in water quality which in some cases has been linked to changes in vegetation structure (e.g. Curtis *et al* 2005) and changes in nutrient cycling rates (RoTAP, in prep), but further work is required to identify long term effects on the relative balance between plant production, soil carbon storage (i.e. decomposition rates) and greenhouse gas emissions for each individual habitat.

With respect to 'area of habitat' which is another parameter used in the assessment of conservation status, large amounts of N pollution may cause a loss of species characteristic of particular habitats, resulting in the area being reclassified as a different habitat. This will lead to changes in the total area of the habitat, and may lead to changes in range extent if outlying areas are affected. However, the analyses conducted in the current project (Stevens *et al* 2011) were not useful for assessing changes in habitat range and area. Species were assigned to habitats before analysis, on the basis of published data on Broad Habitat affinity and (in the case of dry grasslands) their Ellenberg R score. Habitat designations are often determined by thresholds of cover for particular species or species-groups, and a directed analysis of trends in such groups might reveal effects of N pollution on habitat range and area. Countryside Survey has provided estimates of change in habitat extent coupled with recording of plant species composition within plots that can be referred to different Broad and BAP Priority Habitats, and these can be mapped across to HD Annex I habitats (Carey *et al* 2008). Although signals of N deposition in these data have been detected (Maskell *et al* 2010; Smart *et al* 2004) there is no evidence that these changes have been correlated with changes in habitat type and therefore with changes in habitat area. It is possible that borderline areas of vegetation have seen a mapped shift to a more enriched habitat but such an analysis has not been carried out. Apart from local movement between arable land and fallow grassland, the evidence suggests that observed changes in mean Ellenberg N over time have, on average, not been big enough to have moved the vegetation to values more typical of different vegetation types (Smart, Robertson, Shields *et al* 2003). A comparative assessment also examined the magnitude of change in Ellenberg N between 1978 and 1998 along the reduced N gradient relative to the change in this indicator associated with agricultural conversion of semi-natural habitat into either grass ley or arable. This showed the much larger average impact of land-use change on mean Ellenberg N than N deposition. However, it remains a possibility that in places with high N deposition species compositional changes have been sufficient to cause a change, for example, in heathland to acid grassland.

Regarding conservation status of species mentioned in the Habitats Directive Annexes, specific evidence for inhibition is reported for three of the four species/groups (Stevens *et al* 2011) (Tables 6.7-6.10), and their habitat quality has declined due to N deposition. Surprisingly, a positive association was observed for the fourth species/group for which there are data, namely *Sphagnum,* but this relationship was only observed in heathlands. This is contrary to reports from other studies and the reasons for this are unclear. It may suggest a temporary increase in productivity before declines in prevalence later or a real positive response in the long term. Again, little can be reported concerning range and area of suitable habitat.

It is important to note that due to the immobilisation of N in soil organic matter, and/or increased plant productivity in response to N addition, cumulative N deposition can be more important than the present-day deposition rate. N-sensitive species may be at risk following a relatively small increment in N deposition over natural rates. Other species may be affected at larger deposition rates, or after the total cumulative addition has reduced the capacity of the soil and vegetation to buffer deposited N. The importance of the cumulative effect in particular (i.e. the slow build-up of N in the soil resulting in the long-term increase in N availability) has been demonstrated in N addition experiments, as reviewed in Bobbink and Hettelingh (2011) and RoTAP (in prep). This is particularly important when interpreting relationships, or the lack of them, in surveillance data with present-day N deposition rates. The absence of a significant response may indicate a lag in response rather than no impact in the long-term. This is why the critical load approach is important to consider alongside any analysis of survey or experimental data, as this is the risk assessment tool which is more appropriate for assessing future prospects (Appendix 3). Although the UK government is currently investigating actions necessary to meet the NECD and Gothenburg 2010 emissions targets, and new lower targets for 2020 are being negotiated, total reactive N emissions and hence deposition seem unlikely to show a major decline in the period 2010-2020 (ROTAP, in prep). This indicates that 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 control measures have been put in place.

Table 4.3. Impact of N deposition on the Broad Habitat Acid Grassland with implications for Annex I habitats: Species-rich *Nardus* grassland on siliceous substrates in mountain areas and submountain areas in continental Europe (6230); and inland dunes with open *Corynephorus* and *Agrostis* grasslands (2330). Critical loads exceedence is based on critical loads set in 2003 and N deposition modelled using FRAME.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the habitat	
Area	Total area of habitat	
Structure and functions	Status of typical species	No typical species have currently been identified for this habitat.
	Structure	Inhibition of attractive forb species such as *Vicia lathyroides* and *Viola canina,* decline in bryophyte species such as *Racomitrium lanuginosum* and inhibition of CSM positive indicators such as the lichen *Peltigera didactyla* (Stevens *et al* 2011, Stevens *et al* 2004, Maskell *et al* 2010; RoTAP in prep). Clear evidence of reduction in species richness and an increase in grass:forb ratio (Stevens *et al* 2004, Maskell *et al* 2010, Stevens *et al* 2011; RoTAP in prep).
	Function	Habitat has become more eutrophic as indicated by increased Ellenberg N value (Stevens *et al* 2011). Evidence of increased competitive species and production as indicated by increased canopy height and specific leaf area (Stevens *et al* 2011). Loss of moss layer linked to increased nitrate leaching in upland systems (Curtis *et al* 2005). Evidence of a range of changes in soil functions linked to nutrient cycling and soil quality (RoTAP in prep).
Future prospects	Of above parameters	49% of the current area of acid grassland is forecast to receive N deposition in excess of the critical load in 2020.

Table 4.4. Impact of N deposition on the Broad Habitat Calcareous Grassland with implications for Annex I habitats: Alpine and subalpine calcareous grasslands (6170); Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (6210); and Species-rich *Nardus* grassland, on siliceous substrates in mountain areas (and submountain areas in continental Europe (6230). Critical loads exceedence is based on critical loads set in 2003 and N deposition modelled using FRAME.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the habitat	
Area	Total area of habitat	
Structure and functions	Status of typical species	No evidence of any impact on typical species in Stevens *et al* (2011) or other studies
	Structure	Inhibition of forb species such as *Alchemilla alpina* and *Persicaria vivipara* and the important grass species *Bromopsis erecta*. Evidence of increase in other species such as *Stachys officinalis* and the bryophyte *Didymodon vinealis (Stevens et al 2011)* Decline in positive Common Standard Monitoring indicators such as *Campanula glomerata*, *Carlina vulgaris, Carex spicata* and *Centaurea scabiosa* and the lichen *Cladonia folicea (Stevens et al 2011).* Increase in grass:forb ratio, decline in bryophyte cover and overall decline in species richness (Stevens *et al* 2011; RoTAP in prep).
	Function	Increase in competitive species and productivity indicated by increase in canopy height and specific leaf area with N deposition (Stevens *et al* (in prep, Bennie *et al* 2006, RoTAP in prep).
Future prospects	Of above parameters	81% of calcareous grassland is forecast to receive N deposition in excess of the critical load in 2020.

Table 4.5. Impact of N deposition on the Broad Habitat Bogs with implications for Annex I habitats: Active raised bogs (7110); Degraded raised bogs still capable of natural regeneration (7120); Blanket bog (7130); and Depressions on peat substrates of the *Rhynchosporion* (7150) (overlaps with the Broad Habitat type). Critical loads exceedence is based on critical loads set in 2003 and N deposition modelled using FRAME.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the habitat	
Area	Total area of habitat	
Structure and functions	Status of typical species	No evidence of any impact on typical species in Stevens *et al* (2011) or other studies.
	Structure	An inhibition of some species with N deposition such as *Carex limosa* (a positive Common Standard Monitoring indicator), the bryophyte *Anastrophyllum minutum* and lichen *Cladonia portentosa (Stevens et al 2011).* Conflicting evidence of impact of N deposition on *Sphagnum* species. N deposition linked to overall decline in species richness, reduction in bryophyte and lichen cover and changes in the growth and cover of *Calluna vulgaris* (RoTAP in prep). Some species respond positively. Clear experimental evidence that sensitivity to reduced versus oxidised N is highly species dependent, although dry ammonia deposition always more damaging due to high concentration levels (RoTAP in prep).
	Function	Increase in eutrophication status as indicated by an increase in Ellenberg N values (Stevens *et al* 2011). Evidence of other changes in function limited at current critical load threshold and requires further research particularly on overall effect on carbon sequestration and greenhouse gas fluxes as a highly valued service delivered by this habitat.
Future prospects	Of above parameters	43% of the current area of bog is forecast to receive N deposition in excess of the critical load in 2020.

Table 4.6. Impact of N deposition on the Broad Habitat Dwarf Shrub Heath with implications for Annex I habitats: Northern Atlantic wet heaths with *Erica tetralix* (4010)*;* Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix* (4020)*;* European dry heaths (4030); and Dry Atlantic coastal heaths with *Erica vagans* (4040). Critical loads exceedence is based on critical loads set in 2003 and N deposition modelled using FRAME.

Parameter	Quantitative indicators	Evidence of N effects
Range	Total surface area within the geographic extent of the habitat.	
Area	Total area of habitat.	
Structure and functions	Status of typical species.	Evidence of an increase in *Platanthera bifolia* with N deposition, a typical species for 4010 Northern Atlantic wet heaths with *Erica tetralix* in Stevens *et al* (2011).
	Structure	Inhibition of species such as *Viola canina* and *Vaccinium vitis-idaea*, bryophytes such as *Leucobryum glaucum* (Habitats Directive Annex V species) and *Lepidozia pearsonii* and the lichen *Cetraria aculeata* (Stevens *et al* 2011). Declines also noted for positive CMS indicator species such as *Cladonia cervicomis cervicomis and Cladonia cervicomis verticillata, Cladonia glauca, Cladonia portentosa, Cladonia strepsilis and Cladonia subulata* (Stevens *et al* 2011). Overall an increase in grass cover and decline in forb, lichen and bryophyte cover and richness (RoTAP in prep).
	Function	Clear evidence for changes in nutrient cycling, nitrate leaching and soil quality (RoTAP, in prep). Some evidence of increased soil carbon sequestration rates (Evans *et al* 2006).
Future prospects	Of above parameters	41% of current area of heathland is forecast to receive N deposition in excess of the critical load in 2020.

Table 4.7. Impact of N deposition on *Sphagnum* spp.; a group listed in Annex V of the Habitats Directive. New evidence from Stevens *et al* (2011) for *Sphagnum denticulatum, Sphagnum fallax, Sphagnum russowii, Sphagnum squarrosum, Sphagnum subnitens* and *Sphagnum tenellum* in upland heathland.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the species	
Population	Range of proxies designed to provide a measure of the number of mature individuals	Conflicting evidence as to whether area of *Sphagnum* spp will expand or contract.
Habitat for species (to support long-term viable population)	Area of suitable habitat	
	Habitat quality	Positive response of *Sphagnum* spp. may result in accelerated rate of peat formation in heathlands but may be limited in the long term with a risk of a tipping point of *Sphagnum* breakdown and grass invasion which would slow peat formation and change many functions. Evidence of variable response of competitive species and productivity in heathlands as indicated by canopy height (Stevens *et al* 2011). Increase in eutrophication as indicated by an increased Ellenberg N (Stevens *et al* 2011).
Future prospects	Of above parameters	Continuing N deposition and predicted critical load exceedence indicates current damage on upland heathland will continue with change in species composition, and ongoing eutrophication as indicated by increase in Ellenberg N. Conflicting evidence of direction of change for *Sphagnum* spp. and canopy height makes future prospects difficult to forecast.

Table 4.8. Impact of N deposition for *Lycopodium* spp, listed in Annex V of the Habitats Directive. New analysis carried out in Stevens *et al* (2011) provides new evidence for one species; *Lycopodium annotinum* in upland heathland.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the species	
Population	Range of proxies designed to provide a measure of the number of mature individuals	Negative impact of N deposition on *Lycopodium annotinum* demonstrated (Stevens *et al* 2011).
Habitat for species (to support long-term viable population)	Area of suitable habitat	
	Habitat quality	Clear evidence of changes in species composition, increased eutrophication as indicated by Ellenberg N in upland heathland. (Stevens *et al* 2011). Conflicting evidence of direction of change of competitive species and productivity as indicated by canopy height in heathlands (Stevens *et al* 2011). Other work indicates an increase grass:forb ratio and accelerated nitrate leaching (RoTAP in prep).
Future prospects	Of above parameters	Ongoing N deposition and critical load exceedence indicates damage to heathland and inhibition of many species including *Lycopodium annotinum* will continue.

Table 4.9. Impact of N deposition *Leucobryum glaucum* in upland heathland, listed in V of the Habitats Directive. New analysis carried out in Stevens *et al* (2011) provides new evidence.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the species	
Population	Range of proxies designed to provide a measure of the number of mature individuals	Negative impact of N deposition on *Leucobryum glaucum* clearly demonstrated (Stevens *et al* 2011). Reduction by 20% of prevalence at 5-10 kgN/ha/yr relative to prevalence at lowest levels of N deposition, and reduction by 50% prevalence at 15-20 kgN/ha/yr.
Habitat for species (to support long-term viable population)	Area of suitable habitat	
	Habitat quality	Clear evidence of changes in species composition, increased eutrophication as indicated by Ellenberg N in upland heathland (Stevens *et al* 2011). Conflicting evidence of direction of change of competitive species and productivity as indicated by canopy height in heathlands (Stevens *et al* 2011). Other work indicates an increased grass:forb ratio and accelerated nitrate leaching (RoTAP in prep).
Future prospects	Of above parameters	Ongoing N deposition and critical load exceedence indicates damage to heathland and potential inhabitation of many species including *Leucobryum glaucum* will continue.

Table 4.10. Impact of N deposition for *Cladonia subgenus Cladina*, listed in Annexes II, IV and V of the Habitats Directive. New analysis carried out in Stevens *et al* (2011) provides new evidence for *Cladonia portentosa* in heathlands and bogs.

Parameter	**Quantitative indicators**	**Evidence of N effects**
Range	Total surface area within the geographic extent of the species	
Population	Range of proxies designed to provide a measure of the number of mature individuals	Negative impact of N deposition clearly demonstrated (Stevens *et al* 2011) on *Cladonia portentosa* in both heathland and bog habitats. Reduction of 20% prevalence at 10-15 kgN/ha/yr relative to prevalence at the lowest deposition in heathland and at 15-20 kgN/ha/yr in bogs.
Habitat for species (to support long-term viable population)	Area of suitable habitat	
	Habitat quality	Clear evidence of changes in species composition, increased eutrophication as indicated by Ellenberg N in heathlands (Stevens *et al* 2011). Conflicting evidence of direction of change of competitive species and productivity as indicated by canopy height in heathlands (Stevens *et al* 2011). Other work indicates an increased grass:forb ratio and accelerated nitrate leaching (RoTAP in prep). Less evidence for changes in habitat quality of bogs except for clear evidence of reduction of some species (Stevens *et al* 2011).
Future prospects	Of above parameters	Ongoing N deposition and critical load exceedence indicates damage to heathland and bogs and many species including *Cladonia portentosa* will continue.

4.3 Implications for Biodiversity Action Plans

In response to the Convention for Biological Diversity (CBD) Articles 8 and 9, Scotland, England and Wales have developed national biodiversity strategies and action plans which include acting on a set of priority habitats and species identified for the whole of the UK. The UK prepares periodic reports to the CBD on overall progress towards the national biodiversity strategies (CBD, 2009). The aim is to maintain or improve status of wild flora and fauna and their ecosystems and habitats.

There are currently 1150 priority species and 65 priority habitats identified within the UK (UKBAP, 2007). Priority species were selected following an extensive process by expert groups, and include 331 plants and 138 lichens (UKBAP, 2007). The analysis by Stevens *et al* (2011) provided clear evidence of many negative effects of N deposition for four broad habitats with relevance for 7 BAP priority habitats and significant responses to N deposition for two priority species (*Platanthera bifolia* (Lesser Butterfly-orchid) and *Scleranthus annuus* (Annual Knawel)) in lowland heath as well as other species of conservation value (Table 4.11). It is important to consider each species individually as the response to N pollution is species-specific and cannot be generalised for taxonomic or functional groups such as bryophytes, sub-shrubs or even genera. For example, two species of *Calypogeia* in upland bog showed opposite responses to N deposition (Appendix 2).

More species of conservation concern were negatively affected (Table 4.11), including the priority species *Scleranthus annuus,* than were positively affected, but for the priority species *Platanthera bifolia* the relationship was positive. Positive responses to N have been reported elsewhere during the initial stages of N enrichment followed by increased sensitivity to secondary stresses and with subsequent decline in cover. One example is *Calluna vulgaris* (common heather) which experiences an initial increase in productivity and flowering with N addition, but is more susceptible to frost and herbivory damage in later stages of enrichment (RoTAP in prep).

As most relationships were negative and even positive responses may indicate nutrient imbalances and increased susceptibility to secondary stresses, 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. 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 10 years, current aims to maintain and improve status seem unlikely to be achieved for the habitats considered here. Opportunities to improve this situation through management options are discussed in section 4.5.

Table 4.11. The response of priority species and other species of conservation concern to N deposition as established by Stevens *et al* (2011).

Designation	**Species with positive responses**	**Species with negative responses**	**Number of species / groups covered by Stevens *et al* (2011)**
BAP priority species	*Platanthera bifolia* (Lesser Butterfly-orchid)	*Scleranthus annuus* (Annual Knawel)	2
Habitats Directive Annexe II, IV or V	*Sphagnum denticulatum; Sphagnum fallax, Sphagnum russowii, Sphagnum squarrosum, Sphagnum subnitens, Sphagnum tenellum* (bog mosses)	*Cladonia portentosa* (Reindeer lichen*); Leucobryum glaucum* (Large white-moss*); Lycopodium* spp *(clubmosses)*	9
Red List GB assessment - threatened or near threatened (Cheffings and Farrell, 2005)	*Platanthera bifolia* (Lesser Butterfly-orchid)	*Cynoglossum officinale* (Hound’s tongue)*; Scleranthus annuus* (Annual Knawel)*; Spiranthes spiralis* (Autumn Lady's-tresses)	
Nationally rare or scarce		*Lycopodium annotinum* (Stiff clubmoss)	1
Biodiversity list for one or more devolved administrations	*Platanthera bifolia* (Lesser Butterfly-orchid); *Stachys officinalis* (Betony)	*Campanula glomerata* (Clustered Bellflower)*; Centaurea scabiosa* (Greater Knapweed)*; Geranium columbinum (*Long-stalked Crane's-bill); *Trifolium micranthum* (Slender Trefoil)	6
Positive CSM indicator species (NB: no negative CSM indicator species were identified with significant responses to N deposition)	*Sphagnum denticulatum; Sphagnum fallax; Sphagnum russowii; Sphagnum squarrosum; Sphagnum subnitens; Sphagnum tenellum; (peat forming mosses)* *Stachys officinalis* (Betony)	*Arctostaphylos uva-ursi (*Bearberry)*; Campanula glomerata* (Clustered Bellflower)*; Carex limosa* (Bog sedge)*;Carex spicata* (Spiked sedge)*; Carlina vulgaris* (Carline thistle)*; Centaurea scabiosa* (Greater Knapweed)*; Cladonia cervicornis cervicornis; Cladonia cervicornis verticillata; Cladonia foliacea; Cladonia glauca; Cladonia portentosa; Cladonia strepsilis; Cladonia subulata; Cladonia uncialis biuncialis;* (reindeer mosses); *Peltigera didactyla (Alternating dog lichen) Peltigera hymenina;*	23
Number of species with positive or negative responses[1]	8	23	

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[1] Note that some species occur in several categories

4.4 Summary of effects on conservation status and biodiversity targets

In 2010 the EU Environment Council established a headline target of “halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible”. Also in 2010 the Convention on Biological Diversity (CBD) agreed a Strategic Plan for 2011-2020. Its mission is to “take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet’s variety of life, and contributing to human well-being, and poverty eradication”. The Strategic Plan includes 20 headline targets, one of which covers pollution including N deposition “***Target 8*****:** By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.”

The evidence in Tables 4.3-4.6 on habitat quality, Tables 4.7-4.10 on priority species and Table 4.11 on a range of species of conservation concern indicate clear evidence of changes in habitat quality, function and species prevalence due to N deposition. This suggests that the risk assessment of the impacts of N deposition using the critical load approach (Tables 4.2-4.5) have correctly identified the risk to both habitats and species which are now being translated into observable effects on the ground. These changes include inhibition of a wide range of species, increased prevalence of others, change in species richness, increased grass:forb ratios, and change in a range of variables which indicate undesirable changes in ecosystem function.

In summary, there is a large body of evidence now available both from the new analysis provided in Stevens *et al* (2011), and from other evidence e.g. RoTAP (in prep), Countryside Survey (Carey *et al* 2008; Maskell *et al* 2010) which report on the significant and often negative effects of N deposition on vegetation composition and ecosystem functions. Deposition, is unlikely to show a major decline in the period 2010-2020 (ROTAP, in prep) indicating 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. This is compromising our ability to meet the objectives of the Habitats Directive as well as BAP targets. Recovery is only likely in local areas where pollution emissions control measures have been put in place.

4.5 Management options to reduce the future impacts

It has long been recognised that management may affect the sensitivity of ecosystems to N (UBA 2004). Management, in particular the removal of biomass, litter and nutrient elements by grazing or cutting, is known to strongly affect the relative competitive ability of species. Thus even under relatively large rates of N deposition, appropriate management can reduce the competitive advantage of fast- and tall-growing species and consequent loss of small-growing species (Bakema *et al* 1994). Examples of approaches include: increased grazing pressure to reduce the expansion of nitrophilic species, increased removal of above-ground biomass or top soil and thus N, topsoil inversion in neutral grassland to relocate soil N to below the main rooting zone and canopy removal to increase light levels.

Many management processes result in the direct export of N thus slowing the rate of N accumulation which over time leads to change in ecosystem structure and function. The amount of N removed in standard management practices have been calculated as part of one method for calculating critical loads for a range of habitat types. This approach (called the Steady State Mass Balance Method) aims to estimate the amount of N which can be stored in different components of the ecosystem without causing ecosystem change. The calculation also allows for removal of N under what is considered non-damaging conditions.

Values are derived from studies where biogeochemical studies have quantified N pools and fluxes in systems considered undamaged by N deposition. The methods for the calculation in the UK are consistent with the UNECE Mapping Manual (UBA, 2004), although wherever possible model inputs are based on UK data from UK databases or site-based studies. Examples of values include: removal of N by tree harvesting in deciduous woodlands (30 kgN/ha/yr) and managed coniferous woodlands (15 kg N/ha/yr); heathland, acid grassland, montane and bogs management (3 kgN/ha/yr); unmanaged woodlands (0 kgN/ha/yr) and calcareous grassland management (51 kgN/ha/yr) (Hall *et al* 2003). Whilst values in excess of this can be reported for fertilised or high deposition areas, these are the values considered appropriate and sustainable for non-impacted systems. As can be seen, with the exception of calcareous grassland and woodlands, these values are generally small relative to deposition values for much of the UK. Thus the level of management required to significantly mitigate inputs of N ca.5-10 kgN/ha/yr (variable depending on habitat) may be greater than normally recommended for the maintenance of features of interest. This is particularly relevant for nutrient poor upland habitats such as heathland and acid grassland.

Many studies which have recommended increased intensification of management have failed to monitor the impacts on the full range of species and functions but rather focussed on dominant species and measures such as nitrate leaching (e.g. Hardtle *et al* 2006). This can result in conflicts as a result of the management requirements of different taxa. For example, mowing and grazing increase the plant species richness of abandoned calcareous grasslands, whereas the maintenance of diversity of the insect community might depend on allowing areas of taller vegetation or scrub (Bakker and Berendse 1999). There are now several UK studies which suggest there is a risk that the level of management required to remove sufficient N or control competitive species will in itself be damaging to the features which are desirable to protect e.g. lichens and dwarf shrubs. One example of this is available for an acid grassland site where the levels of grazing required to remove N to any significant extent caused a decline of desirable species (Emmett *et al* 2004). Indeed, inappropriately intense levels of management are thought to have contributed to damage observed for several habitats initially assigned solely to N deposition e.g. *Racomitrum* heath, calcareous grassland and heathland (as cited in Negtap 2001). Therefore, it is important to be clear about the conservation objectives and targets, so that appropriate management practices can be implemented. This will prevent the tendency for the management practices themselves to become the conservation goal, rather than the community being restored.

In more nutrient-rich lowland habitats such as hay meadows and calcareous grasslands, offtake rates will help to reduce the accumulation of N. However, it should be recognised that any biomass removal involves the removal of other nutrients such as base cations and phosphorus. In acid-sensitive systems increased intensity of management and accelerated removal of base cations could result in increased risk of acidification and phosphorus deficiency both of which have been clearly demonstrated in experimental and gradient studies (RoTAP in prep).

When considering more intensive management options in severe cases of N enrichment which involve the removal of top soil, the composition of the seed bank needs to be considered as many seed banks include non-target species and those with a wide ecological amplitude (Bakker and Berendse 1999). As these authors point out, the areas with the greatest potential for restoration are those with a short history of N deposition (similar to restoration following agricultural intensification) but it requires reduced ongoing N inputs to occur in tandem. Hence, for successful restoration management of most plant species and plant communities, an overall strong decrease of atmospheric deposition is a prerequisite. Measures to achieve this objective can be successful only when they are taken at a national or European scale (Bakker and Berendse 1999).

There are no known management options for reducing the direct effects of ammonia critical levels on vegetation but an awareness of the highly variable spatial nature of ammonia deposition at a 1km scale and exploitation of the potential scavenging effect of some vegetation such as tree shelter belts (Theobald *et al* 2001) are both tools which may help reduce damaging effects of N deposition at a local scale. However, care needs to be taken to manage any buffer or shelter belts to ensure N scavenged from the atmosphere, thus protecting target vegetation, does not just transfer to soils and freshwater systems (e.g. capture by tree canopy leading to enrichment of the soil and increased nitrate leaching).

In summary, management clearly provides some protection to semi-natural systems when applied at appropriate intensities. However, there is risk of conflict between different conservation targets, and many management options put in place will be compromised if ongoing N deposition remains above the critical load. The desired outcome may be: (a) management options for restoration with an agreed end point, (b) ongoing management to offset continuing chronic inputs of N and/or (c) management options to reduce N transfers. Further theoretical, experimental and modelling work could help understand the inter-linkages between management options proposed for single issues such as N deposition to ensure a whole ecosystem approach i.e. covering all ecosystem services and the interaction with other drivers of change such as climate change. Managing for any single issue (e.g. carbon, N, acidity or biodiversity) or for any single driver of change in isolation may result in unintended and undesirable outcomes. Ultimately, a reduction in emissions and deposition of N is the most desirable approach due to the absence of unintended consequences.

Such an approach would stop further accumulation of N and thus protect areas where accumulation levels have not resulted in species change to date. In areas where species change has already occurred, the approach will minimise further species change or loss as indicated by the different thresholds for species above the critical load indicated in Tables 4.2-4.5. The figures in Stevens *et al* (2011) indicate an increasing number of species being protected for every kilogram of N deposition removed in the long term. It is likely recovery back to pristine conditions, or at least a less N-enriched state, will be slow due to the difficulty of removing N from the soil pool, but N is likely to be stored in more unavailable stores over time and ongoing leaching will reduce the N stored to some extent. However, there are few experimental studies to enable this to be quantified. Modelling approaches are being developed which provide information on rate of change of habitat suitability, but dispersal and other factors then have to be factored in. Currently, there are no reliable estimates of recovery rates for the four habitats which are the subject of this report, although the limited experimental evidence available suggests bryophytes and lichens are likely to be the fastest to respond, as well as a reduction in nitrate leaching (Emmett *et al* 2004; Mitchell *et al* 2004; UKREATE 2007; UKREATE 2010).

5 Site level assessment of chronic N pollution

Site level assessment of N deposition impacts presents a range of difficulties. The time-scale of responses to the background N deposition in the UK is not well documented. Many experiments use relatively high levels of N in their additions on top of ambient N deposition. Although there has been an increasing move towards lower levels of addition many of these experiments have been established relatively recently. Alternative data have been provided by space-time substitutions, using surveys covering a range of deposition (e.g. Stevens *et al* 2010a) but the results from this can be difficult to interpret in terms of temporal changes. Long-term monitoring has also provided some insight but this has only been conducted at a very few locations (e.g. Blake *et al* 1999). Because historic records providing detailed information on vegetation composition and plant and soil chemistry are very rare we frequently do not know how habitats have already changed. Effectively we do not know the ‘starting point’ for a habitat. The result of these problems is that when considering the impact of ambient deposition on a single site we have little knowledge of any time-lags in vegetation change, the extent to which changes have already occurred, whether changes are still occurring, or at what point the system has reached in terms of the scale of potential responses.

Variation in site management (e.g. grazing intensity, scrub removal effort etc) also presents a considerable challenge in determining the site level impact of N deposition (Stevens *et al* 2009). Furthermore, if a site has received nutrient inputs in a form other than atmospheric N deposition, such as fertiliser addition or agricultural runoff then the impacts in vegetation and soils will be very similar and it is unlikely to be possible to separate the effects. The impact of N deposition from an individual source is also often very difficult to separate from those from ‘background’ deposition as these will have the same impact on a site. Other site management factors can also contribute, for example, under-grazing of grassland may result in a tall sward where species must compete for light resulting in reduced species-richness and a dominance of competitive species. This is very similar to potential mechanisms for species loss in response to N deposition.

5.1 Common standards monitoring

In the UK, a system for appraising conservation sites known as Common Standards Monitoring (CSM) has been set up with the aim of standardising SSSI and SAC (Special Areas of Conservation) condition assessment, on the basis of a quick, simple assessment (JNCC, 2004b). Requirements for reporting under the Habitats Directive and other international commitments have guided the development of CSM, but the emphasis is on site-level condition reporting rather than on providing data for the overall assessment of Favourable Conservation Status for reporting under Article 17 of the Habitats Directive.

5.1.1 Indicator species

The Common Standards Monitoring guidance lists species that are monitored as indicators of positive or negative site condition. Stevens *et al* (2008) reviewed species included as indicator species in common standards monitoring for acid grasslands, bogs, heathland and woodland communities. This analysis was conducted using review of the scientific literature, comparison with local and national data sets, ecological floras and Ellenberg values to evaluate positive and negative indicators of site condition in relation to N deposition. The results are summarised below for the communities this study has focussed on together with a comparison with the results obtained from the analysis conducted by Stevens *et al* (2011), and this exercise is repeated for calcareous grasslands. Due to the methods used to allocate species to habitats, the results from Stevens *et al* (2011) tend to be for scarcer species which typically are not those used as CSM ‘indicators’, partly because they are relatively unlikely to be present on all sites designated for that habitat. Where sites are particularly important for rare species they are specified as a notified feature or included as a distinctive local feature in the condition assessment methodology for the site.

a Acid grasslands

Acid grasslands are covered in CSM guidance under upland and lowland acid grasslands (JNCC, 2004a, 2006). Of 42 positive site condition indicators for lowland acid grassland only four were identified by Stevens *et al* (2008) as potential indicators of N deposition impact. These species were *Calluna vulgaris, Campanula rotundifolia, Galium verum* and *Lotus corniculatus*. Six additional species are identified as site condition indicators for upland acid grassland but none were identified as suitable for assessing N deposition impact. Of sixteen negative site condition indicators for lowland acid grassland *Deschampsia flexuosa* was identified as being a potential indicator of N deposition impacts but the report suggests that further research is needed to confirm these indicators. None of these species were included in the analysis of the tetrad and hectad data in Stevens *et al* (2011) because they were either too common or scare for meaningful analysis at the tetrad and hectad scale. Analysis of the quadrat data in this project (Stevens *et al* 2011) showed *Calluna vulgaris* as positively associated with N deposition but this may be because degraded heathlands, where grass had invaded, were included as grasslands in the NVC surveys. This suggests that *C. vulgaris* would not be a suitable indicator of site condition in relation to N deposition. *Deschampsia flexuosa* showed a positive response to N deposition in the Natural England and Countryside Council for Wales data sets and may be suitable as an indicator of N deposition impacts. For many CSM indicator species there was insufficient information about response to N deposition to say if a species was likely to indicate N deposition impact. In surveys which rely on single visits rather than repeated visits change in the abundance of a species on a site cannot be used as a site condition indicator.

b Bog

Bog communities are covered by guidance for ‘upland blanket bog and valley mire communities’ (JNCC, 2006) and ‘lowland raised bogs and blanket bogs’ (JNCC, 2004b). Of a total of 32 positive site condition indicators, *Calluna vulgaris*, *Drosera* spp., *Racomitrium lanuginosum* and *Sphagnum capillifolium* were identified as potential N indicators (Stevens *et al* 2008). Of these species only the bryophytes *Racomitrium lanuginosum* and *Sphagnum capillifolium* were included in the tetrad and hectad analysis of Stevens *et al* 2011 but neither showed a clear change in their probability of presence in response to N deposition. None of these species were among the most strongly responding species in the quadrat data. *Urtica dioica* was identified as a potential negative indicator, but this species was not analysed in the hectad or tetrad data nor the quadrat data. It occurs abundantly in many habitats, making it unsuitable for analysis in the large-scale data, but did not occur in enough bog sites for inclusion in the quadrat data.

c Heathland

Positive and negative site condition indicators were considered from sub-alpine dry dwarf-shrub heath, wet heath - lowland, wet heath - upland and lowland dry heath (JNCC, 2004b, 2006). Potential positive site condition indicators suggested for heathlands were *Racomitrium lanuginosum* and *Drosera* spp. As only species level records were included in the analysis of Stevens *et al* (2011) *Drosera* spp. was not included. None of the *Drosera* species were included individually in the analysis for heathland. *Racomitrium lanuginosum* did not show a significant negative response to N deposition in heathlands so we cannot draw a conclusion regarding the suitability of this species as an indicator of N impact. *Molinea caerulea* and *Nardus stricta* were identified as potential negative site condition indicators in Stevens *et al* 2008. These were not analysed for heathlands in the hectad and tetrad data because they are common species which occur in a number of habitats. They were not among the most strongly responding species in the quadrat data.

d Calcareous grasslands

Calcareous grassland site condition indicators were identified for upland and lowland calcareous grasslands (JNCC, 2004a, 2006). As these indicators have not previously been considered in relation to N deposition, species are considered individually in Appendix 1. This analysis takes account of the results of Stevens *et al* (2011). There are a large number of site condition indicators listed but for many of the species there has been no investigation of their response to N deposition. *Anthriscus sylvestris* was identified as a potential indicator of negative site condition in relation to N deposition. There were more potential indicators for positive site condition with respect to N deposition, these were: *Campanula rotundifolia*, *Campanula glomerata*, *Carlina vulgaris*, *Koeleria macrantha*, and *Thymus polytrichus*.

5.1.2 Species notified as ‘Interest features’

Many of the species used as positive or negative indicator species in CSM were too common to be included in the analysis conducted for this project (Stevens *et al* 2011) but some of the other species analysed do occur as species interest features. Species designated as interest features have to be identified, monitored, assessed and reported on separately which means that there is potentially a larger amount of information held on them than species simply identified as positive or negative site condition indicators. This information could potentially be used to monitor impacts of N deposition if these species are sensitive, and if a species is sensitive to N deposition, the status of the species interest feature on the site may be impacted leading to unfavourable condition.

Fifteen species analysed in this project are species designated as of interest. Only three of these species, *Sphagnum austinii* (lowland bog), *Platanthera bifolia* (lowland heathland) and *Barbilophozia atlantica* (heathland) had sufficient data for analysis, and these showed significant relationships with N deposition in the spatial analysis. *Platanthera bifolia* showed a positive relationship with N deposition and *Barbilophozia atlantica* showed a U-shaped relationship. The relationship between probability of presence for *Sphagnum austinii* and N deposition was unclear in its direction/shape. No species designated as interest features showed responses in the temporal analysis.

Some species designated as interest features on sites are listed on the Habitats Directive Annexes (species of Community Interest). The directive requires reporting of the conservation status of these species every six years (Article 17), but the directive does not specify the sensitivity, frequency or spatial scale of surveillance. This means that the data used for Article 17 reporting may not be useful for assessing impact of N deposition but the information generated from this project may be useful to inform reporting.

5.2 Comparison between CSM and grass:forb ratio at acid grassland sites

Detecting an impact of N deposition in the assessment of site condition is very difficult. Stevens *et al* (2008; 2009) suggested that grass:forb ratio (or graminoid:forb ratio) at an individual site could be used to detect whether N deposition was impacting on the vegetation in acid grasslands. A grass:forb (or graminoid:forb) ratio of greater than five indicated unfavourable site condition in relation to N deposition in acid grasslands. Comparing the results of the most recent condition assessments with the grass:forb ratios measured on sites has the potential to show whether site condition assessment is currently accounting for the impacts of N deposition, and whether sites are designated as favourable when they are being impacted by N deposition.

Using data from surveys of 41 acid grasslands in England belonging to the NVC vegetation community U4 (Rodwell, 1992) a comparison was made between the current condition assessment for sites (taken from Nature on the Map http://www.natureonthemap.org.uk/) and the grass:forb ratio. Data for the grass:forb ratio were taken from Stevens (2004).
There is no clear relationship between the reported site condition and grass:forb ratio (Figure 5.1).

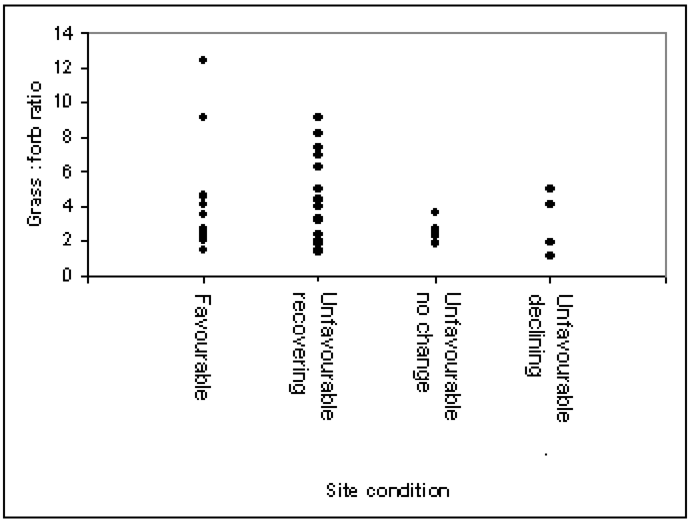

Figure 5.1 Grass:forb ratio against site condition for each of 41 acid grasslands in England.

Figure 5.2 shows the breakdown of the number of sites where the two assessments are in agreement and, where just one or the other method shows the site to be in favourable condition. The results show that for a large number of sites there is no difference between the assessment results (‘0’ in Figure 5.2). However, there are also a large number of sites where the CSM assessment designates it as unfavourable condition but the grass:forb ratio indicates favourable condition with respect to N deposition (‘1’ in Figure 5.2). These are sites that are in unfavourable condition for a reason other than N deposition. The final group (four sites) is sites where CSM condition assessment indicates positive site condition but the grass:forb ratio indicates that the site is impacted by N deposition ‘-1’ in Figure 5.2). This is slightly misleading because acid grassland is not the designated feature on all the sites surveyed. However, focussing on those for which acid grasslands are the designated feature, there are two out of ten sites identified as favourable but where the grass:forb ratio indicates they may be impacted by N deposition. Both of these sites have very high N deposition (> 30 kg N ha^{-1} yr^{-1}) and species poor vegetation. Note that a grass:forb ratio of greater than five only indicates the worst affected sites (i.e. it is very conservative); if this were reduced or another indicator such as species richness were used, the results would be different with more sites showing an impact.

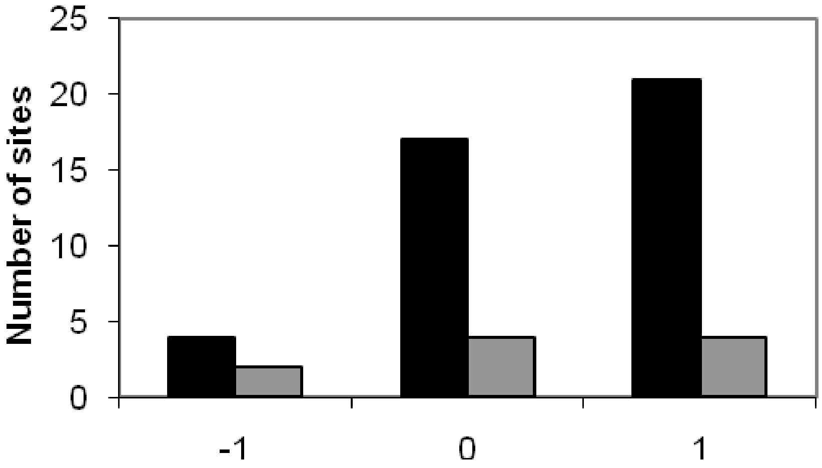

Figure 5.2. Comparison between site condition assessment results from CSM and grass:forb ratio. A score of 0 indicates that for a particular site the two results are the same, 1 indicates that grass:forb ratio gives positive site condition but CSM indicates negative condition, -1 indicates that grass:forb ratio gives negative site condition but CSM indicates positive condition. Black bars include all of the acid grasslands surveyed, grey bars indicate only sites where acid grasslands was the interest feature.

Sites have not been examined individually to determine if the negative condition can really be related to N deposition, there may be other causes of nutrient enrichment or management changes which have led to the dominance of grasses.

5.3 Case studies comparing CSM and N impact assessments on SSSIs

The following case studies were selected because they represented sites for which there were sufficient data for analysis and which previous investigations have suggested no impact of N deposition. Both sites are in the vicinity of ammonia point sources so an impact may have been expected, suggesting further investigation was warranted.

5.3.1 Case study: Minsterley meadows SSSI, Shropshire

Minsterley meadows is an MG5 grassland in Shropshire which is generally well managed and conforms to the expected species composition for the vegetation type. Background N deposition at Minsterley meadows is high (29.8 kg N ha^{-1} yr^{-1}, www.apis.ac.uk). The site consists of two fields with a poultry unit (over 700,000 hens) approx 600m to the west. The vegetation is dominated by species typical of MG5 grasslands and even in areas of more productive vegetation coarse grasses have a low cover. Completing a condition assessment of Minsterley Meadows using CSM suggests that the site is in favourable condition as all criteria for favourable condition are met. The National Vegetation Classification included 194 samples from MG5 grasslands from all over the UK. The mean number of species per sample is reported as 23 with a range from 12 to 38 (Rodwell, 1992). The mean number of species at Minsterley Meadow was 25.1 with a range of 21 to 28. The species richness at Minsterley Meadows is higher than the national average. The vegetation has a high percentage of forb cover giving rise to a low grass:forb ratio. The average grass:forb ratio on the site was 1.01 (i.e. equal percentage cover of grass and forbs) but this ranged from 0.47 (forb cover almost double grass cover) to 1.58 (higher grass cover than forb cover). Ellenberg N (nutrients) values showed very little variation across the two fields. The average

Ellenberg N value was 4.92 (range 4.72-5.32). A score of five indicates intermediate fertility and is what would be expected in this grassland community.

Detrended correspondence analysis showed that species composition has changed over time at Minsterley Meadows (Figure 5.3). There appears to have been little vegetation change between 1995 and 1998. By 2001 there had been a noticeable change in the vegetation and again by 2009. As the poultry unit was established in the 1980s there may already have been impact of the unit on the site. However, it has expanded over time with a rearing house built in 1995 and a conversion to deep pit in 1996. Between 1997 and 2000 three new sheds were constructed. Expansion in the number of animals, as seen here, leads to an increase in ammonia emissions and consequently an increase in N deposition and ammonia concentrations on the site.

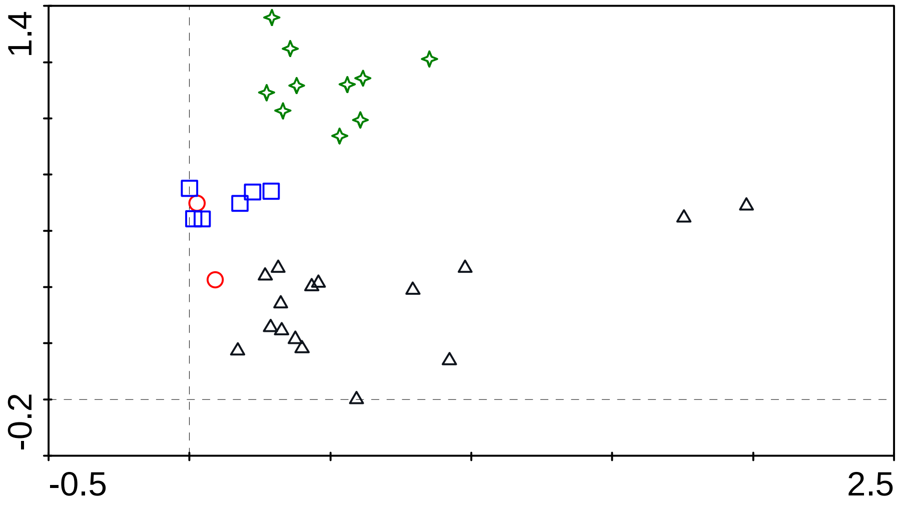

Figure 5.3 DCA of species composition at Minsterley Meadows. Circles represent data from 1995, squares 1998, triangles 2001 and stars 2009.

Ellenberg N values have also changed over time; they have increased by a small amount, indicating a slight eutrophication of the vegetation. It is impossible to say if this is related to the presence of the near-by poultry unit, ambient N deposition or another source of nutrients (Figure 5.4).

Figure 5.4. Mean cover-weighted Ellenberg N value against year.

This analysis has shown that Minsterley Meadows currently remains in favourable condition despite its proximity to a large poultry unit. The species composition is typical of this meadow type and the species richness is above the national average. Despite this, there have been changes in the species composition of the site since the first survey in 1995. Analysis of previous surveys seems to indicate that there has been a slight decline in species richness and species composition has changed. There also appears to have been a slight increase in eutrophic species since 1995 although the historical data must be interpreted with caution because there is no information regarding how these surveys were conducted. These results indicate the importance of repeated monitoring over time.

The changes that have occurred at Minsterley Meadows are very subtle and could not be detected with current common standards monitoring. More detailed monitoring of this site will be needed if future changes in the vegetation species composition are to be detected at an early stage. If grass:forb ratio were included in the assessment (see section 5.2) changes would still not be detected at this site. Subtle changes such as seen here can only be detected with repeated visits over a number of years. This means that the use of single visits with threshold values for indicators may not be suitable for detecting impacts of N deposition.

5.3.2 Case study: Skipwith Common SSSI, Yorkshire

Skipwith Common SSSI is an extensive area of heathland between the lower Derwent and Ouse Valleys in the Vales of York. It contains several habitats including wet and dry heath, fen, reed swamp, open water and woodland. The site is designated for its wet heath (M16 *Erica tetralix-Sphagnum compactum* wet heath), dry heath (M9) and reed swamp habitats (as well as for its breeding birds, invertebrate and dragonfly assemblages). The site is designated as a SAC for its dry and wet heath. A large poultry unit (over 150,000 birds) is located adjacent to the site and another poultry farm and three coal fired power stations are near-by.

The site consists of eight ‘units’, all of which are reported to be in either favourable or unfavourable recovering condition based on Common Standards Monitoring. Some units were previously reported to be unfavourable no change, but scrub clearance and reduction in animal stocking levels means that recovery is now considered underway. The

CSM/Favourable condition table for the heathland features consider habitat extent, cover of dwarf shrubs, bryophytes and lichens, amount of bare ground, *Calluna* growth stages, and presence of forb and gramminoid species. Negative indicator species in lowland heathland include *Rhododendron ponticum, Cirsium arevnse, Juncus effuses and squarrosus, Senecio* spp., and *Urtica dioica*.

Stevens *et al* (2008) concluded that current CSM indicators for heathland were not likely to detect the impact of N deposition on heathland habitats. Stevens *et al* (2011) found several species which showed a relationship between occurrence and N deposition in lowland heathland; these were *Viola canina* which showed a decline and *Platanthera bifolia* which showed a very slight increase. Of these, *Viola canina* is the most likely to be of use as an indicator of N deposition impact. The results from Stevens *et al* (2011) showed both spatial and temporal increases in Ellenberg N score with increasing N deposition. Results failed to show any relationship between species richness and N deposition in heathland. However, in Countryside Survey, a clear negative spatial relationship between species richness in heathlands and bogs and total N deposition has been found within all survey years from 1978 through to 2007 (ROTAP, in prep).

In 2008 Penny Anderson Associates Ltd Consultant Ecologists (PAA) conducted an additional assessment of Skipworth Common, on behalf of Natural England, to look for evidence of impacts consistent with ammonia/ N deposition impacts. They focussed on three areas of M16 heathland at the site: Nightjar Heath, Central Paddock and Washdyke Common. At the time of their assessment Nightjar Heath (closest to the poultry unit) was predicted to receive total N deposition of 32 kg N ha^{-1} yr^{-1} and was in unfavourable condition as a consequence of a lack of *Calluna* in later growth stages, which may be related to overgrazing. Central Paddock received deposition of 22 kg N ha^{-1} yr^{-1} and was in favourable condition. Washdyke Common was the control area with ammonia at background levels and so no extra N deposition above the background levels of 19.5 kg N ha^{-1} yr^{-1}. This area was in unfavourable condition as a consequence of a lack of *Calluna* in later growth stages. Deposition was estimated using modelled data provided by the Environment Agency with background deposition provided by APIS (Carroll, 2008). The report from PAA gives very few details of methodology and exact quadrat locations are not given. This unfortunately makes it impossible to compare data to earlier surveys as was done above for Minsterley Meadows. Not all species were identified to a species level which also makes it more difficult to compare with earlier records and identify changes. As a consequence, it is recommended that in future assessments surveyors are asked to record quadrat locations with a hand-held GPS or locate quadrats on a map and to include raw data in an appendix for future reference.

The PAA report provides summary data for mean percent cover and frequency for species in Central Paddock and Washdyke Common. Management history in these two areas differs, which makes comparison difficult and makes it difficult to assess N deposition impacts as management can potentially have a strong impact on the vegetation composition. The report concluded that there was no clear indication of an ammonia impact on the designated heathland area (Carroll, 2008). We have re-analysed this data using weighted and unweighted Ellenberg N values and species richness to see if the same conclusion is reached.

Species richness in Central Paddock was 15 whereas in the control area, Washdyke Common, it was 22. These values are towards the middle of the range expected for lowland heathland and 15 species is approximately average (see section 5.4). Total richness of the vegetation stand has been considered here. Given that Central Paddock was in favourable condition at the time this survey was conducted and Washdyke Common is in unfavourable condition for poor management this is surprising. Mean Ellenberg N for Central Paddock was 2.34 weighted and 2.71 unweighted whereas in the control area, Washdyke Common, it was 2.45 weighted and 1.87 unweighted. The average values for the site are higher in Central Paddock than Washdyke Common indicating a higher fertility. The magnitude of these changes are only small but results of national analysis of Ellenberg N values (Stevens *et al* 2011) has shown this is common for N deposition impacts. It is difficult to draw firm conclusions without knowing quadrat exact quadrat locations and assessing other reasons for the differences between the two areas but these data appear to indicate N deposition impact is occurring despite not being detected in the assessment carried out by PAA and the condition assessment. However, as these two areas have different management history it is difficult to draw a firm conclusion regarding N deposition impact.

Condition assessment using CSM does not consider species richness or Ellenberg scores for heathland habitats and is therefore unlikely to be sensitive enough to detect N impacts. At the time these data were collected central Paddock was considered to be in favourable condition, yet as is demonstrated in the results above there appears to be an N deposition impact on the site that was not detected. It is very difficult to determine what the eventual impact of this will be over time but we might expect that eventually the site would be sufficiently damaged that CSM assessment would show unfavourable condition, possibly through an increase in grass cover. However, by the time that the impact of N deposition was detected using CSM the site would be heavily impacted by N. CSM is insensitive to N deposition effects; once N does actually adversely affect the attributes recorded in CSM resulting in unfavourable condition, it will be difficult to reverse. There is a need for early warning indicators which CSM does not currently provide. This case study also highlights that even with more detailed data collection, if this data is not collected over time and the correct metrics are not observed, the impact of N deposition on the plant community may not be detected, and that management can make the data collected very difficult to interpret.

5.3.3 Case study conclusions

The conclusion of these case studies and the comparison between site condition and assessment using grass:forb ratio is that changes as a consequence of N deposition are very unlikely to be detected using common standards monitoring even though an impact can be detected using more appropriate techniques. The case studies demonstrate that there are sites designated as in favourable condition where evidence of nutrient enrichment attributed to N deposition can be seen. Individual species of conservation importance such as species interest features may also be impacted by N deposition. There are a wide range of N deposition impacts which are not assessed in CSM including changes in species richness, grass:forb ratio and changes in Ellenberg N value. These measures are not all appropriate for incorporation into the CSM scheme but are the best metrics for determining N deposition impact. Monitoring of changes in vegetation species composition and Ellenberg N values over time was able to detect even subtle changes at Minsterly Meadows and this is the optimal method for detecting impact. The collection of data over a period of time is very important for detecting N deposition impact and wherever possible impact assessments should utilise data collected over a number of years. Where this is not possible impact assessments should take account of the critical load and consider that above this level N will have a cumulative effect with more N causing more damage. Data from Stevens *et al* (2011) support this, showing impacts on habitats and individual species at all levels of deposition. It is possible that once a habitat was sufficiently degraded CSM would detect the impact of N deposition; however, by this stage it is likely that the habitat would have been quite heavily impacted and it may not be possible to restore the habitat to favourable condition.

5.4 Measures for different data types

If data are being collected specifically for the purpose of detecting the impact of N deposition then replicate random quadrats should be used within each vegetation type present on the site with all vascular plants and bryophytes identified to species level and percentage cover estimated. If full quadrat data are available this permits the calculation of grass:forb ratio, average Ellenberg values and species richness. Research data and the graphs below (section 5.5) mean that this can be set within a national context. However, frequently it is not possible to collect data specifically for the purpose of determining N deposition impact and data that have been collected previously or data that are being collected for another purpose must be used.

One of the most commonly collected types of site-specific data is for common standards monitoring. These data are collected with a walk across the site with data collected on the presence or absence of indicator species and the specific criteria outlined for each habitat. Without modification of the CSM protocol these data are not easy to use for determining N deposition impact. However, the species identified in section 5.1.1 as potential indicators of N deposition impact could be used as a guidance of impact, especially if there was a temporal component to data collection. If positive indicators identified for each habitat have decreased over time, and negative indicators have increased over time, this would indicate that site condition with respect to N deposition is likely to be bad. However, further research is needed to develop the list of potential species in many habitats because many of the species identified as indicators of site condition have received little research attention with respect to N deposition.

National vegetation classification (NVC) quadrat data are also held for many sites. This presents very different challenges for use in determining N deposition impact. NVC data contain a large amount of information with all vascular plant and bryophyte species identified and cover estimated using either percentage cover or the DOMIN scale. This means that species richness, Ellenberg N values (weighted and unweighted) and grass:forb ratio (if percentage cover is recorded) can all be calculated offering the best potential for determining N deposition impact. However, the NVC protocol states that quadrats should be located in areas of vegetation typical of the stand. This selection of typical vegetation means that areas of poor vegetation are avoided and the vegetation quality for a site is not actually representative of the site as a whole. This can give results biased towards good areas of vegetation.

In many cases there are not sufficient resources for the collection of NVC data and species lists are determined for the site (with or without dominance determined on the DAFOR scale). These data are not ideal because it gives very little information on cover but it can be used to give a measure of species richness and to determine weighted and unweighted Ellenberg N values for the site. It is important to remember that species richness and Ellenberg N values collected for a site as a whole are scale dependent so will be influenced by the area of the site and cannot be compared with those collected at a quadrat level.

There is some debate about whether weighted or unweighted Ellenberg N values provide the best information. Stevens *et al* (2009) found that for analysis at one point in time unweighted scores were more sensitive for detecting N deposition impact in acid grasslands, possibly because it is the small forb species with low cover that are likely to be most sensitive to N deposition impacts.

If temporal data (i.e. data collected from repeated surveys using the same methodology over several years) are available this adds considerable value, even if the data available are not ideal for determining N deposition impact. Several studies have indicated that the impact of N deposition is cumulative (e.g. Duprè *et al* 2010) so temporal data permit the detection of small incremental changes in species composition that can be used to identify impact at an early stage. For temporal data it is better to use weighted Ellenberg N values because this makes the score more sensitive to small changes.

The most suitable metrics for use with commonly collected data types are given in Table 7.1. Where there is more than one potential metric for the survey type, it is ideal to use as many as possible to increase the chances of determining impact.

Table 5.1. Metric for determining N deposition impact with different data types.

Survey type	Metric
Spatial	
Random or gridded quadrats	Species richness Mean Ellenberg N (unweighted) Grass:forb ratio (percent cover data needed)
NVC quadrats	Species richness Mean Ellenberg N (unweighted) Grass:forb ratio (percent cover data needed)
CSM structured walk	Indicator species
Species list with DAFOR	Species richness Mean Ellenberg N (unweighted)
Species list	Species richness Mean Ellenberg N (unweighted)
Temporal	
Random or gridded quadrats	Species richness Mean Ellenberg N (weighted) and change in Ellenberg N over time Grass:forb ratio (percent cover data needed) and change in grass: forb ratio
NVC quadrats	Species richness Mean Ellenberg N (weighted) and change in Ellenberg N over time Grass:forb ratio (percent cover data needed) and change in grass: forb ratio
CSM structured walk	Indicator species and change in presence of indicator species
Species list with DAFOR	Species richness Mean Ellenberg N (weighted) and change in Ellenberg N over time
Species list	Species richness Mean Ellenberg N (unweighted) and change in Ellenberg N over time

5.5 Setting the national context

In order for information from individual sites to be useful it needs to be set within a national context. To do this we have presented data for species richness, Ellenberg N value and grass:forb ratio from a range of sources. Where possible these include a theoretical value taken from the NVC classification, a typical vegetation value taken from Natural England, Countryside Council for Wales and Scottish Natural Heritage NVC surveys and a wider countryside value taken from Countryside Survey data.

Data for the theoretical value for species richness were taken from the NVC books (Rodwell, 1991; Rodwell, 1992). Communities U1 to 9 were used for acid grassland, CG2, 3, 4, 6, 8, 10, and 11 for calcareous grassland, H1 to 19 excluding H5, 6, and 17 for heathland and M1 to 4, 6, 15 to 21 and 25 for bog (note these are not consistent with the BAP habitat definitions). These communities were selected based on previous selections for Countryside Survey data (Maskell *et al* 2010).

For typical vegetation data, communities were selected as above based on the NVC codes allocated by surveyors. The majority of the NVC data were taken from SSSIs but this was not always the case. Data were taken from all three national databases where possible (Natural England, Scottish Natural Heritage and Countryside Council for Wales) but it should be noted that for bogs, heathlands and upland calcareous grassland, data were only available from Scottish Natural Heritage.

Data for the wider landscape are taken from the Countryside Survey of Great Britain. Data from the 1998 survey have been used here. The dataset comprises of data from 569 1km squares randomly selected from a grid covering Britain and stratified based on their topographic, climatic and geological attributes. 6782 2x2m plots were sampled with all vascular plants and a selected range of the more easily identifiable bryophytes and macrolichens identified and cover estimated to the nearest 5%. Plots were classified to the NVC based on the pseudo-quadrat approach with communities selected as above (Maskell *et al* 2010).

The graphs below could be used by site managers to see how their individual site compares with data collected from across the country. This will provide a clearer idea of whether an individual site is a good example of its habitat type or not. If values show low species richness, high Ellenberg N score or high grass:forb ratio this may indicate N deposition impact.

5.5.1 Species richness

The theoretical mean species-richness plotted is the mean of the species richness presented for these communities using values taken from Rodwell (1991; 1992). Bryophytes are included in this figure and upland and lowland communities could not be separated. The range represents the maximum and minimum recorded for these communities. The typical vegetation example is presented without bryophytes because we could not be certain these had been consistently recorded. Data are presented for upland and lowland habitats. The wider countryside value is presented with and without bryophytes for upland and lowland habitats.

Figure 5.5 shows that in all habitats lowland sites are generally more species rich than upland ones. Although the maximum species richness is generally higher in typical vegetation, a dataset dominated by SSSIs, the mean species richness is very similar to the other data sets, as is the minimum species richness.

Species richness commonly declines with increased N deposition (e.g. Maskell *et al* 2010; Stevens *et al* 2010a). Although there can be many other reasons for low species richness, such as inappropriate grazing regimes and fertilisation, these graphs provide a national picture of species richness. High species richness is not always an indicator of low N deposition impact if the species composition is not appropriate so this needs to be taken into consideration. If management on an individual site is appropriate, relatively low species richness may indicate N deposition impact.

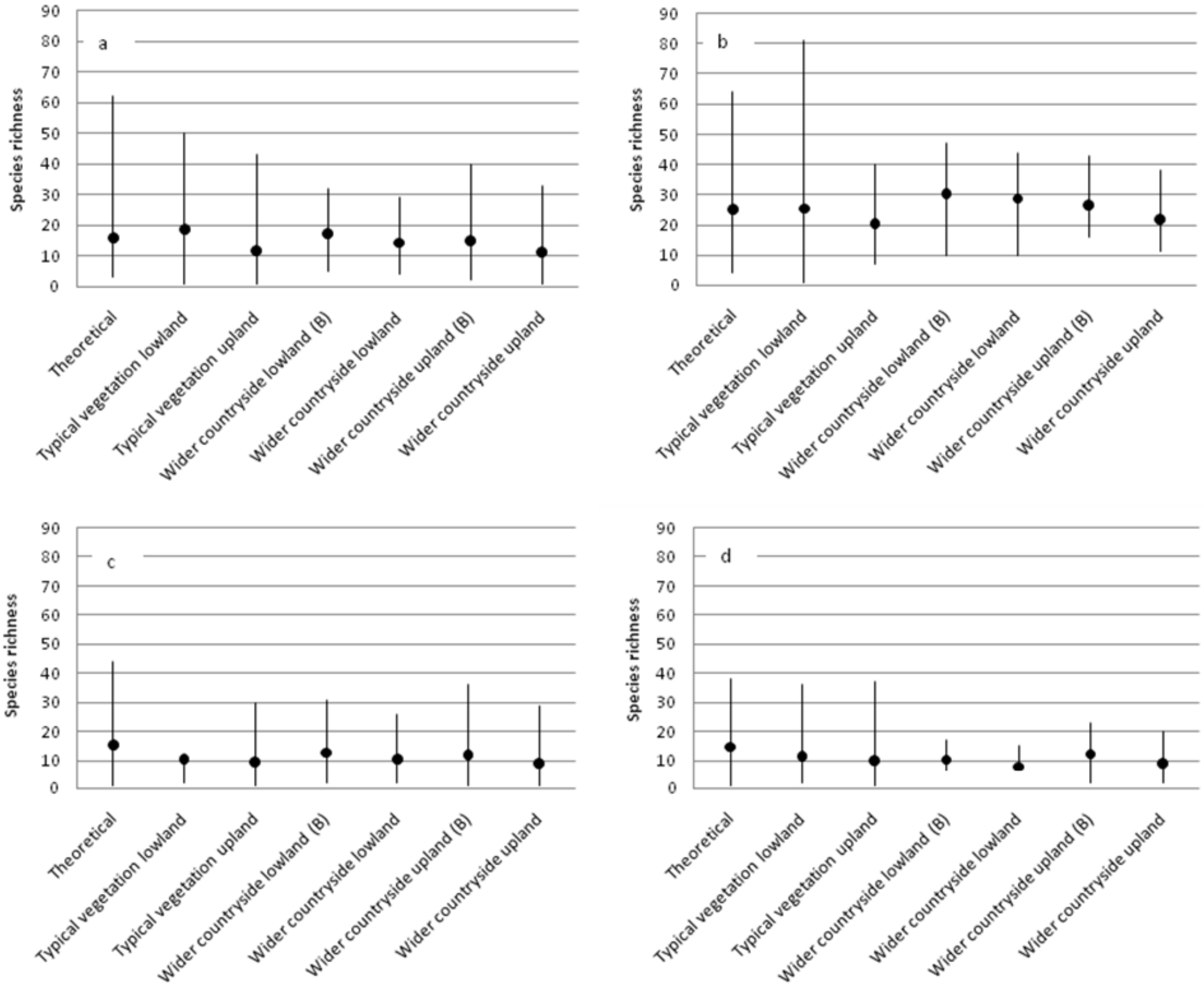

Figure 5.5. Species richness of a) acid grasslands, b) calcareous grasslands, c) heathlands and d) bogs for theoretical communities calculated as an average of species richness in appropriate NVC communities (Rodwell, 1991; Rodwell, 1992)), typical vegetation (uplands and lowlands) calculated as an average of NVC surveys from Natural England, Countryside Council for Wales and Scottish Natural Heritage, and wider countryside (with and without bryophytes for uplands and lowlands) calculated using data taken from Countryside Survey 1998. The spot represents the mean value with error bars to show the range.

5.5.2 Ellenberg N

The theoretical mean Ellenberg N is the mean of the average value calculated for each community using floristic tables presented in Rodwell (1991; 1992) but excluding species with a constancy of 1. The range represents the maximum and minimum recorded for these communities. The typical vegetation data use the mean values for quadrats from NVC surveys. Data are presented for upland and lowland habitats. The wider countryside value is presented for upland and lowland habitats. Ellenberg N values were taken from Hill *et al* (1999).

Figure 5.6 shows that lowland communities tend to have higher Ellenberg N values but, as with species richness, there is generally little difference between Ellenberg N values for the typical vegetation and the wider countryside. Bogs are an exception to this where the mean and maximum species richness is much higher in typical vegetation than the wider countryside.

A high Ellenberg N value indicates a fertile habitat. If a habitat is appropriately managed an average Ellenberg value that is towards the upper end of the scores on these graphs may indicate N deposition impact.

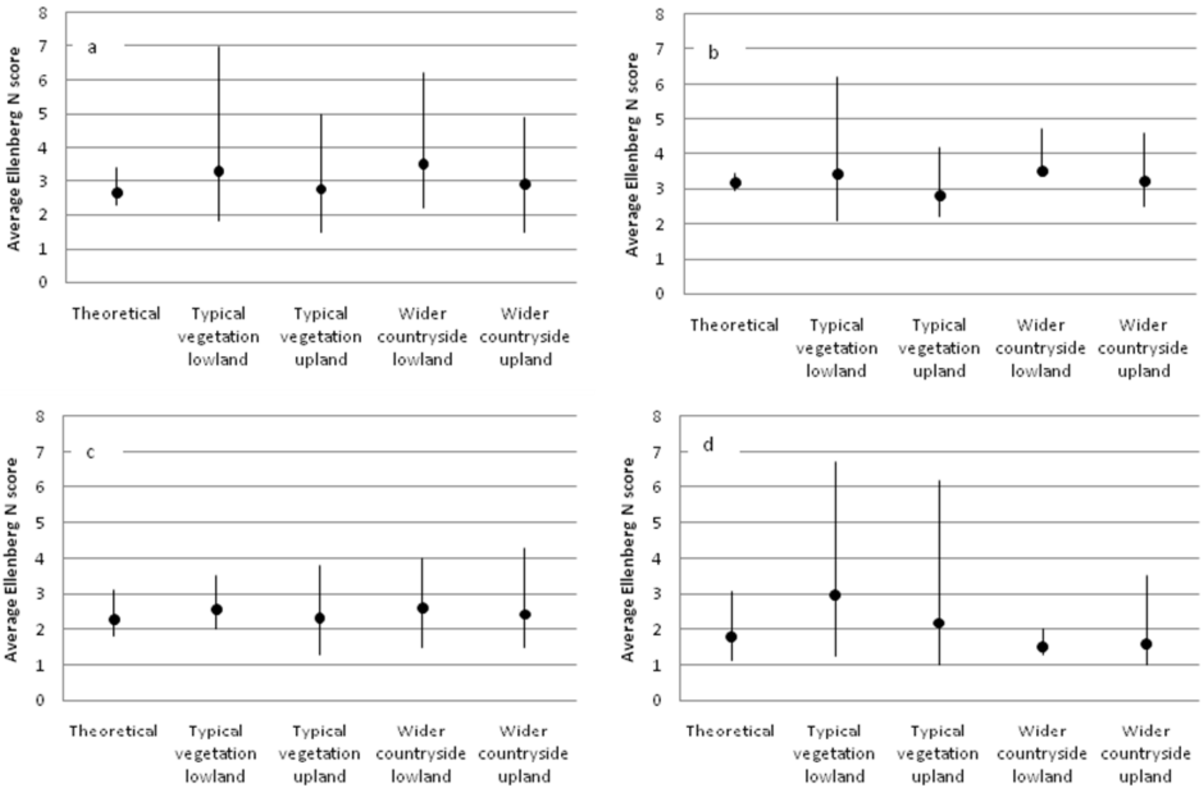

Figure 5.6. Average Ellenberg N value of a) acid grasslands, b) calcareous grasslands, c)heathlands and d) bogs for theoretical communities calculated as an average of species richness in appropriate NVC communities (Rodwell, 1991; Rodwell, 1992)), typical vegetation (uplands and lowlands) calculated as an average of NVC surveys from Natural England, Countryside Council for Wales and Scottish Natural Heritage, and wider countryside (without bryophytes for uplands and lowlands) calculated using data taken from Countryside Survey 1998. The spot represents the mean value with error bars to show the range.

5.5.3 Grass:forb ratio

Because cover is not available in the floristic tables of the NVC books and is recorded as Domin values in NVC surveys, only data for the wider countryside taken from CS is presented. Grass:forb ratio is calculated based on the percentage cover of all grass species against all forb species using the following formulae: grass:forb ratio = ln (cover of grass/ cover forb). Data are presented for upland and lowland where possible.

Figure 5.7 shows the grass:forb ratio for acid grasslands, calcareous grasslands, heathlands and bogs. In all of the habitats there was little difference between upland and lowland. If an individual site has a high grass:forb ratio and management at the site is appropriate this may indicate N deposition impact on the vegetation.

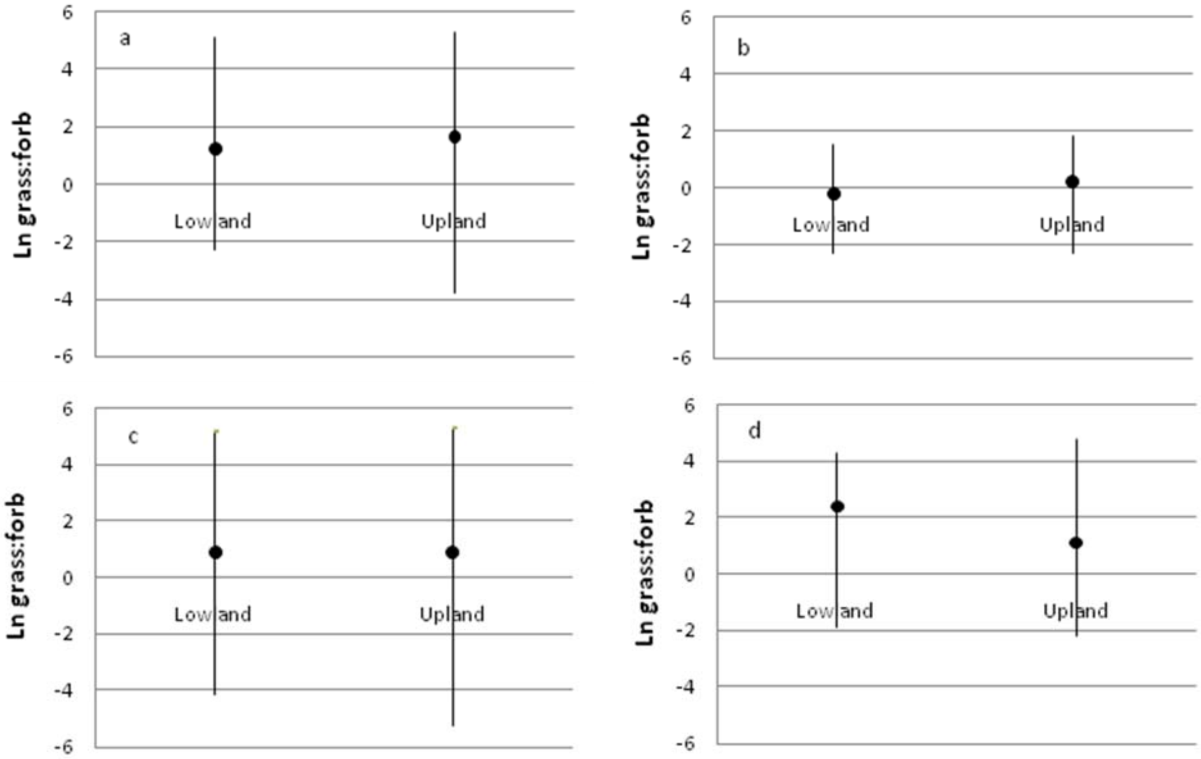

Figure 5.7. Ln grass:forb ratio for a) acid grasslands, b) calcareous grassland, c) heathland, and d) bog. The centre point marks the mean with the line showing the full range of values. Data are for wider countryside only, and taken from CS 1998

5.6 Conclusions

The results presented in this chapter clearly indicate that CSM is not sufficiently sensitive for detecting 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. This is because the attributes recorded are not suitable for detecting N deposition impacts and because there is a lack of temporal comparison. It is likely that there would be an eventual ‘impact’ on CSM attributes and therefore site condition, but by the time this were detected it would be very hard to reverse as a result of the cumulative impacts of N. Impacts may be detected in features such as grass:forb ratio (currently assessed in some habitats such as calcareous grassland and heathland), the cover of some species groups (e.g. rank grasses in lowland purple moor grass and rush pasture), an increase in negative indicator species, or a change in plant community towards a more typically eutrophic one.

From previous research we know that the impacts of N deposition are cumulative (Duprè *et al* 2010). This project (Stevens *et al* 2011) has clearly shown that some species are impacted even at low levels of deposition, indeed losses are potentially greatest when increasing from low levels of deposition (Emmett 2007; Stevens *et al* 2010a). This means that at low background levels of N deposition, such as those found in north-west Scotland, there can still be negative impacts of N deposition on individual species and species composition although it is very unlikely that these will be detected with common standards monitoring and detailed temporal monitoring is likely to be needed to detect change. Stevens *et al* (2011) and other studies (e.g. Maskell *et al* 2010; Stevens *et al* 2010a) have also demonstrated continued negative impact at high levels of deposition. The lack of monitoring over time in CSM means changes in vegetation are unlikely to be detected by CSM even though impacts could be detected by more detailed survey. For individual sites, for example, in the vicinity of a point source, monitoring over time or utilising data collected in previous surveys is very important in detecting the potentially subtle changes associated with N deposition. Where detailed monitoring is not practical due to cost or other reasons critical load exceedence could be used to give guidance on expected impact. However, it must be considered that this does not take into account site specific features such as the presence of particularly sensitive species which may decline at lower levels of deposition than the critical load or the presence of particularly aggressive species which may increase at lower levels of deposition than the critical load.

Providing a national context for individual sites could indicate to managers whether their site is impacted by N deposition. However, without monitoring individual sites over time it is very difficult to separate the subtle changes in vegetation caused by high N deposition from other effects of management.

Although results of CSM assessments may not demonstrate impacts of N deposition, the results of the case studies presented here and the results of the analysis of national data sets (Stevens *et al* 2011) indicate eutrophication of semi-natural habitats. The distribution of some individual species is related to N deposition, with some species beginning to decline in the probability of presence even at very low levels of deposition. This means that SSSIs and SACs containing the habitats investigated in this report (acid grasslands, heathlands, calcareous grasslands and bogs) are likely to be showing widespread impacts of N deposition. In areas of low N deposition (<10 kg N ha^{-1} yr^{-1}) these impacts may only be small or in few sites. An individual site may or may not be impacted. In areas of intermediate deposition (10-25 kg N ha^{-1} yr^{-1}) impacts are likely to be greater and occur in the majority sites. An individual site is likely to be impacted but the severity of these impacts is likely to be variable. In areas of high deposition (>25 kg N ha^{-1} yr^{-1}) it is likely that all sites will be impacted and at some sites these impacts could be affecting the species composition resulting in few sensitive species as well as impacts on soil chemistry and plant tissue chemistry. At a national scale this means that sensitive habitats in large areas of the country are likely to be showing some impacts of N deposition which will continue to get worse due to the continued deposition of N and cumulative impacts.

6 Implications for design of surveillance schemes

6.1 Introduction

This section reviews current vegetation surveillance schemes, considers if there is sufficient evidence available, and makes recommendations for further work and improvements that could be made to the design of schemes.

The evidence considered in the current study (Stevens *et al* 2011) regarding which variables provide indications of N pollution effects is reviewed in relation to Broad Habitats, with the aim of revealing gaps in the evidence base. This could include gaps in research knowledge, gaps in analysis of existing data, or gaps in surveillance data itself. Measurements potentially useful to assess impacts of N pollution impacts on habitats are considered. Current surveillance schemes are reviewed, measurements useful for assessing N deposition impacts are assessed, and some suggestions made for improvements to the surveillance schemes. Although on-site measurements of N pollution and assessments of management activities are potentially useful in attributing change, these were considered beyond the scope of this report. Modelled estimates for rates of deposition of different forms of pollutant N at 5x5km scale are available from www.uk-pollutantdeposition.ceh.ac.uk.

6.2 Current surveillance methods

6.2.1 Countryside Survey

The Countryside Survey assesses floristic composition, soil and water properties and landscape features within a random sample of $1km^2$ squares stratified by 14 UK land classes (Firbank *et al* 2003). Surveys were carried out in 1978, 1984, 1990, 1998 and 2007, with an increase in coverage from 256 squares in 1978 to 591 in 2007. Within each square, BAP Broad Habitats and Priority Habitats are mapped. Floristic data are recorded from several types of permanent plot, including 1x10m plots along linear features and 2x2m plots placed to sample distinctive vegetation at the discretion of the surveyor. The plots include five “X” plots which are randomly allocated across the square and are surveyed in detail, with soil samples taken and concentric rings surveyed separately to quantify species-area effects.

The Countryside Survey provides invaluable data for assessing and attributing change in habitats, in particular the “X” plots with their synlocated recording of floristic and soil properties. For example, analyses of the data have revealed ongoing eutrophication in infertile habitats (Smart *et al* 2003), and have been used to attribute declines in species richness to the effects of N deposition (Maskell *et al* 2010). The Countryside Survey dataset was indispensible for developing niche models for a large subset of British vascular and non-vascular plant species (Smart *et al* 2010). Several more extensive datasets exist for the UK flora, and can be used to relate the occurrence of a given species to characteristics of the overall assemblage, such as mean Ellenberg N score. However, the Countryside Survey provides the only large-scale dataset in which these assemblage characteristics can be linked to soil measurements.

With each repetition of the Countryside Survey the dataset increases in value, in particular for its ability to discriminate the effects of slow-acting drivers. The stratified random design allows accurate statistics to be generated about effects on the wider countryside, although it does limit the coverage of habitats of conservation importance that are sparsely distributed. Countryside Survey data are particularly valuable when they are from repeated plots, and so it would be valuable to retain as many of the historic plots as possible in each survey - a proportion of the plots are lost in each survey due to issues such as urbanisation but also due to denial of access. For detecting N pollution signals, plots with associated soil data are invaluable, and the coverage of soil analyses such as pH, total C, total N and mineralisable N should be maintained or increased in the next survey. A very useful extension to the Countryside Survey dataset would be accurate measurement of vegetation height and/or biomass, as this provides insight into a key mechanism by which N pollution decreases plant diversity. Height is recorded for CS plots, but only using a subjective method and a coarse categorical scale, and the importance of the measurement is not emphasised when training surveyors. In general, however, the Countryside Survey is a vital resource for detecting the chronic and cumulative effects of N pollution because of its permanently located plots and the synlocation of soil and floristic data collection.

6.2.2 Environmental Change Network (ECN)

This is a network of 12 terrestrial and 45 freshwater sites throughout the UK, coordinated from the Centre for Ecology and Hydrology (CEH) Lancaster and with a central data repository. Details of the habitats on the different ECN sites are given in Table 6.1.

Table 6.1. Habitats covered by the 12 Environmental Change Network sites.

ECN Site	**Country**	**Habitats**
Alice Holt	England	Coniferous and deciduous woodland
Drayton	England	Mixed farmland
Moor House	England	Blanket bog (M18b, M19a,b) with deciduous woodland and herb-rich meadows at lower altitudes
North Wyke	England	Lowland grassland and deciduous woodland
Porton	England	Woodland and semi-natural chalk grassland with successional scrub
Rothamsted	England	Agricultural research station with long-term ‘Classical Experiments’ designed to cover cereal growth, grassland management and woodland regeneration
Wytham	England	Woodland (unmanaged ancient and secondary woodland, plantations and small areas of seminatural grassland) and farmland (producing a variety of livestock and crops)
Hillsborough	N Ireland	Improved lowland grassland
Cairngorms	Scotland	Altitudinal sequence of communities, from Caledonian pine woodland at 300m up to arctic-alpine vegetation at 1100m
Glensaugh	Scotland	Semi-natural vegetation, short-term and permanent grassland and woodland
Sourhope	Scotland	Rough grazing, permanent pasture and woodland
Yr Wyddfa	Wales	Acidic unimproved grassland with acidic dry dwarf shrub heath

As well as detailed baseline information, a large set of measurements is taken regularly at each site. These include meteorological variables (e.g. precipitation, air and soil temperature), passive diffusion tubes to measure atmospheric NO_x concentrations, and precipitation chemistry including NH_4 and NO_3 concentrations. A wide range of taxonomic groups is censured, including birds, butterflies and spiders. Whilst N pollution undoubtedly affects animal taxa, e.g. via effects on trophic interactions (Beusink *et al* 2003) or on light availability (Wallisdevries and Van Swaay 2006), understanding of animal niches in relation to N availability is currently insufficiently developed to attribute changes in animal species abundance to N pollution. Soil and floristic measurements on terrestrial ECN sites are summarised in Table 6.2.

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Table 6.2. Regular soil and vegetation measurements taken on terrestrial ECN sites. NVC = National Vegetation Classification.

Soil solution (2-weekly)	Soil (5-yearly)	Vegetation
pH Conductivity Alkalinity Concentrations of Na, K, Ca, Mg, Fe, Al, PO_4-P, NH_4-N, NO_3-N, Cl, SO_4 & DOC	Horizon thicknesses Soil moisture pH Exchangeable Acidity, Na, K, Ca, Mg, Mn, Al Total N, P, S, organic C, inorganic C	Coarse-grain (9-yearly): 50 randomly selected permanent 2x2m plots (species presence in each of 25 cells) plus 10x10m plots in woodland Fine-grain (3-yearly): at least two randomly selected permanent 10x10m plots within each NVC type

Data from most of the terrestrial ECN sites are available from 1993. There are some data gaps, in particular in the soil solution data on drier sites, presumably due to difficulties with obtaining samples from the suction lysimeters. There have also been some difficulties relating floristic data from across the ECN sites (some of which are extensive) to soil and climatic measurements from a particular location. For these reasons, thus far the ECN sites have not been extensively used to study N impacts. The quality and accessibility of ECN data are improving, along with the length of time for which data have been collected. There is potential for more studies of N impacts on these sites, although they are mainly located in unique and exceptional locations and hence the transferability of the results to the wider countryside may be low.

As well as improving the connection between floristic and soil recording data and continuing to measure soil C and N and soil solution N, the ECN protocol could be extended to measure environmental conditions that are particularly relevant for attributing N effects. Mineralisable N measurements would give an indication of available N even for sites where solution N is hard to monitor. Including a measure of vegetation height and/or biomass would allow the effects of N on productivity to be assessed. This could be a simple, objective method such as height by dropped disc or laser range-finder, or standing biomass by clipping. However, in view of the importance of the measurement and the monitoring effort already made at ECN sites, it would be worth considering a measure of annual biomass productivity, which can be estimated by using an exclosure to reduce grazing and measuring the standing biomass increment.

6.2.3 Environmental Change Biodiversity Network

The ECN is being extended to a network of further monitoring sites, the Environmental Change Biodiversity Network (ECBN). This network includes a large set of stakeholders such as Countryside Council for Wales, Natural England and CEH. In an initial phase, 30 sites across England, Wales and Scotland (Table 6.3) have been added to the 12 ECN sites, and the intention is to increase this to 100 sites with long-term monitoring of air, water, soil and biodiversity variables. The focus is on sites with stable management and high conservation value, and so National Nature Reserves form the core of the network.

Measurements will be a slightly reduced subset of those recorded in the ECN, and the protocols used will match those used in the ECN, to allow comparison. The soil variables to be measured have not yet been finalised. Floristic recording will follow the ECN protocol, i.e. using permanent quadrats for coarse-grain and fine-grain sampling. Butterfly and bird populations will be monitored using the same methods as in the ECN.

The ECBN has the potential to improve the evidence base for N pollution effects, since it provides a larger range of sites than the ECN and thus allows more comparison and replication. As with the ECN, the criticism can be made that the sites are unusual, with particularly species-rich examples of habitats, and so do not reflect changes in the wider countryside. However, for this reason the ECN and ECBN are to an extent complementary to the stratified random design of the Countryside Survey. The emphasis has been to harmonise data collection and recording methods, and presently only weather data appear online on the CCW ECBN website. The value of the dataset is likely to increase as more data on the flora, the solid soil and the soil solution are gathered. The ECBN should be encouraged to ensure that floristic and soil data are also made available, and in particular that the location of soil monitoring can be easily related to floristic records. Many of the sites contain a variety of habitats and the soil data are likely to be relatable only to the habitat from which they were recorded. As discussed above for the ECN, extending monitoring to include mineralisable N and a measure of biomass productivity would be very useful for detecting N effects.

Table 6.3. Habitats covered by the 30 current Environmental Change Biodiversity Network sites.

ECBN site	Country	Major Habitats
Ainsdale Dunes & Sands	England	Dunes & vegetated dunes
Bure Marshes	England	Fen (flood-plain, basic), wet woodland, open water
Burnham Beeches	England	Beech woodland & wood pasture; dry & wet heathland; valley mire
Derbyshire Dales	England	Upland limestone grassland, woodland & rivers
East Dartmoor Woods & Heaths	England	Dwarf shrub heath, deciduous woodland
Fenn's, Whixall & Bettisfield Mosses	England	Active raised bog, degraded raised bog.
Finglandrigg Woods	England	Broadleaved mixed and yew woodlands, acid grasslands
Ingleborough	England	Upland wet & dry heath and bog
Lindisfarne	England	Embryonic shifting dunes, Grey dunes, Dunes, Salix arenaria, Humid dune slacks. Dune heath & grassland
Lullington Heath	England	Lowland calcareous grassland, lowland heathland
Martin Down	England	Lowland calcareous grassland
Monks Wood	England	Ancient ash-oak woodland
North Solent	England	Coastal, estuarine, ancient and semi-natural woodland, neutral grassland, acid grassland, heathland
Old Winchester Hill	England	Lowland calcareous grassland
Stiperstones	England	Upland heath
Thursley	England	Lowland heath, valley mire
Creag Meagaidh	Scotland	not yet listed
Berwyn	Wales	upland heather moorland
Coedydd Aber	Wales	mixed woodland, grassland
Cors Caron	Wales	raised bog, fen, wet grassland, rivers and streams, ponds, woodland
Cors Erddreiniog	Wales	fen, acidic heathland, lime-rich springs

ECBN site	Country	Major Habitats
Cors Fochno	Wales	raised bog
Cwm Cadlan	Wales	wet calcareous grassland
Newborough Warren	Wales	dune grassland, dune slacks
Ogof Ffynnon Ddu	Wales	limestone pavement
Oxwich	Wales	dune slacks, limestone cliffs, unimproved grassland
Rhos Llaw Cwrt	Wales	grassland, bog, oak woodland
Skomer	Wales	maritime grassland, streams and ponds
Stackpole	Wales	lakes, woodland, sand dunes, cliffs
Ty Canol	Wales	woodland, heathland

6.2.4 Common Standards Monitoring

The JNCC provides detailed guidance for Common Standards Monitoring, including an overall introduction, and specific guidance for particular habitats (JNCC 2004). The habitats covered in the current study are covered by CSM guidance for Lowland Grassland, Lowland Heathland, Lowland Wetlands, and Upland habitats. The focus is on assessing the feature or features of interest, i.e. the species, habitats or other features for which the site was notified or designated. For each feature of interest, conservation objectives are defined in relation to measurable attributes, for which targets are set for use in assessing favourable condition (see section 5.1). Measurable attributes for interest features directly describe the condition of the feature, rather than factors influencing it. An assessment is also made of threats to the interest features, and management measures which may result in improvements, or maintain features in favourable condition. Any type of threat to the interest feature(s) can be recorded, but air pollution was not included in the original list of agreed threat categories (JNCC 2004), which may have led to under-reporting of this as a threat. However, a more significant factor in under-reporting is the difficulty of attributing site-level effects to N pollution (see section 5).

The CSM guidance is intended to make the judgement process consistent, but states explicitly that it is dependent on the judgement of the person carrying out the assessment. The intention is to “facilitate quick and simple judgements”. The field methodology for making an assessment may include a structured walk to look at the major variations present in habitat structure. For large sites, a representative and sufficiently large subsample of the interest feature is assessed.

For several broad habitat types, lists of positive and negative indicator species have been set out. Some of these species may also serve as indicators of N pollution impacts - 24 out of the 91 species affected by N in spatial and temporal analyses in the current project (Stevens *et al* 2011) also appeared in lists of CSM positive indicator species for one or more habitats. However, these species may change in frequency or cover because of other factors, so such changes provide an indication rather than proof that N pollution is damaging the site. The use of indicator species is discussed further in section 4.4.1.

The CSM methodology was not originally intended to detect N impacts and indeed has been of limited use in doing so (see section 5). In part this is due to the poor comparability between sites and between visits; although recommendations are made for the use of permanent quadrats in CSM guidance for some of the habitats, in most cases quadrats are placed in different locations each time and so it is impossible to separate the effects of environmental change from the effects of relocation. The species listed as positive and negative indicators for certain habitats were not selected on the basis of their N-sensitivity, and these lists could be revised on the basis of current knowledge.

6.2.5 Botanical recording based on quadrats

Several statutory and volunteer organisations have undertaken botanical surveys or operate recording schemes, which can be usefully categorised into those based on recording species occurrence within small areas such as 2x2m quadrats; and those which record species occurrence within larger areas such as hectads or tetrads. Datasets based on quadrat data include the Plantlife Common Plant Survey (CPS), the Countryside Council for Wales Grassland Survey, the Scottish Natural Heritage NVC survey, and the Natural England Grassland Database. These quadrat datasets all record both presence and cover. The CCW, SNH and NE surveys all used NVC protocols, in which all species in 2x2m quadrats (for the short vegetation covered by all of these surveys) are recorded, and most or all of the data are from single site visits.

The CPS is a volunteer scheme that has recorded 65 common species annually since 2000, in two plots of 5x5m and 1x20m with extra plots in habitats of particular interest, giving a total of 3,863 plots. The CCW grassland survey visited all protected grasslands in Wales, resulting in a total of 397 calcareous and 940 acid grassland quadrats. The SNH survey visited selected Scottish sites, resulting in quadrat data from 2,775 mire, 1,100 heathland, 275 calcareous grassland and 118 acid grassland locations. The NE grassland database contains records from 5,332 calcareous and 149 acid grassland sites, with a varying number of 2x2m quadrats per site.

Recording schemes based on occurrence and cover in quadrats were somewhat useful in attributing change to N deposition, but the CCW, SNH and NE surveys were all affected by the potential problem of biased quadrat location. The methodology for NVC recording involves first locating homogenous stands of vegetation, and then placing quadrats within these stands. This means that transitional and unusual stands are less likely to be sampled. Also, if a survey based on NVC methodology is repeated, then if a stand changes over time (e.g. by loss of species along one edge), then quadrats are likely to be relocated within the part of the stand which has changed less. These effects mean that the datasets gathered using NVC methodology are biased against recording change.

The CPS guidance encourages volunteers to repeat the survey on the same plots, and so this survey should not be subject to this bias. The CPS dataset is currently small, particularly when the data are split by habitat, which limits the analyses possible. A limited number of species are covered. However, surveyors are now able to record a larger set of species if they choose, and the dataset is likely to become increasingly useful as more repeated plot records are added.

6.2.6 Botanical recording based on hectads/tetrads

Datasets based on hectads and tetrads include the Vascular Plant Database (VPD) and the Local Change Survey (LCS) which are both run by the Botanical Society of the British Isles; the British Bryological Society (BBS) Database; and the British Lichen Society (BLS) Database. The VPD and the BBS and BLS databases record all species throughout the UK of vascular plant, bryophyte and lichen species, respectively, that grow in the wild within 10x10 km hectads. The VPD includes records since 1930, and changes between the periods 1930-69 and 1987-99 have been analysed. Records in the BBS and BLS databases span the last 50 years. The LCS records all vascular plant species that grow in the wild in 811 2x2km tetrads in a regular grid across GB, and was carried out in 1987-88 and 2003-04.

These recording schemes proved more useful than quadrat-based schemes, in general, for attributing changes in species distributions to N deposition effects (Stevens *et al* 2011). The repeated surveys in the VPD and LCS allowed temporal analysis. While none of these surveys used relocatable permanent quadrats, they were unlikely to have been strongly biased by changes in search location since they aim to search for all species in the hectad or tetrad. However, separating the effects of N pollution from other drivers was difficult, and could have been improved if more was known about other aspects of the site where a species was recorded. In particular, the lack of attribution of species records to Broad Habitats was a major source of uncertainty.

6.3 Gap analysis for current surveillance schemes

An analysis was undertaken to evaluate gaps in the evidence base for N pollution effects on terrestrial broad habitats, considering the different sources of evidence (Table 6.4). Priority habitats associated with each BAP broad habitat are listed at http://jncc.defra.gov.uk/page-5706. The gap analysis table does not include freshwater habitats, which are monitored in the Acid Waters Monitoring Network and freshwater ECN sites; issues are discussed in Kernan *et al* (2010). Marine habitats are also not included, although the table covers supralittoral habitats such as dune grassland. The ECN and ECBN site descriptions were used to indicate the number of monitoring sites under these two schemes where a habitat is present; although the habitat may not currently be included in regular floristic and soil monitoring. The number of ECN and ECBN sites should be taken as an indication - the descriptions often do not allow a specific broad habitat to be assigned, and other habitats may be present.

Table 6.4. Gap analysis for current surveillance schemes.

Broad Habitat	Data from N addition and targeted gradient studies	CS data	Other quadrat data	Hectad/tetrad data	ECN / ECBN sites	Critical load	Implications
1. Broadleaf, mixed and yew woodland	MLURI (A. Hester, R. Hewison & A. Britton) currently carrying out targeted survey of Scottish semi-natural woodland.	Not analysed separately, although plots likely to be sufficient (>100)	Original (Rodwell) NVC survey data (spatial only) and datasets from ICP forest level II plots (spatial and temporal) could be analysed. Bunce 1971 woodland survey quadrats and 2001 re-survey data, and more recent NVC data from targeted survey (e.g. by SNH) are available.	Data could be analysed in a similar fashion to that used in this project, provided records can be successfully attributed to the habitat.	18	Considered reliable. Set separately for some woodland classes	Sufficient surveillance data probably exist, and the priority is to analyse existing datasets, especially ICP forest plots. CEH (Maskell) are currently examining floristic change in broadleaf woodlands. However, the Bunce resurvey (Kirby *et al* 2005) showed that attributing change to N effects is particularly difficult for woodland, with a dominant effect of the clearance / regrowth stage on the ground flora. Effects of N are likely to be observed in faster gap closure and earlier reduction of ground-level light availability after clearcuts, and targeted monitoring of particular successional stages would be useful.
2. Conifer woodland	See MLURI study above.	Not analysed separately, although plots likely to be sufficient (>100)	Original (Rodwell) NVC survey data (spatial only) and datasets from ICP forest level II plots (spatial and temporal) could be analysed.	Data could be analysed in a similar fashion to that used in this project, provided records can be successfully attributed to the habitat.	2	Considered only ‘quite’ reliable for *Pinus sylvestris* woodland - more evidence would be useful	Sufficient surveillance data probably exist, and the priority is to analyse existing datasets, especially ICP forest plots. Issues similar to those in deciduous / mixed / yew woodland.
3. Boundary and linear features	None known	Not analysed separately, although plots likely to be sufficient (>100)	Not covered by original NVC survey.	Data could be analysed in a similar fashion to that used in this project, although small patch sizes may make habitat attribution very uncertain.	0	Not set. Could be set for specific linear habitats e.g. hedgerows if suitable data were available	Sufficient surveillance data probably exist, and the priority is to analyse existing datasets, especially those with linear plots e.g. CS, LCS. Direct pollution effects of fertiliser and pesticide drift are likely. Studies of the N deposition gradient away from roads may provide useful evidence of N effects, although these are likely to be confounded by with other effects of the road/traffic such as salting and other pollutants. CEH (Maskell) will submit a paper shortly on invasive species in linear

Broad Habitat	**Data from N addition and targeted gradient studies**	**CS data**	**Other quadrat data**	**Hectad/tetrad data**	**ECN / ECBN sites**	**Critical load**	**Implications**
							features which examines the importance of N deposition.
4. Arable and horticultural	None known	Not analysed separately, although plots likely to be sufficient (>100)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, provided records can be successfully attributed to the habitat.	2	Not set. Could be set for e.g. orchards and arable weed communities, if suitable data were available	Existing datasets are unlikely to cover arable / horticultural habitats of conservation concern. Targeted surveys would be useful for priority Arable / Horticultural habitats.
5. Improved Grass	None known	Analysed in (Maskell *et al* 2010)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, provided records can be successfully attributed to the habitat.	3	Not set. Fertiliser addition likely to have dominant effect	Atmospheric N pollution unlikely to affect conservation interest, since this is limited, although it is likely to make restoration of species-rich grassland more difficult.
6. Neutral Grass	None known	Not analysed separately; issues with habitat assignation/ definition.	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, provided records can be successfully attributed to the habitat.	2	Considered reliable for dry neutral closed grassland. Only based on 'expert judgement' for hay meadows and moist grasslands - more evidence would be useful	Major gap, in view of susceptibility of neutral grassland priority habitats to damage through eutrophication. Definitional problems in Countryside Survey limit the number of useful plots in this grassland type. Priority is analysis of existing datasets where neutral grassland priority habitats can be distinguished from calcareous, acidic and semi-improved grassland, but targeted monitoring studies of known unimproved neutral grassland sites are likely to be required.
7. Calcareous Grass	N addition experiments and targeted surveys completed, and used as the basis for the CL (Bobbink and	Analysed in Maskell *et al* (2010)	Effects on individual species observed; variable effects on mean Ellenberg N and R observed in NE NVC and LCS	Effects on individual species observed; effects on mean Ellenberg N, plant height and specific leaf area	10	Considered reliable	Given 'reliable' CL, experimental and gradient studies, and analyses in CS and the current study, there is probably not a data gap for this habitat.

Broad Habitat	Data from N addition and targeted gradient studies	CS data	Other quadrat data	Hectad/tetrad data	ECN / ECBN sites	Critical load	Implications
	Hettelingh, 2011; Carroll *et al* 2003).		surveys (current study).	observed in uplands in VPD survey (current study).			
8. Acid Grass	N addition experiments and targeted surveys completed, and used as the basis for the CL (Bobbink and Hettelingh, 2011; Stevens *et al* 2004; Stevens *et al* 2010).	Analysed in Maskell *et al* (2010)	Effects on individual species observed; variable effects on mean Ellenberg N observed in LCS and SNH NVC surveys (current study).	Effects on individual species observed; effects on mean Ellenberg N observed in lowlands in VPD and uplands and lowlands in BBS survey (current study).	5	Considered reliable	Given 'reliable' CL, experimental and gradient studies, and analyses in CS and the current study, there is probably not a data gap for this habitat.
9. Bracken	None known	Not analysed separately, although plots may be sufficient (>50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.		0	Not set.	Bracken cover has to be >95% for the habitat to be mapped as bracken in Countryside Survey; any floristic interest is likely to be in sparser stands which are defined as acid grassland. Encroachment of bracken into other habitats is an issue, but evidence that N is a causal factor is lacking.
10. Dwarf shrub Heath	N addition experiments and targeted surveys completed, and used as the basis for the CL.	Analysed in Maskell *et al* (2010)	Effects on individual species observed; variable effects on e.g. mean Ellenberg N observed in BBS, SNH NVC and LCS surveys (current study).	Effects on individual species observed; effects on mean Ellenberg N and plant height observed in spatial analysis of VPD data (current study).	12	Considered reliable for dry heath. Only considered 'quite reliable' for wet heath - more evidence would be useful	Given 'reliable' CL, experimental and gradient studies, and analyses in CS and the current study, there is probably not a data gap for dry heath, but more analyses of data from wet heaths would be useful.
11. Fen, marsh and swamp	None known	Not analysed separately, although plots may be sufficient (>50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, although small patch sizes may make habitat	5	Only considered 'quite reliable' for valley mires, poor fens and transition mires; based on 'expert judgement' for rich fens - more	Atmospheric N pollution could be of relatively minor importance if there is significant nutrient input from ground water sources. Analysis of Countryside Survey data could be productive. Suitable data from targeted surveys may also exist. Includes priority habitats, so important to

Broad Habitat	Data from N addition and targeted gradient studies	CS data	Other quadrat data	Hectad/tetrad data	ECN / ECBN sites	Critical load	Implications
				attribution very uncertain.		evidence would be useful	understand N deposition impacts, although agricultural run-off may be a more significant source of N pollution.
12. Bog	Mainly physiological effects observed in studies of Whim Bog (M19 blanket mire) (Bobbink and Hettelingh, 2011; UKREATE 2009).	Not analysed separately, although plots likely to be sufficient (>100)	Effects on individual species observed; effects on mean Ellenberg N observed in lowland bogs in SNH NVC survey (current study).	Effects on individual species observed; effects on mean Ellenberg N observed in upland bogs in VPD and BBS surveys (current study).	6	Considered reliable	Given 'reliable' CL, and experimental studies, there is probably not a data gap for this habitat, although specific analyses of CS data would be useful. Targeted monitoring studies likely to be required for raised bogs, as these are underrepresented in Countryside Survey compared to blanket bogs.
15. Montane habitats	Culardoch N addition experiment is in H13 upland heath (Britton and Fisher, 2008; Armitage 2010). Review / analysis of data from MLURI re-survey of historic vegetation plots in montane vegetation would be useful.	Plots likely too few (<50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project; relevant species likely to be restricted to the habitat, so attribution likely to be possible	1	Considered only 'quite' reliable for both moss/lichen and scrub habitats - more evidence would be useful	Major gap, in view of orographic enhancement of deposition and probable N-sensitivity of montane habitats which are likely to be weakly buffered against N pollution due to small soil C stocks. Targeted monitoring studies likely to be required.
16. Inland rock	None known	Plots likely too few (<50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, although small patch sizes may make habitat attribution very uncertain.	1	Not set - evidence would be useful	Likely to be weakly buffered against N pollution due to small soil C stocks. Targeted monitoring studies likely to be required
17. Built up areas and	None known	Plots likely too few	Not covered by original NVC	none known	0	Not set - N effects unlikely.	Not necessary, although there may be research questions regarding the role of N in

Broad Habitat	Data from N addition and targeted gradient studies	CS data	Other quadrat data	Hectad/tetrad data	ECN / ECBN sites	Critical load	Implications
gardens		(<50)	survey. LCS includes a few urban sites.				management / restoration of urban sites for nature conservation.
18. Supralittoral rock	None known	Plots likely too few (<50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, although small patch sizes may make habitat attribution very uncertain.	0	Not set - evidence would be useful	Likely to be weakly buffered against N pollution due to small soil C stocks. Targeted monitoring studies required as evidence base is very small.
19. Supralittoral sediment	CCW survey of sand dune sites in England and Wales (Jones *et al* 2002). Review / analysis of data from Newborough sand dune experiment (Plassmann, Edwards-Jones, and Jones 2009) would be useful. No known studies on shingle habitats or machair	Plots likely too few (<50)	Original (Rodwell) NVC survey data could be analysed for spatial (but not temporal) patterns.	Data could be analysed in a similar fashion to that used in this project, although small patch sizes may make habitat attribution very uncertain.	5	Considered only ‘quite’ reliable for Coastal stable dune grasslands (grey dunes); based on expert judgement for Coastal dune heaths. Shifting coastal dunes, and Moist to wet dune slacks; not set for Shingle or for Machair habitats.	Dune and shingle habitats are likely to be weakly buffered against N pollution due to small soil C stocks. Priority is review of survey & experimental data for dune grassland and dune slack habitats. Lack of information on shingle vegetation is a major gap given probable sensitivity of perennial vegetation of stony banks. Targeted survey or experimental additions is a priority

6.4 Variables potentially useful for surveillance of N effects

The current study (Stevens *et al* 2011) has assessed the responses of individual species to N deposition, and responses of summary variables based on species composition. The results, together with evidence reviewed from previous studies, allow these variables to be assessed for their utility in site surveillance and also in national-scale studies of N pollution impacts.

This section reviews variables with potential for inclusion in surveillance schemes. Sections 6.3.1, 6.3.2 and 6.3.3 discuss floristic and biogeochemical variables that can be directly measured or recorded, and these variables are summarised in section 6.3.4. Sections 6.3.5 and 6.3.6 discuss variables that can be derived from field records, and these variables are summarised in section 6.3.7.

6.4.1 Individual plant species

The recording of plant species presence and abundance has long been used to assess habitat status and change. The presence of species is commonly recorded by intensive searching within a defined area such as a site, homogenous habitat unit, or quadrat. By searching several comparable areas, the frequency of occurrence can be estimated, for example, as in the constancy measure (occurrence in five quadrats) that is used in the NVC. The abundance of a plant species is typically quantified in terms of percentage cover, although other methods such as counts of individuals or flowers are sometimes used.

Species presence is less susceptible to inter-annual variability than is cover, and the analyses in the current study (Stevens *et al* 2011) used to determine whether species responded positively or negatively to N were largely based on occurrence data. The frequency of occurrence of N-sensitive species is probably a more reliable indicator of N pollution than is cover of these species. However, it is likely that changes to cover will precede changes in occurrence, and so assessments of change in cover of N-responsive species may be useful for detecting N impacts. Visual estimation of cover is faster, and may detect more species, than objective pinpointing techniques, although the latter are less subject to observer bias (Vittoz and Guisan 2007).

Specific methods used for floristic recording vary among the recording schemes. In general, floristic data are most useful when they are (arranged by decreasing importance):

- obtained by searching standard size quadrats, typically 10x10m for woodland and 2x2m for other habitats
- obtained repeatedly from the same permanent quadrat(s)
- complete identifications of all species present, including bryophytes and lichens
- associated with estimates of frequency of occurrence, for example, in replicate quadrats
- obtained from a defined/mapped area of known habitat
- associated with measurements or visual estimates of cover

Complete or near-complete lists of species present allow all N-sensitive species to be assessed (including species whose N-sensitivity has not yet been identified), and aggregate measures to be derived (see 6.4.6). However, where it is not feasible to complete full records of occurrence or cover for all species it may be possible to focus the assessment of N impacts on ‘indicator’ species with known sensitivity to N pollution. Changes in occurrence or cover of such species may provide evidence that N pollution is damaging the site. Since these species may be changing in response to management or other factors it is not straightforward to attribute changes to a single cause, but an absence or decline in several indicator species could be considered evidence of N damage.

The point at which conditions on the site become sufficiently unfavourable for a given species to decline depends on soil and vegetation characteristics, the history of cumulative deposition, and the sensitivity of the species to nutrient-N exposure and/or low soil pH. This sensitivity is also affected by factors such as canopy height (Smart *et al* 2010). Species near to their threshold conditions for decline on the site or in the region in question would be an appropriate focus for surveillance. Such species could be identified using linked biogeochemistry - niche models, but these have not yet been widely tested and are currently not accessible for use by non-specialists. However, the threshold N loads identified for N-sensitive species (Tables 2.2-2.5) provide an indication of which species are most suitable for monitoring under a given current N load.

The set of species identified as having clear positive or negative responses in the spatial and temporal datasets are likely to be useful indicator species for N impacts. This set of species was identified by analysis of extensive datasets using a rigorous statistical approach and strict criteria applied to determine whether the response was significant, hence the evidence for these species' responses can be considered reliable. A further set of species, those identified as condition indicators in Common Standards Monitoring (CSM) guidance, have also been assessed for their ability to indicate N impacts by examining published evidence (see Appendix 1, and Stevens *et al* (2008)). These species were originally identified as an indicator of general habitat condition, rather than specifically to indicate N pollution impacts. Many of these CSM indicator species did not respond to N pollution, and the strength of evidence for responses to N varied among the species. Summarising the evidence for responses of CSM indicator species in the different habitats, Stevens *et al* (2008) identified none with strong evidence for effects of N deposition in acid grassland; four negative and eight positive indicator 'species' (one is in fact the genus *Sphagnum*) in bogs; and two positive indicator 'species' (one is the genus *Cladonia*) for heathland. In Appendix 1, five positive and one negative indicator species were identified for calcareous grassland. These species are tabulated together with those with significant responses identified in the current study in Table 6.5.

Table 6.5. Species potentially useful as indicators of N deposition in different habitats: those having significant positive or negative relationships with total N deposition in one or more of the databases analysed in (Stevens *et al* 2011) (unlabelled), excluding species with contradictory relationships in different analyses; plus species identified in Stevens *et al* (2008) or in Appendix 1 as "good", "possible" or "potential" indicators for atmospheric N deposition (labelled with *).

Habitat	Positive indicator species (negatively affected by N)		Negative indicator species (positively affected by N)	
Acid Grassland	*Cetraria aculeata*	*Peltigera didactyla*		
Lowland Acid Grassland	*Anthriscus caucalis* *Cerastium arvense* *Chamaemelum nobile* *Ophioglossum azoricum* *Ornithopus perpusillus* *Phleum phleoides*	*Thymus serpyllum* *Trifolium arvense* *Trifolium glomeratum* *Trifolium micranthum* *Veronica verna* *Vicia lathyroides*	*Lotus angustissimus* *Lotus subbiflorus* *Myosotis ramosissima*	*Trifolium scabrum* *Trifolium striatum*
Upland Acid Grassland	*Frullania tamarisci* *Racomitrium lanuginosum*	*Scapania gracilis*	*Archidium alternifolium* *Gymnocolea inflata* *Leptodontium flexifolium*	*Lophozia ventricosa* *Racomitrium ericoides* *Sanionia uncinata*

Habitat	**Positive indicator species (negatively affected by N)**	**Negative indicator species (positively affected by N)**
Lowland / upland Calcareous Grassland	*Cladonia foliacea* *Campanula rotundifolia** *Campanula glomerata** *Carlina vulgaris** *Koeleria macrantha** *Thymus polytrichus**	*Anthriscus sylvestris**
Lowland Calcareous Grassland	*Allium vineale* *Anacamptis pyramidalis* *Bromopsis erecta* *Campanula glomerata* *Carex spicata* *Carlina vulgaris* *Centaurea scabiosa* *Cynoglossum officinale* *Daucus carota* *Echium vulgare* *Geranium columbinum* *Ononis repens* *Rosa micrantha* *Spiranthes spiralis*	*Lathyrus nissolia* *Stachys officinalis*
Upland Calcareous Grassland	*Alchemilla alpine* *Dryas octopetala* *Luzula spicata* *Persicaria vivipara* *Saussurea alpina* *Saxifraga hypnoides* *Silene acaulis*	*Alchemilla xanthochlora* *Didymodon vinealis* *Leiocolea turbinata* *Myosotis alpestris* *Saxifraga aizoides* *Saxifraga oppositifolia* *Selaginella selaginoides* *Sesleria caerulea* *Tofieldia pusilla*
Lowland / upland Bog	*Cladonia portentosa* *Hylocomium splendens** *Dactylorhiza maculata** *Drosera intermedia** *Drosera rotundifolia** *Pedicularis sylvatica** *Pinguicula vulgaris** *Polygala serpyllifolia** *Sphagnum spp.**	*Deschampsia flexuosa** *Molinia caerulea** *Polytrichum commune** *Vaccinium myrtillus**
Upland Bog	*Anastrophyllum minutum* *Calypogeia sphagnicola* *Carex limosa* *Lepidozia pearsonii* *Odontoschisma denudatum* *Scapania umbrosa*	*Calypogeia neesiana* *Dicranum bonjeanii* *Gymnocolea inflata* *Lophozia incisa* *Pleurozia purpurea*
Lowland/upland Heathland	*Cetraria aculeata* *Cetraria muricata* *Cladonia cervicornis cervicornis* *Cladonia cervicornis verticillata* *Cladonia glauca* *Cladonia portentosa* *Cladonia strepsilis* *Cladonia subulata* *Cladonia uncialis biuncialis* *Cladonia spp.** *Dibaeis baeomyces* *Hylocomium splendens** *Lichenomphalia hudsoniana* *Lichenomphalia umbellifera* *Peltigera hymenina*	
Lowland Heathland	*Scleranthus annuus*	*Platanthera bifolia* *Radiola linoides* *Scilla verna*
Upland Heathland	*Anastrophyllum minutum* *Arctostaphylos uva-ursi* *Empetrum nigrum* *Fossombronia wondraczekii* *Lepidozia pearsonii* *Leucobryum glaucum* *Lycopodium annotinum* *Microlejeunea ulicina* *Trientalis europaea* *Vaccinium vitis-*	*Aulacomnium palustre* *Barbilophozia hatcheri* *Calypogeia arguta* *Cephalozia connivens* *Dicranella* *Polytrichum commune* *Racomitrium ericoides* *Scapania irrigua* *Sphagnum denticulatum* *Sphagnum fallax*

Habitat	Positive indicator species (negatively affected by N)	Negative indicator species (positively affected by N)
	idaea	*schreberiana* *Fissidens bryoides s.l.* *Gymnocolea inflata* *Hylocomium splendens* *Mylia anomala* *Odontoschisma sphagni* *Sphagnum russowii* *Sphagnum squarrosum* *Sphagnum subnitens* *Sphagnum tenellum*

It should also be emphasised that several of the species that were positively affected by N are of conservation concern under different designations (see Appendix 2). Increases in the frequency of occurrence and/or cover of such species should not be taken as a sign of negative habitat condition, although such increases may indicate that N pollution is affecting the habitat. If an increase in occurrence or cover of positively-responding species in response to N pollution is causing detrimental effects on other species, changes to these other species should be detectable directly.

Whilst difficulties of assigning species records to a particular habitat introduced some uncertainty into the analysis of species associated with N impacts, it is unlikely that a species would respond very differently to N pollution in different habitats. No species were found with significant opposite responses in different habitats. It should be noted that species were included in Table 6.5 if they responded to N in one or more habitats, even if no significant effect was recorded in other habitats. The statistical approach used was not able to detect effects in habitats where the species was very widespread (mainly present) or scarce (mainly absent), and so the absence of a significant effect in a particular habitat not should be overinterpreted as evidence that the species is not N-sensitive. For example, the positive responses to N observed in several *Sphagnum* species in upland heathland indicate that these particular *Sphagnum* species are likely to respond positively to N in general, even though this response was not detected in other habitats. Conversely, the lack of negative responses detected in the current study in other *Sphagnum* species should not be taken as evidence that these other species do not respond negatively.

Species that have been identified as N-sensitive are obvious candidates for focused monitoring, although the best method for recording changes to these species is debatable. The current or recent suitability of a site or habitat for a given species can be assessed by recording cover and/or frequency of presence in standard quadrats, although care should be taken that these quadrats are representative of the site / habitat. Species cover may be more sensitive to environmental change than presence/absence, but cover may also be subject to more variation due to short-term effects of management or weather.

Monitoring the occurrence of N-sensitive species within national botanical datasets may reveal ongoing effects of N pollution. These species may also be suitable for site-scale monitoring.

6.4.2 Field assessment of aggregate floristic measures

Plant assemblages can be assessed by analysis of systematically collected quadrat data on species presence and cover, and such approaches are the most objective and consistent. However, rapid assessments of overall characteristics can be carried out in the field and may be of some value in detecting N impacts.

The assignment of stands to particular habitat classes is common in site mapping. This is an important issue, albeit indirectly, since many of the effects of N pollution on individual species in the current study (Stevens *et al* 2011) were only observed in specific Broad Habitats. We can therefore only be confident about effects on these species where the Broad Habitat is known. Post-hoc assignments to a Broad Habitat can be made based on floristic composition, but it is easy and informative to allocate a Broad Habitat whilst in the field, for example, using the key in Maskell *et al* (2008).

Field surveyors commonly assign stands to NVC communities by reference to the descriptions and constancy tables in Rodwell (1991-2000) without formally calculating cover and constancy values across five quadrats as in the prescribed method. However, such assignations require simultaneous assessment of the whole species assemblage, and not surprisingly are strongly influenced by the surveyor (Hearn *et al* 2011). Field-assessed conformity to an NVC community is therefore not a suitable basis for assessing N pollution impacts.

Field assessment of plant functional type composition, such as proportional cover of subshrubs or graminoids, is comparatively simple. Many field surveyors are accustomed to estimating such proportions since they are used to allocate major habitat classes such as grassland vs. heathland, but volunteer recorders would probably require training before these measures could be included in volunteer-based schemes. The grass/forb cover ratio is useful as an indicator of N pollution in heathlands, acid and calcareous grasslands (Stevens *et al* 2009; Maskell *et al* 2010), and may be relevant in other habitats.

6.4.3 Biogeochemical measures, including dynamic model inputs

A variety of biogeochemical measurements on soil, plant and litter components of ecosystems have been proposed as indicators of N pollution (Morecroft *et al* 2005). These measurements are mainly based on concentrations of N or N-containing compounds in soil or in plant tissue. Ratios between N and P concentrations have also been used to assess the relative limitation by these two elements, and physiological responses of plants to N availability (e.g. enzyme production) represent another set of potentially useful measurements. However, while many significant responses have been found in specific studies, concentrations of N, P and metabolites in plant tissue are highly dependent on the species and on the age of the tissue, which presents some difficulties for their use in surveillance schemes.

Dynamic biogeochemical models have been used to calculate critical and target N deposition loads for particular habitats, using knowledge of biogeochemical processes to assess the load which will cause the habitat to go beyond a critical threshold for a chemical criterion such as pH or N leaching (Hettelingh *et al* 1995). The VSD model (Posch and Reinds 2009) is currently used in the UK to calculate critical loads and habitat areas exceeding the critical load, and it provides forecasts of changes to bulk soil properties such as C/N ratio. More sophisticated models that can predict changes to plant-available N are being developed. In recent years, biogeochemical models of N dynamics in vegetation and soil have been coupled with regression models of species occurrence in relation to measures of N availability, allowing the consequences of different N deposition rates for particular species to be predicted (de Vries *et al* 2010). Such regression models, as included in CliMOVE (Smart *et al* 2010) have great potential for connecting biogeochemical change to indicators of conservation status.

An obstacle to the development and application of dynamic modelling approaches is the lack of data on soil properties, in particular N status. National-scale modelling relies on default values for soil properties which are assigned on the basis of soil type or soil-habitat combination. Data used to generate the default values were collated mainly from acid-sensitive soils, and so dynamic model outputs for calcareous systems are particularly uncertain. Some soil properties are quick and cheap to measure in the field or using a small sample, and local measurements add greatly to the ability to detect and attribute change on a given site. Potential soil measurements are assessed in Table 6.6.

The use of dynamic models of vegetation succession, i.e. the accumulation (and removal through management) of biomass and nutrient element stocks in different types of plant such as herbs, subshrubs and trees, has been investigated within some of the model chains developed within scientific fora of the Convention on Long Range Transboundary Air Pollution. While much work remains to be done to improve the predictions from such models, the importance of vegetation structure in determining ground-level light availability means that measurements of vegetation characteristics are highly relevant to impact surveillance. Succession model inputs include management drivers such as stocking rates and grazer-specific effects on plant functional types, which are beyond the scope of this report. However, measures of vegetation structure are useful checks on the outputs from such models, as well as being very useful *per se* as indicators of stock (e.g. habitat characteristics used in CSM assessments) and of pressure (since low ground-level light availability is a key pressure influencing species occurrence). Simple biomass and canopy height measures are therefore also included in Table 6.6.

The variables considered can be divided into those useful as chemical indicators or to set up and test dynamic models (soil measurements, biomass and canopy height), and those which are more directly relevant to conservation status (species lists), although the latter are also important for testing the latest generation of niche occupancy models.

6.4.4 Summary of variables that can be directly measured or recorded

Table 6.6. Directly measurable variables with potential for inclusion in site and national surveillance schemes

Measurement	How	Sensitivity to N impacts	Discrimination from other drivers	Relationship to dynamic models of N impacts	Assessment
Species occurrence	Presence of all or selected species	Poor to good, depending on the species	Good, if rigorous statistical approach used	Good, for niche occupancy models	Moderately expensive (may depend on trained field surveyors). Focused survey of sensitive species may be cheaper.
Species cover	Cover of all or selected species	Less evidence than for occurrence data	unknown	Not currently a model output	Moderately expensive (may depend on trained field surveyors)
Broad Habitat	Using key	variable	none	Key input parameter	Cheap and very useful for modelling and analysis, although sensitivity to N impacts unknown and variable
Grass/Forb cover ratio	Visual estimation	Good for some habitats	poor	Not currently a model output	Cheap and useful for some habitats
Soil organic horizon depth	In the field e.g. by inserting rod	unknown	none	Key input parameter	Cheap and very useful as an input parameter
Soil pH in water	On 0-15 cm sample, in laboratory	Sensitive to acidification	Poor; [recovery from] S deposition remains the dominant driver	Key output for model testing	Cheap. Field measurement may be possible.
Soil total C / N ratio	On 0-15 cm sample, in laboratory	Limited - slow to change, and may be stabilised by C inputs	Good	Key input parameter	Depends on lab facilities; moderately cheap.
Soil available N concentration	On 0-15 cm sample, in laboratory	Sensitive	Good	Key output for testing more detailed soil models	Depends on lab facilities; expensive.
Plant tissue N concentration	On standard sample, in laboratory	Sensitive, within a given species	Good	Not currently a model output	Moderately cheap; promising if standardised for species and type/age of tissue.
Canopy height	e.g. visual assessment; dropped disc; laser rangefinder	Management-dependent	Poor; e.g. greatly affected by management	Key output for testing detailed vegetation models, and key input for niche models	Indicator of light availability, although not of production. Cheap.
Standing biomass	Peak biomass harvest, in summer.	Management-dependent	Poor; e.g. greatly affected by management	Key output for testing detailed vegetation models	Moderately expensive
Productivity	Peak or repeated biomass harvest, from a grazing exclosure.	Sensitive	Reasonable, where N limits production	Key output for testing detailed vegetation models	Requires repeated visits. Likely to underestimate total productivity due to small (e.g. invertebrate) grazers.

6.4.5 Species diversity

Species diversity, whether defined simply as richness (number of species) or using an index that includes a measure of the evenness of the assemblage such as the Shannon index, is an important aspect of overall biodiversity, and is sometimes referred to in CSM guidance or other legislative aspects of conservation status. However, species richness is difficult to assess quickly, since all species should be identified. Other indices of diversity depend also on abundance (e.g. cover) estimates for each species, so are still more time-consuming. Species richness is strongly scale-dependent, hence cannot be compared between, for example, quadrat data and species lists for a habitat or site.

Species-richness was not always significantly negatively related to N deposition in analyses of national-scale quadrat data, in contrast to effects seen in previous work (e.g. Maskell *et al* 2010). This may be an artefact, for the reasons discussed in Stevens *et al* (2011). In particular, since the quadrats in these datasets were located with the intention of sampling specific NVC communities, overall changes to the habitat on a site may have been obscured.

6.4.6 Species-groups

The term species-group is used here to describe measures which depend on groups of species, whether these groups are taxonomic, phytosociological, related to growth characteristics, or (as with Ellenberg scores) related to the ecology of the species. Most of the discussion here relates to variables summarising occurrence data, but variables summarising cover data are also considered.

Taxonomic groups (at levels higher than species) are of doubtful value for surveillance of N effects, since differential responses have been observed of individual species in the same genus, family or division. For example, positive and negative responses to N deposition were observed in different bryophyte species, and in different species of *Trifolium*. The genus *Sphagnum* deserves particular mention since it is included in Annexe V of the HD; although only positive (or non-significant) effects of N deposition were observed in the current study, negative effects of N have frequently been observed in other studies, and so recording at the genus level does not seem a suitable basis for surveillance.

Phytosociological groups have been systematised for the UK in the NVC (Rodwell 1991-2000), and, given suitable data on the frequency of occurrence, and cover, of species, the similarity of a plant assemblage to particular NVC communities or sub-communities can be quantified. However, whilst NVC categories are used in CSM to describe habitats, the CSM guidance warns against using conformity to NVC as a criterion for assessing the status of a habitat feature. The consistency of NVC assignment by different surveyors has been questioned, mainly because of the difficulty of assigning boundaries to stands of a particular NVC type (Hearn *et al* 2011). If quadrats are spatially assigned at random, and objective methods are used to assess similarity to NVC types, there is some potential to assess habitat status, particularly if permanent quadrats are used to eliminate the problem of prior habitat assignment.

N deposition increases grass:forb cover ratios in heathland and in acid and calcareous grassland (Maskell *et al* 2010; Stevens *et al* 2009), so this summary variable is useful for N surveillance, as described in section 6.4.2. However, variables summarising occurrence in relation to plant growth characteristics showed little promise in the analyses of national datasets. There was little consistency of response in the occurrence of species with similar growth-form, such as graminoids or sub-shrubs. Different responses of occurrence and cover are perhaps to be expected, since occurrence niches are highly species-specific. There was some evidence that N deposition increased mean typical canopy height for present species (in Lowland Acid Grassland and in Upland Calcareous Grassland) and mean specific leaf area for present species (in Lowland and Upland Acid and Calcareous Grassland), but this response was not consistent for all habitats. Further work would be required to determine whether these values for mean canopy height and specific leaf area, as derived from typical values for present species, can be related to field measurements of canopy height or specific leaf area.

Species-groups based on broader ecological characteristics were more clearly related to N deposition. Ellenberg R score has been shown to have a negative relationship with N deposition in calcifuge grasslands (Stevens *et al* 2010), and may have some potential for use in surveillance, although there were few clear effects of N deposition on mean Ellenberg R score in the current study (Stevens *et al* 2011). Ellenberg N score, in contrast, showed a fairly consistent increase with N deposition across analyses of different datasets for Lowland acid grassland, Upland calcareous grassland, Upland bog and Upland heathland.

6.4.7 Summary of variables derivable from floristic measurements

Summary variables for floristic data are summarised in Table 6.7. Variables that can be derived from floristic records can also be calculated from outputs from the niche occupancy models, which predict likely occurrence of individual species. This provides an important test of such models.

Table 6.7. Derived variables with potential for inclusion in site and national surveillance schemes

Derived variable	**How**	**Sensitivity to N impacts**	**Discrimination from other drivers**	**Assess-ment**
Species richness	Number of species present	Sensitive, in some habitats	Poor	Useful
Diversity/ evenness indices	From cover data e.g. Shannon index	Sensitive, in some habitats	Poor	Useful
Abundance of broader taxa	e.g. cover of bryophytes	Depends on taxon, e.g. bryophytes vary in N response	Poor	Not useful
Cover proportions of plant functional types	e.g. grass/forb ratio	Sensitive, in some habitats	Poor	Useful
Similarity to target assemblage	e.g. similarity to NVC community	Unknown	Poor	Probably useful
Composition in terms of target species	e.g. comparison to CSM indicator lists	Unknown	Poor	Probably not useful
Mean Ellenberg R	mean for present species	Sensitive, in some habitats	Poor; affected by S deposition	Useful
Mean Ellenberg N	mean for present species	Sensitive, in many habitats	Reasonable, although other drivers such as temperature and phosphorus affect productivity and hence Ellenberg N	Useful
Mean typical canopy height	Mean typical height for present species	Sensitive, in some habitats	Unknown	Probably useful
Mean typical specific leaf area	Mean typical SLA for present species	Sensitive, in some habitats	Unknown	Probably useful

6.5 Improving surveillance for N effects

6.5.1 Relating evidence of species effects to critical loads

The risk of impacts of atmospheric N pollution are assessed using the concept of critical load (CL), a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge. Critical loads for N are set empirically, using evidence from: long-term field experiments with realistic manipulations of N load; targeted field surveys; and, to a lesser extent, broader ecological surveillance datasets. The CL values used in Europe were revised in June 2010 in a workshop in Noordwijkerhout (Bobbink and Hettelingh, 2011). Habitat-specific CLs will be discussed in section 6.4.2. Pressure due to N pollutant deposition is mainly quantified in terms of CL exceedence, which is mapped at national scale by the National Focal Centre (http://critloads.ceh.ac.uk).

The evidence used in the recent revision of CLs was based mainly on effects observed in field and mesocosm N addition studies, with targeted field studies used as additional evidence, and some consideration of outputs from dynamic ecosystem models. Evidence from broader ecological surveillance datasets, such as the niche models defined in (Smart *et al* 2010) or in the current study (Stevens *et al* 2011) was not included in the revision. Response models for individual species with respect to N deposition and/or availability thus provide independent evidence of N effects that could be used to evaluate or compare with the existing CLs.

Critical loads for habitats included in the current study, as set at the 2010 Noordwijkerhout workshop, are set out in Table 6.8. The species identified in Tables 2.2-2.5 as being inhibited include many inhibited at deposition rates of only 5-10 kg N ha^{-1} y^{-1}, in each habitat. However, some species were not found to be inhibited until much higher deposition loads.

Table 6.8. Critical loads (Bobbink and Hettelingh 2011) for habitats included in Stevens *et al* (2011).

Habitat	EUNIS class	Critical load kg N ha^{-1} y^{-1}
Acid grasslands	E1.7	10-15
Calcareous grasslands	E1.26	15-25
Heathlands	F4.11, F4.2	10-20
Bogs	D1	5-10

In conclusion, evidence from this project broadly supports the critical loads risk assessment approach, although some species continue to be lost both above and below the critical load.

6.5.2 Coverage of broad habitats by critical loads

For habitats which were not covered by the current study, it is useful to refer to habitat-specific critical loads as defined by the Noordwijkerhout workshop datasets (Bobbink and Hettelingh 2011). These are listed for selected UK habitats in Table 6.9.

Table 6.9. Critical loads (Bobbink and Hettelingh 2011) for selected terrestrial UK habitats not included in Stevens *et al* (2011). The reliability of the critical load is indicated by: ## reliable; # quite reliable; and (#) expert judgement.

Habitat	**EUNIS class**	**Critical load kg N ha^{-1} y^{-1}**
Mid-upper, and pioneer and low-mid, salt marshes	A2.53, A2.54, A2.55	20-30 (#)
Shifting coastal dunes	B1.3	10-20 (#)
Coastal stable dune grasslands (grey dunes)	B1.4	8-15 #
Coastal dune heaths	B1.5	10-20 (#)
Moist-to-wet dune slacks	B1.8	10-20 (#)
Valley mires, poor fens and transition mires	D2	10-15 #
Rich fens	D4.1	15-30 (#)
Montane rich fens	D4.2	15-25(#)
Low and medium altitude hay meadows	E2.2	20-30 (#)
Molinia caerulea meadows	E3.51	15-25 (#)
Heath (Juncus) meadows and humid (Nardus stricta) swards	E3.52	10-20 #
Moss- and lichen dominated mountain summits; Alpine and subalpine acid grasslands; Alpine and subalpine calcareous grasslands	E4.2, E4.3, E4.4	5-10 #
Arctic, alpine and subalpine scrub habitats	F2	5-15 #
Fagus woodland	G1.6	10-20 (#)
Acidophilous Quercus-dominated woodland	G1.8	10-15 (#)
Meso- and eutrophic Quercus woodland	G1.A	15-20 (#)
Pinus sylvestris woodland south of the taiga	G3.4	5-15 #
Broadleaved deciduous woodland	G1	10-20 ##
Coniferous woodland	G3	5-15##

Critical loads for the majority of these habitats are “based on expert judgment” i.e. fall into the lowest reliability class. The evidence base for these habitats could be strengthened using several approaches:

a review existing N manipulation and/or gradient studies within these habitats to ensure that none were left out of the Noordwijkerhout review;
b establish new N manipulation and/or gradient studies within these habitats;
c analyse species occurrence datasets in relation to these habitats, as was done for acid and calcareous grasslands, heathlands and bogs;
d analyse species occurrence without relating to habitats, and subsequently assign species to habitats they are likely to occur in.

Relevant N manipulation and/or gradient studies within several of these habitats are probably available. For example, while the Noordwijkerhout review makes some reference to analyses of ICP Forest Level II plots, it is not evident that data on floristic change in UK forests were included. A thorough review of the published and grey literature from UK studies would be useful. New manipulation and gradient studies are expensive to set up, and so may not be a viable source of evidence in the short term.

The habitats included in Stevens *et al* (2011) were chosen mainly on the basis of their sensitivity to N, but they are also extensive habitats for which many data exist even in non-targeted surveys. Extending the approach to other habitats is possible in principle, and some suggestions have been made in Table 6.4 as to where data may exist for other habitats, but a more thorough preliminary study of data availability for each habitat would be advisable.

Approach d assumes that species responses are not habitat-dependent. This assumption is probably true in most cases, but is hard to test. As noted above, the lack of a significant response in one habitat should not be overinterpreted as evidence of no response to N deposition. The absence of species with opposite responses in different habitats in Stevens *et al* (2011) provides some indication that responses are species- rather than habitat-specific, but cannot be said to be solid evidence. Nevertheless, this approach may be the most viable for habitats where data are lacking. As well as the occurrence models fitted with respect to N deposition in Stevens *et al* (2011), models are available that relate species occurrence to soil N characteristics, via mean Ellenberg N (Smart *et al* 2010). Neither of these studies has included exclusively coastal species, and so coastal habitats present an evidence gap, although the models in Smart *et al* (2010) do include many species typical of dune grasslands.

6.5.3 Recommendations for recording schemes

Species data are critical components of a monitoring scheme, and improving the objectivity of species data recording would greatly increase the ability of CSM and the NVC-based recording schemes to detect N pollution signals. Declines in presence or abundance of species of conservation concern may in some cases be a direct indication of N pollution damage, since 32 out of the 91 species affected by N in spatial and temporal analyses in the current project also appeared in lists of species of direct conservation concern (Table 6.11). Changes in the presence and abundance of typical species (identified in Article 17 reporting), or those known to be responsive to N pollution, would also be very informative.

Consideration should be given to including N-sensitive species in lists of indicator species of site condition. However, complete species lists, preferably including measures of frequency and cover, are undoubtedly the most useful. These also allow comparison with past datasets, and allow for future changes in the set of species considered most useful to monitor.

Broad-scale surveys are likely to reveal many species that are present in nearly all examples of a given habitat, and species that are very rarely present. It is difficult to examine the effects of environmental drivers on occurrence of such highly prevalent or rare species, and so the species for which effects of N could be shown in Stevens *et al* (2011) all had low to intermediate prevalence. Effects on rare species are very significant from a conservation perspective. Targeted surveys of sites where rare species are known to occur are more likely to give sufficient presence data to allow effects of N pollution to be assessed, and this approach has proved successful in assessing the N-sensitivity of four rare coastal species (Jones 2007).

The threat from N pollution to a species on a particular site is related to the niche for that species in relation to N availability, to current and cumulative N deposition, and to the buffering capacity of the ecosystem. Where site-specific data exist for soil and vegetation properties, and using modelled estimates of local N deposition rate, it may be possible to identify species at particular risk on a given site, and thus in particular need of monitoring.

Some soil and vegetation properties useful for setting up and testing dynamic models are cheap and quick to measure, and could be added to broad-scale as well as site-based monitoring schemes. Including the collection of a small soil sample in monitoring schemes would allow pH and C/N to be measured where resources allow.

Measurements of vegetation structure and productivity are very useful for assessing effects of N on above-ground plant competition. Productivity can be estimated by harvesting biomass from a grazing exclosure, but this requires repeated visits and sample drying and weighing facilities so is unsuitable for most recording schemes. Biomass under normal management is also informative, but also requires sample processing. Vegetation height is relatively quick to measure, and is a useful indicator of vegetation structure. Height data could be improved by standardising methods for visual estimation, or considering more objective approaches such as using a dropped disc or laser rangefinder.

Recommendations for recording schemes aimed at improving the evidence base for N pollution effects are made in Table 6.10. This gives an overall indication of whether the suggested variables are useful for detecting and discriminating effects of N pollution and appropriate for the different types of scheme, although some of the recommended variables have only been proven to respond to N pollution in particular habitats. Relative collection and analysis costs of these variables are also indicated. Decisions on which variables should be added to which schemes should be made on the basis of more detailed cost:benefit analysis, including the likely number of sites to be assessed. Volunteer schemes are likely to prove increasingly useful sources of surveillance data, and thought should be given to the possibility of incorporating variables sensitive to N pollution into the Local Change Survey or other volunteer schemes.

Table 6.10. Recommendations for changes to field-based surveillance schemes to improve detection and attribution of N pollution effects in broad scale hectad/tetrad-based, broad scale quadrat-based surveillance (e.g. national floristic recording schemes) and site-specific surveillance. These are assessed without considering costs, as unsuitable (N), desirable (D) or essential (E). Relative cost is indicated separately.

Recommendation	**Cost**	**Broad-scale hectad/ tetrad**	**Broad-scale quadrat**	**Site-specific**
Use a defined area for recording, preferably 2x2m.	Low	N	E	E
Record quadrat locations so they can be re-found	Low	N	E	E
Record presence of taxa known to be N-sensitive	Low	D	D	D
Identify all taxa to species level, including bryophytes and lichens.	Medium	D	D	D
Estimate cover as well as presence	Low	N	D	D
Estimate grass:forb cover ratio in the field	Low	N	D	E
Record the Broad Habitat within which each measurement is taken.	Low	E	E	E
Record the height of the vegetation (including tree canopy) e.g. by visual estimation or using a laser range-finder	Low	D	D	D
Record the standing biomass of the vegetation e.g. by harvesting a defined area	Medium	N	N	D
Record the potential production of the vegetation e.g. by installing exclosures and measuring peak biomass	High	N	N	D
Sample soil and analyse for simple indicators of acidification and eutrophication (see below). Sampling the 0-15 cm depth layer allows comparison with the large Countryside Survey dataset.	Low to High	N	D/E	D/E
• Measure soil pH	Low	N	E	E
• Maintain accessible databases, including metadata on units and methods, preferably on the National Biodiversity Network (http://www.nbn.org.uk/). Measure soil total N% and C%	Medium	N	D	D
• Measure soil available N	High	N	D	D
• Measure soil organic horizon depth	Low	N	D	D
Measure N content in standard plant tissue	Medium	N	D	D

Recommendation	Cost	Broad-scale hectad/ tetrad	Broad-scale quadrat	Site-specific
Record the location of soil sampling in relation to floristic recording.	Low	N	E	E
Install suction lysimeters to sample soil solution and analyse for NH4, NO3 and if possible dissolved organic N.	High	N	N	D

Once floristic data have been recorded in the field and transferred into a usable form such as a database, summary variables can be derived. The derived summary variables listed in Table 6.11 have been shown to be affected by N deposition, at least in certain habitats, and so provide a useful focus for analysis of floristic data.

Table 6.11. Recommendations for analyses of variables that can be derived from field data, to improve detection and attribution of N pollution effects.

Recommendation	Cost
Analyse floristic presence / cover data for species-richness and Shannon diversity/evenness index	Low if data exist
Analyse floristic presence / cover data using species-groups based on:	Low if data exist
• proven N-sensitivity	Low if data exist
• Ellenberg N score	Low if data exist
• Ellenberg R score	Low if data exist
• grass:forb cover ratio	Low if data exist
• typical height of present species	Low if data exist
• typical Specific Leaf Area of present species	Low if data exist
Maintain accessible databases, including metadata on units and methods, preferably on the National Biodiversity Network (http://www.nbn.org.uk/).	Medium

6.6 Conclusions for surveillance

Ample evidence exists that N pollution is having chronic effects on UK habitats, causing the loss of sensitive species and an overall decline in habitat quality. Such changes were observed in the current study (Stevens *et al* 2011) by analysis of large-scale surveillance datasets, and provide good evidence that critical load exceedence can be related to biodiversity loss. However, detecting such changes on individual sites is difficult, since the decline and loss of species is gradual and therefore hard to observe without specific monitoring over time. In particular, the most sensitive species are likely already to have been lost from a given site in a high deposition area, and it is not easy to identify which species are next at risk.

N effects on the broad habitats covered in the current study (upland and lowland heath, bog, calcareous grassland and acid grassland) have perhaps received adequate attention. Other habitats for which sufficient survey data probably exist include broadleaf and coniferous woodland, linear features, wet heath and fen, and further desk-based study could reveal the importance of N pollution for these habitats. Several broad habitats are either unlikely to be affected by N pollution or have little nature conservation interest, such as urban habitats and bracken, although more understanding of N effects on bracken extent would be useful. Sufficient field data do not currently exist to assess N effects in several habitats: priority arable and horticultural habitats such as field margins and orchards; neutral grassland; raised bogs; montane habitats; inland rock; supralittoral rock; and supralittoral sediment.

Key recommendations for improving the ability of site monitoring to detect N effects are to use permanent quadrats for floristic recording, preferably recording all species to maximise the flexibility of subsequent analyses; and to include measures of N availability (e.g. total C /

total N ratio, or mineralisable N) and of biomass productivity, to increase the chance that observed floristic change can be attributed to N effects.

By further analysis of existing datasets, by continuing the excellent work carried out under the different surveillance schemes to extend the time-series of the datasets, and by making the relatively small changes to such schemes that have been suggested in this section, the evidence base for N effects on biodiversity could be considerably strengthened.

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Appendix 1 Calcareous grassland CSM indicator species

Assessment of the suitability of CSM indicator species for calcareous grasslands for detection of N deposition impacts

For calcareous grassland the existing CSM guidance (JNCC 2004a, 2006) for positive and negative site condition indicators have been examined to identify whether they can be used to detect and attribute impacts of N deposition using review of the scientific literature, comparison with local and national data sets, ecological floras and Ellenberg values to evaluate positive and negative indicators. In this section the term ‘evidence’ refers to peer-reviewed literature. Responses to both eutrophication and acidification are considered as acidification is clearly related to N deposition but only responses to N deposition are considered e.g. eutrophication from other sources is not considered. Positive site condition indicators could be described as indicators of lower levels of N deposition. Negative site condition indicators are indicators of higher levels of N deposition. Indicators that are not species based (i.e. a group of species or a genus) have been removed as different species in the group may respond differently making them less useful as indicators.

Lowland calcareous grassland (JNCC 2004)

a Positive site condition indicators

- *Acinos arvensis* - Fertiliser experiments have shown reductions in this species (Davis *et al* 1993) but these were not N alone so further investigation is needed into the response of this species.

- *Agrimonia eupatoria* - This is a species of more or less infertile environments (Hill *et al* 1999) but there has been no specific research on it in relation to N deposition.

- *Angelica sylvestris* - This is a species of moderately fertile environments (Hill *et al* 1999) so may not be suitable as an indicator of good site condition with respects to N deposition but there has been no specific research on it in relation to N deposition.

- *Antennaria dioica* - In controlled experiments *A. dioica* has been shown to be negatively impacted by low pH and high concentrations of ammonium (van den Berg, Dorland *et al* 2005) but no effects of N addition were found in pot experiment (van den Berg *et al* 2008).

- *Anthyllis vulneraria* - This is a species of infertile habitats (Hill *et al* 1999) but although it may be expected to decline with N addition this species has not been investigated in relation to N deposition.

- *Armeria maritima* - Mainly restricted to coastal areas, but otherwise inland very locally distributed e.g. mine waste sites making it unsuitable as an indicator of N deposition.

- *Asperula cynanchica* - This is a species of infertile habitats (Hill *et al* 1999) but although it may be expected to decline with N addition this species has not been investigated in relation to N deposition.

- *Astragalus danicus* - Although this species is restricted to low nutrient habitats (Hill *et al* 1999) there is no evidence in the literature that it is impacted by N deposition. Consequently separating a response from other sources of eutrophication (e.g. fertilisation) would not be possible.

- *Campanula glomerata* - Objective 1 of this study found a negative response for *C. glomerata* in response to N deposition in BSBI Local Change data (Stevens *et al* 2011) suggesting it may be suitable as an indicator of N deposition

- *Campanula rotundifolia* - *C. rotundifolia* is a species of infertile habitats (Preston *et al* 2002; Hill *et al* 1999) and is described as intolerant of competition with vigorous grasses (Sinker *et al* 1991). Stevens *et al* (2004) identified this as a species that showed declines along the UK gradient of N deposition in acid grasslands. This is a potential indicator of N deposition although further investigation would be needed to determine if the decline identified in acid grasslands could also be found in calcareous grasslands.

- *Carex flacca* - Carroll *et al* (2003) found significant declines in this species in response to N addition in an experimental manipulation but these effects were not significant until very high treatment levels. Further research is needed to confirm whether this species is impacted at lower deposition levels.

- *Carlina vulgaris* - Stevens *et al* (2011) found a clear decline of this species in a spatial analysis of species occurrence with N deposition in lowland calcareous grassland using vascular plant database data suggesting it may be a suitable indicator of N deposition impact.

- *Centaurea nigra* - This is a species of moderately fertile environments (Hill *et al* 1999) so may not be suitable as an indicator of good site condition with respects to N deposition but there has been no specific research on it in relation to N deposition.

- *Centaurea scabiosa* - Stevens *et al* (2011) found a decline in probability of presence of this species with increasing N deposition in lowland calcareous grassland using BSBI local change data, however, the trend was not clear and further investigation is needed to confirm whether this species is suitable as an indicator of site condition in response to N deposition.

- *Centaurium erythraea* - Stevens *et al* (2011) found no significant increases or decreases in probability of presence of this species with respect to N deposition.

- *Cirsium acaule* - Stevens *et al* (2011) found no significant increases or decreases in probability of presence of this species with respect to N deposition.

- *Cirsium heterophyllum* - This species is restricted to Northern England and Scotland so may not be suitable for use as an indicator of response to N deposition.

- *Clinopodium vulgare* - Stevens *et al* (2011) found no significant increases or decreases in probability of presence of this species with respect to N deposition.

- *Cochlearia pyrenaica* - This species has a very restricted distribution so may not be suitable for use as an indicator of response to N deposition.

- *Dianthus deltoids* - Stevens *et al* (2011) found no significant increases or decreases in probability of presence of this species with respect to N deposition.

- *Draba incana* - This species has a very restricted distribution so is not suitable as an indicator if N deposition.

- *Dryas octopetala* - There is no evidence linking occurrence of this species to N deposition.

- *Erigeron acer* - This species is restricted in its distribution to areas of high N deposition so is unlikely to make a good positive indicator.

- *Erodium cicutarium* - This species is found at intermediate nutrient levels (Sinker *et al* 1991; Hill *et al* 1999). This means it is unlikely to be suitable as a positive indicator of site condition in relation to N deposition.

- *Filipendula ulmaria* - This competitive species is likely to increase with N deposition (Pauli *et al* 2002) so would not make a good positive indicator of site condition in response to N deposition.

- *Filipendula vulgaris* - This competitive species is likely to increase with N deposition (Wilson *et al* 1995) so would not make a good positive indicator of site condition in response to N deposition.

- *Fragaria vesca* - Several surveys in calcareous woodlands have found increases in this species (e.g. Diekmann and Falkengren-Grerup 2002) which have been related to N deposition. There has been no work on this species in grasslands in relation to N deposition.

- *Galium saxatile* - This species is described by Preston *et al* (2002) as a useful indicator of unimproved grasslands, however, it has an Ellenberg N value indicative of intermediate nutrient status (Hill *et al* 1999). Despite frequently occurring in a survey of acid grasslands in relation to N deposition there was no evidence to indicate that *G. saxatile* responded to N deposition (Stevens *et al* 2006).

- *Galium sterneri* - This species is typical of very infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Galium verum* - *G. verum* occupies a wide range of habitats (Preston *et al* 2002) but is vulnerable to competition from vigorous grasses. Mesocosm experiments have shown dramatic declines in this species in competition with grasses (van den Berg, Tomassen *et al* 2005).

- *Gentiana verna* - This species is typical of very infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Geranium sanguineum* - There were no significant effects of N deposition on this species in the vascular plant database analysis conducted by Stevens *et al* (2011) suggesting it may not be suitable as an indicator of N deposition.

- *Geranium sylvaticum* - Although there has been some research into responses of *G. sylvaticum* in forests (e.g. Diekmann *et al* 1999; Diekmann and Falkengren-Grerup 1998) to N deposition this has not been investigated in calcareous grasslands.

- *Geum rivale* - As with *G. sylvaticum* although there has been some research into responses of this species in forests (e.g. Diekmann *et al* 1999; Diekmann and Falkengren-Grerup 1998) to N deposition this has not been investigated in calcareous grasslands.

- *Helianthemum nummularium* - In an experiment in the Peak District N addition was found to increase tissue N content (Morecroft *et al* 1994; Horswill *et al* 2008) but impact on the cover or occurrence of this species have not been reported.

- *Helianthemum oelandicum* - This species is typical of very infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Hippocrepis comosa* - *H. comosa* is typical of infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Hypericum pulchrum* - *H. pulchrum* is typical of infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Knautia arvensis* - Stevens *et al* (2011) found no clear increases or decreases in this species in relations to N deposition.

- *Leontodon hispidus* - Phoenix *et al* (2004) found changes in the tissue chemistry of this species but changes in presence or occurrence have not been investigated.

- *Leontodon saxatilis* - This species is typical of infertile conditions (Hill *et al* 1999) but has not been investigated in relation to N deposition.

- *Linum catharticum* - This species is typical of infertile conditions (Hill *et al* 1999) and has very small stature suggesting it would struggle to compete for light in a dense canopy but it has not been investigated in relation to N deposition.

- *Listera ovata* - This species is typical of intermediate fertility (Hill *et al* 1999) so is unlikely to be a positive indicator of site condition in response to N deposition.

- *Lotus corniculatus* - *L. corniculatus* is a species of nutrient-poor habitats (Hill *et al* 1999; Sinker *et al* 1991). It potentially forms N_2 fixing symbiosis so would be expected to be N sensitive. Stevens *et al* (2004) identified this as a species that showed declines along the UK gradient of N deposition in acid grasslands but it has not been investigated in calcareous grasslands.

- *Mercurialis perennis* - This species has not been investigated in relation to N deposition in calcareous grasslands but in forests Diekmann and Falkengren-Grerup (2002) suggested that *M. perrennis* is favoured by N deposition.

- *Myosotis alpestris* - There is no evidence linking the occurrence of this species to N deposition.

- *Origanum vulgare* - Spatial and temporal analysis by Stevens *et al* (2011) found no relationship with N deposition in either the vascular plant database or BSBI Local change data suggesting it is not a good indicator of N deposition.

- *Ornithopus perpusillus* - A negative response was found in temporal analysis of this species in BSBI local change data but in the vascular plant database the relationship was not significant in the spatial analysis and hump-backed in the temporal analysis (Stevens *et al* 2011) suggesting further research is needed to confirm the response of this species.

- *Parnassia palustris* - In heathlands this species has shown a negative response to N addition (Roem *et al* 2002) but there has been no investigation of its response in calcareous grasslands.

- *Persicaria vivipara* -In the BSBI Local Change data the spatial response was hump-backed suggesting further research is needed to confirm the response of this species (Stevens *et al* 2011).

- *Pilosella officinarum* - *P. officinarum* has a low Ellenberg N value (Hill *et al* 1999) but it is found in more nutrient rich habitats and across the whole country (Preston *et al* 2002) suggesting it is not very sensitive to N deposition. It is also part of a taxonomically difficult group, making it less suitable for use as an indicator.

- *Pimpinella saxifraga* - *P. saxifraga* is commonly suppressed in fertilised grassland (Grime *et al* 2007) and has a moderately low Ellenberg N value (Hill *et al* 1999). There is no evidence of a response to N deposition.

- *Pinguicula vulgaris* - *P. vulgaris* is an insectivorous plant typical of infertile habitats (Hill *et al* 1999). There has been no research relating the presence of this species in calcareous grasslands to N deposition.

- *Plantago coronopus* - This species has an intermediate Ellenberg N value (Hill *et al* 1999) and there is no evidence relating it to N deposition.

- *Plantago maritime* - This species is restricted to coastal sites making it unsuitable for use as an indicator of N deposition.

- *Plantago media* - *P. media* is a species of more or less infertile sites (Hill *et al* 1999) but its response to N deposition has not been investigated.

- *Polemonium caeruleum* - This species has a rather limited distribution so is not suitable as an indicator of N deposition.

- *Potentilla erecta* - This species is found in too great a range of nutrient status to be an indicator of N deposition in calcareous grasslands.

- *Primula farinosa* - This species has a very limited distribution so is not suitable as an indicator of N deposition.

- *Primula veris* - *P. veris* has shown a negative response to N deposition in forests (Diekmann and Falkengren-Grerup 1998) but has not been investigated in calcareous grasslands.

- *Rumex acetosella* - *R. acetosella* has a moderately low Ellenberg N score (Hill *et al* 1999) and is not tolerant of competition with tall grasses (Sinker *et al* 1991). It is a colonist of bare ground on acid soil which may affect its suitability as an indicator of N deposition.

- *Sanguisorba minor* - Stevens *et al* (2011) found no significant effect of N deposition on *S. minor* in tetrad and hectad data indicating it may not be suitable as an indicator of N deposition.

- *Sanguisorba officinalis* - This species is typical of habitats with medium to high nutrient levels (Hill *et al* 1999) so is not suitable as a positive indicator of N deposition impacts.

- *Saxifraga hypnoides* - *S. hypnoides* showed no significant effect of N deposition in the spatial analysis of vascular plant data but did show a negative effect in the temporal analysis (Stevens *et al* 2011). The inconsistency of the results means that further investigation is needed to assess the suitability of this species as an indicator of N deposition.

- *Scabiosa columbaria* - Wilson *et al* (1995) found a negative response in the above-ground biomass of this species to N addition but this was not significant until levels of 80 kg N ha-1 yr-1. This level is much higher than current N deposition in the UK so the results suggest that it is not sensitive enough to be an indicator of N deposition.

- *Sedum acre* - This species is found in very nutrient poor environments (Hill *et al* 1999) but is limited to skeletal, or virtually non-existent, acidic or basic soils (Preston *et al* 2002) which may make it less suitable as an indicator in dry acid grasslands.

- *Sedum anglicum* - As with *S. acre*, *S. anglicum* is found in nutrient poor habitats but is typical of open rock, mine spoil and old walls (Preston *et al* 2002) meaning it may not be suitable as an indicator of N deposition in dry acid grasslands.

- *Selaginella selaginoides* - There is no evidence relating this species to N deposition.

- *Serratula tinctoria* - This is a species of nutrient poor habitats (Hill *et al* 1999) but there is no evidence of it responding to N deposition or fertiliser addition.

- *Sesleria caerulea* - There is no evidence relating this species to N deposition.

- *Stachys officinalis* - This species showed a mix of non-significant and positive relationships with N deposition in analysis of large-scale vegetation data (Stevens *et al* 2011) suggesting it is not suitable as a positive indicator of site condition with respect to N deposition.

- *Succisa pratensis* - *S. pratensis* has been shown in a laboratory experiment to have a reduced biomass at high ammonia concentration and low pH (van den Berg, Dorland *et al* 2005) but there is no field evidence to show the response of this species in the field.

- *Teesdalia nudicaulis* - This species has a low Ellenberg N value (Hill *et al* 1999) but there is no evidence relating it to N deposition.

- *Thalictrum minus* - This species is typical of more or less infertile situations but its response to N deposition has not been investigated.

- *Thymus polytrichus* - Experimental additions of N resulted in significant reductions in the cover of this species (Carroll *et al* 2003) suggesting that it may be a suitable indicator of N deposition.

- *Trinia glauca* - This species is typical of infertile situations (Hill *et al* 1999) but its response to N deposition has not been investigated.

- *Valeriana officinalis* - This species is typical of more or less infertile situations (Hill *et al* 1999) but its response to N deposition has not been investigated in calcareous grasslands.

- *Viola hirta* - This species is typical of infertile situations (Hill *et al* 1999) but its response to N deposition has not been investigated in calcareous grasslands.

b Additional species included in upland calcareous grassland (JNCC 2006).

- *Alchemilla alpina* - Analysis of large-scale data showed no significant result in tetrad data from BSBI local change survey (Stevens *et al* 2011).

- *Briza media*- This tissue chemistry of this species responds to N addition *(*Morecroft *et al* 1994) suggesting it is likely to be sensitive to N deposition but its response in terms cover and probability of presence is not known.

- *Carex capillaris* - Analysis of large-scale data showed no significant result in the vascular plant database spatial analysis (Stevens *et al* 2011).

- *Carex caryophyllea* - This tissue chemistry of this species responds to N addition (Carroll *et al* 2003; Horswill *et al* 2008) suggesting it is likely to be sensitive to N deposition but its response in terms cover and probability of presence is not known.

- *Carex panacea* - *C. panicea* occurs in wide range of habitats where competitors are suppressed by nutrient poor or grazed conditions (Grime *et al* 2007). It is in decline due to habitat loss but its response to N in heathlands is not known.

- *Carex pulicaris* - This species favours slightly minerotrophic soil conditions of varied pH so is unlikely to be N sensitive.

- *Cetraria islandica* - In large-scale analysis of British Lichen Society data this species showed no significant relationship with N deposition (Stevens *et al* 2011) so is unlikely to be a good indicator of N deposition.

- *Cochlearia alpine* - The response of this species to N deposition has not been investigated.

- *Coelocaulon aculeatum* - Lichens are generally thought to be very sensitive to air quality and but further research is needed to determine whether this species is a suitable indicator of N deposition.

- *Kobresia simpliciuscula* - This is a species of very infertile situations (Hill *et al* 1999) but it has not been investigated in relation to N deposition.

- *Koeleria macrantha* - Experimental results from calcareous grasslands show that the biomass and tissue chemistry of this species is impacted by N addition (Phoenix *et al* 2004) suggesting that this species is a good potential indicator of N deposition.

- *Luzula spicata* - There is no evidence relating this species to N deposition.

- *Salix reticulata* - This is a species of more or less infertile habitats (Hill *et al* 1999) but it has not been investigation in relation to N deposition.

- *Saxifraga aizoides* - There is no evidence relating this species to N deposition.

- *Saxifraga oppositifolia* - This species showed a mix of no significant relationships with N deposition in analysis of large-scale vegetation data (Stevens *et al* 2011).

- *Sibbaldia procumbens* - This species is typical of more or less infertile sites (Hill *et al* 1999) but the response of this species to N deposition has not been investigated.

- *Silene acaulis* - There is no evidence relating this species to N deposition.

- *Thalictrum alpinum* - This species showed a mix of non-significant and hump-backed relationships with N deposition in analysis of large-scale vegetation data (Stevens *et al* 2011) suggesting it is not suitable as a positive indicator of site condition with respect to N deposition.

c Negative site condition indicators

- *Anthriscus sylvestris* - *A. sylvestris* is thought to respond positively to N deposition and increase in its above- and below-ground growth in response to N addition (Hansson 1994). In deciduous forests in Southern Sweden *A. sylvestris* was found to be increasing in abundance in relations to N deposition (Diekmann and Falkengren-Grerup 2002; Falkengren-Grerup and Schottelndreier 2004). This species is a potential indicator of nutrient enrichment.

- *Bellis perennis* - *B. perennis* showed no response to N deposition in an experiment on a calcareous dune system (Plassmann *et al* 2010) suggesting that it is not likely to be suitable as in indicator of N deposition.

- *Cirsium arvense* - *C. arvense* is a species of richly fertile habitats (Hill *et al* 1999). There is currently no specific evidence to suggest that it increases at high N deposition.

- *Cirsium vulgare* - *C. vulgare* is also a species of richly fertile habitats (Hill *et al* 1999). As with *C. arvense*, there is currently no evidence to suggest that it increases at high N deposition.

- *Chamerion angustifolium* - a known competitive species of disturbed and burnt ground (Preston *et al* 2002) this is more likely to determine its distribution than N deposition.

- *Cynosurus cristatus* - *C. cristatus* has a wide tolerance of nutrient levels and is found in both nutrient-poor and -rich habitats (Sinker *et al* 1991) meaning it unlikely to be a good indicator of N deposition.

- *Galium aparine* - a species of very fertile habitats (Hill *et al* 1999); its presence in calcareous grasslands is more likely to indicate disturbance or localised eutrophication rather than N deposition.

- *Holcus lanatus*- In woodlands *H. lanatus* has been shown to occur more frequently close to point sources of ammonia (Pitcairn *et al* 1998) but there is no evidence of response in calcareous grasslands.

- *Lolium perenne* - This is a species typical of improved grasslands. Although it is found in very fertile conditions and is certainly an indicator of nutrient rich habitats there is no evidence relating it to N deposition.

- *Plantago major* - *P. major* is a species of richly fertile habitats (Hill *et al* 1999) but is more typically characterised by its presence in areas of heavy trampling. There is no evidence to suggest it increases with N deposition.

- *Rumex crispus* - This species is typical of very fertile habitats but there is no specific evidence linking it to N deposition.

- *Rumex obtusifolius* - This species is typical of very fertile habitats but there is no specific evidence linking it to N deposition.

- *Senecio jacobaea* - There is no evidence to link prevalence of *S. jacobea* with N deposition.

- *Trisetum flavescens* - This species is typical of infertile habitats (Hill *et al* 1999) but there is no evidence relating occurrence to N deposition.

- *Trifolium repens* - *T. repens* is another species of fertile habitats (Hill *et al* 1999) but again, there is no evidence to suggest it increases with N deposition making it hard to separate impacts from other causes of nutrient enrichment.

- *Urtica dioica* - a species of very fertile habitats (Hill *et al* 1999); its presence in calcareous grasslands is more likely to indicate disturbance or localised eutrophication rather than N deposition.

d Additional species included in upland calcareous grassland (JNCC 2006)

- *Arrhenatherum elatius* - *A. elatius* is a species of richly fertile habitats (Hill *et al* 1999). Although it responds to nutrient enrichment there is no published literature relating it to N deposition.

- *Ranunculus repens* - *R. repens* is a species of richly fertile habitats (Hill *et al* 1999). Although it responds to nutrient enrichment there is no published literature relating it to N deposition.

- *Juncus effuses* - This is a species of generally nutrient poor wet pastures, but there is no evidence that it is affected by N deposition in calcareous grasslands.

e Potential indicators

Potential indicators of N deposition impact are *Anthriscus sylvestris* (-), *Campanula rotundifolia* (+), *Campanula glomerata* (+), *Carlina vulgaris* (+), *Koeleria macrantha* (+), and *Thymus polytrichus* (+). There is not conclusive evidence for any of these species and further research is needed to determine their value as indicators of N deposition and whether impacts can be separated from management effects.

Appendix 2 Conservation designations for species that responded to N deposition

Conservation designations for species that showed significant responses to N pollution (Stevens *et al* 2011), consistent in one or more datasets. Species may be listed for more than one habitat. Habitat codes (Acid Grassland = AG; Calcareous Grassland = CG, Bog = B and Heathland = H) are prefixed with U for upland, L for lowland and ? where these were not distinguished. Significant effects of N deposition are signified with + for an increase with N deposition and - for a decrease in N deposition, in the spatial (S) and temporal (T) analyses on data from the Vascular Plant Database (VPD), Local Change Survey (LC), British Lichen Society (BLS), British Bryological Society (BBS), and summarised from all surveys where there was a response in the “Overall” column. HD = appearing in Annexe 2, 3 or 4 of the Habitats Directive. IUCN = on the IUCN Red List, based on 2001 guidelines (E = Endangered, N = Near-threatened, V = Vulnerable). National = on the UK list of rare and scarce species, not based on IUCN criteria (R = Nationally Rare, S = Nationally Scarce). Subnational = on a biodiversity list for a UK devolved administration (E = England: NERC section 41 list, S = Scottish Biodiversity List, W = Wales: NERC section 42 list, N = Northern Ireland: Wildlife (Northern Ireland) Order 1985). BAP = UK Biodiversity Action Plan priority species. CSM +ve = positive indicator species listed in CSM guidance for one or more of Lowland or Upland dry acid grassland, Upland blanket bog and valley mire, Lowland raised bog, Sub-alpine dry dwarf shrub heath, Lowland wet heath, Upland wet heath, Lowland dry heath. None of the species included was listed as a negative CSM indicator for these habitats. Where genera are listed as CSM indicators, all responsive species were included, but larger taxonomic groupings such as “pleurocarpous mosses” were omitted.

Species	**Habitat**	**VPD(S)**	**VPD(T)**	**LC(S)**	**LC(T)**	**BLS (S)**	**BBS (S)**	**Overall**	**HD**	**IUCN**	**National**	**Subnational**	**BAP**	**CSM +ve**
Alchemilla xanthochlora	UCG	+						+						
Allium vineale	LCG	-						-						
Anacamptis pyramidalis	LCG	-						-						
Anastrophyllum minutum	UH						-	-						
Anastrophyllum minutum	UB						-	-						
Archidium alternifolium	UAG						+	+						
Arctostaphylos uva-ursi	UH	-						-						+
Aulacomnium palustre	UH						+	+						
Barbilophozia hatcheri	UH						+	+						
Bromopsis erecta	LCG			-				-						
Calypogeia arguta	UH						+	+						
Calypogeia neesiana	UB						+	+						
Calypogeia sphagnicola	UB						-	-						
Campanula glomerata	LCG						-	-				S		+
Carex limosa	UB		-					-						+
Carex spicata	LCG		-	-				-						+
Carlina vulgaris	LCG	-						-						+
Centaurea scabiosa	LCG			-				-				S		+
Cephalozia connivens	UH						+	+						
Cerastium semidecandrum	LAG		-					-						
Cetraria aculeata	?H					-		-						
Cetraria aculeata	?AG					-		-						
Cetraria muricata	?H					-		-						

Species	**Habitat**	**VPD(S)**	**VPD(T)**	**LC(S)**	**LC(T)**	**BLS (S)**	**BBS (S)**	**Overall**	**HD**	**IUCN**	**National**	**Subnational**	**BAP**	**CSM +ve**
Cladonia cervicornis cervicornis	?H					-		-						+
Cladonia cervicornis verticillata	?H					-		-						+
Cladonia foliacea	?CG					-		-						+
Cladonia glauca	?H					-		-						+
Cladonia portentosa	?H					-		-	✓					+
Cladonia portentosa	?B					-		-	✓					+
Cladonia strepsilis	?H					-		-						+
Cladonia subulata	?H					-		-						+
Cladonia uncialis biuncialis	?H					-		-						+
Cynoglossum officinale	LCG	-						-		N				
Daucus carota	LCG			-				-						
Dibaeis baeomyces	?H					-		-						
Dicranella schreberiana	UH						+	+						
Dicranum bonjeanii	UB						+	+						
Didymodon vinealis	UCG						+	+						
Echium vulgare	LCG	-						-						
Fissidens bryoides s.l.	UH						+	+						
Fossombronia wondraczekii	UH						-	-						
Frullania tamarisci	UAG						-	-						
Geranium columbinum	LCG	-						-				S		
Gymnocolea inflata	UH						+	+						
Gymnocolea inflata	UAG						+	+						
Gymnocolea inflata	UB						+	+						
Hylocomium splendens	UH						+	+						
Lathyrus nissolia	LCG	+						+						
Leiocolea turbinata	UCG						+	+						
Lepidozia pearsonii	UB						-	-						
Lepidozia pearsonii	UH						-	-						
Leptodontium flexifolium	UAG						+	+						
Leucobryum glaucum	UH						-	-	✓					
Lichenomphalia hudsoniana	?H					-		-						
Lichenomphalia umbellifera	?H					-		-						
Lophozia incisa	UB						+	+						
Lophozia ventricosa	UAG						+	+						
Lycopodium annotinum	UH				-			-	✓		S			
Microlejeunea ulicina	UH						-	-						
Mylia anomala	UH						+	+						
Myosotis ramosissima	LAG		-					-						
Odontoschisma denudatum	UB						-	-						
Odontoschisma sphagni	UH						+	+						
Ononis repens	LCG	-		-				-						
Ornithopus perpusillus	LAG				-			-						
Peltigera didactyla	?AG					-		-						+
Peltigera hymenina	?H					-		-						+
Platanthera bifolia	LH	+						+		V		E	✓	

Species	**Habitat**	**VPD(S)**	**VPD(T)**	**LC(S)**	**LC(T)**	**BLS (S)**	**BBS (S)**	**Overall**	**HD**	**IUCN**	**National**	**Subnational**	**BAP**	**CSM +ve**
												S W		
Pleurozia purpurea	UB						+	+						
Polytrichum commune	UH						+	+						
Racomitrium ericoides	UH						+	+						
Racomitrium ericoides	UAG						+	+						
Racomitrium lanuginosum	UAG						-	-		N				
Rosa micrantha	LCG	-						-						
Sanionia uncinata	UAG						+	+						
Scapania gracilis	UAG						-	-						
Scapania irrigua	UH						+	+						
Scapania umbrosa	UB						-	-						
Scleranthus annuus	LH				-			-		N			✓	
Sphagnum denticulatum	UH						+	+	✓					+
Sphagnum fallax	UH						+	+	✓					+
Sphagnum russowii	UH						+	+	✓					+
Sphagnum squarrosum	UH						+	+	✓					+
Sphagnum subnitens	UH						+	+	✓					+
Sphagnum tenellum	UH						+	+	✓					+
Spiranthes spiralis	LCG	-						-		N				
Stachys officinalis	LCG	+						+				N		+
Trientalis europaea	UH				-			-						
Trifolium arvense	LAG	-	-					-						
Trifolium micranthum	LAG				-			-				S		
Vicia lathyroides	LAG	-						-						

Appendix 3 Nitrogen deposition exceedence areas for devolved adminstrations and UK

Table 10.1. Percentage of acid grassland area in the UK and in the devolved administrations receiving different amounts of atmospheric N deposition, as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model.

N Deposition (kg/ha/y)	**England**		**Scotland**		**Wales**		**N Ireland**		**UK**	
	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020
<5			0.7	7.7				0.1	0.4	4.2
5-10	0.0	0.4	36.2	38.7	1.1	4.1	6.4	10.1	20.4	22.7
10-15	3.7	15.3	30.6	38.2	12.5	25.2	18.3	53.2	21.3	32.8
15-20	24.2	48.4	27.6	15.4	43.9	53.7	42.5	26.8	31.6	29.9
20-25	34.4	27.1	4.7	0.1	36.7	16.8	20.6	8.1	17.7	8.8
25-30	24.4	7.2	0.1		5.7	0.2	7.4	1.6	6.0	1.4
30-40	11.2	1.6					4.6	0.2	2.3	0.3
40-50	2.1								0.4	
>50		0.03					0.1		0.01	0.005
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total (km^2)	2620	2620	8283	8283	3146	3146	1197	1197	15247	15247

Table 10.2. Percentage of calcareous grassland area in the UK and in the devolved administrations receiving different amounts of atmospheric N deposition, as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model.

N Deposition (kg/ha/y)	**England**		**Scotland**		**Wales**		**N Ireland**		**UK**	
	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020
				2.0				<5		0.01
5-10	0.1	0.4	37.1	44.2	2.7	2.7	3.6	41.9	0.6	1.9
10-15	5.0	16.3	21.9	46.3	24.8	24.8	72.4	39.8	7.4	17.5
15-20	42.0	62.4	41.0	7.6	48.8	48.8	12.8	9.9	41.8	60.9
20-25	32.7	13.7			23.7	23.7	1.9	7.7	31.4	12.9
25-30	10.3	5.8					8.2	0.6	9.7	5.4
30-40	9.5	1.5					1.1		8.9	1.4
40-50	0.3								0.3	
>50		0.02								0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total (km^2)	3312	3312	24	24	171	171	70	70	3578	3578

Table 10.3. Percentage of ombrotrophic bog area in the UK and in the devolved administrations receiving different amounts of atmospheric N deposition, as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model.

N Deposition (kg/ha/y)	**England**		**Scotland**		**Wales**		**N Ireland**		**UK**	
	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020
<5			1.4	21.5				0.1	1.0	15.5
5-10		0.1	65.0	59.7	4.0	6.7	2.9	11.2	47.3	44.3
10-15	0.5	18.7	23.4	16.0	13.6	39.7	23.8	63.5	19.2	20.7
15-20	19.3	39.6	8.6	2.8	42.0	29.4	53.8	23.6	14.7	11.5
20-25	38.9	36.8	1.5	0.02	25.8	17.1	15.6	1.6	9.7	7.0
25-30	31.4	4.5	0.01		14.5	7.1	3.7	0.05	6.2	0.9
30-40	9.5	0.3					0.2	0.01	1.7	0.1
40-50	0.4								0.1	
>50										
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total (km^2)	1007	1007	4005	4005	56	56	467	466	5535	5534

Table 10.4. Percentage of heathland area in the UK and in the devolved administrations receiving different amounts of atmospheric N deposition, as interpolated for 2006-2008 by the CBED model, and forecast for 2020 by the FRAME model.

N Deposition (kg/ha/y)	**England**		**Scotland**		**Wales**		**N Ireland**		**UK**	
	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020	2006-8	2020
<5			1.2	11.5				0.01	0.9	9.4
5-10	0.1	0.4	55.0	57.8	0.4	1.7	5.1	8.7	45.1	47.7
10-15	7.5	20.9	30.7	25.3	7.7	14.7	16.4	43.9	26.8	25.2
15-20	23.9	52.4	12.2	5.3	38.7	59.9	38.7	34.8	15.5	13.6
20-25	41.1	21.8	1.0	0.01	42.7	23.5	24.2	11.3	7.7	3.7
25-30	19.6	4.1	0.02		10.5	0.3	11.1	1.2	2.9	0.5
30-40	7.3	0.4					4.5	0.1	0.9	
40-50	0.5									
>50							0.1			
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total (km^2)	2466	2466	20284	20284	1094	1094	983	982	24826	24826

Table 10.5. Changes in species prevalence in acid grassland with increasing nitrogen deposition. The level of nitrogen deposition is shown where a species' occurrence fell by 10%, 20%, 50% and 80% relative to occurrence at the lowest N deposition levels, and for upper and lower confidence intervals are presented. N.O is 'Not Observed' and indicates that a reduction in prevalence of the relevant % was not observed within the range of N deposition included in this study. BLS is the British Lichen Society; BBS is the British Bryological Society.

Species	**Change according to mean**				**Change according to upper limit**				**Change according to lower limit**				**Altitude**	**Data Source**
	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change		
Cerastium arvense	5-10	5-10	10-15	15-20	10-15	10-15	10-15	25-30	0-5	0-5	0-5	0-5	Lowland	Plant Atlas
Vicia lathyroides	5-10	5-10	10-15	15-20	10-15	10-15	15-20	25-30	0-5	0-5	0-5	5-10	Lowland	Plant Atlas
Trifolium arvense	5-10	5-10	10-15	20-25	10-15	10-15	15-20	40-50	0-5	0-5	5-10	10-15	Lowland	Plant Atlas
Peltigera didactyla	5-10	5-10	15-20	25-30	10-15	10-15	20-25	30-40	0-5	0-5	5-10	15-20	NA	BLS
Cetraria aculeata	5-10	5-10	10-15	20-25	10-15	10-15	15-20	20-25	0-5	0-5	0-5	15-20	NA	BLS
Cerastium semidecandrum	5-10	5-10	10-15	20-25	10-15	10-15	15-20	30-40	0-5	0-5	5-10	15-20	Lowland	Plant Atlas
Viola canina	5-10	10-15	15-20	20-25	10-15	15-20	20-25	25-30	0-5	0-5	10-15	15-20	Lowland	Plant Atlas
Scapania gracilis	5-10	10-15	15-20	30-40	10-15	15-20	30-40	30-40	5-10	5-10	10-15	15-20	Upland	BBS
Racomitrium lanuginosum	10-15	10-15	N.O	N.O	N.O	N.O	N.O	N.O	5-10	10-15	N.O	N.O	Upland	BBS
Frullania tamarisci	10-15	15-20	30-40	N.O	N.O	N.O	N.O	N.O	5-10	10-15	25-30	30-40	Upland	BBS

Table 10.6. Changes in species prevalence in calcareous grassland with increasing nitrogen deposition. The level of nitrogen deposition is shown where a species' occurrence fell by 10%, 20%, 50% and 80% relative to occurrence at the lowest N deposition levels, and for upper and lower confidence intervals are presented. N.O is 'Not Observed' and indicates that a reduction in prevalence of the relevant % was not observed within the range of N deposition included in this study. BLS is the British Lichen Society.

Species	**Change according to mean**				**Change according to upper limit**				**Change according to lower limit**				**Altitude**	**Data Source**
	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change		
Spiranthes spiralis	5-10	5-10	5-10	10-15	5-10	10-15	10-15	15-20	0-5	0-5	0-5	0-5	Lowland	Plant Atlas
Bromopsis erecta	5-10	5-10	5-10	10-15	5-10	5-10	10-15	10-15	5-10	5-10	5-10	5-10	Lowland	BSBI
Allium vineale	5-10	5-10	15-20	25-30	15-20	15-20	20-25	40-50	0-5	0-5	0-5	0-5	Lowland	Plant Atlas
Geranium columbinum	5-10	5-10	15-20	20-25	10-15	15-20	20-25	30-40	0-5	0-5	0-5	5-10	Lowland	Plant Atlas
Centaurea scabiosa	5-10	5-10	5-10	10-15	10-15	10-15	10-15	10-15	5-10	5-10	5-10	5-10	Lowland	BSBI
Daucus carota	5-10	5-10	10-15	N.O	10-15	10-15	15-20	N.O	5-10	5-10	5-10	10-15	Lowland	BSBI
Carlina vulgaris	5-10	10-15	20-25	30-40	15-20	20-25	25-30	N.O	0-5	0-5	0-5	20-25	Lowland	Plant Atlas
Ononis repens	5-10	10-15	10-15	30-40	10-15	10-15	15-20	30-40	5-10	5-10	10-15	15-20	Lowland	BSBI
Carex spicata	10-15	10-15	10-15	15-20	10-15	10-15	15-20	15-20	5-10	5-10	10-15	10-15	Lowland	BSBI
Ononis repens	10-15	10-15	20-25	40-50	15-20	15-20	>50	>50	5-10	10-15	15-20	30-40	Lowland	Plant Atlas
Echium vulgare	10-15	15-20	20-25	30-40	20-25	20-25	25-30	N.O	0-5	0-5	0-5	0-5	Lowland	Plant Atlas
Rosa micrantha	10-15	15-20	20-25	25-30	20-25	20-25	20-25	30-40	0-5	0-5	0-5	0-5	Lowland	Plant Atlas
Cynoglossum officinale	10-15	15-20	20-25	30-40	20-25	20-25	25-30	30-40	5-10	10-15	15-20	25-30	Lowland	Plant Atlas
Cladonia foliacea	10-15	15-20	20-25	N.O	20-25	20-25	25-30	N.O	0-5	0-5	0-5	20-25	NA	BLS
Melica nutans	15-20	15-20	20-25	20-25	20-25	20-25	20-25	25-30	0-5	0-5	0-5	0-5	Upland	Plant Atlas
Campanula glomerata	15-20	20-25	25-30	25-30	25-30	25-30	25-30	25-30	15-20	15-20	15-20	25-30	Lowland	BSBI

Table 10.7. Changes in species prevalence in heathland with increasing nitrogen deposition. The level of nitrogen deposition is shown where a species' occurrence fell by 10%, 20%, 50% and 80% relative to occurrence at the lowest N deposition levels, and for upper and lower confidence intervals are presented. N.O is 'Not Observed' and indicates that a reduction in prevalence of the relevant % was not observed within the range of N deposition included in this study. BLS is the British Lichen Society; BBS is the British Bryological Society.

Species	**Change according to mean**				**Change according to upper limit**				**Change according to lower limit**				**Altitude**	**Data Source**
	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change		
Fossombronia wondraczekii	5-10	5-10	5-10	10-15	5-10	10-15	10-15	30-40	0-5	0-5	0-5	0-5	Upland	BBS
Cladonia cervicornis verticillata	5-10	5-10	10-15	15-20	10-15	10-15	10-15	25-30	0-5	0-5	0-5	5-10	NA	BLS
Cladonia strepsilis	5-10	5-10	5-10	10-15	10-15	10-15	10-15	15-20	0-5	0-5	0-5	0-5	NA	BLS
Arctostaphylos uva-ursi	5-10	5-10	5-10	10-15	10-15	10-15	10-15	10-15	0-5	0-5	0-5	5-10	Upland	Plant Atlas
Anastrophyllum minutum	5-10	5-10	10-15	15-20	10-15	10-15	15-20	20-25	0-5	0-5	0-5	0-5	Upland	BBS
Lepidozia pearsonii	5-10	5-10	10-15	15-20	10-15	10-15	10-15	15-20	0-5	0-5	0-5	0-5	Upland	BBS
Cetraria aculeata	5-10	5-10	10-15	15-20	10-15	10-15	15-20	20-25	0-5	0-5	5-10	15-20	NA	BLS
Cetraria muricata	5-10	5-10	10-15	15-20	10-15	10-15	10-15	25-30	0-5	0-5	0-5	10-15	NA	BLS
Cladonia uncialis biuncialis	5-10	5-10	10-15	20-25	10-15	10-15	15-20	30-40	0-5	0-5	0-5	15-20	NA	BLS
Lichenomphalia umbellifera	5-10	5-10	15-20	25-30	15-20	15-20	20-25	30-40	0-5	0-5	0-5	0-5	NA	BLS
Microlejeunea ulicina	5-10	5-10	10-15	10-15	10-15	10-15	10-15	15-20	0-5	0-5	5-10	5-10	Upland	BBS
Cladonia cervicornis cervicornis	5-10	5-10	15-20	30-40	10-15	15-20	25-30	30-40	0-5	0-5	5-10	20-25	NA	BLS
Cladonia subulata	5-10	5-10	15-20	20-25	10-15	10-15	15-20	25-30	0-5	0-5	5-10	15-20	NA	BLS
Leucobryum glaucum	5-10	5-10	15-20	30-40	10-15	10-15	30-40	N.O	0-5	5-10	10-15	20-25	Upland	BBS
Cladonia portentosa	5-10	10-15	15-20	30-40	10-15	15-20	20-25	N.O	0-5	0-5	10-15	20-25	NA	BLS
Vaccinium vitis-idaea	5-10	10-15	15-20	20-25	10-15	20-25	20-25	25-30	0-5	5-10	10-15	15-20	Upland	BSBI
Viola canina	10-15	15-20	15-20	N.O	15-20	15-20	N.O	N.O	0-5	0-5	15-20	15-20	Lowland	Plant Atlas
Dibaeis baeomyces	15-20	15-20	20-25	25-30	20-25	20-25	25-30	30-40	0-5	0-5	0-5	0-5	NA	BLS
Peltigera hymenina	15-20	20-25	25-30	40-50	20-25	25-30	N.O	N.O	0-5	0-5	20-25	25-30	NA	BLS
Cladonia glauca	15-20	15-20	20-25	25-30	20-25	20-25	25-30	N.O	0-5	0-5	0-5	0-5	NA	BLS

Table 10.8. Changes in species prevalence in bogs with increasing nitrogen deposition. The level of nitrogen deposition is shown where a species' occurrence fell by 10%, 20%, 50% and 80% relative to occurrence at the lowest N deposition levels, and for upper and lower confidence intervals are presented. N.O is 'Not Observed' and indicates that a reduction in prevalence of the relevant % was not observed within the range of N deposition included in this study. BLS is the British Lichen Society; BBS is the British Bryological Society.

Species	**Change according to mean**				**Change according to upper limit**				**Change according to lower limit**				**Altitude**	**Data Source**
	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change	N dep at 10% change	N dep at 20% change	N dep at 50% change	N dep at 80% change		
Odontoschisma denudatum	5-10	5-10	10-15	15-20	10-15	10-15	10-15	15-20	0-5	0-5	0-5	0-5	Upland	BBS
Anastrophyllum minutum	5-10	5-10	10-15	15-20	10-15	10-15	10-15	15-20	0-5	0-5	5-10	10-15	Upland	BBS
Scapania umbrosa	5-10	10-15	10-15	20-25	10-15	10-15	15-20	N.O	0-5	5-10	10-15	10-15	Upland	BBS
Calypogeia sphagnicola	10-15	10-15	15-20	20-25	15-20	15-20	20-25	25-30	0-5	0-5	0-5	0-5	Upland	BBS
Cladonia portentosa	15-20	15-20	20-25	25-30	15-20	20-25	25-30	N.O	10-15	15-20	15-20	20-25	NA	BLS