May 2014

Operationalising a metric of nitrogen impacts on biodiversity for the UK response to a data request from the Coordination Centre for Effects

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Rowe EC, Jarvis S, Hall J, Monteith D, Henrys P, Evans CD & Smart S (2014) Operationalising a metric of nitrogen impacts on biodiversity for the UK response to a data request from the Coordination Centre for Effects. Final report on Defra project AQ0832, "A metric for assessing changes in biodiversity for the UK's response to a data request under the Convention on Long-range Transboundary Air Pollution". CEH project NEC05090.

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Executive summary

As a signatory party to the Convention on Long Range Transboundary Air Pollution (CLRTAP), the UK has been requested to provide biodiversity metrics for use in assessing impacts of atmospheric nitrogen (N) pollution. Models of soil and vegetation responses to N pollution can predict changes in habitat suitability for many plant and lichen species. Metrics are required to relate changes in a set of species to biodiversity targets. In a previous study, the suitability of the habitat for a set of positive indicator-species was found to be the measure, out of potential outputs from models currently applicable to the UK, which was most clearly related to the assessment methods of habitat specialists at the Statutory Nature Conservation Bodies (SNCBs). This report describes the calculation of values for a metric, based on this principle, for a set of example habitats under different N pollution scenarios. The examples are mainly from Natura-2000 sites, and are defined at EUNIS Level 3 (e.g. F4.1 Wet heath). Values for the biodiversity metric were shown to be greater on all sites in the "Background" scenario than in the scenario with greater N and S pollution, illustrating a positive response of biodiversity to reduced pollution.

Results of the study were submitted in response to the 'Call for Data 2012-14' by the CLTRAP Co-ordination Centre for Effects (CCE), and presented at the 24th CCE Workshop in April 2014. Metrics calculated on a similar basis were also presented by the Netherlands, Switzerland and Denmark. Such metrics indicate biodiversity status more accurately than other types of metric such as Simpson index or similarity to a reference community, so it was decided to adopt habitat-suitability for positive indicator-species as a common basis for a biodiversity metric in this context. Further work is needed to determine the typical range of metric values in different habitats, and threshold values for damage and recovery. Requirements are likely to be specified in detail in the next CCE Call for Data. The current study shows that a biodiversity metric based on habitat-suitability for positive indicator-species is a useful and responsive method for summarising outputs of models of air pollution impacts on ecosystems.

Contents

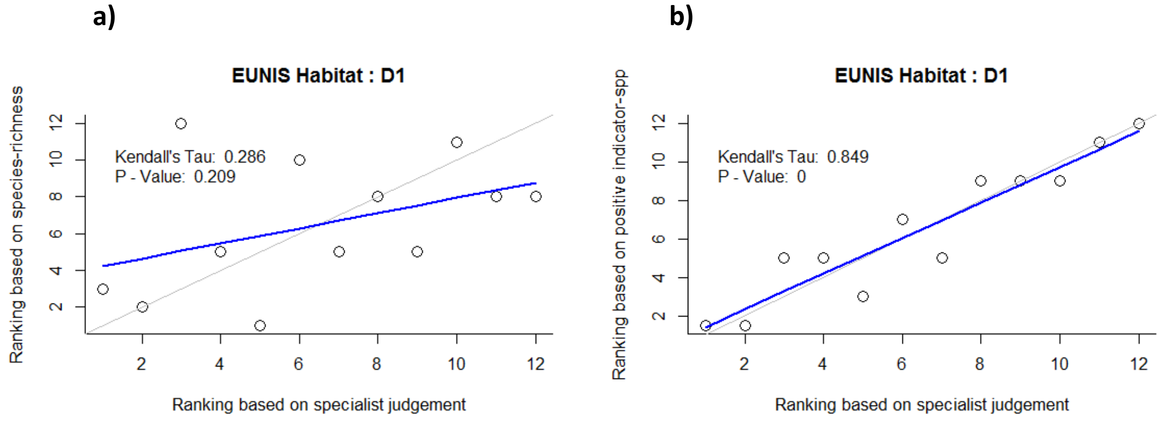
1. Introduction

Nitrogen tends to accumulate in ecosystems and cause delayed and cumulative effects. The time-course of many of these effects can be predicted using models of soil and vegetation chemistry, and by coupling these to niche models effects on habitat suitability for individual plant and lichen species can also be predicted. However, the use of such predictions in scenario analysis and to inform policy development has hitherto been limited, since changes in individual species or sets of species have not been clearly related to biodiversity targets. This report describes the calculation of biodiversity metrics to summarise the predicted floristic changes on a set of example sites, under different N pollution scenarios.

Under the Convention on Long Range Transboundary Air Pollution (CLRTAP), the Co-ordination Centre for Effects (CCE) is responsible for the development of modelling and mapping methodologies for the integrated assessment of European air pollution effects. The CCE issued a "Call for Data" in November 2012 (http://wge-cce.org/Activities/Call_for_Data), which was aimed at enabling the calculation of country-specific biodiversity indicators for assessing changes in biodiversity driven by atmospheric deposition. The ultimate aim of the CCE is to assess the extent to which "no net loss of biodiversity" is achieved, under air pollution scenarios, using suitable biodiversity endpoints as a measure. The CCE require a metric to be defined for each EUNIS (Level 2 or 3) habitat within each country. This metric must be one-dimensional, and must vary between a high value for the biodiversity endpoint, i.e. the target, and a low value for a damaged or degraded example of the habitat.

The study was restricted to widespread habitats known to be affected by N pollution and for which the available UK models work reasonably well – bogs, grasslands, and heathlands. In summer 2013, the specialists for these habitats at the UK Statutory Nature Conservation Bodies (SNCBs) were consulted using a combination of semi-structured interviews and quantitative ranking. The specialists were asked to discuss the reasoning behind their evaluation of sites as good, poor or degraded examples of the habitats, and to rank a set of examples of their habitat. The specialists discussed a variety of considerations when assessing sites and habitats, such as the need to monitor designated features, which often include scarce species, or the need to assess whether the integrity of a habitat is being maintained by functionally important species. However, the presence and abundance of positive indicator-species emerged as a key consideration. These are comparatively small sets of species that have been identified as indicating favourable condition for a habitat, and tend to be distinctive but not very scarce. The number of positive indicator-species within an example proved to be consistent indicator of the habitat quality of the example as assessed by specialists (e.g. Figure 1). The study is described in detail in Rowe et al. (2014a).

Figure 1. Correlations of habitat specialists' rank scores for a set of 12 examples of raised or blanket bog with rank scores based on: a) species richness; and b) number of positive indicator-species.



The previous study helped considerably with determining an appropriate basis for a biodiversity metric for use in this context. However, to meet the Call for Data additional steps were required:

- Select example sites, preferably Natura 2000 sites, for which at least floristic data and location are available.
- Derive mean values from floristic data for plant traits: Ellenberg N, Ellenberg R, Ellenberg W and Grime Height.
- Calibrate the MADOC biogeochemical model (Rowe et al., 2014c) to these trait-means, making use of statistical relationships that have been established between trait-means and biogeochemical variables that are predicted by MADOC: soil pH, soil available-N content, soil total C/N ratio and standing biomass.
- Run the MADOC model forward to 2100 under different deposition scenarios provided by the CCE, to calculate the likely future environmental conditions.
- Derive a local list of positive indicator-species, based on the species identified in Common Standards Monitoring guidance, but filtered to include only those that occur in the local 10 x 10 km square.
- Calculate the habitat-suitability for each of these species under the future conditions, using the MultiMOVE floristic model (Butler, 2010).
- Calculate the value for the biodiversity metric, as the mean habitat suitability for locally-occurring positive indicator-species.

These steps will be outlined in more detail in the following section.

2. Methods

2.1 Selecting sites

The focus of the study was on ‘Mire, bog and fen habitats’ (EUNIS class D), ‘Grassland and tall forb habitats’ (E) and ‘Heathland, scrub and tundra habitats’ (F). Eighteen sites were chosen (Table 1). These are mainly Natura 2000 sites of international importance for nature conservation, i.e. Special Areas of Conservation (SACs) or Special Protection Area (SPAs), or nationally important sites (SSSIs). Some additional sites were included on the basis that they are part of integrated long-term monitoring networks, either the Environmental Change Network (ECN) or the Habitats Monitoring Network (HMN), also managed by ECN. The sites all have data on floristic composition, i.e. species lists with cover estimates for each species. Some of the sites also have measurements of soil pH, soil carbon content, and other biophysical measurements. These biophysical measurements are useful for model checking, but are not essential since the method applied used floristic data to establish many of the environmental characteristics of the site.

Figure 2. Locations of example sites.

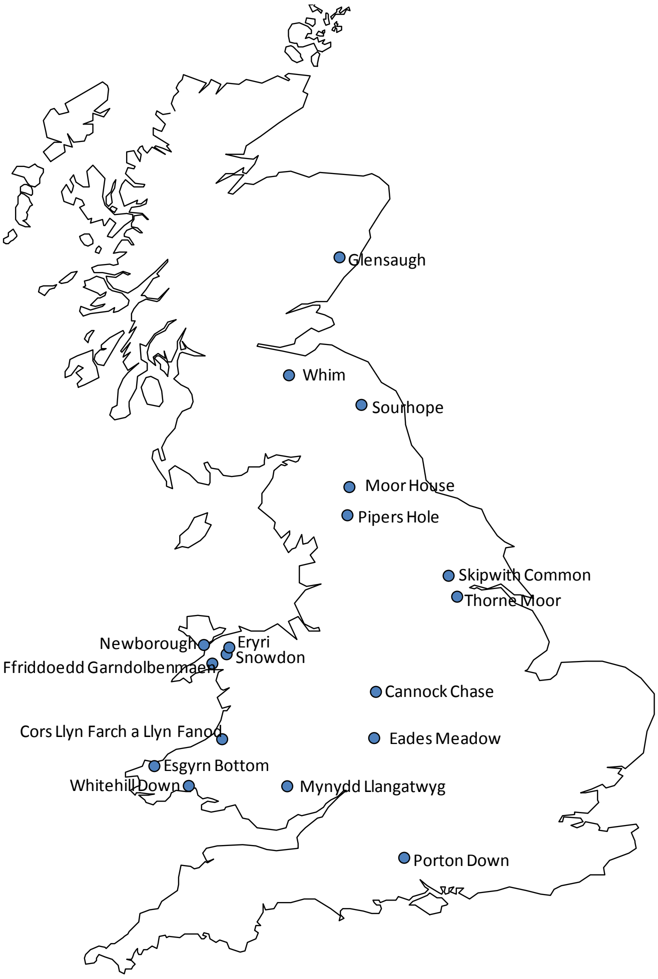


Table 1. Sites representing different habitats, with conservation designation (Des.: N2K = Natura 2000 site i.e. SAC or SPA; UK = UK designation i.e. SSSI), location (E = UK easting, 100m; N = UK northing, 100m; Alt = altitude, m), environmental conditions as indicated by floristic trait-means (E_R = Ellenberg R, an indicator of alkalinity; E_N = Ellenberg N, an indicator of productivity; E_W = Ellenberg W or F, an indicator of site moisture; G_H = Grime height score), and long-term climatic means (T_{max} = July maximum temperature, ^{o}C; T_{min} = January minimum temperature, ^{o}C; Prec = annual precipitation, mm; all UK Climate Impacts Programme 1961-90). Derived values for biophysical conditions are also shown: MC = soil moisture content, g 100 g^{-1} dry soil; pH = soil pH in water; Ht = vegetation canopy height, cm.

EUNIS	Site	Des.	E	N	Alt	E_R	E_N	E_W	G_H	T_{max}	T_{min}	Prec	MC	pH	Ht
D1.1 raised bogs	a) Whim Moss	UK	3204	6532	288	2.11	1.58	6.84	3.81	19.9	-4.6	889	0.62	3.78	74
	b) Thorne Moor	N2K	4738	4161	2	2.67	2.10	6.50	3.79	24.0	-3.8	583	0.58	4.13	72
D1.2 blanket bogs	a) Moor House	N2K	3755	5335	554	3.57	2.55	6.97	3.47	19.0	-6.1	1677	0.64	4.68	56
	b) Mynydd Llangatwyg	N2K	3188	2131	412	2.32	1.80	6.92	3.74	23.1	-6.3	1414	0.63	3.92	69
D2.2 poor fens and soft-water spring mires	a) Esgyrn Bottom	N2K	1976	2347	80	2.58	2.13	6.92	4.04	22.4	-3.9	1330	0.63	4.08	90
	b) Cors Llyn Farch a Llyn Fanod	UK	2594	2635	308	3.31	2.38	7.75	4.15	22.0	-5.0	1223	0.73	4.52	99
E1.2 perennial calcareous grassland and basic steppes	a) Porton Down	N2K	4255	1365	133	6.43	4.21	4.82	3.31	26.3	-6.2	768	0.35	6.44	45
	b) Newborough	N2K	2428	3644	11	5.45	3.42	4.33	3.17	22.7	-2.3	896	0.29	5.82	43
E1.7 closed dry acid and neutral grassland	a) Snowdon	N2K	2635	3545	440	3.98	3.06	5.79	3.32	20.1	-5.2	3666	0.49	4.87	49
	b) Friddoedd Garndolbenmaen	UK	2505	3445	214	4.88	3.48	5.40	3.43	22.6	-3.5	1557	0.43	5.44	53
E2.2 Low and medium altitude hay meadows	a) Eades Meadow	UK	3981	2647	83	6.04	4.48	5.23	3.74	26.2	-5.8	642	0.40	6.18	69
	b) Piper's Hole	N2K	3737	5033	268	5.88	4.72	5.24	3.58	21.0	-4.7	1700	0.39	6.10	61
E3.5 moist or wet oligotrophic grassland	a) Sourhope	-	3865	6215	390	4.65	3.61	5.69	3.69	18.5	-4.7	944	0.48	5.24	67
	b) Whitehill Down	UK	2290	2135	16	4.79	2.86	6.19	3.69	23.9	-4.3	1229	0.54	5.40	70
F4.1 wet heath	a) Glensaugh	-	3665	7795	259	3.15	2.54	6.39	3.57	19.2	-3.8	897	0.56	4.44	62
	b) Cannock Chase	N2K	3997	3142	216	3.74	3.47	5.63	3.60	24.4	-6.2	679	0.45	4.70	61
F4.2 dry heath	a) Skipwith Common	N2K	4660	4385	9	2.65	1.95	6.81	4.26	23.7	-3.8	595	0.63	4.20	108
	b) Eryri	N2K	2660	3617	825	2.41	2.06	5.35	3.62	17.5	-6.0	3153	0.42	3.97	63

2.2 From floristic data to environmental conditions

Species lists were obtained for each site and mean trait scores were calculated from the species composition. Environmental conditions were inferred for each site using mean trait values for the species present, which can provide a quick and robust means of assessing local conditions (Diekmann, 2003). Mean values for floristic traits (Table 1) were calculated using indicator-scores (Ellenberg et al., 1991; Grime et al., 1988). These are scores on ordinal scales, usually with nine points, that reflect abiotic gradients; species have been assigned values which reflect best their position along each gradient. For this study, 'Ellenberg' indicator-scores as adapted for UK vascular plants (Hill et al., 2004) and bryophytes (Hill et al., 2007) were used to represent gradients in water availability (E_W), alkalinity (E_R) and nutrient availability (E_N).

The gradient in ground-level light availability was represented using the typical maximum heights of the vascular plant species present, obtained from PlantAtt (Hill et al., 2004). These were converted to the Grime height scale (Grime et al., 1988), and a mean value G_H calculated, weighted as follows. When calculating mean values for the E_W, E_R and E_N traits, no cover-weighting was applied, since all the species present are valid indicators of the soil conditions that govern these aspects of the environment. However, the species that are present may themselves influence light availability, so the calculation of mean G_H was weighted by relative cover. Visual or pinpoint estimates of cover were used for most sites. For ECN and HMN sites (Moor House, Porton Down, Sourhope, Snowdon and Glensaugh) species lists were produced from the most recent vegetation survey for each site, and the proportional frequency of each species within 180-440 small (40 x 40 cm) cells was used as a proxy for cover.

To translate between floristic trait-means and the biophysical variables used in the MADOC model, transfer functions that have been established using large datasets were applied (Table 2). These equations were used to calculate values for biophysical conditions that are used either to set up (soil water content) or to calibrate (soil pH, soil available N, soil total C/N, canopy height) MADOC. The equations were inverted to calculate trait-mean values based on the biophysical conditions predicted by MADOC for the different scenarios, for subsequent MultiMOVE modelling.

Table 2. Conversion equations used to estimate biophysical properties of the site from floristic trait-means. E_W = mean Ellenberg 'moisture' score for species present; E_R = mean Ellenberg 'alkalinity' score for present species; E_N = mean Ellenberg 'fertility' score for present species; G_H = mean Grime 'height' score for present species; *CN* = CN ratio, g C g^{-1} N; *H* = canopy height, cm. Mean G_H was weighted by observed cover or occurrence frequency; other means were not weighted.

Value to be estimated	Equation	Source
Soil water content (g g^{-1} fresh soil)	exp((E_W × 0.55) - 3.27)/(1 + exp((E_W × 0.55) - 3.27))	Smart et al. (2010)
Soil pH	E_R × 0.61 + 2.5	Smart et al. (2004)
Soil available N (g m^{-2} year)	10^ ((E_N – 1.689 – (0.0284 × (1000/*CN*))) / 0.318)	Rowe et al. (2011)
Canopy height (cm)	$e^{\frac{G_H+1.22}{1.17}}$	Rowe et al. (2011)
Above-ground biomass (g C m^{-2})	EXP((Ln(100 × *H*)+7.8319)/1.1625)	derived from Parton (1978) and Yu et al. (2010)

2.3 Biogeochemical modelling

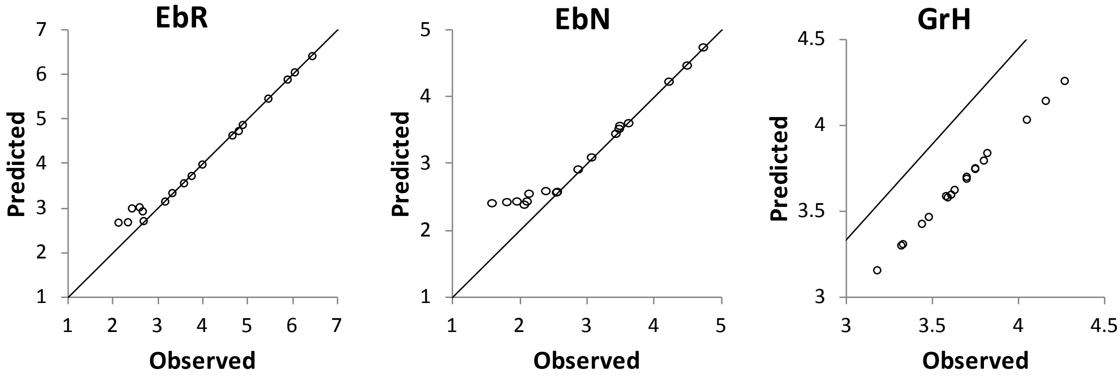
Deposition sequences

The CCE requested that the Call for Data response be calculated on the basis of deposition sequences as estimated by the European Monitoring and Evaluation Programme (EMEP). The MADOC model requires total inputs of S, N and other elements, which were calculated on the following basis. The EMEP values for deposition of non-marine S and N were used, and scaled through time using the EMEP temporal sequence for the site. Marine S inputs were obtained from Concentration Based Estimated Deposition (CBED) model estimates for the site, and marine inputs of Ca, Mg, K, Na and Cl were calculated using sea-salt ratios to S. Non-marine Ca inputs were also obtained from CBED model estimates, and were temporally scaled using the same sequence of ratios as for S. Non-marine inputs were assumed to be zero until 1850 and then to scale up to the EMEP estimates for 1880.

Calibrating MADOC

The MADOC model (Rowe et al., 2014c) was set up for each of the sites using the deposition sequences described above, and climatic inputs, i.e. annual mean temperature and annual precipitation, obtained from UKCIP (1961-1990 means). Values for soil drainage (runoff) were those used by the UK National Focal Centre (http://cldm.defra.gov.uk/) for the 1 x 1 km square containing the site. The model was calibrated to current environmental conditions by adjusting free (unknown) parameters to minimize the sum of absolute differences between observed and predicted values for the floristic trait-means. The mean E_N value was obtained by adjusting the proportion of mineral N than can be immobilised into soil organic matter, and the pre-industrial N-fixation rate. The mean E_R value was obtained by adjusting the calcium weathering rate and the density of exchangeable protons on dissolved organic carbon. The mean G_H value was obtained by adjusting the proportion of total plant C which is present as standing biomass. It proved impossible to simulate E_N scores below 2, presumably since few such low values were present in the training dataset used to develop the transfer function, but otherwise this calibration resulted in model outputs that matched observed values (Figure 3).

Figure 3. Observed values for floristic trait-means: E_N = mean Ellenberg 'fertility' score for present species, E_R = mean Ellenberg 'alkalinity' score for present species, and G_H = mean Grime 'height' score for present species; plotted against predicted values as obtained by calibrating the MADOC model.



2.4 Selecting local indicator-species

A current JNCC project aims to identify suitable indicator-species for UK habitats as defined using EUNIS (Chris Cheffings, *pers com.*), but results were not available in time to use in the study. The primary source of information on suitable positive indicator-species was therefore the Common Standards Monitoring (CSM) guidance (e.g. JNCC, 2006), which lists indicator-species for several habitats. However, some consideration was needed before these lists could be applied to the current task. The habitats described in CSM guidance do not correspond to EUNIS classes and judgements have had to be made as to the corresponding habitat. Some species appear as both positive and negative indicators for different sub-types of the habitat in question. Groups of species are sometimes used, such as sedges or forbs, and it is necessary to decide which of these species should be included. The judgements made, and full lists of species included as positive indicators for the habitats included in the study, were presented in Rowe et al. (2014a), with the exception of "Poor fens and soft-water spring mires" (D2.2). Positive indicator-species have now been derived for this EUNIS class from the "desirable species" listed for NVC M4 and M5 communities in the Lowland Wetlands CSM guidance (Table 3).

Table 3. Positive indicator-species for D2.2 Poor fens and soft-water spring mires

Aulacomnium palustre	*Menyanthes trifoliata*	*Sphagnum palustre*
Carex rostrata	*Potentilla erecta*	*Sphagnum subnitens*
Carex lasiocarpa	*Potentilla palustris*	*Sphagnum squarrosum*
Carex nigra	*Ranunculus flammula*	*Sphagnum teres*
Epilobium palustre	*Rumex acetosa*	*Stellaria uliginosa*
Eriophorum angustifolium	*Sphagnum cuspidatum*	*Succisa pratensis*
Galium palustre	*Sphagnum denticulatum*	*Viola palustris*
Lychnis flos-cuculi	*Sphagnum fallax*	

A site might be unsuitable for a particular species due to an unsuitable climate rather than because of effects of N pollution. For this reason, those positive indicator-species that do not occur in the local area were excluded from the list for a particular site. The local area was defined as the 10 x 10 km square containing the site. Species lists for each surrounding 10km area were obtained from databases of vascular plant, bryophyte and lichen occurrences courtesy of the Botanical Society of the British Isles, British Bryological Society and British Lichen Society, and accessed through the National Biodiversity Network Gateway. The species used to calculate the value for the metric at each site (i.e. those that are positive indicators for the habitat, have MultiMOVE models, and occur in the local area) are listed in Table 4.

Table 4. Positive indicator-species used to calculating overall Habitat Quality at each site. For explanation of habitat and example codes, see Table 1.

Habitat:	D1.1		D1.2		D2.2		E1.2		E1.7		E2.2		E3.5		F4.1		F4.2	
Example:	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Species																		
Achillea ptarmica													x	x				
Agrimonia eupatoria							x	x			x	x						
Aira caryophyllea								x	x	x								
Aira praecox								x	x	x							x	x
Alchemilla vulgaris agg.								x				x						
Anacamptis pyramidalis							x	x			x			x				
Anagallis tenella														x		x		
Andromeda polifolia	x	x		x														
Anemone nemorosa									x	x								
Angelica sylvestris							x	x					x	x				
Antennaria dioica								x										
Anthyllis vulneraria							x	x										
Armeria maritima								x										x
Asperula cynanchica							x											
Astragalus danicus							x											
Aulacomnium palustre					x	x												
Berula erecta											x							
Briza media							x	x										

Habitat:	D1.1		D1.2		D2.2		E1.2		E1.7		E2.2		E3.5		F4.1		F4.2	
Example:	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Species																		
Calluna vulgaris	x	x	x	x					x	x			x	x	x	x	x	x
Campanula glomerata							x											
Campanula rotundifolia							x	x	x	x								
Carex bigelowii			x															
Carex binervis															x			
Carex caryophyllea							x	x										
Carex curta															x	x		
Carex dioica																x		
Carex distans								x										
Carex disticha								x								x		
Carex echinata								x							x	x		
Carex flacca							x	x							x	x		
Carex hostiana								x								x		
Carex humilis							x											
Carex nigra					x	x	x	x							x	x		
Carex ovalis							x	x							x	x		
Carex panicea							x	x										
Carex pilulifera								x							x	x		
Carex pulicaris								x										
Carex rostrata					x	x												
Carex sylvatica							x	x							x			
Carex vesicaria																x		
Carlina vulgaris							x	x										
Carum verticillatum														x				
Centaurea nigra							x	x			x	x	x	x				
Centaurea scabiosa							x	x										
Centaurium erythraea							x	x	x	x								
Cephalanthera damasonium							x											
Cerastium fontanum							x	x										
Cirsium acaule							x											
Cirsium heterophyllum												x						
Cladonia bellidiflora									x	x								
Cladonia coniocraea	x	x	x	x			x	x	x	x					x	x		
Cladonia deformis			x															
Cladonia digitata			x						x	x						x		
Cladonia fimbriata	x	x	x	x			x	x	x	x					x	x		
Cladonia floerkeana		x	x	x			x		x	x								
Cladonia foliacea							x	x										
Cladonia glauca		x																
Cladonia gracilis			x	x				x	x									
Cladonia macilenta	x	x	x	x			x		x							x		
Cladonia pocillum	x		x	x			x	x	x	x								
Cladonia pyxidata			x	x			x	x	x	x								
Cladonia rangiferina			x						x									
Cladonia rangiformis			x	x			x	x										
Cladonia strepsilis									x	x								
Cladonia subcervicornis			x	x					x	x								
Clinopodium vulgare							x	x										
Conopodium majus											x	x						
Crepis paludosa													x					
Danthonia decumbens								x										
Drosera intermedia		x														x		
Drosera rotundifolia	x	x	x	x											x	x		
Epilobium palustre					x	x												
Epipactis helleborine							x		x		x	x						
Epipactis palustris								x				x						
Erica cinerea	x		x						x	x					x	x	x	x
Erica tetralix	x	x	x	x					x	x			x		x	x	x	x
Erigeron acer							x	x										
Eriophorum angustifolium	x	x	x	x	x	x												
Eriophorum vaginatum	x	x	x	x														
Erodium cicutarium agg.							x	x		x							x	
Eupatorium cannabinum											x			x				
Filipendula ulmaria							x	x			x	x	x	x				
Filipendula vulgaris							x	x			x	x						
Fragaria vesca							x	x										
Galium palustre					x	x					x	x	x	x				

Habitat:	D1.1		D1.2		D2.2		E1.2		E1.7		E2.2		E3.5		F4.1		F4.2	
Example:	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Species																		
Galium saxatile								x	x	x					x	x	x	x
Galium uliginosum											x	x	x					
Galium verum							x	x	x	x	x	x					x	x
Genista anglica															x		x	
Gentianella amarella							x	x										
Gentianella campestris								x										
Geranium sanguineum								x										
Geranium sylvaticum												x						
Geum rivale							x	x				x	x	x				
Goodyera repens													x					
Gymnadenia conopsea							x	x	x	x	x	x	x					
Helianthemum nummularium							x	x										
Hippocrepis comosa							x											
Hydrocotyle vulgaris												x	x	x				
Hypericum hirsutum							x	x										
Hypericum humifusum							x	x										
Hypericum perforatum							x	x										
Hypericum pulchrum							x	x										
Hypochaeris radicata																	x	x
Knautia arvensis							x	x										
Koeleria macrantha							x	x										
Lathyrus linifolius							x	x	x	x	x	x						
Lathyrus pratensis											x	x						
Leontodon hispidus							x	x			x	x	x	x				
Leontodon saxatilis							x	x	x	x	x	x						
Linum catharticum							x	x										
Listera cordata								x					x					
Listera ovata							x	x			x	x	x	x				
Lotus corniculatus							x	x	x	x	x	x					x	x
Lotus pedunculatus											x	x	x	x				
Lychnis flos-cuculi					x	x					x	x	x	x				
Lythrum salicaria													x	x				
Mentha aquatica											x	x	x	x				
Menyanthes trifoliata	x		x	x	x	x												
Myrica gale		x																x
Narthecium ossifragum	x		x	x									x	x		x		
Ophrys apifera							x	x			x							
Orchis mascula							x	x	x	x	x	x	x	x				
Origanum vulgare							x	x										
Ornithopus perpusillus								x		x								
Parnassia palustris								x										
Pedicularis palustris													x	x				
Pedicularis sylvatica									x	x			x	x				
Pilosella officinarum							x	x	x	x								
Pimpinella saxifraga							x	x	x	x	x	x						
Pinguicula vulgaris								x							x	x		
Plantago coronopus								x		x								
Plantago lanceolata																	x	x
Plantago maritima								x										
Plantago media							x											
Platanthera chlorantha							x			x	x	x	x	x				
Polygala calcarea							x											
Potentilla erecta					x	x	x	x	x	x	x	x	x	x	x	x	x	x
Potentilla palustris					x	x						x	x	x				
Primula veris							x	x			x	x						
Racomitrium lanuginosum	x		x	x													x	
Ranunculus flammula					x	x					x	x						
Rhinanthus minor											x	x						
Rhynchospora alba		x																
Rumex acetosa					x	x												
Rumex acetosella							x	x	x	x							x	x
Sanguisorba minor								x										
Sanguisorba officinalis											x	x		x				
Scabiosa columbaria							x											
Scilla verna								x										
Sedum acre							x	x	x	x							x	x
Sedum anglicum								x	x	x								

Habitat:	D1.1		D1.2		D2.2		E1.2		E1.7		E2.2		E3.5		F4.1		F4.2	
Example:	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Species																		
Serratula tinctoria							x		x	x	x	x		x				x
Silaum silaus											x	x						
Sphagnum capillifolium	x	x	x	x									x		x	x		
Sphagnum compactum		x											x		x			
Sphagnum contortum	x																	
Sphagnum cuspidatum		x	x	x	x	x							x			x		
Sphagnum fimbriatum	x	x	x	x									x			x		
Sphagnum fuscum			x										x					
Sphagnum girgensohnii	x		x										x		x			
Sphagnum magellanicum			x										x					
Sphagnum molle													x					
Sphagnum palustre	x	x	x	x		x							x		x	x		
Sphagnum papillosum		x	x	x									x		x			
Sphagnum quinquefarium													x		x			
Sphagnum russowii		x	x										x		x			
Sphagnum squarrosum	x	x	x										x		x	x		
Sphagnum subnitens	x	x	x	x		x							x		x			
Sphagnum tenellum			x	x									x					
Sphagnum teres			x										x					
Sphagnum warnstorfii			x															
Stachys officinalis							x	x	x	x	x	x						
Succisa pratensis					x	x	x	x	x	x	x	x	x	x	x	x		
Teesdalia nudicaulis								x										
Thalictrum flavum											x							
Thalictrum minus								x										
Thymus polytrichus							x	x	x	x								x
Thymus pulegioides							x											
Trichophorum cespitosum	x		x	x														
Trollius europaeus												x	x					
Ulex gallii																x		x
Vaccinium myrtillus	x		x	x					x	x					x	x	x	x
Vaccinium oxycoccos	x	x	x													x		x
Vaccinium vitis-idaea	x		x												x	x		x
Valeriana dioica											x	x	x					
Valeriana officinalis													x	x				
Veronica officinalis							x	x	x	x								
Viola hirta							x											
Viola palustris					x	x			x	x		x		x				
Viola riviniana									x	x							x	x

2.5 Habitat suitability for plant and lichen species

Values for biophysical conditions predicted by MADOC were used to estimate likely values for floristic trait-means, using transfer functions (Table 2). These trait-means, together with climate data for the sites, were used to determine the suitability of the site under the predicted conditions for a set of plant and lichen species, using the Generalised Additive Model method as applied in MultiMOVE v1.0.1 (Butler, 2010). This predicts habitat suitability for each of 1200 UK plant species, on the basis of seven input variables: mean plant-trait scores for wetness (E_W), alkalinity (E_R) and fertility (E_N); cover-weighted mean plant-trait score for canopy height (G_H); and three climate variables (maximum July temperature, minimum January temperature and total annual precipitation). Climate data were provided by the UK Met Office under the UK Climate Impacts Programme (available at www.metoffice.gov.uk) for the period 1961-1990.

Habitat suitability at each site under each scenario was estimated for all species that were: a) positive indicator-species for the habitat (see Section 2.4); and b) present in the surrounding 10x10 km square. Because the probability of occurrence reflects how often the species occurs within the training dataset as well as the environmental suitability of the site, it is necessary to rescale this value to enable comparisons among species. The probabilities calculated using MultiMOVE were therefore rescaled using the method developed by Albert & Thuiller (2008):

$$HSR = \frac{P/(1-P)}{n_1/n_0 + P/(1-P)}$$

where HSR is rescaled habitat-suitability; P is raw probability as fitted by MultiMOVE; and n_1 and n_0 are the respective numbers of presences and absences in the training dataset.

2.6 Calculating values for a biodiversity metric

As noted in Section 1, the number of positive indicator-species present in an example of a habitat was a good indicator of the value assigned to the example by habitat specialists. This metric cannot be directly calculated from MultiMOVE outputs, since it is not currently possible to translate these into an artificial assemblage. The outputs represent habitat suitability, whereas actual occurrence depends also on dispersal and extinction rates. The species-richness at the site (the number of species within a defined area such as 2x2m) is also uncertain. However, the mean habitat suitability for positive indicator-species gives a good indication of the overall suitability of the site for these species. We therefore calculated a habitat quality metric (*HQ*) as:

***HQ* = mean prevalence-corrected habitat suitability for locally-present positive indicator-species**

2.7 Scenarios

The models were set up to assess changes in *HQ* on example sites under the scenarios provided by the CCE. Models were set up to match current conditions, and run forward under two scenarios: 'Gothenburg' with the N and S emissions reductions expected under the Gothenburg Protocol held constant after 2020; and 'Background', in which N and S inputs were scaled down from Gothenburg Protocol levels in 2020 to natural background levels by 2030, and then run forward at natural background levels. Since the slow and passive organic matter pools in the MADOC model take a long time to stabilise, the model was run forward under each scenario to 2500, to provide an indication of equilibrium conditions. Additional scenarios were also run, to illustrate the effects of decreases in N or S deposition alone, and to explore effects of a partial decrease in N deposition to half of the Gothenburg rate.

The environmental conditions that are affected by N deposition are mainly fertility and alkalinity, which are expressed in MultiMOVE in terms of the E_N and E_R traits. Canopy height may also be affected if N increases vegetation productivity, although this depends on whether management intensity increases to compensate for the extra herbage production. Responses of canopy height to the interacting effects of N fertilisation and management are uncertain. The assumption was therefore made that management would be adjusted to maintain canopy height, and G_H, at the present-day value for the site. Moisture availability, expressed as E_W, was also assumed not to change. The MultiMOVE model was therefore solved using projected values for E_N and E_R and present-day values for E_W, G_H and climatic variables, to determine the habitat suitability for locally-occurring indicator species. These habitat suitabilities were calculated for the year 2500, i.e. after the MADOC model had stabilised.

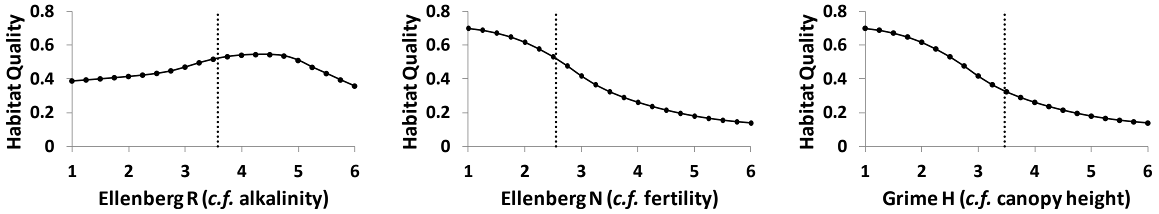
3. Results

3.1 Sensitivity of metric values

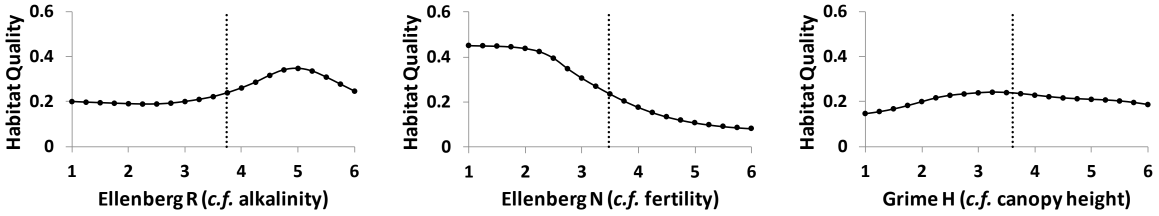
To assess how responsive the *HQ* metric is, it is useful to explore how its value changes as site conditions change. The environmental conditions that are affected by N deposition are mainly fertility and alkalinity, although canopy height may also be affected if N increases vegetation productivity and management intensity does not increase (see Section 2.7). These axes are defined respectively by the E_N, E_R and G_H trait-means. Responses of the *HQ* metric to variation in these conditions are illustrated in Figure 4. At both of the sites shown, greater values for the *HQ* metric were seen under different conditions to those currently observed at the site. In both cases, lower values for the E_N fertility indicator would increase *HQ*, implying that reductions in N deposition would improve habitat quality. Both sites also appeared to have alkalinity (E_R) scores that were below optimal, implying that less acidic conditions would favour the positive indicator-species for these habitats. Canopy height was slightly super-optimal at the wet heath site, but canopy height did not greatly influence HQ at this site. By contrast, at the blanket bog site a decrease in canopy height would clearly favour the positive indicator-species, on average. It should be noted that although this analysis suggests that conditions on these sites could be improved in some respects, they would in most cases still be assessed as being in good or "favourable" condition.

Figure 4. Responses of habitat quality to variation around observed environmental conditions, for blanket bog at Moor House (top row of plots) and wet heath at Cannock Chase (bottom row of plots). Observed values are shown as vertical dashed lines: Moor House $E_R = 3.6$, $E_N = 2.6$, $G_H = 3.5$; Cannock Chase $E_R = 3.7$, $E_N = 3.5$, $G_H = 3.6$.

Moor House

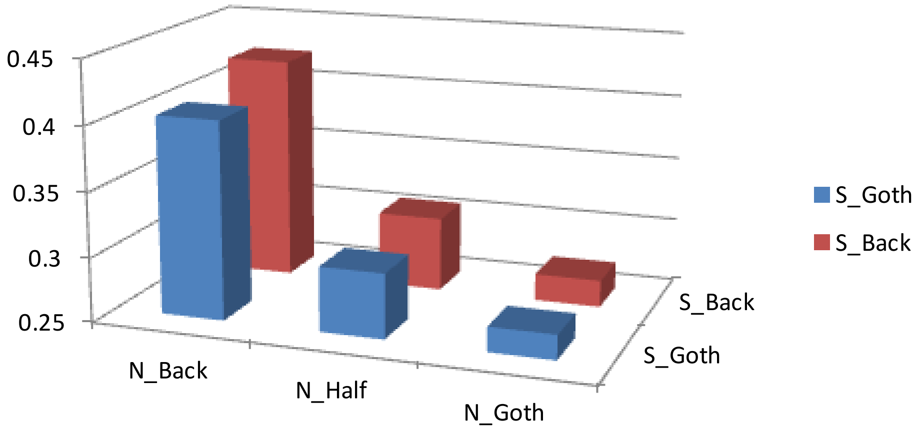


Cannock Chase



The separate effects of N and S deposition are illustrated by the sensitivity of the model to changes in deposition of these two pollutants onto a "poor fen /soft-water spring mire" site, Esgyrn Bottom (Figure 5). Decreasing N deposition had a much greater effect on *HQ* at this site than did decreasing S deposition. Much of the predicted change in *HQ* at this site was due to recovery from acidification – the greater effect of a decrease in N deposition was because N is now the dominant acidifying pollutant at this site. A decrease to background deposition rate took S inputs from 54 to 33 meq m^2 yr^{-1} at this site, whereas a decrease to background N deposition took N inputs from 43 to 2 meq m^2 yr^{-1}. However, a decrease in the E_N fertility index at the site to a value of 2.20, from a peak value of 2.56, was also responsible for some of the increase in *HQ*.

Figure 5. Sensitivity of biodiversity metric values (HQ) at Esgyrn Bottom to variation in N and S deposition, as represented by the Gothenburg (Goth) scenario (6 kg N + 7 kg non-marine S ha^{-1} yr^{-1}), Background (Back) scenario (0 kg N + 0 kg non-marine S ha^{-1} yr^{-1}) and an intermediate scenario (Half) for N (3 kg N ha^{-1} yr^{-1}). Values of HQ calculated for 2500 A.D. to allow effects to stabilise.

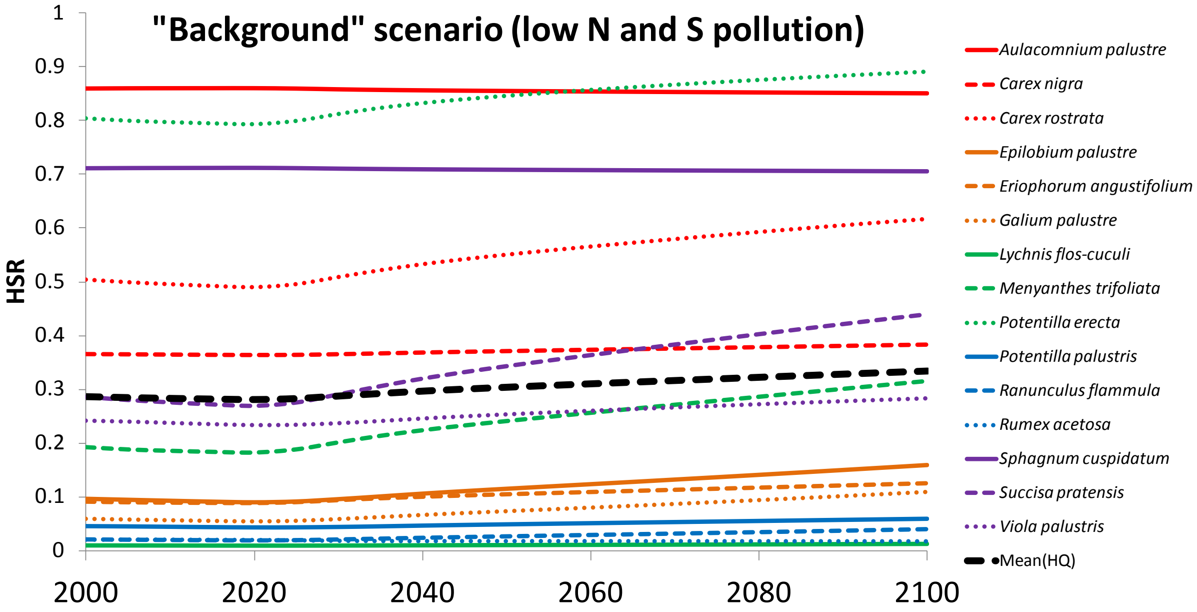


3.2 Responses of indicator-species

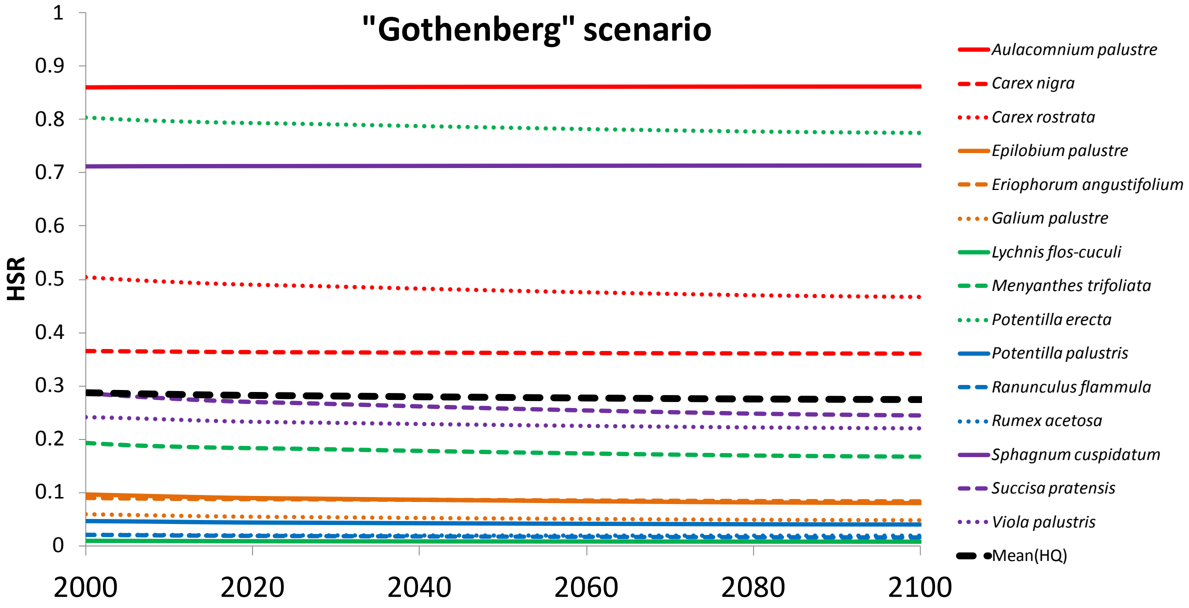
The outputs of the MADOC-MultiMOVE model chain represent the suitability of the habitat for individual species under a set of environmental conditions, e.g. in a particular year under a certain scenario. Results are illustrated for one of the study sites, soft-water mire at Esgyrn Bottom, in Figure 6. Predicted responses varied among the set of positive indicator-species. During the 2000-2100 period the mean habitat suitability for these species, *HQ*, which is presumed to indicate overall habitat quality, increased by 16% under the Background scenario and decreased by 5% under the Gothenburg scenario.

Figure 6. Changes in habitat suitability (HSR) for individual locally-occurring positive indicator-species, and in and in the mean suitability for these species (HQ), in a soft-water mire, Esgyrn Bottom. Changes were predicted using the MADOC-MultiMOVE model chain under (a) “Background” and (b) “Gothenburg” deposition scenarios.

a)



b)



3.3 Response to Call for Data

An initial response was made on 3rd March 2014, and an update was submitted to the CCE on 11th June, representing the UK response to the Call for Data 2013-14. The data submitted on 11th June are described below. The format for responding to the Call for Data is prescribed. National Focal Centres are asked to provide a response within three tables. Two of these tables, however, are only necessary for countries intending to use the VSD+ model (the '*Ecords*' table provides inputs suitable for VSD+), and/or to calculate biodiversity metric values as the "Czekanowski distance" from a reference assemblage of species (the '*Composition*' table provides species lists for the reference and predicted assemblages). These tables are not relevant to the UK response. The third table, '*DRpoint*', will be used for developing dose-response relationships and has been populated in the current project. The most important element in this table is the values that have been calculated for the biodiversity metric under the two scenarios, which are shown in Table 5.

Table 5. Values for a biodiversity metric (mean rescaled habitat suitability for locally-occurring positive indicator-species) calculated for 2500 for example sites under the Gothenburg emissions scenario (GOT2500), and a scenario in which N and S deposition decline to background rates (BKN2500). The percentage increase when changing from the Gothenburg to Background scenarios is shown.

EUNIS	**Site**	**GOT2500**	**BKG2500**	**% change**
D1.1 raised bogs	a) Whim Moss	0.439	0.534	21
	b) Thorne Moor	0.400	0.463	16
D1.2 blanket bogs	a) Moor House	0.497	0.543	9
	b) Mynydd Llangatwyg	0.385	0.467	21
D2.2 poor fens and soft-water spring mires	a) Esgyrn Bottom	0.270	0.425	57
	b) Cors Llyn Farch a Llyn Fanod	0.525	0.645	23
E1.2 perennial calcareous grassland and basic steppes	a) Porton Down	0.376	0.430	15
	b) Newborough	0.385	0.474	23
E1.7 closed dry acid and neutral grassland	a) Snowdon	0.489	0.493	1
	b) Friddoedd Garndolbenmaen	0.345	0.454	31
E2.2 Low and medium altitude hay meadows	a) Eades Meadow	0.118	0.318	170
	b) Piper's Hole	0.114	0.247	117
E3.5 moist or wet oligotrophic grassland	a) Sourhope	0.288	0.293	2
	b) Whitehill Down	0.542	0.701	29
F4.1 wet heath	a) Glensaugh	0.468	0.539	15
	b) Cannock Chase	0.186	0.245	31
F4.2 dry heath	a) Skipwith Common	0.242	0.311	29
	b) Eryri	0.328	0.417	27

4. Discussion

4.1 Uncertainties

The response to the CCE Call for Data 2012-14 as described in this report must be seen as preliminary, since the methods being applied are still under development. In this section we review uncertainties at each stage of the model chain. A full statistical analysis of how these uncertainties propagate through the model chain, and in particular whether the combination of uncertainties at each stage increase or reduces overall uncertainty, was beyond the scope of the project, but subjective assessments are made and key uncertainties highlighted.

Floristic responses to changes in N deposition rate

The principle that large N deposition rates lead to the loss of particular species from sites has a strong empirical basis, with observed effects of N pollution on the distributions of 91 UK plant and lichen species (Emmett et al., 2011b). Experimental additions of N have been demonstrated to cause declines in the abundance of particular species, particularly with greater or more sustained N applications (Phoenix et al., 2012). However, the complete loss of species is not seen often in N addition experiments. There are fewer experiments in which N deposition rate has been decreased (following a period of N addition). These have also shown changes in the abundance of species, but the reappearance of previously-lost species has rarely been observed (Rowe et al., 2014b). The limited responses seen in experiments as compared to surveys are probably due to previous additions of N that have accumulated in the ecosystem. On a given site, sensitive species are likely already to have been lost, and changes in current deposition are unlikely to have abrupt effects.

It is clear that species are put at risk by increased N deposition, and that this risk is reduced when N deposition decreases. However, the timescales of N impacts and recovery are not well-established, with uncertainties over how quickly chemical conditions (such as plant-available N in soil) will recover, and over how quickly species will respond to the improved chemical environment.

Choice of biogeochemical model

Numerous biogeochemical models are available which predict transformations of N as it flows through ecosystems. The MADOC model applied in the current project represents an advance on the VSD model used hitherto by the UK National Focal Centre to simulate air pollution impacts, for instance by representing current understanding that additional N can increase soil C/N ratio by stimulating litter production. Soil organic matter is not simulated as single homogeneous quantity, but subdivided into pools with different turnover rates. This allows the N release from soil to be simulated in different phases, with rapid release of some N, but very slow release of other parts of the soil N. This pattern of release is thought to be more realistic than the single-pool saturation approach taken in VSD. The N14C soil organic matter model (Tipping et al., 2012) that is used within MADOC has been widely tested for UK sites against radio-carbon dates for soil organic matter and observed soil C/N ratios. The overall performance of MADOC in predicting pH change has also been tested against independent observations (Rowe et al., 2014c). The biogeochemical model used is probably appropriate, and most currently available soil organic matter models take a similar multiple-pool approach. However, uncertainty remains as to whether the best available biogeochemical model has been used. This uncertainty could be reduced, or at least better understood, by applying an ensemble of alternative models.

Calibrating the biogeochemistry model

The approach of using floristic trait-means to infer the abiotic environment has advantages and disadvantages. The major advantage is in terms of data availability – accurate biogeochemical measurements using standardised methods are lacking for most sites, but floristic data are often available. Also, the species composition provides an integrated and presumably accurate reflection of the environment experienced by the plants over the period preceding the observations, since the plant species that are present are likely to change only gradually. Biogeochemical measurements, in particular of nutrient availability, are more subject to change and sampling error, so cannot be seen as more accurate. The disadvantage is that inferring a biophysical quantity such as pH from a floristic trait-mean inevitable introduces uncertainty. There is scatter in the transfer functions used, and the inferred quantity may not correspond to actual measurements at the site. This is a particular problem at low values of E_R and E_N (see Figure 3), and predictions for sites with E_R values below 3.1 or E_N values below 2.9 must be seen as more uncertain. However, these transfer functions give the most likely value for the site and are likely to perform well on average. If biophysical measurements were used instead, this would eliminate this source of uncertainty, but it would still be necessary to use a transfer function to derive a floristic trait-mean for the site and this would often differ from the measured value. This difference would be a more serious problem when calculating habitat suitabilities for species than would the potential inaccuracies in calibrating the biogeochemical model.

Floristic change

The MultiMOVE niche models are derived from statistical modelling of species occurrence data. Uncertainties here derive from: the representativeness of the datasets used; the choice of explanatory axes; the choice of statistical model, in particular the forms of the curves fitted and the ways that interactions among the explanatory axes are expressed; the methods used to transform the raw probabilities predicted by the model onto a scale that is comparable among species. These uncertainties are considerable, but they are managed during the statistical model fitting by automatically eliminating axes that add no explanatory power from each species' model. Uncertainty in the niche models is also reduced by only including species for which there were sufficient observations of presence (>30) within the training dataset. The most suitable explanatory axis for nutrient availability is much debated. In the UK the MultiMOVE team have used mean Ellenberg N as the basis for this axis, in contrast to the European-scale model (PROPS) being developed in the Netherlands which currently relates species occurrence to a combination of measured soil mineral N and modelled N deposition rate. As noted in the previous section, biophysical measurements and floristic trait-means both have advantages and disadvantages. The uncertainties involved with using biophysical measurements of nutrient availability are considerable, as illustrated by several changes in recent years in the biophysical measurements used for this axis in PROPS.

Selection of indicator-species

The choice of positive indicator-species will affect the values calculated for the proposed metric. For the current study, species-lists were derived from Common Standards Monitoring guidance documents (e.g. JNCC, 2004) as described in Rowe et al. (2014a). These lists were originally developed after lengthy discussion by habitat experts, with the aim of selecting species that work consistently across the UK as indicators of favourable condition (Richard Jefferson, *pers. com.*). However, there are some ambiguities in the lists, notably where species-groups are used. For example, "*Carex* spp." is listed as a positive indicator for lowland calcareous grasslands, but the genus *Carex* contains species with a wide variety of environmental preferences. The suitability of the environment for aquatic or montane *Carex* species would not indicate favourable condition for lowland calcareous grassland. Some judgement was therefore applied in selecting indicator-species for the current project. Another problem is the variation in the number of species included as positive indicators, ranging from 42 for dry heath to 282 for perennial calcareous grassland (these numbers include multiple species in some large genera such as *Carex* and *Cladonia*). These difficulties are likely to be resolved or at least reduced by current initiatives at UK level and to define indicator-species for EUNIS classes (Chris Cheffings, *pers com.*).

Another source of uncertainty related to indicator-species is the geographical filtering applied, which can result in somewhat different sets of indicator-species on different sites. This issue will be discussed in the following section.

Values for the habitat quality metric

The values given for the biodiversity metric *HQ* will be of limited use until they are placed in the context of typical values for the habitat. These are likely to span a range from a minimum, below which a site is so unsuitable that it would not be classified as this habitat, to a maximum, at which the site is highly suitable for the positive indicator-species. If the approach is to be applied within the framework of air pollution integrated assessment modelling, it will also be necessary to determine a threshold value below which the site is considered damaged, and above which the site is considered undamaged or recovered. These minimum, maximum and threshold values will be habitat-specific. There will also be some geographic variation due to the exclusion of species for which the site is climatically unsuitable.

Variation in typical values was not examined in the current project. If current values were calculated for sufficient sites (by solving MultiMOVE for the climate data, as inferred from location, and floristic trait-means, as calculated from a species list with cover values) it would be possible to determine the range of values observed for each habitat, and the influence of geographic variation. It would be particularly useful to assess sites in relation to their current condition assessment, since it should be possible to observe differences in metric values between sites in favourable, unfavourable or recovering condition, and use these to determine threshold levels.

In the overall analysis of submissions to the CCE in response to the Call for Data, all metric values were re-scaled such that the value determined for the site under the “background” scenario was 100%, and values for polluted scenarios were presented as percentages of this value. Alternative methods for determining the maximum value are available:

- Modelled value for an unpolluted scenario, as noted above;
- Maximum value calculated from observations at high-quality sites;
- Theoretical maximum value from all possible combinations of environmental variables.

For this reason, and to avoid confusion with the raw values for the metric which are in the range 0-1, metric values were not expressed as percentages in the current study. However, it would aid clarity if metric values were presented as percentages, so the appropriate maximum should be investigated.

Floristic change modelling

The presence of a species on a site depends not only on the suitability of the habitat but on establishment and extinction processes. Species may persist despite adverse environmental conditions, or conversely fail to establish on sites which are suitable because they cannot disperse to or establish on the site. These processes cause ‘biological delays’ (Posch et al., 2004) to responses to changes in pollutant deposition and soil chemistry. Losses or gains of species are essentially stochastic events, which are not taken into account in the static niche modelling approach used in

MultiMOVE. Although some attempts have been made to account for the effects of local species-pools and establishment processes (Emmett et al., 2011a) these methods are not sufficiently developed to be applied with confidence. Outputs from the MultiMOVE model must therefore be seen as indicating habitat-suitability rather than the current probability of presence of the species. Habitat-suitability reflects the likelihood that a species would occur on the site at equilibrium, i.e. after processes of dispersal, establishment and loss had stabilised.

4.2 Conclusions from the study

The study has shown the practicability of applying the MADOC-MultiMOVE model, even for sites where only floristic and climatic records exist. This represents a major step forward from models that require many biogeochemical measurements, since these measurements are often not available for a given site and the use of default values introduces uncertainty.

The values calculated for the metric under the different scenarios represent a summary of the changes in habitat suitability for positive indicator-species due to variation in N and S deposition. These changes are driven by the effects of fertility and alkalinity on individual species. The effects of changes in canopy height, soil moisture and climatic conditions have not been incorporated in the current study, mainly for clarity, but if changes in these aspects of the environment can be predicted then their effects on species could also be taken into account. Using this mechanistic approach allows many different responses to be incorporated. However, this approach also means that a negative response of the biodiversity metric to increased N and S deposition is not a foregone conclusion. Responses at a particular site will depend on current conditions, and for example if canopy height is currently sub-optimal, N deposition could result in an increase in habitat suitability. It is therefore encouraging to note that for all the example sites included in the study, a decrease in N and S deposition (from the Gothenburg to the Background scenario) resulted in an increase in the biodiversity metric.

The metric incorporates changes in habitat suitability for many species, and at a given site fertility, alkalinity and canopy height only some of these are likely to be strongly affected by changes to N deposition rate (see Figure 6). The rate of change of metric values under different scenarios was not explored in the current study, but gradual environmental changes such as marginal decreases in N deposition rate seem likely to cause gradual changes to metric values. This reflects the gradual and insidious nature of N pollution impacts, and delays to recovery following a decrease in deposition due to the accumulation of N in ecosystems. The rate of change of metric values is likely to reflect the actual pace of damage to, or recovery of, habitat quality.

Applying the method to further example sites would likely increase confidence in the applicability of the MADOC-MultiMOVE model chain and in the biodiversity metric derived from its outputs. Further work will be required to determine typical values for the biodiversity metric in different habitats, and to establish threshold values below which the habitat should be considered damaged. Typical values for the metric are likely to vary geographically, because of the effects of climate on habitat suitability for positive indicator-species, and because different species will be included after geographic filtering. Nevertheless, the UK response to the Call for Data 2012-14 showed that it is possible to achieve consensus on methods for evaluating model outputs in terms of biodiversity, and to apply these methods to real sites without extensive input data.

4.3 Outcomes of the CCE Workshop

The results of the study were presented at the 24th Workshop of the CCE, held in Rome in April 2014. An overall analysis of responses to the Call for Data 2012-14 showed that metric values often increased with more N pollution. This counter-intuitive result is probably due to the selection by several countries of metrics that do not reflect current understanding of biodiversity, such as the Simpson evenness index, or the similarity of the species-assemblage to a (perhaps inappropriate) reference assemblage. Metrics based on positive indicator-species were presented by the Dutch, Swiss and Danish National Focal Centres, as well as the UK. In the "training session" for modellers attending the workshop, it was proposed (Le-Gall, 2014) that:

- "The habitat suitability index is proposed as a common biodiversity indicator for all countries to use, possibly next to country-specific indicators.
- Step one in this approach is listing the 'typical' or 'positive indicator species' for a site or a EUNIS/habitat type.
- Such a step can be part of the next call for data in order to test its properties and compare to other indices."

Acknowledgements

We are grateful to Laurence Jones, Jan Sherry, Peter Jones and Stuart Smith for providing floristic data for example sites. We would also like to thank the Botanical Society of the British Isles, the British Bryological Society and the British Lichen Society for allowing the use of distribution data.

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