United Kingdom

National Focal Centre

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Introduction

In response to the "CCE Call for Data 2014-15" the UK NFC has:

- carried out minor updates to the UK critical load database;
- applied the MADOC-MultiMove model chain to calculate critical loads based on a habitat quality metric for 40 sites. Details are provided below.

Updates to UK critical load database

The UK critical loads data for terrestrial habitats are mapped nationally on a 1x1km grid of the Ordnance Survey British National Grid. For the data submission these data are referenced by the longitude-latitude for the centre point of each 1x1km grid square. The critical loads data for the 1752 freshwater catchments have been sub-divided to the same grid resolution for consistency with the terrestrial data and to ensure future compatibility with the new EMEP grid resolutions.

In previous years the NFC has submitted empirical nutrient nitrogen critical loads for the designated features of Natura 2000 sites, i.e. Special Areas of Conservation (SACs) and Specially Protected Areas (SPAs) (Hall et al., 2011). However, as these sites can overlap with the UK broad habitat critical loads data they could not be used by the CCE due to double counting of habitat areas in assessments. To overcome this, the nutrient nitrogen critical loads for broad habitats, SACs and SPAs have been integrated into a single database, without duplicating the areas. This has been achieved by:

- Identifying the designated features that are the same EUNIS class as the UK broad habitats.
- Identifying the 1x1km squares that contain individual UK broad habitats and all or part of any SAC and/or SPA.
- Assigning the appropriate nutrient nitrogen critical load for each relevant EUNIS class to each 1x1km square, using the lowest value if there are differences between the values for the broad habitat, the SAC and/or SPA.
- Assuming that the habitat area for the designated feature habitat within the 1x1km square is the same as the area that has been

mapped for that broad habitat. This is necessary as spatial data on the location and areas of designated feature habitats within sites is not available.
- Setting the "protection" score for the 1x1km squares according to the codes provided by the CCE (1: SPA, 2: SAC, 3: SPA and SAC, -1: protection status unknown).

The critical load values applied to feature habitats of UK SACs and SPAs are values (within the published ranges) agreed nationally for use in air pollution impact assessments. For some habitats these values will be the same as the "UK mapping values" applied to broad habitats and based on UK evidence; where no UK evidence exists, the values may be based on expert opinion or set to the minimum of the published range.
It should be noted that the resulting database tables do not include: (a) designated feature habitats that are not mapped nationally; (b) areas of SACs/SPAs that fall outside of the broad habitat areas mapped nationally. In total 13.3% of the UK 1x1km critical load records submitted for nutrient nitrogen represent the designated feature habitats of SACs and/or SPAs (Table GB.1).

Table GB.1: The percentage of UK 1x1 km broad habitat grid squares that contain designated feature habitats of SACs and/or SPAs.

EUNIS class	% of 1x1 km squares in the following categories:				
	Broad habitat only	Broad habitat + SPA	Broad habitat + SAC	Broad habitat + SAC + SPA	Broad habitat + any site combination
A2.5	32.9	17.0	12.3	37.7	67.1
B1.4	60.5	11.4	14.2	14.0	39.5
D1	70.1	2.8	9.1	18.0	29.9
E1.7	94.0	0.5	5.5	0.0	6.0
E3.52	96.6	1.3	2.1	0.0	3.4
E4.2	64.4	2.3	19.5	13.8	35.6
E1.26	94.6	0.0	5.4	0.0	5.4
F4.11	79.3	4.7	6.8	9.2	20.7
F4.2	84.7	1.8	9.7	3.9	15.3
G4	97.1	1.1	1.5	0.3	2.9
G1.6	92.2	0.0	7.8	0.0	7.8
G1.8	88.1	0.0	11.9	0.0	11.9
G3.4	71.4	0.0	28.6	0.0	28.6
All the above	86.7	2.2	6.5	4.6	13.3

The UK database includes acidity and nutrient nitrogen critical loads for a number of different woodland categories (EUNIS classes G1, G1.6, G1.8, G3, G3.4, G4). The methods used to derive the critical loads for these (and all other UK habitats) are described in detail in Hall et al. (2015). The UK NFC has received acidity and nutrient nitrogen critical loads data for 167 UK forest plots from ICP Forests, however these have not been incorporated into the UK database since they currently lack additional data and information to enable a full comparison to be made between the UK methods and results and those used by ICP Forests.

Biodiversity-based critical loads

The methods and results applied to calculate biodiversity-based critical loads are summarised here. A more complete description of the study can be found in Rowe et al. (2015).

Introduction

Air pollution by sulphur (S) and nitrogen (N) causes soil acidification, and nitrogen has additional effects on ecosystems through mechanisms such as eutrophication and formation of ground-level ozone. Substantial reductions in S pollution since the 1980s have led to a widespread recovery from acidification (Emmett et al., 2010) except on some weakly-buffered soils (Evans et al., 2012). Nitrogen pollution has also decreased, but by a smaller proportion. The current approach to assessing effects of N pollution is based on its contribution to acidification, using a comparatively simple mass-balance approach; and on its eutrophying and other effects, which are summarised using the "empirical critical load" approach. Empirical critical loads for N have been established by assessing evidence from experiments and some survey studies (Bobbink and Hettelingh, 2011). However, experimental studies may not capture the medium-term and long-term effects of N, since the effects of N deposition can be persistent and cumulative, and at many sites changes induced by N are likely to have already occurred when the experiment started. Also this approach does not adequately represent the combined effects of N and S pollution. For these reasons, the CCE has encouraged the development of dynamic modelling approaches that capture the combined effects of air pollution on biodiversity (e.g. Hettelingh et al., 2008). Progress was initially slow due to lack of consensus on how the outputs from such models (e.g. changes in habitat-suitability for each of a large set of plant and lichen species) should be interpreted in terms of policy targets such as "no net loss of biodiversity". However, work funded by Defra under the AQ0828 and AQ0832 projects (Rowe et al., 2014a; Rowe et al., 2014b) has defined an index of Habitat Quality (HQI) for use in this context, i.e. mean habitat-suitability for positive indicator-species. Here we describe the application of this index to the dynamic modelling of N and S impacts.

The third aim of the CCE Call for Data 2014-15 was to "Apply novel approaches to calculate nitrogen and sulphur critical load functions taking into account their impact on biodiversity. For this, National Focal Centres are encouraged to use the 'Habitat Suitability Index' (HS - index) agreed at the M&M Task Force meeting". This aim was met by applying the habitat quality metric (HQI) developed in the AQ0828 and AQ0832 projects. The MADOC-MultiMOVE model (Butler, 2010; de Vries et al., 2010; Rowe et al., 2014c) was used to determine combinations of N and S likely to cause habitat quality to decline below a threshold, i.e. biodiversity-based critical load functions. This report outlines the approach taken and illustrates this approach for a set of example sites.

Methods

The basis of the study is the capacity to predict changes in habitat suitability for species under different pollutant deposition scenarios, which has been developed by linking dynamic models of biogeochemical change with regression models of habitat-suitability for individual species. The biogeochemistry model used in the current study was

MADOC (Rowe et al., 2014c), essentially a combination of the Very Simple Dynamic (VSD) acid-base chemistry model (Posch and Reinds, 2009) with a simple model of carbon (C) dynamics (Tipping et al., 2012). It is analogous to the VSD+ model (Bonten et al., 2010) which is being developed using a different model of C dynamics to extend VSD, but in the UK model more emphasis has been placed on processes that are important in upland systems and more C-rich soils, such as the production of dissolved organic C. The MADOC model responds to several environmental drivers such as the deposition loads of N and S, and was used to predict changes in soil pH, soil total C/N ratio, and the annual flux of available N from deposition and release from soil organic matter.

The habitat-suitability model used in the current study was MultiMOVE (Butler, 2010). This predicts the suitability of a site for each of around 1300 plant and lichen species, depending on the current environmental conditions. These conditions are expressed using four indicators that are based on trait-means for the species present (mean "Ellenberg R" for alkalinity; mean "Ellenberg N" for eutrophication; mean "Ellenberg F" for wetness; mean "Grime Height" for vegetation height) and three climate-based indicators (minimum January and maximum July temperature, and annual precipitation). The habitat-suitability values predicted by MultiMOVE were rescaled by prevalence in the training dataset, using the method of Real et al. (2006). Values rescaled in this way are comparable among species and can be used to reconstruct a plausible set of plant species for a given site (Rowe et al., 2014a).

Habitat-suitability for a large set of species could be analysed and interpreted in many different ways. The AQ0828 and AQ0832 studies established that the most suitable indicator of overall habitat quality that can be calculated from these outputs is the mean habitat suitability for positive indicator-species. This conclusion was reached following a detailed consultation with habitat specialists of the Statutory Nature Conservation Bodies (Rowe et al., 2014b). In the current study, species-level model outputs were summarised using this Habitat Quality Index (HQI). To calculate N and S critical load functions using such an index requires definition of a threshold value below which the site should be considered to be in damaged or unfavourable condition. To establish this threshold, the value of HQI was calculated under a scenario where N deposition was set to the empirical N critical load (CLempN), using the 'mapping value' for CLempN as determined for each site by the UK National Focal Centre, and no anthropogenic sulphur deposition. The CLempN was originally set, on the basis of evidence and/or expert judgement, at a level intended to avoid damage in the near- and long-term. By running the model chain forward at the critical load for an extended period, the resulting value of HQI can be assumed to correspond to a threshold or critical value. The model chain was run forward to 2100 as recommended by the CCE. This date is a compromise between capturing the effects of N persisting over many decades (although with diminishing impacts) and the increasing uncertainty associated with predicting effects in future centuries.

Using the threshold established in this way, a more complete picture of N and S effects on ecosystems can be obtained, by running the model chain at different rates of N and S deposition to determine which combinations cause HQI to decline below the threshold. The combinations that give HQI = HQIcrit were assumed to correspond to the 'biodiversity-based' Critical Load function which was the goal of the exercise. Such a CL function is illustrated for a hypothetical site in Figure GB.1.

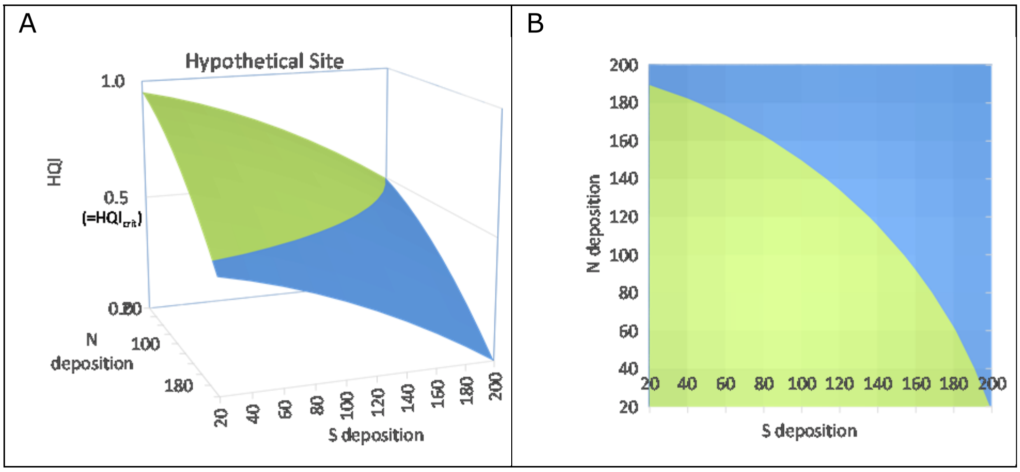

Figure GB.1 Hypothetical response, illustrated in A) three and B) two dimensions, of a habitat quality index (HQI; vertical axis in graph A) to variation in S and N deposition. The light green area represents combinations which maintain HQI above a threshold value, HQIcrit, assumed here to be 0.5. The contour where HQI = HQIcrit corresponds to a 'biodiversity-based' critical load function.

Responses to the Call for Data were requested in the form of two points on the plot, defined by values on each of the S and N deposition axes: CLNmin, CLSmax, CLNmax and CLSmin, as illustrated in the Call for Data instructions (see Appendix A). Clearly such a simple function can only be an approximation of a curvilinear function.
Example sites (Figure GB.2) were chosen from the database of Special Areas for Conservation (SACs) maintained by the NFC. Example SACs with either E1.7 'Closed non-Mediterranean dry acid and neutral grassland' or F4.11 'Northern wet heaths' were selected at random from the database. The MADOC model was set up using deposition sequences for S and N provided by EMEP, and values collated by the UK NFC for climate and soil parameters. The model was calibrated to match present-day values of two key observations, soil pH and soil total C/N ratio, by adjusting parameters whose true value is unknown. The target values for pH and C/N used in the current study were mean values for the broad habitat corresponding to the EUNIS class for the site, as observed in Countryside Survey 2007 (Emmett et al., 2010). Soil pH was matched by adjusting calcium weathering rate or the density of exchangeable protons on dissolved organic carbon. Soil total C/N ratio was matched by adjusting the rate of N fixation during the pre-industrial period. The calibrated model was then run again with N and S deposition set, for the period 1980-2100, to CLempN. The simulated environmental conditions in 2100 were used to calculate habitat-suitability for positive indicator-species, and thence HQI. The HQI under this Critical Load scenario was assumed to correspond to a threshold level for the site, HQIcrit. The model chain was then re-run, to find combinations of N and S deposition below which this HQIcrit value was exceeded.

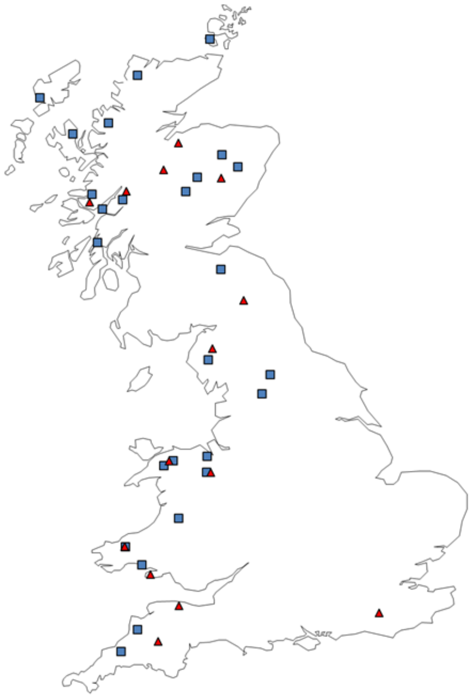

Figure GB.2. Locations of Special Areas for Conservation for which biodiversity-based Critical Load functions were submitted in response to the CCE Call for Data. Blue squares = E1.7 Dry acid grassland; red triangles = F4.11 Wet heath.

The biogeochemical conditions predicted by MADOC for 2100 under three Critical Load scenarios were then used to estimate positions on each of the gradients that define habitat-suitability for species in the MultiMOVE model. These gradients are mean values for floristic traits – for wetness (EW), alkalinity (ER), fertility (EN) and vegetation height (GH). Together with climate variables (maximum July temperature, minimum January temperature and total annual precipitation), these trait-means define the environmental conditions at a site. Biogeochemical conditions were related to trait-means using relationships established from empirical data (Table GB.2).

Table GB.2. Conversion equations used to estimate floristic trait-means (used to predict habitat-suitability for species) from biogeochemical conditions. EW = mean Ellenberg 'moisture' score for species present; ER = mean Ellenberg 'alkalinity' score for present species; EN = mean Ellenberg 'fertility' score for present species; GH = mean Grime 'height' score for present species; MC = soil moisture content, g water 100 g^{-1} fresh soil; pH = soil pH; Nav = available N, g N m^{-2} yr^{-1}; CN = CN ratio, g C g^{-1} N; H = canopy height, cm; Cplant = total plant biomass C. Mean GH was weighted by observed cover or occurrence frequency; other trait-means were not weighted.

Value to be estimated	Calculated as	Source
EW	$\frac{ln\left(\frac{\mathrm{MC}}{100-\mathrm{MC}}\right)+3.27}{0.55}$	Smart et al. (2010)
ER	$\frac{\mathrm{pH}-2.5}{0.61}$	Smart et al. (2004)
EN	$0.318\,log_{10}\,\mathrm{N_{av}} + 1.689 + \frac{284}{\mathrm{CN}}$	Rowe et al. (2011)
G_H	$\max(1, 1.17 \times ln\,\mathrm{H} - 1.22)$	Rowe et al. (2011)
H	$\left(\frac{\mathrm{C_{plant}}}{14.21 \times 3}\right)^{1/0.814}$	derived from Parton (1978) and Yu et al. (2010)

Whether changes in vegetation height should be included is debatable. If management intensity increases to compensate for extra herbage production, the vegetation height may not change. However, faster closure of gaps is probably a key driver of species loss as systems become more productive, since the diversity of strategies for colonising new gaps is an important factor in maintaining overall plant diversity. This argues for the inclusion of an effect on ground-level light availability of extra biomass production, even if the vegetation height changes little, and this approach was taken in the current study, with simulated changes in height taken into account in the species modelling.

The MultiMOVE model was used to determine the suitability of the site for positive indicator-species for the habitat, under the conditions projected to occur in 2100 under the CL scenario. The model predicts habitat-suitability using several statistical modelling techniques in an ensemble approach (Butler, 2010), and for the current study the model-average habitat-suitability was used. Raw suitabilities predicted by the model were standardised for prevalence in the training dataset using the method of Real et al. (2006). Habitat suitability was estimated for all species that were: a) positive indicator-species for the habitat (see below); and b) present in the surrounding 10x10 km square. The lists of indicator species used to calculate HQI in the original AQ0832 study (Rowe et al., 2014b) were derived from common standards monitoring (CSM) guidance documents (e.g. JNCC, 2006). Judgements were made as to which species to include or exclude as positive indicators. Since that study, lists of positive indicator-species have been made available as a result of a combined effort by the Joint Nature Conservation Committee (JNCC) and the Botanical Society of the British Isles (BSBI) (Kevin Walker, pers. com.) and were used in the current study. However, neither the CSM guidance nor the more recent effort lists species for EUNIS habitat classes, which need to be used for the CCE data submission. To obtain suitable lists for these classes we used

correspondence tables developed under the JNCC AND-UP project (Jones et al., in prep). At a given site, particular positive indicator-species might not be present due to unsuitable climate rather than because of the effects of pollution. To avoid underestimating the overall habitat-suitability for positive indicator-species, species that had never been recorded from a particular grid-square were excluded when calculating the mean habitat-suitability. The records used for this filtering were obtained from the Botanical Society of the British Isles, the British Lichen Society and the British Bryological Society.
Following calibration of MADOC to match the C/N ratio and soil pH values obtained from the NFC database for the soil and vegetation type, this model was run forward to 2100 with deposition set to each of the CL combinations of N and S. The resultant abiotic conditions were used to predict the value of HQI under each of these CL combinations, and the mean value was used as HQIcrit for the site. Ideally, the new CL function would be established by determining the exact combinations of N and S deposition that result in HQI = HQIcrit. Routines to do this could be developed, but would require calibration of the whole MADOC-MultiMOVE chain, which would currently be too time-consuming. Instead, the model chain was run using 10 x 10 combinations of N and S deposition, evenly covering ranges from 20% to 200% of CLempN and CLmaxS, respectively. This allowed the response surface to be plotted, and a contour-fitting routine was applied to interpolate the new CL function. This function was simplified into the two-node form required for responding to the CCE Call for Data, by positioning these nodes so that differences from the interpolated function were minimised within these deposition ranges.

Results
The dynamic effects of different air pollution scenarios extended over the 21st century are illustrated below for the Snowdon acid grassland site. The time course of N and S deposition is shown for i) current legislated emissions, and for three Critical Load combinations: ii) S deposition at CLmaxS; iii) S deposition at CLmaxS together with N deposition at CLminN; and iv) the empirical N critical load, CLempN (Figure GB.3). At this site CLempN is greater than the current legislated emissions, so the CLempN scenario causes relative increases in C/N (due to stimulated production of plant litter with a high C/N), N availability and vegetation height (Figure GB.4). Sulphur pollution was reduced in all the CL scenarios, so these showed increases in pH, although N leaching in the CLempN scenario caused pH to decrease in the longer term.

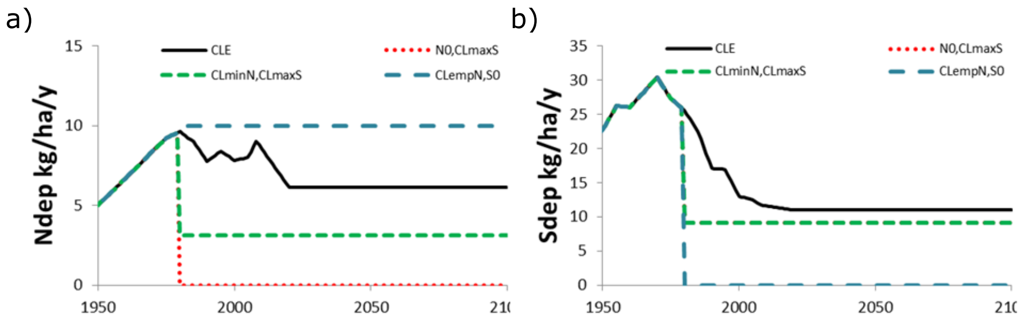

Figure GB.3. Deposition rates of a) nitrogen and b) sulphur at Snowdon (a Welsh acid grassland site) under four scenarios: i) deposition predicted with current legislated emissions under the Gothenberg protocol; ii) N = 0, S = CLmaxS; iii) N = CLminN, S = CLmaxS; and iv) N = CLempN, S = 0.

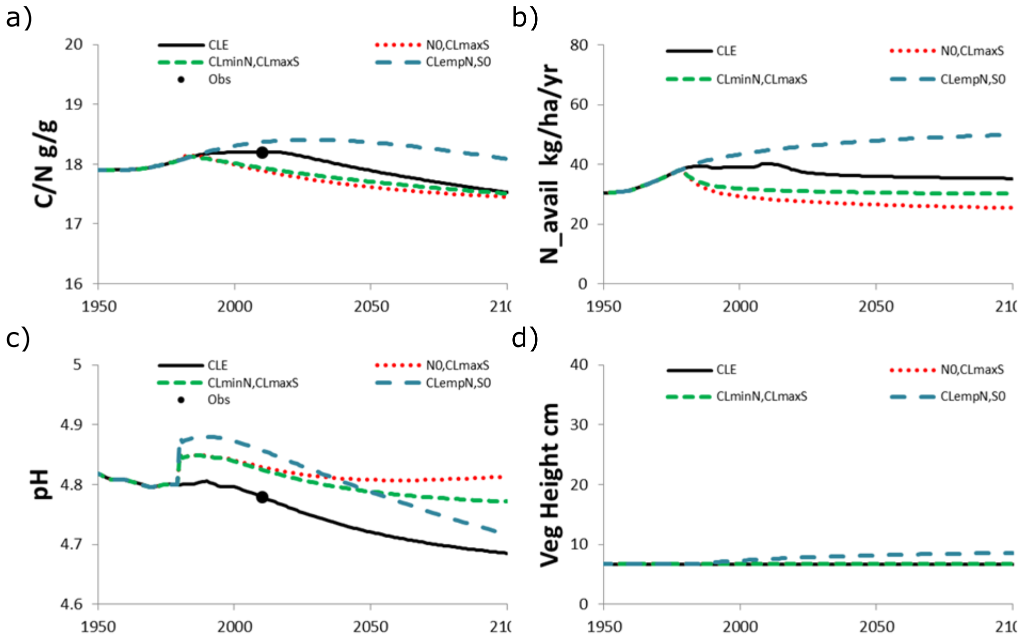

Figure GB.4. Simulated responses at Snowdon (a Welsh acid grassland site) of a) soil C/N, g g^{-1}, b) available N, kg N ha^{-1} yr^{-1}, c) soil pH and d) vegetation height, cm, to four N and S deposition scenarios: i) deposition predicted with current legislated emissions under the Gothenberg protocol; ii) N = 0, S = CLmaxS; iii) N = CLminN, S = CLmaxS; and iv) N = CLempN, S = 0.

The sensitivity of the MADOC-MultiMOVE model chain was explored by varying N deposition over the range of 20-200 % of CLempN and S deposition over the range of 20-200 % of CLmaxS (Figure GB.5). Increases in both N and S caused pH to decline. Soil C/N ratio and plant-available N both increased with greater rates of N deposition but were not affected significantly by S deposition.

a) b) c)

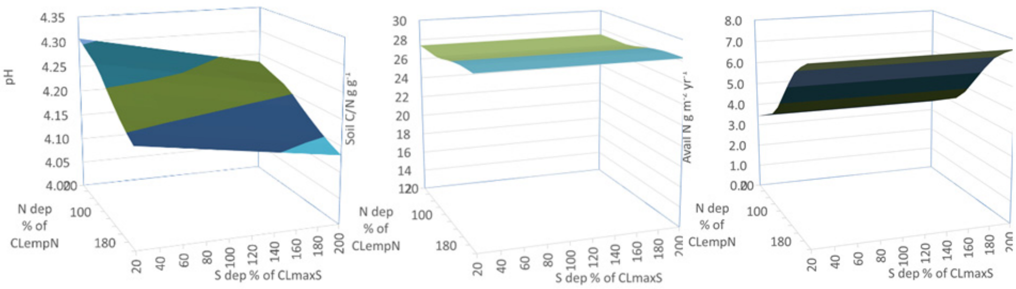

Figure GB.5. Simulated sensitivity of biogeochemical properties: a) pH; b) C/N ratio, g C g^{-1} N; c) plant-available N, g N m^{-2} yr^{-1}, to variation in nitrogen and sulphur deposition at the Whim Moss blanket bog site.

The habitat-suitability for individual species is calculated on the basis of floristic trait-means, the values of which are inferred from biogeochemical properties (see Table GB.2). The sensitivity of the three trait-means that are most responsive to N and S deposition was assessed over ranges of 20-200 % of CLempN and 20-200 % of CLmaxS (Figure GB.6). The response of the alkalinity trait to N and S was similar to the pH response. Trait-means representing fertility and vegetation height both increased with more N deposition but were hardly affected by S deposition.

a) b) c)

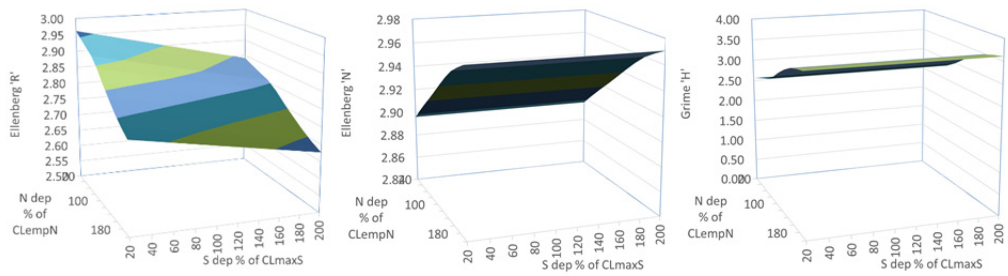

Figure GB.6. Simulated sensitivity of mean values for floristic traits: a) Ellenberg R i.e. alkalinity; b) Ellenberg N i.e. fertility; c) Grime H i.e. height, to variation in nitrogen and sulphur deposition at the Whim Moss blanket bog site.

The trait-mean values calculated above were used to explore the sensitivity of individual species to variation in N and S pollution. Three of the positive indicator-species for blanket bog were selected to illustrate different types of response (Figure GB.7). Habitat-suitability for all three species declined with more N deposition, steeply in the case of Drosera rotundifolia. This species was relatively insensitive to S deposition. The other two species illustrated show contrasting responses to increased S deposition, which made the site more suitable for Vaccinium myrtillus but less suitable for Trichophorum cespitosum.

a) b) c)

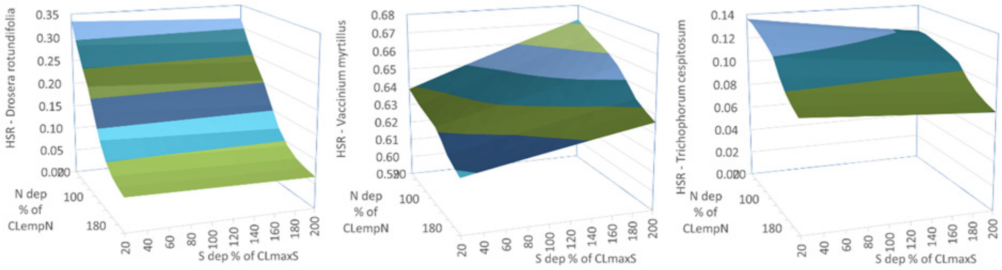

Figure GB.7. Simulated sensitivity of habitat suitability (rescaled by prevalence) for selected positive indicator-species: a) Round-leaved sundew; b) Bilberry; c) Deergrass, to variation in nitrogen and sulphur deposition at the Whim Moss blanket bog site.

The overall response of the habitat was summarised using the HQI metric, i.e. mean habitat suitability (rescaled by prevalence) for all locally-occurring positive-indicator species. The sensitivity of HQI to variation in N and S deposition was assessed over ranges of 20-200 % of CLempN and 20-200 % of CLmaxS for the Whim Moss blanket bog site (Figure GB.8). Although other positive indicator-species were included, the response is similar to the surface that would be obtained by averaging the responses for the three species illustrated in Figure GB.7. Clearly positive and negative responses to S deposition (i.e. principally to acidification) cancelled out, and there was no overall response of HQI to variation in S deposition within this range. By contrast there was a strong overall response of HQI to N deposition (i.e. principally to eutrophication and increased vegetation height), with clear decline at greater N deposition rates. At the Glensaugh wet heath site, HQI declined with both N and S deposition.

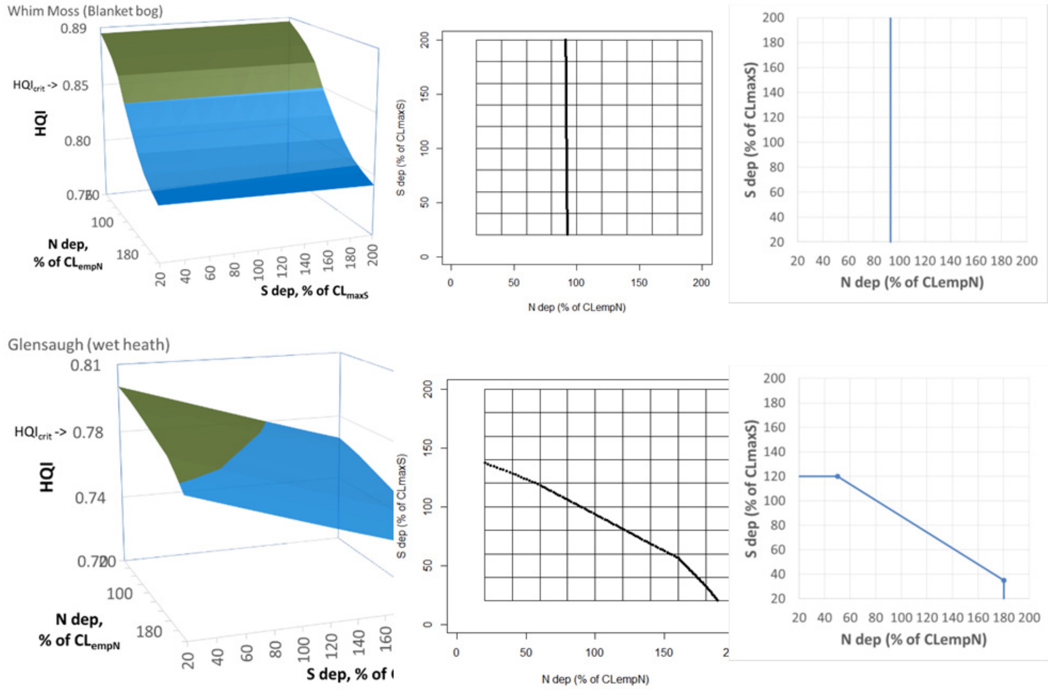

Figure GB.8. Simulated sensitivity of an overall habitat quality index HQI, the mean habitat-suitability (rescaled by prevalence) for locally-occurring positive indicator-species, to variation in nitrogen and sulphur deposition at the Whim Moss (blanket bog) and the Glensaugh (wet heath) sites.

A threshold value for the habitat quality metric, HQIcrit, was determined by calculating the HQI value in 2100 under a scenario with N deposition set to the empirical critical load. Combinations of N and S deposition that result in HQI values below this threshold were assumed to be in exceedance of the biodiversity-based critical load. The biodiversity-based CL function was derived as the line of combinations of N and S deposition that gave an HQI value of exactly HQIcrit. This function is illustrated for in the left-hand and middle columns of plots in Figure GB.8. An approximation of each function, required for the CCE Call for Data response and made by fitting two points on the N x S plane to minimise differences from the exact function, is shown in the right-hand column of plots in Figure GB.8.

The responses of HQI to N and S pollution at the wet heath site illustrated were broadly as expected, in that HQI values declined with both N and S deposition, and it was possible to make an approximate function of the form required for the Call for Data response. At the blanket bog site, HQI declined with N pollution, but changes in S pollution had little effect on HQI. This is presumably due to the combination of two effects. Firstly, the soil pH at the site was calibrated to a typical value for UK blanket bog, 4.51 (Emmett et al., 2010). This is quite acid, and because pH is measured on a negative logarithmic scale, further decreases in pH require substantial additions of acid anions. Secondly, many of the species that are positive condition indicators for blanket bog are typical of acid environments. Although habitat-suitability for such species is expected to decline at very low pH values, these low values were not represented in the MultiMOVE training dataset so the niche models do not show a decline at low pH. It is probably true that naturally-acid habitats are not extremely susceptible to acid pollution, but the model chain may underrepresent the effects of large S loads that reduce pH to unnatural levels.

Following an initial analysis of example sites, it was decided to prepare the revised Call for Data response for only two habitats, E1.7 'Dry acid grassland' and F4.11 'Northern wet heath'. This decision was made partly due to time constraints – biodiversity-based CL functions could be developed for other habitats but would require more exploratory work. The E1.7 and F4.11 habitats are those for which there is currently most confidence in the simulated responses of HQI and in the derived CL functions. Critical loads functions were derived and submitted in the Call for Data response for 26 E1.7 Dry acid grassland sites and 14 F4.11 Wet heath sites. A selection of representative examples is shown in Figure GB.9. Of the wet heathland sites, ten had responses similar to that in Figure GB.9a (i.e. when N deposition is 20% of CLempN, the CLbdiv function was exceeded with S deposition of less than 200% of CLmaxS) and four had responses similar to that in Figure GB.9b (i.e. when N deposition is 20% of CLempN, CLbdiv was exceeded only with S deposition > 200% of CLmaxS). Of the dry acid grassland sites, 18 had responses similar to that in Figure GB.9c, four similar to Figure GB.9d, and four similar to Figure GB.9e (i.e. very sensitive to S pollution, such that CLbdiv was exceeded with only 20% of CLmaxS).
The CLbdiv functions for all sites were approximated using two points on the N x S plane (see Figure GB.8) and these points were submitted on 18th May 2015 as part of the UK response to the Call for Data 2014-15. The submitted data are reproduced in Table GB.3.

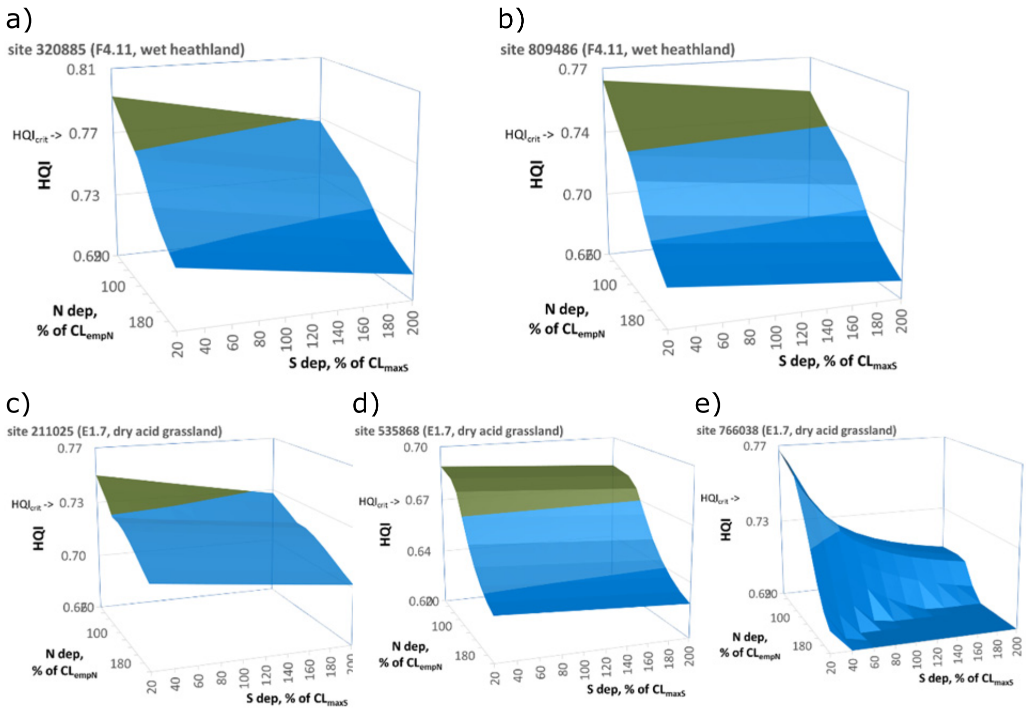

Figure GB.9. Examples of biodiversity-based Critical Load functions, defined as the line where a habitat quality index reaches a critical value and shown as the boundary between green and blue areas in the above plots, for: a) & b) a wet heath site; c), d) and e) a dry acid grassland site. See text for discussion of response types.

Table GB.3. Biodiversity-based Critical Load functions and critical values for the habitat quality metric submitted to the CCE in response to the Call for Data 2014-15. SiteID = UK National Focal Centre code for the 1 x 1 km gridcell and EUNIS habitat; CLNmin, CLSmax = coordinates of first point defining the CLbdiv function; CLNmax, CLSmin = coordinates of second point defining the CLbdiv function; HScrit = critical value for the habitat quality metric, referred to as HQIcrit in the text.

E1.7 Dry acid grassland sites					
SiteID	**CLNmin**	**CLSmax**	**CLNmax**	**CLSmin**	**HScrit**
211025006	178.5	682.5	536	137	0.732
248732006	357	441	643	10.5	0.710
272407006	107.1	798	678	4.2	0.758
299095006	7.14	682	536	4.8	0.754
310949006	7.14	528	571	16	0.775
332841006	7.14	1080	714	144	0.683
345461006	107.1	874	714	19	0.696
356609006	107.1	840	714	20	0.719
371994006	178.5	800	657	140	0.705
374674006	7.14	704	500	110	0.770
380313006	7.14	815	700	16.3	0.777
390087006	357	1326	607	780	0.734
425781006	7.14	612	486	1.7	0.729
453939006	142.8	900	714	180	0.680
549823006	7.14	986	714	16.8	0.787

E1.7 Dry acid grassland sites

SiteID	CLNmin	CLSmax	CLNmax	CLSmin	HScrit
565303006	7.14	1012	714	138	0.705
585592006	214.2	900	657	205	0.725
651322006	7.14	1107	714	492	0.721
656178006	7.14	1056	735	6.4	0.782
661066006	7.14	798	557	5.7	0.823
668121006	335.58	962	664	156	0.666
717085006	7.14	552	571	4.6	0.727
747117006	7.14	684	521	4.5	0.753
766038006	7.14	810	714	40.5	0.768
834632006	285.6	1008	657	252	0.752
857711006	249.9	668	621	267	0.784

F4.11 Wet heath sites

SiteID	CLNmin	CLSmax	CLNmax	CLSmin	HScrit
320885009	7.14	873	707	3.8	0.768
348866009	7.14	533	714	4.1	0.746
358040009	7.14	672	714	8.2	0.729
371918009	7.14	738	728	4.7	0.697
383071009	7.14	1188	714	4.4	0.668
486869009	7.14	907	700	5.6	0.773
537929009	7.14	979	714	5.1	0.662
656873009	7.14	1209	714	7.7	0.669
668827009	7.14	2327	700	16.5	0.747
747116009	7.14	1346	707	4.5	0.703
776549009	7.14	3255	678	15.5	0.756
809486009	7.14	1519	714	3.1	0.736
817443009	7.14	1829	714	3.1	0.753
847259009	7.14	1403	728	8. 4	0.696

Discussion

The MADOC-MultiMOVE model was successfully applied to the task of deriving simple functions that describe combinations of N and S deposition above which the habitat is likely to be damaged. Inevitably the results are a simplification, in that environmental conditions and pollution history at a site are imperfectly known, species occurrence is affected not only by habitat-suitability but by dispersal and extinction processes, and interpretation of species change in terms of conservation targets is inevitably somewhat subjective. Nevertheless, the approach reproduces to a large extent the expected effects of N and S pollution, with changes to individual species dependent on their sensitivity to acidification, eutrophication and/or shading, and, generally, declines in overall habitat quality with greater rates of pollution.

Nitrogen pollution consistently caused declines in habitat quality. Sulphur pollution often had a relatively weak effect, causing little decline in simulated HQI even at rates of 200 % or more of CLmaxS at some sites. This may be because the habitats studied (dry acid grassland and wet heath) are relatively insensitive to acidification – even though soil pH in these habitats can be pushed to low levels by acid pollution, their positive indicator-species are not greatly affected by low pH. However, an alternative explanation is that the models do not capture the negative impacts of very low pH, in particular when very acid sites have not been included in the datasets used to derive species niche models. More exploration of individual species' responses would help in assessing which of these explanations is more correct. However, the negative effects of N via eutrophication and shading seem to be well-captured by the model chain.

The study demonstrated that a model chain that predicts changes in habitat-suitability for individual species can be used to assess the likelihood of biodiversity loss under different pollution scenarios. The model was applied using data held by the UK NFC, showing that predictions can be obtained for any UK 1 km grid square that has been mapped as containing an acid-sensitive or N-sensitive habitat. The biodiversity-based Critical Load functions derived in the study are plausible, showing strong effects of N pollution on habitat quality, and effects of S pollution that depend on the site and habitat's sensitivity to acidification. These effects were not inevitable, but rather emerged from the evidence provided by the responses of individual species. Uncertainties remain with many aspects of the model chain, but considerable progress has been made with applying MADOC-MultiMOVE, and with summarising outputs into forms that can be used in policy analysis and development.

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