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Methods for the calculation of critical loads and their exceedances in the UK

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CONTENTS **PAGE**

Executive Summary

EXECUTIVE SUMMARY

This report describes the calculation and mapping of critical loads and their exceedances in the UK. It consolidates information from earlier "UK Status Reports" into a single report.

Part I describes the methods and data used to (a) map the distribution of 14 UK habitats sensitive to acidification and/or eutrophication: acid grassland, calcareous grassland, dwarf shrub heath, bog, montane, freshwaters, dune grassland, saltmarsh and a number of managed and unmanaged woodland habitats; (b) calculate critical loads of acidity and of nutrient nitrogen for these habitats, as appropriate.

The methods used to calculate UK critical loads are based on internationally agreed approaches and the best available national-scale data sets available. Acidity critical loads for terrestrial habitats are based on the mineralogy and chemistry of the dominant soil type in each 1km grid square together with habitat-specific data. For woodland habitats simple mass balance equations, based on balancing the acidic inputs to, and outputs from a system, are used to derive a critical load that ensures the selected chemical criterion is not exceeded. Acidity critical loads for surface waters are calculated using the catchment-based First-Order Acidity Balance (FAB) model.

Critical loads of nutrient nitrogen for natural, semi-natural, and unmanaged (non-productive) woodlands are empirically derived values based on observed changes in the structure or function of ecosystems. For managed (productive) woodlands a nitrogen mass balance approach is used to derive critical loads that will prevent an increase in the leaching of nitrogen compounds and ensure sustainable production.

It should be noted that the habitat distribution maps and areas used for UK critical loads (acidity, nitrogen) research (a) only include areas where data exist for the calculation or derivation of critical loads; (b) may differ from other national habitat distribution maps or estimates of habitat areas. This may also result in a difference in the total habitat areas mapped for acidity and for nutrient nitrogen critical loads.

Part II describes the calculation of critical load exceedances (ie, the amount of excess deposition above the critical load) and presents results and maps based on UK deposition data for 2009-2011. The summary statistics are published to monitor progress in the areas at risk from air pollution over time; to this end they are used for:

- Defra: Environmental Statistics – Key Facts
  https://www.gov.uk/government/publications/environment-statistics-key-facts
- Welsh Government: Sustainable Development Indicators for Wales
  http://wales.gov.uk/topics/statistics/headlines/sustaindev/120829/?lang=en
- Scottish Government: Key Scottish Environment Statistics
  http://www.scotland.gov.uk/Topics/Statistics/Browse/Environment/
- UK Biodiversity Indicators in Your Pocket: JNCC; biodiversity indicator for assessing the pressures from air pollution
  http://jncc.defra.gov.uk/page-4233

For acidity, the area of sensitive habitats in the UK with exceedance of critical loads has fallen from 73% based on 3-year mean deposition data for 1995-97, to 45% based on mean deposition data for 2011-13. Over the same time period the Average Accumulated Exceedance has more than halved from 0.78 to 0.29 keq ha^{-1} $year^{-1}$.

For nutrient nitrogen, the changes have been smaller, with 75% of habitats exceeding critical loads by mean nitrogen deposition for 1995-97 and 63% with mean data for 2011-13. The Average Accumulated Exceedance for nutrient nitrogen has declined from 9.5 kg N ha^{-1} $year^{-1}$ to 6.2 kg N ha^{-1} $year^{-1}$ over the same time period.

In addition to their applications in the UK, the UK critical loads data are submitted to the Coordination Centre for Effects (CCE) in the Netherlands for incorporation in European maps and integrated assessment activities under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP).

Part III describes the application of acidity and nutrient nitrogen critical loads to features of designated sites: Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs) and Specially Protected Areas (SPAs).

PART I: CRITICAL LOADS

1. Introduction to critical loads

1.1 Introduction

The air pollutants sulphur dioxide, nitrogen oxides and ammonia can contribute to acidification, and nitrogen oxides and ammonia can contribute to terrestrial eutrophication. Both problems can adversely affect semi-natural ecosystems. The Review of Transboundary Air Pollution (RoTAP) recently reviewed the impacts of air pollutants on UK ecosystems and prospects for recovery (RoTAP, 2012). Measuring and quantifying the potential ecological damage by air pollutants is not a simple matter. The common measure, used across Europe since the 1980s, is the critical load. This is defined as 'a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' (Nilsson & Grennfelt, 1988).

The amount of deposited pollutant that exceeds the critical load of acidity or nutrient nitrogen, is called the 'exceedance'. Exceedance of critical loads is an indication that the ecosystem is at risk from potential harmful effects in the long term. Therefore, exceedance is not a quantitative estimate of "damage" to the environment; it does not necessarily mean that harmful or adverse effects have already occurred or may be observed, but that there is a risk of damage in the long-term. Critical loads are a concept for "long-term" protection of ecosystems from the impacts of acid or nitrogen deposition; they do not provide information on the timescales for damage (when the critical load is exceeded) or recovery (when deposition is reduced below the critical load). Timescales for damage and recovery vary greatly, depending on the environmental receptor and the pollutant combination; to estimate these dynamic models are required. Dynamic models have been (and continue to be) developed under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), but are not discussed in this Report.

The application of critical loads has proved very useful for policy development, both in the UK and in Europe. Critical loads and their exceedances provide an 'effects-based' approach where the environmental benefits of emission reductions can be gauged. Preventing or minimising the exceedance of critical loads for ecosystems across Europe remains one of the objectives of emission control agreements under the UNECE CLRTAP (http://www.unece.org/env/lrtap/status/lrtap_s.html) and the EC Thematic Strategy on Air Pollution (COM(2005)446). UK critical loads data are submitted to the CLRTAP Coordination Centre for Effects (CCE) for incorporation into European-scale maps of critical loads and integrated assessment studies.

1.2 Calculation and mapping of critical loads

The preparation of critical load maps has two main components: (i) mapping the distribution of the habitats sensitive to the pollutant (ie, the receptors) and (ii) calculation of critical loads to assign to those habitats. This report documents the data and procedures used to map the habitat distributions and calculate and assign critical loads based on the latest scientific findings.

Maps of the main terrestrial habitats, on a 1km grid, are generated using the CEH Land Cover Map 2000 (LCM2000, Fuller et al, 2002a & 2002b) and additional data, such as species distributions. In general, the aim was to map Biodiversity Action Plan Broad Habitats sensitive to acidification and/or eutrophication. However, in some instances other sensitive categories are mapped (eg, Acidophilous oak woodland). In addition, in order to harmonise the naming and classification of habitats across Europe, habitat codes from the EUNIS habitat classification scheme (Davies & Moss, 2002) are also provided for each of the habitat types for which critical loads are mapped.

A number of methods exist to determine the critical loads of acidity or nutrient nitrogen, which fall into two broad categories:

(i) Empirical approaches, where the critical load is estimated rather than calculated. For nutrient nitrogen empirical critical loads are based on relatively short-term (1-5 years) experiments or field evidence for the ecosystem response to nitrogen deposition. Basing a critical load on such short-term data could over-estimate the critical load needed to protect the ecosystems in the longer term (20-30 years)(Hornung et al, 1995a); this also means that the critical loads cannot guarantee to offer protection to ecosystems over longer timescales. For acidity, the empirical critical loads are based on mineralogy data for the dominant soil type; these aim to protect the soil from long-term changes due to anthropogenic activities which cannot be compensated for by natural soil processes (Nilsson, 1986).

(ii) Mass balance models or equations, which balance the long-term chemical inputs and outputs (affecting acidity or nitrogen) and represent steady-state conditions; these require long-term averages for input fluxes. In this context, for forest ecosystems long-term may be 100 years, representing one rotation period. These methods are based around a chemical criterion chosen to reflect a change in the ecosystem that would lead to damage.

Appropriate methods, critical chemical criteria and ranges for empirical critical loads are agreed by the UNECE/CLRTAP International Cooperative Programme on Modelling and Mapping (ICPM&M). These methods are summarised in the UNECE's "Mapping Manual" (http://wge-cce.org/Publications/Mapping_Manual). The methods currently used in the UK to calculate acidity and nutrient nitrogen critical loads are consistent with the guidance in the Mapping Manual and are summarised in the table below (Table 1.1).

Table 1.1: Summary of the methods used to calculate critical loads for sensitive habitats in the UK

Habitat type	**Method to assign critical load for acidity**	**Method to assign critical load for nutrient nitrogen**
Unmanaged woodland	Steady State Mass Balance	Empirical
Managed woodland	Steady State Mass Balance	Steady State Mass Balance
Non-woodland terrestrial habitats	Empirical, based on dominant soil type	Empirical
Freshwater lakes and streams	First Order Acidity Balance [FAB]	Not used[1]

[1] The freshwater sites selected for mapping acidity critical loads are potentially sensitive to eutrophication, but there is currently a lack of data to apply nutrient nitrogen critical loads to these sites (see Section 2.6.5).

The critical load methods are described in detail in Sections 3-6.

Research on the ecological effects of acidification and eutrophication continues in the UK and Europe. As new findings emerge, it may become necessary to update the critical load values. Changes in critical load values can emerge as a result of:

a) changes in the underlying data sets used to calculate critical loads, e.g. land cover, soil maps.
b) changes in the effects criterion used to determine damage, e.g. threshold value of ANC (Acid Neutralising Capacity) for freshwaters
c) changes in the methodology to calculate critical loads, e.g. calculation of acidity critical loads for peats.
d) new empirical evidence on UK impacts of nitrogen deposition on sensitive ecosystems.

Part II of this report describes the calculation of critical load exceedances and presents summary maps and results, and Part III describes the application of critical loads to designated sites.

2. Habitat mapping

2.1 Introduction

Critical loads are mapped for habitats sensitive to acidification and/or eutrophication. Therefore information on the location and distribution of these habitats is required to enable them to be mapped. The terrestrial habitats are mapped at 1km resolution based on the CEH Land Cover Map 2000 (LCM2000: Fuller et al, 2002(a),(b)) and refined using ancillary data sets on species distributions (Preston, Pearman & Dines, 2002), vegetation classification data (NVC: Rodwell 1991-2000) and 1km soil maps (NSRI, Macaulay, DardNI). It should be noted that an updated land cover map (LCM2007: Morton et al, 2007) is now available, but has not been applied in this project. Freshwaters are mapped for 1752 lake and stream catchments sampled by ENSIS/ECRC at University College London (Curtis & Simpson, 2011). Table 2.1 below lists the habitats mapped nationally for critical loads of acidity and for eutrophication (nutrient nitrogen); note that some other habitats may also be sensitive to acidification and/or eutrophication and of importance on a site-specific scale, but there is a lack of data to map their areas on a national scale.

Table 2.1: Habitat distributions mapped for acidity and for nutrient nitrogen critical loads (Y=yes, N=no).

Habitat	Mapped for acidity	Mapped for nutrient nitrogen
Acid grassland (wet & dry)	Y	Y
Calcareous grassland	Y	Y
Dwarf shrub heath (wet & dry)	Y	Y
Montane	Y	Y
Bog	Y	Y
Managed coniferous woodland	Y	Y
Managed broadleaved woodland	Y	Y
Beech woodland (unmanaged)	Y (mapped together)	Y
Acidophilous oak woodland (unmanaged)		Y
Scots Pine (unmanaged)		Y
Other unmanaged woodland		Y
Freshwaters	Y	N
Dune grassland	N	Y
Saltmarsh	N	Y

LCM2000 is derived from satellite imagery, with land parcels assigned to land cover classes and further refined using contextual and ancillary information (Fuller et al, 2002(a)(b)). LCM2000 is used as the base map for all terrestrial habitats maps for critical loads purposes, since this additionally provides the area of habitat within each 1km grid square. These area values are used in the national scale and European scale assessments of critical load exceedance to determine the area of habitats at risk from adverse impacts from atmospheric pollutants. For freshwaters the catchment area is used.

2.2 Refining habitat distributions – an overview

The LCM2000 identified 16 target classes (level 1), which are further sub-divided into 27 sub-classes (level 2) to allow the construction of the widespread Broad Habitats (Fuller et al, 2002(a)&(b)). However, there are limitations in using satellite data to map some specific habitat types. Therefore in collaboration with LCM2000 experts and other habitat experts, a method was developed to refine the LCM2000 habitat distributions using additional data sets (such as species distributions, altitude, etc).

To produce the habitat maps for acid grassland, calcareous grassland, dwarf shrub heath and bog, maps of species distributions have been used to refine the LCM2000 data. Preston *et al.* (2003) identified all species associated with individual BAP Broad Habitats, and produced 10km resolution maps showing the percentage of species in each 10km square, making adjustments for the latitudinal gradient in species diversity in the UK.[1] In collaboration with habitat experts, a cut-off value for the percentage of species that best represent the key areas for the habitats has been applied. For calcareous grassland, the cut-off value is 50% (i.e. 10km squares where more than 50% of the species pool is present have been selected). In all other cases, a cut-off of 40% has been used. Note that for the coastal habitats (saltmarsh and dune grassland) 10km data for a few key species were identified to refine the habitat distributions; the full distribution of these was used without applying a cut-off value.

The 10km squares selected using the species distribution data were overlaid on the corresponding 1 km LCM2000 habitat map, and the 1km LCM2000 squares falling within the 10km squares were mapped to represent the habitat.

In some cases, additional data have also been used to sub-divide the habitats. The 1km Hydrology of Soil Types (HOST: Boorman et al, 1995) data were used to distinguish between wet and dry areas of acid grassland and of dwarf shrub heath. For the coniferous and broadleaved woodland habitats, a combination of LCM2000 and Forest Research data have been used to distinguish the managed and unmanaged woodland areas. The sub-categories of unmanaged woodland have been identified using LCM2000 data and 10km mapped classes of the National Vegetation Classification (NVC: Rodwell, 1991-2000). The montane habitat (represented by *Racomitrium* heath) required a combination of LCM2000 data, 10km NVC data and altitude data.

The 10km data sets (species distributions, NVC) are useful to refine the habitat distributions but cannot be used alone, since they do not provide the habitat area values at the required resolution. Further information on the combinations of data used to map the individual habitats is given later in Section 2.6.

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[1] Preston *et al.* (2003) used habitat associations of vascular plants, based on field quadrat data to calculate the frequency of plant species within the BAP Broad Habitat types. Two major sources of quadrat data were used: (i) the original data used to derive the National Vegetation Classification (Rodwell, 1991(a), 1991(b), 1992, 1995, 2000); (ii) quadrat samples collected by Countryside Survey 2000 (Haines-Young *et al*., 2000). The table of frequencies from these datasets was used to calculate preference indices for species to broad habitat categories. Species diversity in a 10km square was defined simply as the number of species for each habitat type that were recorded for the square. Species distribution data were derived from the *New Atlas* of plants (Preston *et al.*, 2002); records prior to 1930 were excluded. The species diversity in a 10km square was then compared to the species diversity of its biogeographic zone to account for the latitudinal gradient in species diversity within the UK.

2.3 Harmonising habitat classifications at the UNECE CLRTAP level

It is useful for UK policy purposes to map critical loads for the Broad Habitats (where possible). However, different habitats may be more appropriate in other countries. This leads to critical loads being assigned to a wide range of habitat types across Europe. In order to improve transparency at the UNECE CLRTAP level, in 2000, the UK National Focal Centre (NFC) carried out a study as a "contribution in kind" to the International Cooperative Programme on Modelling and Mapping (ICPM&M) to harmonise the definitions of ecosystems for which countries submitted critical loads data (Hall, 2001). This resulted in a recommendation for countries to use the European Nature Information System (EUNS: Davies & Moss, 1999, 2002), a hierarchical habitat classification scheme developed for pan-European applications.

The key advantage of EUNIS to critical loads work nationally and internationally is that it provides a consistent method of habitat classification between studies or between countries. EUNIS has been adopted by the Coordination Centre for Effects (CCE) and ICPM&M, and the UNECE expert workshops (2002, 2010) on empirical nutrient nitrogen critical loads (Bobbink *et al.*, 2003; Bobbink & Hettelingh, 2011) have used the EUNIS classification as a basis for setting critical load values for sensitive habitats across Europe.

2.4 Assigning EUNIS codes to UK habitats

For the UK, although national mapping activities are focused on broad habitats, the data submitted to the CCE need to have the relevant EUNIS habitat codes assigned. Empirical critical loads for nutrient nitrogen have been agreed at the UNECE level using EUNIS codes to identify the habitats. The UK NFC has therefore identified the corresponding broad habitat, so that UK critical loads for nutrient nitrogen can be consistently mapped in terms of broad habitats. Conversely, all other critical loads (for acidity and mass balance nutrient nitrogen) have been mapped on the broad habitat level, and the UK NFC has identified the corresponding EUNIS classes. The relationships between the UK Biodiversity Action Plan (BAP) Broad Habitats, EUNIS classes and the habitats mapped for critical loads are given in Table 2.2. *However, it should be noted that there is rarely a direct relationship between the broad habitats and the EUNIS classes; the two schemes are not directly interchangeable.*

Table 2.2: Relationships between BAP Broad Habitats, EUNIS classes and critical load habitat maps.

UK critical load habitat map[1]	**BAP Broad Habitat (BH)**	**EUNIS class(es) assigned to each BH**[2]	**Relationship between BH and EUNIS**[3]
Broadleaved woodland (managed)	Broadleaved, mixed & yew woodland	G1 Broadleaved woodland	BH overlaps with G1
Beech woodland (unmanaged)		G1.6 Beech woodland	
Acidophilous oak woodland (unmanaged)		G1.8 Acidophilous oak-dominated woodland	
Coniferous and/or broadleaved woodland (unmanaged)		G4 Mixed woodland	BH overlaps with G4
Coniferous woodland (managed)	Coniferous woodland	G3 Coniferous woodland	BH overlaps with G3
Scots Pine woodland (unmanaged)		G3.4 Scots Pine woodland	
Calcareous grassland	Calcareous grassland	E1.26 Sub-Atlantic semi-dry calcareous grassland	BH contains E1.26
Dry acid grassland[4]	Acid grassland	E1.7 Non-Mediterranean dry acid & neutral closed grassland	BH contains E1.7
Wet acid grassland[4]		E3.52 Moist or wet oligotrophic grassland	BH overlaps with E3.5
Dry heathland[5]	Dwarf shrub heath	F4.2 Dry heaths	BH contained in F4
Wet heathland[5]		F4.11 Northern wet heaths	
Bog	Bog	D1 Raised & blanket bog	BH equal to D1
Montane	Montane	E4.2 Moss & lichen dominated mountain summits	BH contains E4.2
Dune grassland	Supralittoral sediment	B1.4 Stable dune grasslands	BH contains B1
Saltmarsh	Littoral sediment	A2.53 Mid-upper saltmarsh A2.54/55 Pioneer & low-mid saltmarsh	BH contains A2
Freshwaters (defined by catchment boundaries for 1752 sites only)	Standing open water & canals	C1 Surface standing waters	BH overlaps with C1
	Rivers & streams	C2 Surface running waters	BH overlaps with C2

[1] Broad habitats as mapped for defining distributions of habitats sensitive to acidification and/or eutrophication; data submitted to the CCE by EUNIS class.

[2] EUNIS class closest to broad habitat and critical loads habitat; class used for assigning empirical nutrient nitrogen critical loads and for classifying UK critical loads data for submission to the CCE.

[3] Relationships taken from NBNdictionary_habitat_correspondances_20_05_2008.xls downloaded from JNCC website: http://jncc.defra.gov.uk/page-1425 (derived from NBN Habitats Dictionary at http://habitats.nbn.org.uk/)

[4] Wet and dry acid grassland mapped as a single map for the UK (each 1km square either mapped as wet or dry acid grassland); data submitted to the CCE by separate EUNIS class.

[5] Wet and dry heathland mapped as a single map for the UK (each 1km square either mapped as wet or dry heathland); data submitted to the CCE by separate EUNIS class.

2.5 Overview of uncertainties

The critical load habitat maps have been produced using the best available data and have been discussed and agreed by habitat experts. Although *they may not include every small area of each sensitive habitat at the regional or local scale, they do give **national** pictures of the main habitat types*, adequate for ***national*** critical loads mapping purposes.

There are however, uncertainties associated with the maps. The main reasons are:

- There are uncertainties in all the data sets used (land cover, forest land use data, species distributions, NVC classes, soils data, altitude data)
- The critical load habitat maps are presented at a resolution of 1km, for consistency with the critical loads data, however, they are based on a combination of data sets at different resolutions (e.g. 1km land cover and 10km species distributions).
- Where the 10km species distribution maps are used to refine habitat areas from the LCM2000, the 10km grid squares selected represent the broad habitat in terms of the species composition present (above the percentage threshold used). However, this does not necessarily mean that all the species occur within every 1km grid square within each 10km square; the habitat area could therefore be overestimated.
- The 10km NVC class maps have the same uncertainties associated with them as the 10km species data above.

It should be noted that the habitat distribution maps and areas used for UK critical loads (acidity, nitrogen) research (a) only include areas where data exist for the calculation or derivation of critical loads; (b) may differ from other national habitat distribution maps or estimates of habitat areas. This may also result in a difference in the total habitat areas mapped for acidity and for nutrient nitrogen critical loads.

2.6 Mapping critical load habitat distributions

The methods and data used to map each individual habitat that critical loads of acidity and/or eutrophication are assigned to, are described below and summarised in Table 2.3. The habitat distributions are shown in figures 2.1-2.4; these maps show all 1km grid squares that contain any area of habitat (ie, the same 1km squares can contain areas of several habitat types). The areas of each habitat mapped for acidity and/or nutrient nitrogen critical loads are given in Table 2.4. Note that as mentioned above there can be differences in the areas mapped for the different critical loads; this is because some of the input data needed for critical loads calculations cover different spatial areas.

Table 2.3: Summary of data used to map UK habitats sensitive to acidification and/or eutrophication

UK habitat mapped	**EUNIS class(es) assigned**	**Data used:**				**Habitat mapped for:**	
		LCM2000 class(es)	**10km species data**	**10km NVC class(es)**	**Other**	**Acidity**	**Nutrient nitrogen**
Managed (productive) broadleaved woodland	G1	1.1	-	-	FC managed/unmanaged data	Y	Y
Managed (productive) coniferous woodland	G3	2.1	-	-	FC managed/unmanaged data	Y	Y
Unmanaged coniferous and/or broadleaved woodland	G4	1.1 & 2.1	-	-	FC managed/unmanaged data	Y	Y
Beech woodland	G1.6	1.1	-	W12 W14 W15	FC managed/unmanaged data	As part of G4	Y
Acidophilous oak woodland	G1.8	1.1	-	W11 W16 W17	FC managed/unmanaged data	As part of G4	Y
Scots pine woodland	G3.4	2.1	-	W18	FC managed/unmanaged data	As part of G4	Y
Calcareous grassland	E1.26	7.1	Y	-	Soil critical loads map[1]	Y	Y
Dry acid grassland	E1.7[2]	8.1	Y	-	HOST soil class	Y	Y
Wet acid grassland	E3.52		Y	-	HOST soil class		Y
Wet heathland	F4.11	10.1 & 10.2	Y	-	HOST soil class	Y	Y
Dry heathland	F4.2		Y	-	HOST soil class		Y
Bogs	D1	12.1	Y	-	-	Y	Y
Standing waters (lakes, reservoirs)	C1	-	-	-	Upstream catchment area	Y	N
Rivers & streams	C2	-	-	-			
Montane	E4.2	15.1 & 16.1	-	U10	Altitude data (excludes areas <600m)	Y	Y
Dune grasslands	B1.4	19.1 & 7.1	Y	-	2km coastal buffer	N	Y
Saltmarsh	A2.53/A2.54/A2.55	21.2	Y	-	-	N	Y

[1] For acidity areas of habitat that coincide with soil acidity critical loads <2 keq ha^{-1} $year^{-1}$ are removed.

[2] The definition of E1.7 includes both acid and neutral grassland, but only acid grassland is mapped for the UK; the nutrient nitrogen critical loads assigned to this class are based on evidence for acid grasslands only (Section 6.2.3.5).

Table 2.4: Areas of habitats mapped in the UK for acidity and for nutrient nitrogen critical loads.

Habitat mapped for critical loads	EUNIS class(es)	Area (km^2) mapped for acidity critical loads	Area (km^2) mapped for nutrient nitrogen critical loads
Acid grassland (wet & dry)	E1.7 & E3.52	15336	15235
Calcareous grassland	E1.26	1808	3578
Dwarf shrub heath (wet & dry)	F4.11 & F4.2	24705	24826
Bog	D1	5454	5526
Montane	E4.2	3054	3129
Coniferous woodland (managed)	G3	8374	8383
Broadleaved woodland (managed)	G1	7452	7482
Beech woodland (unmanaged)	G1.6	Included in G4	719
Acidophilous oak woodland (unmanaged)	G1.8	Included in G4	1434
Scots pine woodland (unmanaged)	G3.4	Included in G4	204
Unmanaged (coniferous and/or broadleaved) woodland	G4	4011	1761
Freshwaters	C1 & C2	7857	Not mapped
Dune grassland	B1.4	Not mapped	323
Saltmarsh	A2.5	Not mapped	427
All habitats		78051	73027

2.6.1 Woodland habitats

The UK BAP identified two woodland broad habitats: “broadleaved, mixed and yew woodland” and “coniferous woodland”. For critical loads both managed and unmanaged woodlands are included, since the long-term protection of the whole ecosystem function (ie, soils, trees, linked aquatic ecosystems) is important. However, these managed and unmanaged systems are treated separately as the critical loads are determined by different approaches. While LCM2000 distinguishes between broadleaved and coniferous woodland, satellite imagery cannot be used alone to separate managed from unmanaged woodland, or to identify specific types of woodland, such as Acidophilous oak woods. Therefore, a combination of LCM2000 data, Forest Research (FR) data and National Vegetation Classification (NVC) data have been used in the mapping of these habitats. The FR data consisted of a combination of the National Inventory of Woodland and Trees (NIWT) and the Ancient and Semi-natural Woodland Inventories of English Nature, the Countryside Council for Wales and Scottish Natural Heritage (FC, 2001; FC, 2002a; FC 2002b; FC 2003). Together these data identified areas of:

- managed coniferous woodland
- managed broadleaved woodland
- unmanaged coniferous and/or broadleaved woodland

The unmanaged woodland therefore consists of ancient and semi-natural woodland, including Scots Pine; this “unmanaged woodland” is assumed to be “managed” for biodiversity or amenity, but not timber production. All other coniferous and broadleaved woodland is assumed to be primarily managed as **productive** forest where harvesting and removal of trees takes place. Following the first mapping exercise in 2003 (Hall et al, 2004) some areas of managed broadleaved woodland were found to coincide with 1km squares dominated by peat soils; FR considered this unlikely and came to the conclusion that this discrepancy had arisen due to a decision to include young trees as managed broadleaved woodland. In 2004 the data sets were updated to remove these areas from the managed broadleaved map and add them to the managed conifer map (Hall et al, 2004). Critical loads of acidity are calculated separately for each of the three woodland categories above.

For nutrient nitrogen the unmanaged woodland category is further sub-divided into the following categories to which critical loads can be applied:

- Acidophilous oak woodland
- Beech woodland
- Scots pine woodland
- All other unmanaged coniferous and/or broadleaved woodland

This results in a total of seven separate woodland habitat distribution maps; each is presented as a separate map because it is possible for more than one woodland type to occur in a 1km grid square. For consistency with the mapping of other habitats, the LCM2000 data provides the basis for the woodland habitat areas. The LCM2000 woodland data were compared with the FR data; although the two sets of data coincide in many areas, there is not a complete match for a number of reasons:

- The data sets have been generated using different methods and for different purposes.
- LCM2000 is a map of land cover, whereas the FR data are for land use.
- Unlike FR data, LCM2000 does not distinguish between the managed and unmanaged woodland areas.
- FR data can include other habitat types, for example, areas of young trees that would be classified as non-woodland cover types (eg, grassland, heathland) on the LCM2000.

To overcome these differences, a method was developed in agreement with FR, that uses the ratio of the three different FR woodland types in each 1km square to estimate the areas of woodland from the LCM2000 data (see below).

Managed (productive) coniferous woodland (EUNIS class G3, Figure 2.1a)

The FR 1km data for managed coniferous woodland were overlaid onto the LCM2000 class (2.1) for coniferous woodland. Then the distribution of managed coniferous woodland was mapped as those 1km grid squares where both FR and LCM2000 data occur. The managed coniferous woodland areas were calculated as:

Managed conifers = (ratio of FR managed coniferous woodland area to FR total woodland area)
* LCM2000 coniferous woodland area

where FR total woodland area = sum of managed and unmanaged coniferous and broadleaved woodland.

Managed (productive) broadleaved woodland (EUNIS class G1, Figure 2.1b)

The FR 1km data for managed broadleaved woodland were overlaid onto the LCM2000 class (1.1) for broadleaved and mixed woodland. Then the distribution of managed broadleaved woodland was mapped as those 1km grid squares where both FR and LCM2000 data occur. The managed broadleaved woodland areas were calculated as:

Managed broadleaved = (ratio of FR managed broadleaved woodland area to FR total woodland area) * LCM2000 broadleaved & mixed woodland area

Unmanaged coniferous and/or broadleaved woodland (EUNIS class G4, Figure 2.2b)

The FR data for unmanaged broadleaved and coniferous woodland were overlaid onto the LCM2000 classes for all woodland (ie, sum of LCM2000 classes 1.1 and 2.1). Then the distribution of unmanaged woodland was mapped as those 1km grid squares where both FR and LCM2000 data occur. Areas mapped as Acidophilous oak woods, Beech woodland or Scots pine (see below) form sub-sets of the unmanaged woodland area and for nutrient nitrogen critical loads where values are applied to each of these separately, they were removed from this map. For acidity, the whole area of unmanaged woodland is treated as a single map. The unmanaged woodland areas were calculated as:

Unmanaged woodland = (ratio of FR unmanaged area to FR total woodland area) * LCM2000 total woodland area

Beech woodland, Acidophilous oak woodland, Scots pine woodland (Figures 2.1d, 2.1c, 2.2a)

In generating these maps the above unmanaged woodland distribution is used as the base map. This map was overlaid with the 10km spatial data sets of the relevant National Vegetation Classification (NVC) woodland communities (Rodwell, 1991)(Table 2.3).

Table 2.3: List of NVC classes used in the creation of woodland distribution maps for Beech woodland, acidiophilous oak woodland, and Scots pine woodland.

Habitat	**EUNIS class**	**NVC class(es)**
Beech woodland	G1.6	W12 *Fagus sylvatica-Mercuralis perennis* W14 *Fagus sylvatica-Rubus fruticosus* W15 *Fagus Sylvatica-Deschampsia flexuosa*
Acidophilous oak woodland	G1.8	W11 *Quercus petraea-Betula pubescens-Oxalis acetosella* W16 *Quercus spp.-Betula spp.-Deschampsia flexuousa* W17 *Quercus petraea-Betula pubescens-Dicranum majus*
Scots pine woodland	G3.4	W18 *Pinus sylvestris-Hylocomium splendens*

Note: based on correspondence table relating NVC classes to EUNIS classes http://jncc.defra.gov.uk/page-1425 (derived from NBN Habitats Dictionary at http://habitats.nbn.org.uk/)

The distributions for EUNIS classes G1.6, G1.8 and G3.4 were generated by extracting the 1km unmanaged woodland squares from within the 10km squares of the relevant NVC classes. In some instances the 10km squares of the NVC classes for G1.6 overlapped with those for G1.8; in order to provide an estimated area for both G1.6 and G1.8, the area of unmanaged woodland in each 1km square was divided equally between the two woodland classes.

All remaining 1km squares of unmanaged woodland that did not fall within the NVC squares for these woodland types, were mapped in a fourth category, EUNIS class G4 as “unmanaged mixed woodland” and a nitrogen critical load assigned to protect the ground flora (see Section 6.2.3.11). Note that this distribution of unmanaged woodland therefore covers a smaller area than the “unmanaged woodland” category mapped for acidity critical load purposes.

Woodland areas for Northern Ireland

The LCM2000 includes areas of coniferous and broadleaved woodland for Northern Ireland. However, data were not available for this region to distinguish managed from unmanaged woodland. The Environment and Heritage Service (David Mitchel, EHS, pers. Comm.; now Northern Ireland Environment Agency) advise that (a) all the coniferous woodland in NI would be managed; (b) the majority of broadleaved woodland is semi-natural with only a small percentage of broadleaved plantation; the latter is not necessarily managed, as a large proportion is estate amenity woodland. The data for the NVC classes for these woodland types did not include any squares in NI. Therefore only two categories of woodland are mapped for NI:

- Managed (productive) coniferous woodland based on LCM2000 class 2.1 (coniferous woodland) and assuming all areas to be managed.
- Unmanaged broadleaved woodland based on LCM2000 class 1.1 (broadleaved/mixed woodland) and assuming all areas to be unmanaged.

2.6.2 Grassland habitats

Two grassland broad habitats are mapped for critical loads: acid grassland and calcareous grassland. It is not possible to distinguish these grassland habitats using satellite imagery alone. A three-class “soil acid sensitivity” map (Hornung *et al*., 1995a), based on soil pH and base saturation, was used in combination with the original grassland imagery in LCM2000 to produce three separate acid, neutral and calcareous LCM2000 grassland classes (Table 3.1 below; Fuller *et al.,* 2002(a) & 2002(b)).

This method worked reasonably well for defining the acid grassland areas. The calcareous grassland areas may be overestimated as the “soil acid sensitivity” class (pH >5.5) used is likely to include some areas of grassland with a more neutral pH. However, the calcareous grassland map obtained using this method shows a reasonable correspondence with the species data for this habitat. Acid and calcareous grassland are therefore included in the critical load habitat maps and species data have been used to refine their distributions (see below). However, neutral grassland is excluded, and critical loads for acidity and nutrient nitrogen for neutral grassland are not mapped for two reasons:

- The pH range of the “soil acid sensitivity” map class used for this grassland type (Table 2.4) tends towards the acid side of neutral, so areas of neutral grassland are likely to be overestimated. Species data for neutral grassland do not help in this case since they cover many areas where grassland does not appear on LCM2000.
- Neutral grassland in the UK is largely composed of improved grasslands, including hay meadows.

Table 2.4: Definition of the three classes of the “soil acid sensitivity” map by Hornung et al (1995a) and their use in LCM2000

Soil acid sensitivity class	**Base saturation**	**pH**	**LCM2000 grass category**
Highly sensitive	<20%	<4.5	Acid grassland
Moderately sensitive	20-60%	>4.5 and < 5.5	Neutral grassland
Low sensitivity	>60%	>5.5	Calcareous grassland

Calcareous grassland (EUNIS class E1.26, Figures 2.2c, 2.2d)

Two maps of calcareous grassland have been generated: one to derive the areas sensitive to acidification and the other to derive areas sensitive to eutrophication. For nutrient nitrogen critical loads the 1km map of calcareous grassland (LCM2000 class 7.1) was overlaid with the 10km species data for this broad habitat, and the 1km LCM2000 areas within the 10km squares selected for mapping.

Some of the 1km calcareous grassland squares mapped for nutrient nitrogen critical loads coincide with 1km squares that have low empirical soil acidity critical loads (ie, below 2.0 keq ha^{-1} year^{-1}). The soil acidity critical loads are based on the dominant soil type mapped in each 1km square (see Section 3.2); soils derived from base-poor rocks are more acid and result in low critical loads. Calcareous grassland may occur in 1km squares that have a low soil acidity critical load, but is unlikely to be found on the acid soil determining the low soil critical load. The soils upon which the calcareous grassland occurs are likely to have a higher acidity critical load. Therefore, when mapping acidity critical loads for calcareous grassland nationally, squares with an empirical soil acidity critical load below 2.0 keq ha^{-1} year^{-1} are omitted from the map, on the basis that the critical load (calculated using the empirical method based on the dominant soil) is not appropriate for this grassland soil.

Acid grassland (EUNIS classes E1.7 & E3.5, Figure 2.3a)

To provide the habitat distribution map for acidity critical loads the LCM2000 acid grassland class (8.1) was overlaid with the 10km species data for the habitat, and the 1km LCM2000 areas within the 10km squares selected. For nutrient nitrogen the areas of acid grassland needed to be separated into areas of wet and dry grassland to represent and map the different critical loads for two EUNIS classes (Table 2.2). The 29 classes of the 1km Hydrology of Soil Types (HOST: Boorman et al, 1995) map were divided into wet and dry categories (Table 2.5). The HOST class for each 1km grid square is based on the dominant soil type in the square, so each square can only be defined as having either wet or dry soils. These 1km data have been overlaid on the acid grassland map defined above, enabling wet and dry grassland to be mapped separately. However, for the UK mapping purposes these have been combined into a single "acid grassland" map, since only wet or dry grassland can be mapped in any 1km grid square.

2.6.3 Heathland habitats (EUNIS classes F4.11 & F4.2, Figure 2.3b)

The dwarf shrub heath habitat map is based on the LCM2000 classes for dwarf shrub heath (10.1) and open shrub heath (10.2). The habitat area is further refined by selecting the LCM2000 areas within the 10km squares of the Broad Habitat species map. For nutrient nitrogen, empirical critical loads have been set for two EUNIS classes: dry heaths (F4.2) and Northern wet heaths (F4.11), the latter comprising *Calluna*-dominated and *Erica tetralix*-dominated wet heaths. Satellite imagery cannot identify individual species, nor separate areas of wet and dry heathland. The HOST data (Table 2.5) have been used to identify areas of wet and dry heaths which, for UK mapping purposes, are combined into a single "dwarf shrub heath" map as only wet or dry heath can be mapped in any 1km grid square.

Table 2.5 Division of the HOST classes into wet and dry soils

HOST class	**Soil characteristics**	**Substrate hydrogeology**	**Groundwater or aquifer**	**Soil: Wet (W) Dry (D)**
1	Mineral soil, no impermeable or gleyed layer within 100cm	Weakly consolidated, microporous, by-pass flow uncommon (chalk)	Normally present and at >2m	D
2	Mineral soil, no impermeable or gleyed layer within 100cm	Weakly consolidated, microporous, by-pass flow uncommon (limestone)	Normally present and at >2m	D
3	Mineral soil, no impermeable or gleyed layer within 100cm	Weakly consolidated, macroporous, by-pass flow uncommon	Normally present and at >2m	D
4	Mineral soil, no impermeable or gleyed layer within 100cm	Strongly consolidated, non or slightly porous, by-pass flow common	Normally present and at >2m	D
5	Mineral soil, no impermeable or gleyed layer within 100cm	Unconsolidated, macroporous, by-pass flow very uncommon	Normally present and at >2m	D
6	Mineral soil, no impermeable or gleyed layer within 100cm	Unconsolidated, microporous, by-pass flow common	Normally present and at >2m	D
7	Mineral soil, either no impermeable or gleyed layer within 100cm, or impermeable layer within 100cm or gleyed layer at 40-100cm	Unconsolidated, macroporous, by-pass flow very uncommon	Normally present and at <=2m	D

HOST class	**Soil characteristics**	**Substrate hydrogeology**	**Groundwater or aquifer**	**Soil: Wet (W) Dry (D)**
8	Mineral soil, either no impermeable or gleyed layer within 100cm, or impermeable layer within 100cm or gleyed layer at 40-100cm	Unconsolidated, microporous, by-pass flow common	Normally present and at <=2m	D
9	Mineral soil, gleyed layer within 40cm (IAC <12.5)	Unconsolidated, mircoporous, by-pass flow common	Normally present and at <=2m	W
10	Mineral soil, gleyed layer within 40cm (IAC >=12.5)	Unconsolidated, mircoporous, by-pass flow common	Normally present and at <=2m	W
11	Peat soil, drained	Unconsolidated, mircoporous, by-pass flow common	Normally present and at <=2m	D
12	Peat soil, undrained	Unconsolidated, mircoporous, by-pass flow common	Normally present and at <=2m	W
13	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm	Strongly consolidated, non or slightly porous, by-pass flow common	Normally present and at >2m	D
14	Mineral soil, gleyed layer within 40cm	Strongly consolidated, non or slightly porous, by-pass flow common	Normally present and at >2m	W
15	Peat soil	Strongly consolidated, non or slightly porous, by-pass flow common	Normally present and at >2m	W
16	Mineral soil, no impermeable or gleyed layer within 100cm	Slowly permeable	No significant groundwater or aquifer	D
17	Mineral soil, no impermeable or gleyed layer within 100cm	Impermeable (hard)	No significant groundwater or aquifer	D
18	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC >7.5)	Slowly impermeable	No significant groundwater or aquifer	W
19	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC >7.5)	Impermeable (hard)	No significant groundwater or aquifer	W
20	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC >7.5)	Impermeable (soft)	No significant groundwater or aquifer	W
21	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC <=7.5)	Slowly impermeable	No significant groundwater or aquifer	W

HOST class	**Soil characteristics**	**Substrate hydrogeology**	**Groundwater or aquifer**	**Soil: Wet (W) Dry (D)**
22	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC <=7.5)	Impermeable (hard)	No significant groundwater or aquifer	D
23	Mineral soil, impermeable layer within 100cm or gleyed layer at 40-100cm (IAC <=7.5)	Impermeable (soft)	No significant groundwater or aquifer	W
24	Mineral soil, gleyed layer within 40cm	Slowly impermeable	No significant groundwater or aquifer	W
25	Mineral soil, gleyed layer within 40cm	Impermeable (soft)	No significant groundwater or aquifer	W
26	Peat soil	Slowly permeable	No significant groundwater or aquifer	W
27	Peat soil	Impermeable (hard)	No significant groundwater or aquifer	W
28	Peat soil	Eroded peat	No significant groundwater or aquifer	W
29	Peat soil	Raw peat	No significant groundwater or aquifer	W

Note: HOST classes 18, 20, 21 and 23 may be dry soils in areas where agricultural drainage occurs. However, as the HOST data are being used to define habitats in non-agricultural areas, this should not pose a problem.

2.6.4 Montane habitat (EUNIS class E4.2, Figure 2.3c)

The BAP montane broad habitat includes “moss and lichen dominated heaths of mountain summits”, also represented by EUNIS class E4.2 for which empirical nitrogen critical loads have been set. However, this habitat cannot easily be mapped from satellite data alone. Additional information is required, such as species distributions and altitude. *Racomitrium* heath, found within montane habitats, is considered to be very sensitive to eutrophication and acidification. The 10km distribution map of the NVC class (U10) for *Carex bigelowii-Racomitrium lanuginosum* moss heath has been overlaid onto the LCM2000 data for the montane (15.1) and inland bare ground (16.1) classes. The LCM2000 areas within the 10km squares have been selected and finally using a digital elevation model, any areas below 600m were excluded from the map.

2.6.5 Wetland habitats

The wetland habitats considered for critical loads in the UK are (i) bogs, (ii) standing open water, and (iii) rivers and streams. Bogs are mapped for critical loads of acidity and nutrient nitrogen. Only a sub-set (total 1752) of UK standing open waters, rivers and streams are mapped, and due to the nature of the sites selected they are considered in terms of acidification only.

Bogs (EUNIS class D1, Figure 2.3d)

The LCM 2000 class for bog habitats (12.1) is based on a combination of the satellite imagery and the British Geological Survey (BGS) peat map. For this work, the habitat distribution has been further refined by overlaying the 10km species data for the bog Broad Habitat onto the LCM2000 map, and then selecting the LCM2000 areas within the 10km squares. The same map is used for mapping both acidity and nutrient nitrogen critical loads.

Standing open water, rivers and streams (EUNIS clases C1 & C2, Figures 2.4c, 2.4d)

Critical loads for freshwaters are based on the water chemistry samples for 1752 sites across the UK: 425 in England, 344 in Wales, 856 in Scotland and 127 in Northern Ireland. They consist of a mixture of standing waters (lakes) and low-order streams, found largely in upland areas sensitive to acidification. Rigorous screening of the dataset used to map freshwater ecosystems has been undertaken (Section 5). These specific freshwater sites are potentially sensitive to eutrophication since nitrogen limitation of primary production is fairly common, but there is currently a lack of UK evidence for the “harmful effects” to apply nutrient nitrogen critical loads with confidence (Curtis & Simpson, 2011). Therefore, at present only acidity critical loads are available for them, but it may be possible to apply nutrient nitrogen critical loads in the future. The data for standing waters are not mapped separately from those for rivers and streams. However, the data have been submitted to the CCE by separate EUNIS class: C1 (surface standing waters) and C2 (surface running waters). The areas of these sites are defined from their digitised catchment boundaries (ie, the land area draining into the lake or stream at the sampling point). Two maps are presented for this habitat: one showing the location of the sites as point data (Figure 2.4c) and the other showing the catchment areas (Figure 2.4d)

2.6.6 Marine and coastal habitats

Two habitats sensitive to eutrophication, for which empirical nitrogen critical loads are available, have been mapped for the UK: dune grassland and saltmarsh.

Dune grassland (EUNIS class B1.4, Figure 2.4a)

This habitat falls within the LCM2000 class (19.1) for the broad habitat “supralittoral sediment”. In 2003 this habitat was mapped as a combination of EUNIS classes B1.3 (shifting coastal dunes) and B1.4 (stable dune grassland). The extent of B1.3 around the UK is fairly small and due to a lack of sufficient national data to enable this habitat to be adequately mapped, areas of B1.3 are no longer included in the distribution map. The current dune grassland habitat distribution (representing B1.4) is derived by selecting the areas of this land class within a 2km buffer around the UK coast, to remove any anomalous data points away from the coastal zone. In addition, 10km species data for *Ammophila arenaria* are used to further refine the habitat distribution. Nitrogen critical loads have been defined for both acid and calcareous dune grassland (Bobbink & Hettelingh, 2011); 10km squares where *Corynephorus canescens* has additionally been recorded were used to identify the distribution of acid dunes. The resulting habitat distribution identified most areas of dune grassland in England, Wales and Northern Ireland; areas in Scotland were under-represented. After examining possible options for improving the distribution across Scotland, it was agreed to include areas of LCM2000 calcareous grassland (class 7.1) that fell within the 2km coastal buffer and within the species distribution for Scotland. Only LCM2000 class 7.1 squares that were not already captured within the calcareous grassland habitat map (Section 2.6.2) were included in the final dune grassland map.

Saltmarsh (EUNIS classes A2.53/4/5, Figure 2.4b)

LCM2000 includes a saltmarsh class (21.2), but as for other habitats it was decided to refine and confirm the habitat distribution using ancillary data sets. In this case species distribution data for *Puccinellia maritime* (common saltmarsh grass) and *Juncus maritimus* (sea rush) were used. The saltmarsh distribution map was defined by selecting the 1km LCM2000 squares that fall within the 10km species distribution squares. This combination of data identified all the key areas of saltmarsh in the UK

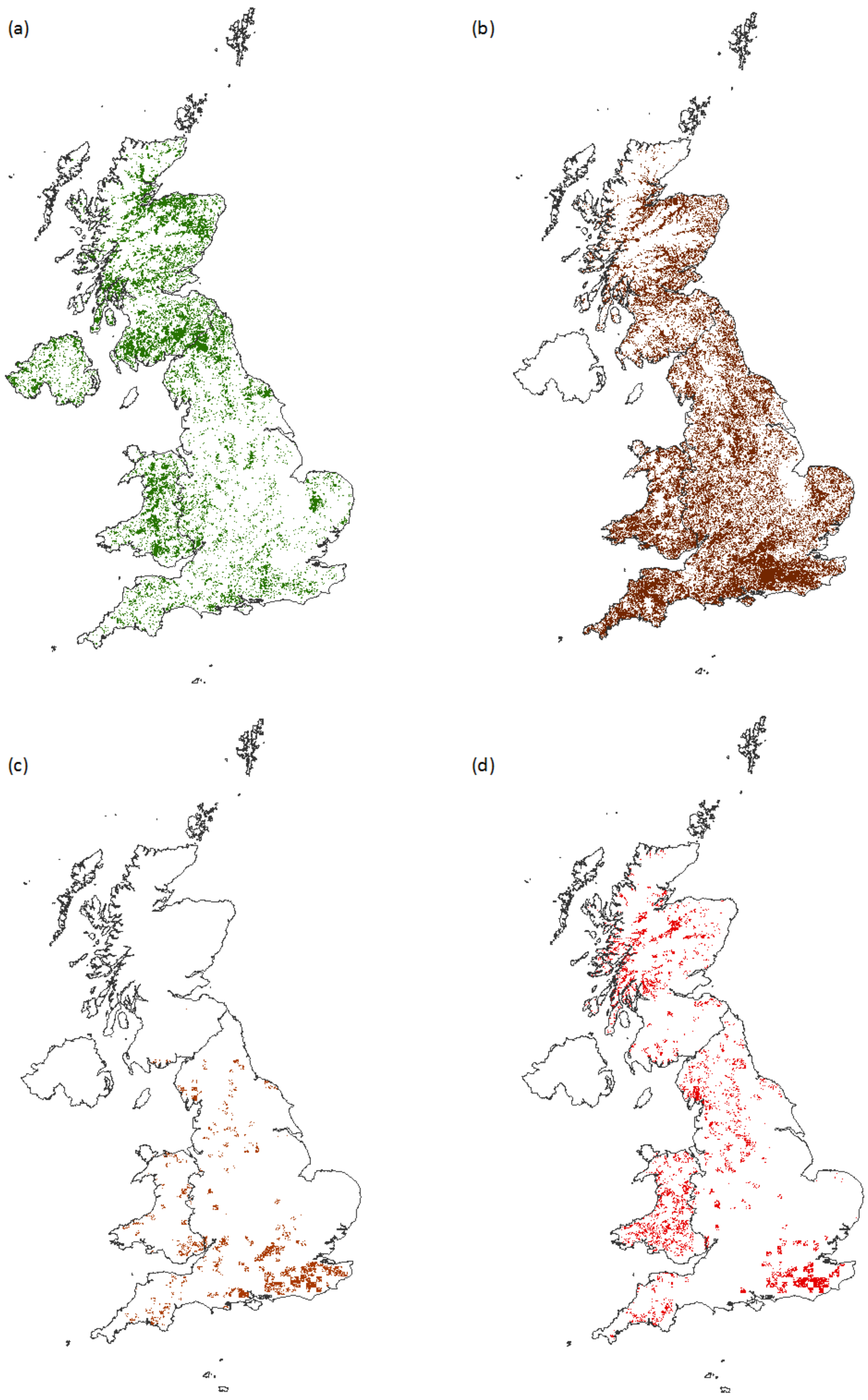


Figure 2.1: Habitat distributions for (a) managed coniferous woodland; (b) managed broadleaved woodland; (c) Beech (Fagus) woodland; (d) Acidophilous oak (Quercus) dominated woodland.

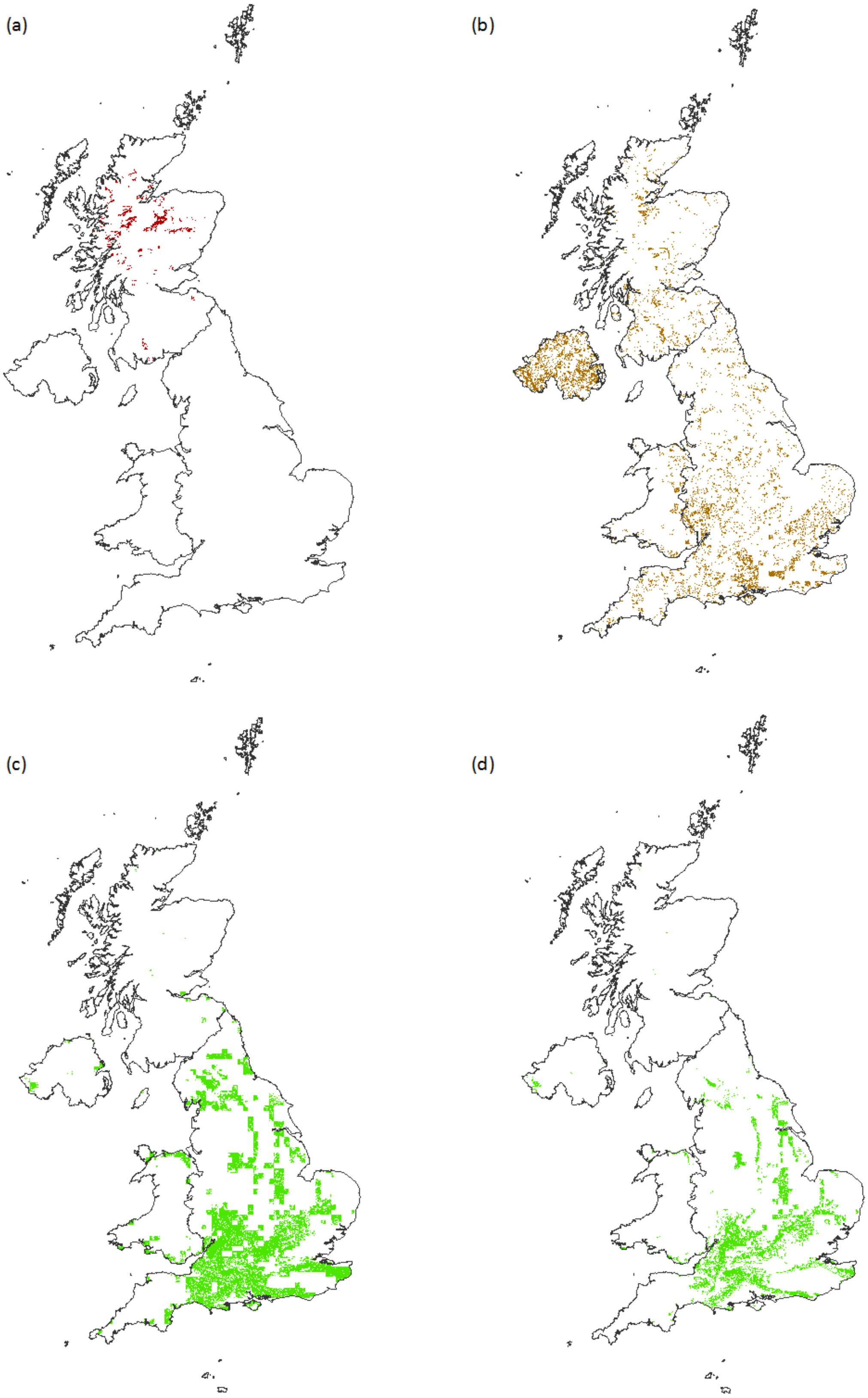


Figure 2.2: Habitat distributions for (a) Scots Pine woodland; (b) unmanaged mixed woodland; (c) calcareous grassland as mapped for nutrient nitrogen; (d) calcareous grassland as mapped for acidity (see Section 2.6.2).

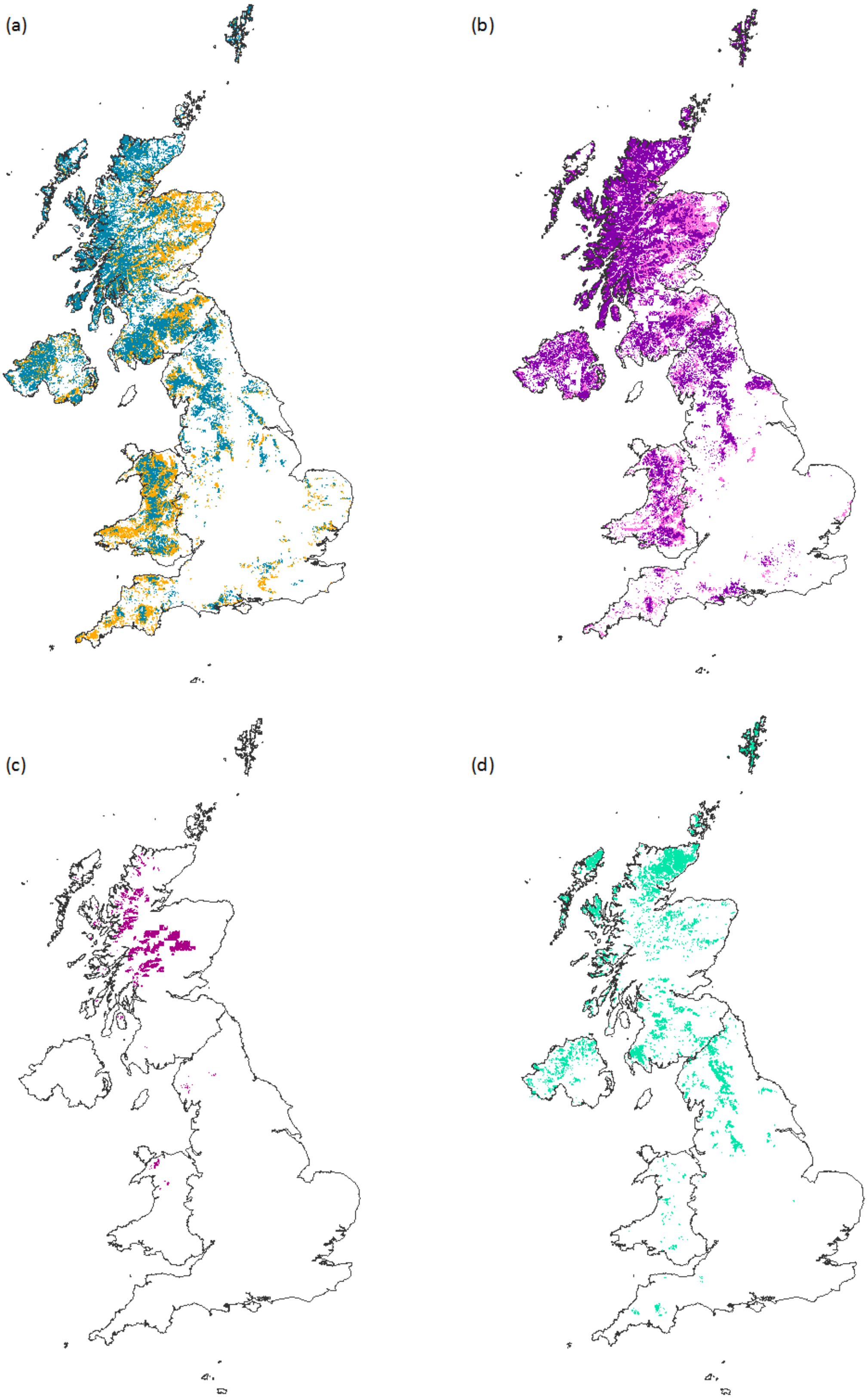


Figure 2.3: Habitat distributions for (a) Dry acid grassland (orange) and wet acid grassland (blue); (b) dry dwarf shrub heath (pink) and wet dwarf shrub heath (purple); (c) montane; (d) bog.

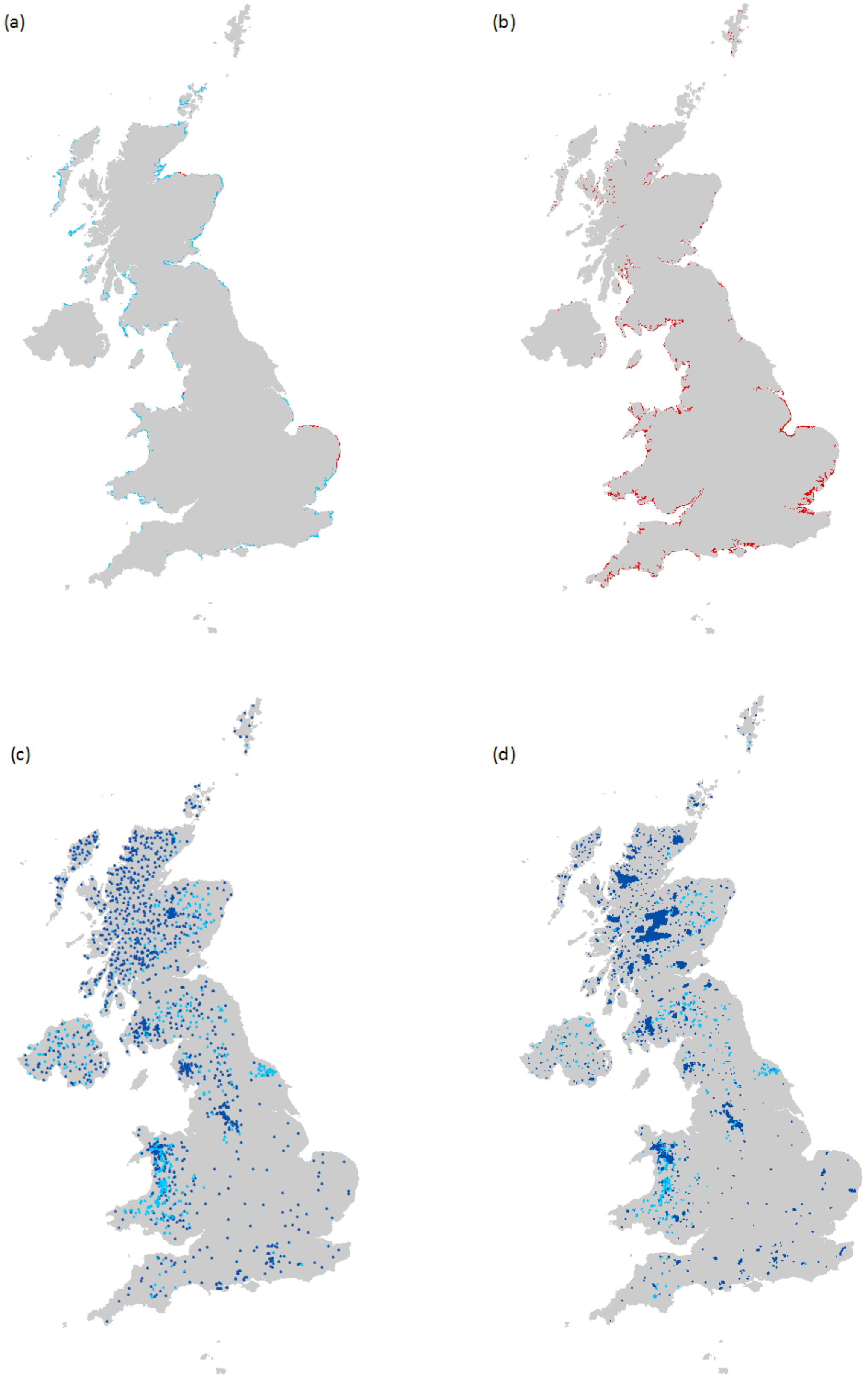


Figure 2.4: Habitat distributions for (a) acid dune grassland (red) and calcareous dune grassland (blue); (b) saltmarsh; (c) sampling points for standing waters (dark blue) and streams (light blue); (d) catchment areas for standing waters (dark blue) and streams (light blue).

3. Critical loads of acidity for terrestrial habitats

3.1 Introduction

Acidification is caused by nitrogen and sulphur deposition. In the calculation of critical load exceedance maps, it is assumed that all nitrogen (derived from nitrogen oxides or ammonia) is acidifying in the long term. This is consistent with the critical load being a steady state concept (with long timescales being required to reach the steady state). However, there is still much debate within the scientific community to understand the fate of deposited nitrogen. The acidity critical load exceedance maps are considered a worst case scenario, and the future role of nitrogen deposition in acidification and recovery of soils (and waters) remains an important research topic.

Both methods make use of the empirical critical loads of acidity for soils and this section begins with a description of these.

3.2 Critical loads of acidity for soils

Critical loads are assigned to each 1km square according to the dominant soil type occurring in each square. The critical loads are calculated using two methods: one for mineral and organo-mineral soils and another for peat soils. Both are described below. The combination of the critical loads for all soil types into a single map produces a map called the empirical critical loads of acidity for soils (Figure 3.1).

3.2.1 Empirical critical loads of acidity for mineral and organo-mineral soils

The UK methodology for calculating and mapping acidity critical loads for mineral and organo-mineral soils (Hornung *et al.*, 1995c) remains unchanged. One of five critical load classes is assigned to each 1km grid square based on the mineralogy and weathering rate of the dominant soil (series or map unit) in each square. Some of the classes assigned were revised according to additional information, such as soil drainage or texture (Hornung *et al.*, 1995c). Each critical loads class is associated with a range of critical load values based on the amount of acid deposition that could be neutralised by the base cations produced by mineral weathering. However as a single value is usually required for each square (eg, for the calculation of exceedances), the mid-range value is used, with the exception of the critical loads in class 1 where the value is set to the top of the range (Table 3.1). This is consistent with work on soil weathering rates by Langan *et al.* (1995) and Sverdrup *et al.* (1990).

Table 3.1: Deriving critical loads for mineral and organo-mineral soils (Hornung et al, 1995; Nilsson & Grennfelt, 1988)

Minerals controlling weathering	**Critical loads class**	**Critical loads range (keq ha^{-1} year^{-1})**	**Mid-range value used in UK (keq ha^{-1} year^{-1})**
Carbonates	1	>2.0 <=4.0	4.0 (upper limit used)
Pyroxene, Epidote, Olivine	2	>1.0 <=2.0	1.5
Biotite, Amphibole	3	>0.5 <=1.0	0.75
Muscovite, Plagioclase, Biotite	4	>0.2 <=0.5	0.35
Quartz, K-feldspar	5	<=0.2	0.1

As the empirical map of soil critical loads is based on the dominant soil type, any changes to the underlying soil databases will lead to changes in the empirical map; modifications were last made to this map in 2003.

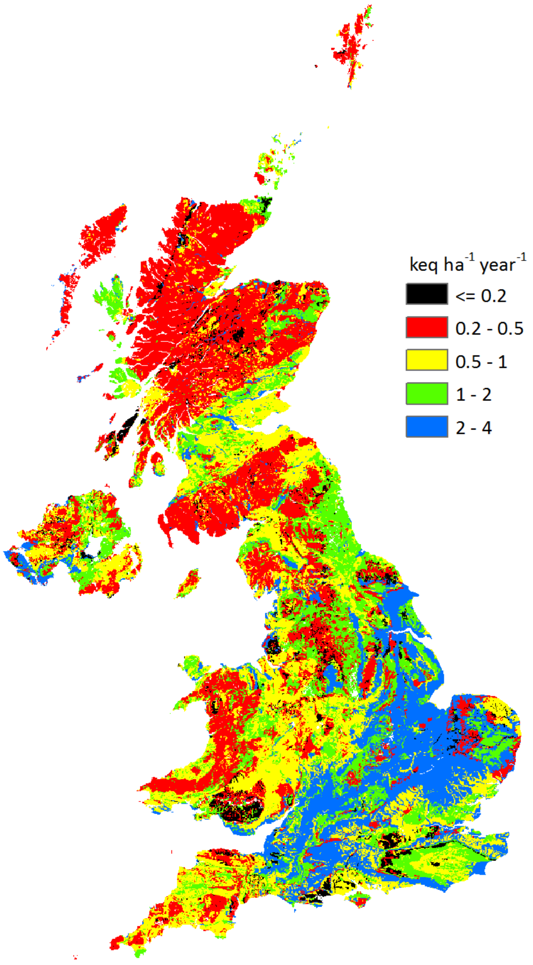


Figure 3.1: Empirical critical loads of acidity for the dominant soil type in each 1km grid square (ie, combining the critical loads for peat and non-peat soils).

3.2.2 *Critical loads of acidity for peat soils*

The method used for calculating acidity critical loads for peat soils was last updated in 2003 (Hall et al, 2003). Critical loads of acidity for peat soils are treated differently from those for mineral soils because of the absence of inputs of alkalinity from mineral weathering (Smith et al, 1992; Gammack et al, 1995; Hornung et al, 1995c & 1995d). Research has demonstrated that the chemical and biological response to acidity in peat is closely related to an effective rain pH threshold of 4.4: Yesmin et al (1996) showed that the best correlation between transformed mycorrhizal infection of *Calluna* roots and deposition parameters was with effective rain pH; Dawod (1996), Proctor & Maltby (1998), and Parveen (2001) have shown that peat soil solution pH equals effective rain pH.

A review of the critical loads concept by Cresser (2000) concluded that for peat soils especially, critical load quantification could only sensibly be based upon the prediction of the pH of soil solutions. Such a method could then be meaningfully related to biological and physicochemical effects (Sanger et al, 1996; Cresser et al, 1997). Close scrutiny of the results of Proctor & Maltby (1998), as reproduced by Charman (2002) demonstrates that fitting a curve to their experimental data for pH versus effective rain pH is more appropriate than using linear regression, and results in an equilibrium value at ca. pH 4.4. This pH reflects the buffering effects of organic acids upon peat drainage water pH. There is no justification for attempting to protect the pH of peat soil solution to a value above this equilibrium threshold value. The evidence therefore suggests that critical loads of acidity for peat soils should be set at a value corresponding to the amount of acid deposition that would give rise to an effective rain pH value of 4.4. The following equation is used to calculate the soil acidity critical load for all UK 1km grid squares dominated by peat soils:

$CLA = Q * [H^+]$
where:
Q = runoff in metres (mean 1km values for 1941-1970)
$[H^+]$ = critical hydrogen ion concentration equivalent to pH 4.4

This method is supported by UK data published by Calver (2003), Skiba & Cresser (1989) and Calver et al (2004). A meeting between UK soil critical load experts discussed how this method related to those applied to other soil types and whether this effective rain pH could be translated into a critical soil solution pH, a commonly used criterion in the Simple Mass Balance (SMB) equation. It was agreed that the corresponding soil solution pH to an effective rain pH of 4.4, would also be pH 4.4. Therefore this method can be expressed as an SMB with a criterion of critical soil solution pH 4.4. The equation used remains the same as that above, as the leaching of aluminium and base cation weathering, as included in the SMB equation (see Box 1), can both be set to zero for peat soils.

This method is applicable to upland and lowland acid peat soils, but not to the lowland, arable fen peats. The peat soils in these lowland arable fen areas are not as sensitive to acidification as those in other regions and therefore require a higher critical load to be set. The critical loads for the lowland arable fen areas are re-set to 4.0 keq ha^{-1} $year^{-1}$; this high value is at the top of the empirical range of critical load values for soils (Hornung et al, 1995c). This value was applied to 1km squares dominated by peat soils where the dominant land cover, according to LCM2000, was arable. The resulting map is shown in figure 3.2.

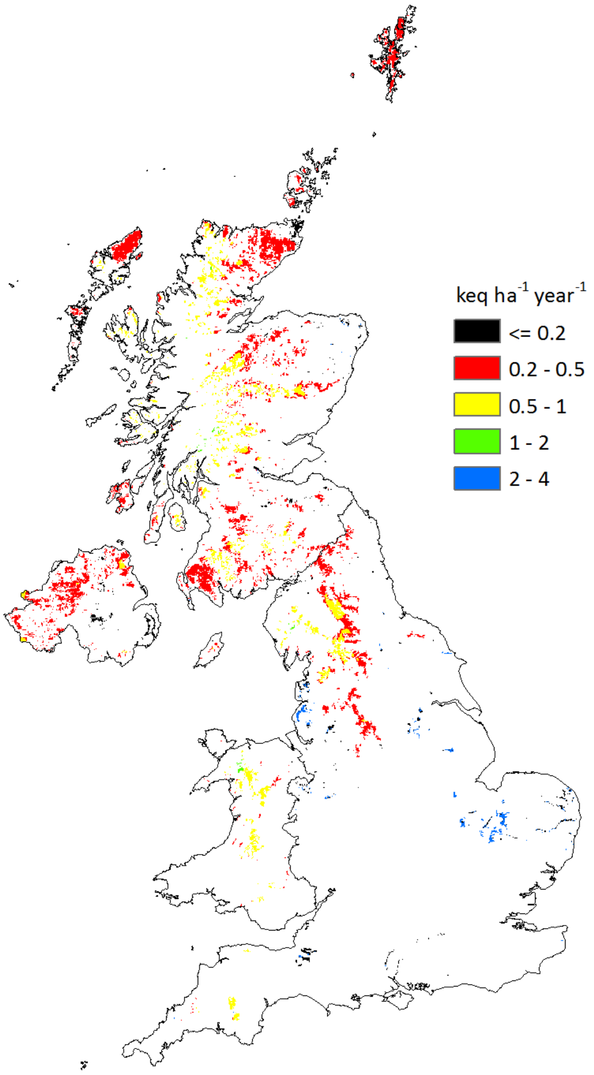


Figure 3.2: Acidity critical loads for 1km squares dominated by peat soils.

3.3 Critical loads of acidity for non-woodland terrestrial habitats

The empirical critical loads described above (Section 3.2) are used to set the acidity critical loads to protect the soils on which the non-woodland habitats depend. As the soil critical loads are based on the dominant soil in each 1km grid square, this means that the critical load for all habitats occurring within a single 1km grid square are also based on the same dominant soil type. The exception to this is the bog habitat, defined by LCM2000 as “Bogs include ericaceous, herbaceous and mossy swards in areas with a peat depth >0.5m” (Fuller et al, 2002b). It is therefore assumed that this habitat will only occur on peat soils and the critical loads should be based on the above method for peat soils (Section 3.2.2). In order to calculate the parameters for the Critical Loads Function (CLmaxS, CLminN, CLmaxN) for each habitat, additional habitat-specific data are used (Section 4).

3.4 Critical loads of acidity for woodland habitats

The SMB equation is the most commonly used model in Europe for the calculation of critical loads for woodland ecosystems. This model is based on balancing the acidic inputs to and outputs from a system, to derive a critical load that ensures a critical chemical limit (related to effects on the ecosystem) is not exceeded (Sverdrup et al, 1990; Sverdrup & De Vries, 1994). The equation has been derived from a charge balance of ions in leaching fluxes from the soil compartment, combined with mass balance equations for the inputs, sinks, sources and outputs of sulphur and nitrogen (Posch et al, 1995).

In the UK acidity critical loads for the woodland habitats are calculated using SMB equations (see Box 1) with different chemical criteria for woodlands on mineral or organo-minerals soils, and on peat soils; Table 3.2 summarises the methods applied to each woodland/soil combination, as well as those for non-woodland habitats. Critical loads are calculated for both managed and unmanaged woodlands in order to protect the long-term ecosystem function of the woodland habitats; this also aims to protect the land under managed conifer forest for possible future non-forest use and reversion to semi-natural land uses. As for the non-woodland habitats, additional habitat-specific data are used to calculate the Critical Load Function parameters: CLmaxS, CLminN, CLmaxN (Section 4).

Box 1:
SMB equation using Ca:Al ratio as chemical criterion for mineral and organo-mineral soils
(NB. Base cation (BC) terms here relate to calcium only).

CLA = $ANC_w - ANC_{le(crit)}$

where:

CLA = *critical loads of acidity (in eq* ha^{-1} $year^{-1}$*)*
[divide by 1000 to give keq ha^{-1} $year^{-1}$*]*

ANC_w = *Acid Neutralising Capacity produced by weathering (eq* ha^{-1} $year^{-1}$*)*
*(base cation weathering)**

$ANC_{le(crit)}$ = *critical leaching of ANC (eq* ha^{-1} $year^{-1}$*)*
= $-Al_{le(crit)} - H_{le(crit)}$

$Al_{le(crit)}$ = *critical leaching of aluminium (eq* ha^{-1} $year^{-1}$*)*
= $((1.5 * BC_{le}) / Ca{:}Al) * 1000$

BC_{le} = *calcium leaching (keq* ha^{-1} $year^{-1}$*)*
= $BC_a - BC_u$

BC_u = *net uptake of calcium (keq* ha^{-1} $year^{-1}$*)*
= $\mathrm{minimum}(u, BC_u)$

u = *calcium uptake (keq* ha^{-1} $year^{-1}$*)*

BC_a = *calcium availability (keq* ha^{-1} $year^{-1}$*)*
= $\mathrm{maximum}(Ca_w + Ca_{dep} - BC_{lemin}, 0)$

Ca_w = *calcium weathering (keq* ha^{-1} $year^{-1}$*)*

Ca_{dep} = *total (marine plus non-marine) calcium deposition to woodland (keq* ha^{-1} $year^{-1}$*)*

BC_{lemin} = *minimum calcium leaching (keq* ha^{-1} $year^{-1}$*)*
= $Q * [BC_l] * 0.01$

Q = *runoff (metres* $year^{-1}$*)*

$[BC_l]$ = *limiting concentration for uptake of calcium (2µeq* l^{-1}*)*

$H_{le(crit)}$ = *critical leaching of hydrogen ions (eq* ha^{-1} $year^{-1}$*)*
= $(1.5 * ((BC_{le} * 1000) / (K_{gibb} * Ca{:}Al)))^{1/3} * (Q * 10000)^{2/3}$

K_{gibb} = *gibbsite equilibrium constant (*$[m^6\ eq^{-2}]$*)*

$Ca{:}Al$ = *Calcium:Aluminium ratio*

** Base cation contributions from phosphate or potassium fertilisers are added to* ANC_w *in the calculation of critical loads for managed woodlands on organo-mineral and peat soils.*

Table 3.2: Summary of acidity critical load (CLA) methods and parameters applied by terrestrial habitat and soil type

Habitat	**Soil**	**Method**	**Chemical criterion**	**Kgibb m^6 eq^{-2}**	**Ca uptake keq ha^{-1} $year^{-1}$**	**Ca deposition (years)**	**Rock P[#] keq ha^{-1} $year^{-1}$**
Managed conifer woodland	Mineral	SMB	Ca:Al=1	950	0.16	1998-2000	-
	Organo-mineral	SMB	Ca:Al=1	100	0.16	1998-2000	0.177
	Peat[*]	SMB	Critical pH 4.4	-	-	-	0.417
Managed broadleaf woodland	Mineral	SMB	Ca:Al=1	950	Ca-poor soils = 0.195 Ca-rich soils = 0.29	1998-2000	-
	Organo-mineral	SMB	Ca:Al=1	100	0.195 (assumes all Ca-poor)	1998-2000	0.08
	Peat[*]	SMB	Critical pH 4.4	-	-	-	0.417
Unmanaged mixed woodland	Mineral	SMB	Ca:Al=1	950	zero (assumes no tree harvesting/removal)	1998-2000	-
	Organo-mineral	SMB	Ca:Al=1	100	zero (assumes no tree harvesting/removal)	1998-2000	-
	Peat[*]	SMB	Critical pH 4.4	-	-	-	-
Non-woodland terrestrial habitats	Mineral	Empirical soil	-	-	-	-	-
	Organo-mineral	Empirical soil	-	-	-	-	-
	Peat[*]	SMB	Critical pH 4.4	-	-	-	-

[*] In SMB equation for peat soils ANC_w and $ANC_{le(crit)}$ set to zero, so CLA = $H_{le(crit)}$. In addition the CLA is set to 4.0 keq ha^{-1} $year^{-1}$ for squares dominated by peat soil and by arable land.

[#] Application of rock phosphate as fertilizer (see Section 3.4.5 and Box 1)

The paragraphs below describe the key inputs to the SMB and any default values applied.

3.4.1 Chemical criteria

The SMB equation is parameterised according to the appropriate critical chemical criteria and critical limits, below which adverse effects of acidification would be expected to occur. A critical molar ratio of calcium to aluminium of one (Ca:Al = 1) in soil solution is a common criterion applied in the SMB to protect the fine roots of trees. This criterion is used in the SMB equation applied to UK woodland occurring on mineral and organo-mineral soils (ie, mineral soils with a peaty top), where soil water aluminium needs to be accounted for when considering acidification processes in these soils. For woodland on organic (peat) soils, the critical loads based on a critical soil solution pH of 4.4 as described in Section 3.2.2 are applied.

3.4.2 Gibbsite equilibrium constant

The gibbsite equilibrium constant (K_{gibb}) simulates the relationship between aluminium and hydrogen ions in soil solution. Values for this constant are based on the percentage of organic matter in the soil. For the UK, the value applied is based on the soil type as follows: 950 m^6 eq^{-2} for mineral soils, 100 m^6 eq^{-2} for organo-mineral soils (UBA, 1996; CLRTAP, 2013).

3.4.3 Calcium deposition

The calculation of acidity critical loads for woodlands on mineral or organo-mineral soils is based on the Ca:Al criterion which requires total calcium deposition (ie, wet plus dry, marine and non-marine) values to estimate the calcium availability (Box 1). The values currently used in the critical load calculations are the "Concentration Based Estimated Deposition" (CBED; see Section 9) mean data for 1998-2000; these are not updated when the CBED data are updated, as this would alter the critical load values every time the deposition was updated. The values for 1998-2000 provide an estimate of the long term calcium inputs from deposition.

3.4.4 Base cation and calcium weathering

In its simplest form the SMB equation can be expressed as:

$CLA = ANC_w - ANC_{le(crit)}$

where:

ANC_w = acid neutralising capacity (ANC) generated by base cation weathering

$ANC_{le(crit)}$ = critical leaching of ANC

The empirical critical loads of acidity for soils (Section 3.2.1) are based on the mineralogy and weathering rate characteristics of the dominant soil, and can therefore be used to provide ANC_w inputs to the SMB. The base cation weathering rate is set to zero for those 1km grid squares dominated by peat soils due to the absence of inputs of alkalinity from mineral weathering in these soils.

The formulation of the SMB adopted in the UK for woodland on mineral and organo-mineral soils uses a critical molar Ca:Al ratio in soil solution as the chemical effects criteria. This means that the base cation terms in the calculation of $ANC_{le(crit)}$ need to be considered in terms of calcium only (Box 1). As calcium weathering is a fraction of the total base cation weathering, estimates are obtained by applying "calcium correction" values to the base cation values (ANC_w):

Calcium weathering = ANC_w * calcium correction factor

The correction factors were provided by UK soil experts for each soil type. The calcium weathering rate is set to zero for the peat-dominated grid squares.

3.4.5 Contributions to base cation budget from fertilizer application

The application of phosphate and potassium fertilisers (primarily rock phosphate and muriate of potash) as a contribution to the base cation budget to managed woodlands on organo-mineral and peat soils is taken into account in the calculation of acidity critical loads (Table 3.2 and Box 1). Forest Research provided fertiliser application rates based on published practice guidance (Taylor, 1991). The dynamics of base cation release from fertilisers are not considered because the SMB approach works on a rotation length timeframe.

3.4.6 Base cation, calcium and nitrogen uptake (removal) values

These uptake values are required for the calculations of critical loads for managed woodland habitats. Calcium uptake is included in the acidity SMB (see Box 1), base cation uptake is included in the derivation of CLmaxS (Section 4), and nitrogen uptake is included in the derivation of CLminN (Section 4) and in the nitrogen mass balance equation used to calculate critical loads of nutrient nitrogen for managed woodlands (Section 6.3). For unmanaged woodlands, all uptake terms are set to zero assuming that no harvesting, and therefore no removal of base cations, calcium or nitrogen, takes place.

The methods used to estimate base cation (Bc), calcium (Ca) and nitrogen (N) losses by uptake and removal during harvesting and thinning operations in forests and woodlands are based on site-specific measurements made at the ten UNECE/ICP Forests Intensive Forest Health monitoring sites (Level II) in the UK operated by Forest Research between 1995 and 2003. The estimates of uptake are calculated using average volume increments (ie, a measurement of yield) which are converted into the amount (Bc etc) removed in harvest based upon the wood density and the concentrations in the wood. All calculations used the same equation:

$$\underset{(\text{keq ha}^{-1}\text{ year}^{-1})}{\text{Loss from site}} = \underset{(\text{m}^{3}\text{ ha}^{-1}\text{ year}^{-1})}{\begin{array}{c}\text{average volume}\\ \text{increment}\end{array}} * \underset{(\text{g m}^{-3})}{\begin{array}{c}\text{basic wood}\\ \text{density}\end{array}} * \underset{(\text{keq g}^{-1})}{\begin{array}{c}\text{concentration}\\ \text{in wood}\end{array}}$$

Cumulative volume production including yield from thinnings are predicted from forest yield tables (Edwards and Christie, 1981). Rotation length is based on felling at maximum mean annual increment (MAI) for the two conifer species. In the case of oak, the rotation is extended beyond maximum MAI to 120 or 140 years to reflect typical practice. Overbark (ie, including bark) volumes (as given in the yield tables) are converted to underbark (ie, excluding bark) volumes using industry-accepted, species specific conversion factors (Hamilton, 1975) providing separate estimates of wood and bark volumes.

The three oak plots are assumed to be thinned, while of the conifer species, Sitka spruce is assumed unthinned, and Scots pine, thinned. The mean of the three broadleaved and seven conifer plots are then taken as representative values for their respective forest categories. The mean yield class of these two forest categories (5.0 m^{3} ha^{-1} $year^{-1}$ broadleaf and 15.8 m^{3} ha^{-1} yr^{-1} conifer) are higher than the average for the 0.9 MHa of the Forest Enterprise estate (3.2 and 11.6 m^3 ha^{-1} yr^{-1} respectively), and thus uptake values have been scaled accordingly.

Species specific densities for wood and bark (Lavers, 1969; Hamilton, 1975) are used to calculate biomass. For broadleaved species, branch biomass is calculated additionally, accounting for small diameter timber taken off site for pulp and firewood.

Site specific measured stemwood and bark nutrient concentrations together with published values of branch nutrient concentrations (Allen et al., 1974: for oak only) are then used to estimate total quantities of Ca, Bc and N taken offsite during the rotation. Uptake is assumed to occur at a constant rate over the course of the rotation.

In the case of Ca and Bc uptake by broadleaved species, two of the sites (Savernake and Alice Holt) are assumed to represent calcium-rich soils, and one (the Lakes), calcium poor soils. N uptake of broadleaved species was calculated as the mean of all three sites.

Table 3.3: Base cation, calcium and nitrogen uptake values for managed coniferous and managed broadleaved woodland.

Woodland type	**Uptake values (keq ha^{-1} $year^{-1}$)**		
	Base cations	**Calcium**	**Nitrogen**
Managed conifers	0.27	0.16	0.21
Managed broadleaf on Ca-rich soils	0.41	0.29	0.42
Managed broadleaf on Ca-poor soils	0.315	0.195	

Notes:

- Conifer values based on the mean of four Sitka (Coalburn, Tummel, Loch Awe, Llyn Brianne) and three Scots pine (Thetford, Sherwood, Rannoch) sites.
- Broadleaved values for Ca-poor soils based on the Grizedale oak site and values for Ca-rich soils based on the mean of data for Alice Holt and Savernake oak sites.
- Where the SMB is applied to unmanaged broadleaved and unmanaged coniferous woodland, all uptake terms are set to zero, assuming that no harvesting takes place.

4. Acidity Critical Loads Function (CLF) for terrestrial habitats

4.1 Introduction

Deposition of both sulphur and nitrogen compounds can contribute to exceedance of the acidity critical load. The Critical Load Function, developed under the UNECE CLRTAP (Posch *et al.*, 1999; Posch & Hettelingh, 1997; Posch *et al.*, 1995; Hettelingh *et al.*, 1995), defines combinations of sulphur and nitrogen deposition that will not cause harmful effects. In its simplest form, an acidity critical load can be defined graphically by a 45 degree diagonal line on a sulphur-nitrogen deposition plot (Figure 4.1a). The line intercepts the x-axis (representing nitrogen deposition) and y-axis (representing sulphur deposition) at chemically equivalent points, each representing the nitrogen or sulphur deposition equal to the critical load for acidity. Each point along the diagonal line represents the critical load in terms of some combination of sulphur and nitrogen deposition.

To allow for the long-term nitrogen removal processes by the soil and through harvesting of vegetation, the simple diagonal line is shifted along the nitrogen axis to increase the nitrogen values across the entire CLF (Figure 4.1b). More nitrogen can then be deposited before the acidity critical load is exceeded. There are no similar removal processes that need to be considered for sulphur.

The intercepts of the CLF on the sulphur and nitrogen axes (Figure 4.1c) define the following terms:

- The "maximum critical load of sulphur" (CLmaxS): the critical load for acidity expressed in terms of sulphur only, ie, when nitrogen deposition is zero.
- The "maximum critical load of nitrogen" (CLmaxN): the critical load for acidity expressed in terms of nitrogen only (when sulphur deposition is zero).
- The "minimum critical load of nitrogen" (CLminN): the long-term nitrogen removal processes in the soil (eg, nitrogen uptake and immobilisation) and harvesting of vegetation.

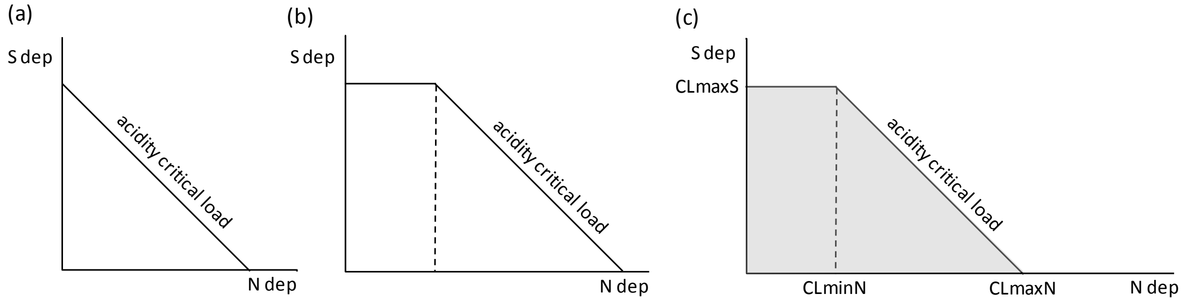


Figure 4.1: Development of the CLF: (a) acidity critical load defined by equal amounts of sulphur and nitrogen deposition; (b) shifting the acidity critical load diagonal line to allow for nitrogen removal processes; (c) the 3 nodes of the CLF: CLmaxS, CLminN, CLmaxN. The area shown in grey represents the combinations of sulphur and nitrogen deposition that are below the critical load (ie, critical load is not exceeded).

The acidity critical load values CLmaxS, CLminN, CLmaxN are calculated for each habitat, for each 1km grid square in which the habitat is mapped. These values, together with the data used to calculate them, form part of the data that the NFC is required to submit to the CCE.

The paragraphs below describe the methods used to calculate these critical loads for terrestrial habitats; the calculations for freshwaters are dealt with separately in Section 5.6. The calculations of exceedance of acidity critical loads using the CLF are described in Part II of this report.

4.2 Maximum critical load of sulphur: CLmaxS

CLmaxS is based on the acidity critical load values but also takes into account the net base cation deposition to the soil system and base cation removal from the system:

$\text{CLmaxS} = \text{CLA} + BC_{dep} - BC_u$

Where:

CLA = acidity critical load (empirical or SMB)
BC_{dep} = non-marine base cation (less non-marine chloride) deposition
BC_u = base cation uptake (removal)

The base cation and chloride deposition used in these calculations are the CBED values for 1998-2000 (Section 9); as with the deposition values incorporated into the SMB acidity critical loads (Section 3.4.3) these values are not updated when the CBED data are updated. The base cation uptake (removal) values are set to zero for acid grassland, dwarf shrub heath, bog and montane habitats, based on Rawes & Heal (1978) and Reynolds et al (1987). The removal of base cations in calcareous grassland is set at 0.222 keq ha^{-1} year^{-1} based on figures for removal by sheep grazing. The uptake values for managed (productive) coniferous and broadleaved woodland are given in Table 3.3; uptake is set to zero for unmanaged woodland assuming no harvesting, and therefore no base cation removal, is taking place.

4.3 Minimum critical load of nitrogen: CLminN

As described above CLminN is the sum of the long-term nitrogen removal processes from the soil and vegetation, and is calculated as:

$\text{CLminN} = N_u + N_i + N_{de} + N_{fire}$

Where:

N_u = nitrogen uptake (removal)
N_i = nitrogen immobilisation
N_{de} = denitrification
N_{fire} = nitrogen losses through fire (applicable to dwarf shrub heath only)

The derivation of nitrogen uptake values for managed coniferous and broadleaved woodland are given in Section 3.4.6. The values applied to each habitat are summarised in Table 4.1. Values of N_i and N_{de} have been assigned by according to the dominant soil type in each 1km grid square (Table 4.2).

For the dwarf shrub heath habitat, nitrogen losses through fire are additionally included in the calculation of CLminN, in accordance with the Mapping Manual (CLRTAP, 2013). Separate values are applied to areas of wet and dry heathland. The N_{fire} value for dry heaths is 10 kg N ha^{-1} year^{-1} based on work by Power et al (2004) and Terry et al (2004). The N_{fire} value for wet heaths is 4.5 kg N ha^{-1} year^{-1} based on data by Allen (1964) which showed that for a blanket peat in the Pennines 45 kg N ha^{-1} year^{-1} could be lost in a single burn. The burn frequency in the Pennines varies from 7-20 years; assuming an average burn frequency of 10 years results in the figure of 4.5 kg N ha^{-1} year^{-1}.

Table 4.1: Summary of nitrogen uptake values applied to different habitats.

Habitat	**N uptake (kg N ha^{-1} year^{-1})**	**Comment**
Managed coniferous woodland	2.94	See section 3.4.6
Managed broadleaved woodland	5.88	
Unmanaged woodland	0	
Calcareous grassland	10	Value assigned prior to 2003 and there remains some concern that this value is too high
Acid grassland	1.14	Based on data from Frissel (1978)
Dwarf shrub heath	0.5	The literature (Perkins, 1978; Rawes & Heal, 1978; Reynolds et al, 1987; Batey, 1982; Gordon et al, 2001) suggests a value for dwarf shrub heath in the range 0.5-1.0 kg N ha^{-1} year^{-1}; a value of 0.5 has been applied. The same value is appropriate for bog and montane habitats (Reynolds, Woodin, pers.comm)

4.4 Maximum critical load of nitrogen: CLmaxN

CLmaxN is calculated as:

CLmaxN = CLminN + CLmaxS

Therefore any changes to the inputs to CLminN and CLmaxS will lead to changes in CLmaxN.

Table 4.2: Estimates of long-term nitrogen immobilisation and denitrification by soil type.

Soil code[#]	**Soil description**	**N immobilisation kg N ha^{-1} $year^{-1}$**	**Denitrification kg N ha^{-1} $year^{-1}$**
1	Terrestrial raw soil	3	1
1.1	Raw sands	1	1
2	Raw gley soils	1	1
2.2	Unripened gley soils	1	4
3	Lithomorphic soils	1	1
3.1	Rankers	1	1
3.2	Sand rankers	1	1
3.4	Rendzinas	1	1
3.6	Sand parendzinas	1	1
3.7	Rendzina-like alluvial soils	1	1
4	Pelosols	1	2
4.1	Calcareous pelosols	1	2
4.2	Non-calcareous pelosols	1	2
4.3	Argillic pelosols	1	2
5	Brown soils	1	1
5.1	Brown calcareous earths	1	1
5.2	Brown calcareous sands	1	1
5.3	Brown calcareous alluvial soil	1	1
5.4	Brown earths	1	1
5.5	Brown sands	1	1
5.6	Brown alluvial soils	1	1
5.7	Argillic brown earths	1	1
5.8	Paleo-argillic brown earths	1	1
6	Podzolic soils	3	1
6.1	Brown podzolic soils	3	1
6.3	Podzols	3	1
6.4	Gley podzols	3	1
6.5	Stagnopodzols	3	1
7	Surface water gley soils	1	4
7.1	Stagnogley soils	1	4
7.2	Stagnohumic gley soils	3	4
8	Ground-water gley soils	1	4
8.1	Alluvial gley soils	1	4
8.2	Sandy gley soils	1	4
8.3	Cambic gley soils	1	4
8.4	Argillic gley soils	1	4
8.5	Humic-alluvial gley soils	1	4
8.6	Humic-sandy gley soils	1	4
8.7	Humic gley soils	1	4
9	Man-made soils	1	1
9.2	Disturbed soils	1	1
10	Peat soils	3	1
10.1	Raw peat soils	3	1
10.2	Earthy peat soils	3	1

[#] Based on the NSRI classification of soils for England and Wales

5. Critical loads of acidity for freshwaters

5.1 Introduction

Surface waters begin to acidify when the deposition of acidity exceeds the buffering provided by base cations in catchment soils, resulting in run-off water becoming more acid (with a lower acid neutralising capacity) and containing more aluminium ions which may be toxic in high concentrations to some aquatic fauna. The waters most sensitive to acidification are those receiving high rainfall (and hence higher amounts of acid deposition) and where waters are located in areas draining peat or acid soils overlying rocks with low weathering rates.

Since 1994 acidity critical loads for UK freshwaters have been calculated using the catchment-based First-Order Acidity Balance (FAB: Henriksen & Posch, 2001) model. The key advantage of the FAB model is that it can be used to derive a steady-state mass balance for nitrogen, taking account of several key nitrogen processes in catchments, such as denitrification, nitrogen immobilisation, nitrogen removal in harvested vegetation (ie, forestry), and nitrogen retention in lakes. Hence FAB allows acidity critical loads to be determined to take account of the impacts from both sulphur and nitrogen deposition. Updates to the inputs and parameterisation of FAB have been made over the last two decades; this section focuses on the current formulation and inputs to FAB in the UK.

5.2 Mapping dataset

FAB is currently applied to 1752 sites across the UK, summarised in Table 5.1 below. The sites comprise a mixture of mainly upland, first-order streams (ie, streams that feed into other larger streams, but do not have any other streams draining into them), lakes and some reservoirs (Figure 2.4c & 2.4d). There are no plans to extend the dataset to other sites. The critical load calculations are based on the most recent, best available estimate of annual mean water chemistry data.

Table 5.1: Summary of freshwater sites by type and country

Country	Number of sites:			Totals
	Streams	Lakes	Artificial	
England	95	178	152	425
Wales	139	159	46	344
Scotland	109	699	48	856
Northern Ireland	52	65	10	127
UK	395	1101	256	1752

5.3 Seasalts screening

The calculation of critical loads using the FAB model can result in ambiguous results for waters with low concentrations of non-marine (ie, seasalt corrected) base cations, mainly in northern and north-west Scotland. Such sites may genuinely be acid, but the FAB model cannot distinguish between sources of acidification (ie, anthropogenic deposition versus natural seasalt inputs). Therefore to maintain the rigour of data screening and quality assurance all sites with non-marine base cation concentrations <-20 µeq l^{-1} were removed from the mapping data set. Note that it cannot be said with confidence that these sites are not impacted by anthropogenic acid deposition.

5.4 Nested catchments

The amalgamation of various datasets in certain regions led to the occurrence of a number of nested catchments in the mapping dataset. This means the catchment area could be double-counted if each catchment were reported separately in the exceedance calculations. In 2004 there were 118 sites with one or more sub-catchments; it was therefore decided to calculate a “net” or “unique” catchment area for each site to avoid any double-counting of habitat area in exceedance calculations. A further 30 sites have been added to the mapping dataset since 2004 (making the total 1752 sites); these are mainly small catchments and have not been screened for the presence of sub-catchments.

5.5 The chemical criterion ANC_{crit}

The critical chemical criterion used to indicate the threshold for damage, and determine the critical loads for freshwaters, is ANC (Acid Neutralising Capacity). Studies linking ANC to biological damage have been carried out in Norway, where hundreds of lakes have been surveyed for fish population data and water chemistry. These surveys provided data for a widely used dose-response function linking ANC to the probability of damage to brown trout populations (Lien et al, 1992; 1996), where damage is defined as a reduction in fish populations. Since brown trout is a widespread and economically important species in UK freshwaters, it provides an ideal indicator species for national critical load applications.

In Norway and many other countries in Europe the critical ANC (ie, ANC_{crit}) concentration selected for critical loads applications is 20 µeq l^{-1}, representing a 10% probability of damage to brown trout populations. In the UK, a stakeholder workshop was held in 2004 to review the threshold(s) to apply in the critical load calculations for UK freshwaters (Curtis & Simpson, 2004). It was agreed that an ANC_{crit} value of 20 µeq l^{-1} should be applied to all sites with the exception of sites meeting any of the conditions below, where ANC_{crit} = 0 µeq l^{-1} is more appropriate and should be used:

- Palaeolimnological reconstruction of pH in 1850 equates to an ANC value of <20 µeq l^{-1}.
- MAGIC model hindcasts indicate an ANC in 1850 of <20 µeq l^{-1}.
- FAB model critical loads calculated using ANC_{crit} = 20 µeq l^{-1} returns a zero value, suggesting that the pre-industrial ANC value was never this low.

5.6 Application of FAB to UK freshwaters

The FAB model is a catchment-based model for calculating critical loads of sulphur and nitrogen (CLmaxS, CLminN, CLmaxN) taking into account the sources and sinks of sulphur and nitrogen within the lake (for a lake site) and its terrestrial catchment. The lake and catchment are assumed small enough to be properly characterised by average soil and lake-water properties (Henriksen & Posch, 2001). The current version of FAB takes account of direct deposition to the lake surface, whereas the previous version (Posch et al, 1997) assumed that all deposited nitrogen had to first pass through the terrestrial catchment before reaching surface waters.

In Henriksen & Posch (2001) three possible scenarios of nitrogen deposition and leaching are envisaged:

(i) No terrestrial N leaching: $N_{dep} < (N_{imm} + N_{den})$

(ii) Terrestrial N leaching except from forested areas:
$(N_{imm} + N_{den}) < N_{dep} < (N_{imm} + N_{den} + N_{upt})$

(iii) Terrestrial N leaching from all areas: $N_{dep} > (N_{imm} + N_{den} + N_{upt})$
[N_{dep} = N deposition; N_{imm} = N immobilisation; N_{den} = denitrification; N_{upt} = N uptake]

Note that the nitrogen sink terms above (ie, N_{imm}, N_{den}) are equivalent to those used for terrestrial ecosystems (Section 4.3) and the net nitrogen uptake (N_{upt}) uses the same terms as those for managed coniferous and broadleaved woodlands (Section 3.4.6).

Case (ii) above may underutilize the potential sink for nitrogen in forests by assuming that the only nitrogen input to forested areas is via direct deposition. However, if nitrate leaching occurs from moorland areas (within a catchment) that are upslope of forested areas, there may be further scope for uptake of nitrogen beyond that which is directly deposited. Therefore this formulation provides a “worst case” nitrate leaching scenario for forested catchments. For the UK application of FAB we have modified the published equations to assume that the terrestrial nitrogen sink including forest uptake, is averaged over the whole terrestrial catchment; although this is a “best-case” nitrate leaching scenario for forested catchments, it is more consistent with the approach taken in FAB for modelling soil-based sinks for nitrogen, where the whole-catchment values for nitrogen immobilisation and denitrification are the catchment-weighted means for all soil types. Under this assumption there are only two possible scenarios for nitrogen deposition and leaching:

- No terrestrial nitrate leaching (Ndep <= CLminN)
- Terrestrial nitrate leaching occurs (Ndep > CLminN)

For stream catchments where direct deposition to the water surface is negligible, the equations remain the same as the previous formulation (Posch et al, 1997). The equations currently in use in the UK are summarised in Box 2.

5.6.1 Forest N uptake data

The removal of nitrogen by harvesting of trees provides a potential sink for nitrogen within catchments containing areas of managed (productive) woodland. The FAB calculations include the net removal of biomass from the catchment (N_{upt}). The area of managed coniferous and/or broadleaved woodland within each site catchment has been calculated from the habitat maps described in Section 2.6.1. FAB uses the same nitrogen uptake values as applied in the SMB for managed woodlands (Table 3.3): 5.88 kg N ha^{-1} year^{-1} for managed broadleaved woodland, and 2.94 kg N ha^{-1} year^{-1} for managed coniferous woodland.

5.6.2 Denitrification data

The UK parameterisation of FAB uses the default denitrification values by soil type given in Table 4.2. Work under the Defra Freshwater Umbrella (Curtis et al, 2006) suggests that these default values are much more appropriate than the method in the UNECE Mapping Manual (UBA, 1996; CLRTAP, 2013) of assuming between 10% and 80% denitrification determined by the percentage cover of peat soils. The assumption of very high denitrification rates in peat soils disguises the fact that most retained nitrogen in mass balance models is probably immobilised in soils rather than denitrified. Even assuming that over the longer term, N immobilisation may decline as soils become N saturated, experimental testing of potential denitrification rates in the field and laboratory under excess nitrate availability showed denitrification fluxes much closer to the empirical values of Table 4.2 than the 10-80% fluxes suggested by the Mapping Manual (Curtis et al, 2006).

5.6.3 Long-term nitrogen immobilisation

Results from the first Freshwaters Umbrella contract (Curtis, 2001; Curtis 2003) suggest that current rates of N_{imm} are much higher than the long-term default values provided in the UNECE Mapping Manual (UBA, 1996). This phenomenon is well known (and stated in the Mapping Manual) and presents a key problem for parameterisation of mass balance models for N. The major uncertainty is related to the process of N saturation and the capacity of a catchment to assimilate N through time until increased N leaching occurs, i.e. what is the sustainable rate of N immobilisation under enhanced N deposition? This question is particularly difficult to address because of the complex dynamics of N, links to the carbon cycle, and the potentially long timescales involved, superimposed on a situation of ecological and climatic change. The process is not yet sufficiently well understood to allow adaptation of steady-state models, so default values based on soil type (Table 4.2) continue to be used.

Box 2:
First-order Acidity Balance (FAB) model

Charge balance from Posch et al (1997):
$N_{dep} + S_{dep} = \{fN_{upt} + (1\text{-}r)(N_{imm} + N_{den}) + r(N_{ret} + S_{ret})\} + AN_{leach}$

Where:
$N_{dep} + S_{dep}$ = *atmospheric inputs of total nitrogen and sulphur deposition*
N_{upt} = *net growth uptake of N by forest vegetation (removed by harvesting)*
N_{imm} = *long term immobilisation of N in catchment soils*
N_{den} = *N lost through denitrification in catchment soils*
N_{ret} = *in-lake retention of N*
S_{ret} = *in-lake retention of S*
AN_{leach} = *acid anion leaching from catchment*
f = *fraction forested area in the catchment*
r = *lake:catchment ratio*
All units are expressed in equivalents (moles of charge) per unit area and time. Braces enclsoe "internal" catchment processes, ie, those terrestrial and in-lake processes which operate on acid anion inputs to control the net export in catchment runoff.

The acid anion balance of the FAB model can provide the critical leaching rate of acid anions (critical $AN_{leach} = L_{crit}$*) which will depress ANC below the pre-selected critical value (*ANC_{crit}*) as in the SSWC model (Henriksen et al, 1992).*

The critical loads function (CLF) calculations for stream catchments using fixed denitrification term (Curtis et al, 2006):

$CLmaxS = L_{crit}$
$CLminN = fN_{upt} + N_{imm} + N_{den}$
$CLmaxN = CLminN + CLmaxS$

The critical loads function (CLF) calculations for lake catchments (Henriksen & Posch, 2001) using a fixed denitrification term (Curtis et al, 2006):

$CLminN = fN_{upt} + (1\text{-}r)(N_{imm} + N_{den})$
The calculations of CLmaxS and CLmaxN are dependent on the deposition load relative to CLminN:

Case 1: $N_{dep} <= CLminN$ *(no terrestrial nitrate leaching)*
$CLmaxS = L_{crit}/(1\text{-}\rho_S)$
$CLmaxN = L_{crit}/r(1\text{-} \rho_N)$

Case 2: $N_{dep} > CLminN$ *(terrestrial nitrate leaching occurs)*
$CLmaxS = L_{crit}/(1\text{-}\rho_S)$
$CLmaxN = (L_{crit}/r(1\text{-} \rho_N)) + CLminN$

Where:
ρ_S = *in-lake retention fraction for S*
ρ_N = *in-lake retention fraction for N*

5.6.4 In-lake retention component

It has been suggested by critics of the FAB model that the default mass-transfer coefficients employed in FAB, derived from studies in large Canadian lakes, may be inappropriate for UK conditions, and could underestimate net in-lake retention. However, there is no evidence from existing data to suggest that in-lake retention of S and N is being under-estimated in the model, and if anything it may actually be over-estimated. Monthly measurements of water chemistry in upland lake inflows and outflows over 2 years under a previous DoE contract (CLAG) indicated very little difference in concentrations of nitrate or sulphate from the inflow to the outflow, except for a time lag related to lake retention time (Figure 5.1; Curtis & Simpson, 2007). Norwegian studies (Berge *et al.*, 1997) have also found negligible in-lake retention in acid-sensitive upland lakes. It may be true that in-lake retention can be significant in eutrophic lowland lakes but there is little to suggest this is a major sink for acidity in oligotrophic, acid-sensitive upland lakes in the UK. It is true that FAB ignores denitrification in rivers, but no major rivers are included in the UK freshwaters mapping dataset - sites are either standing waters or low order streams. Denitrification from streams is not quantified but there is no evidence that this is a major sink for N in the low-order, acid-sensitive upland streams which show critical load exceedance.

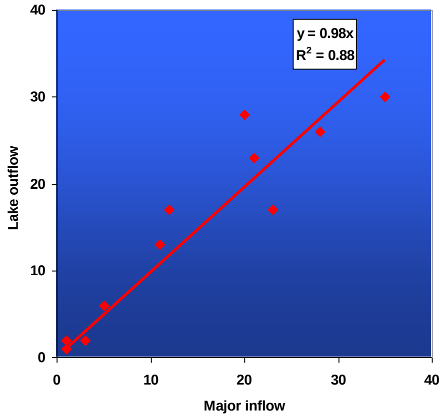


Figure 5.1: Comparison of mean nitrate concentrations (µeq l^{-1}) in lake outflow and major inflow streams (CLAG Nitrogen Network sites; Curtis & Simpson, 2007).

6. Critical loads of nutrient nitrogen for terrestrial habitats

6.1 Introduction

Nitrogen is the main soil derived nutrient and plays a major role in plant and ecological processes. Through industrial and agricultural activity, humans have significantly increased the conversion of inert N_2 into reactive chemical forms of nitrogen. These compounds may all be assimilated by plants and soils and contribute to their nitrogen demand. As increasing amounts of pollutant nitrogen become available, plants and soils suffer from an excessive supply or 'eutrophication'. The optimum amount of nitrogen required varies widely for different systems and this gives rise to the range of critical loads for habitats within the UK. While agricultural crops are unlikely to be directly affected by typical rates of nitrogen deposition, many natural and semi-natural ecological communities are more sensitive because nitrogen is the main limiting nutrient. These systems, such as heaths, moors, bogs and grassland, are adapted to low nutrient supply and the plants survive and compete successfully in these impoverished conditions.

The ultimate consequence of an excessive nitrogen supply to nutrient-poor communities is a shift in the composition of the community so that nitrogen-sensitive plants are lost and an overall reduction is seen in biodiversity. There is strong evidence that nitrogen deposition has significantly reduced the species richness in a range of habitats of high conservation value over large areas of the UK (RoTAP, 2012). The mechanisms through which nitrogen causes these changes are many, owing to the different N pollutant forms deposited, the contrasting plant receptors and the diverse range of processes in which nitrogen is involved. The potential effects of nitrogen are summarised below.

(i) Direct toxic effects of nitrogen pollutants on above ground parts of plants resulting in poor growth and performance
(ii) Accumulation of nitrogen compounds in soil and subsequent increase in their availability to plants causing change in plant community composition
(iii) Increased susceptibility of plants to secondary stress and disturbance factors such as frost, drought, pathogens and herbivores.
(iv) Increased leaching of nitrogen from soils into waters with consequences for stream water chemistry and aquatic biota
(v) Acidification of soils leading to nutrient imbalance and changes in plant community composition

This wide range of possible impacts means that different types of critical load may be appropriate for use, depending on the impacts of concern. The CLRTAP "Mapping Manual" (UBA, 1996: CLRTAP, 2013) recommends two main approaches for calculating critical loads for nutrient nitrogen:

- The steady state mass balance approach (Section 6.3) in which the long-term inputs and outputs of nitrogen from the system are calculated, with the critical load being exceeded when any excess nitrogen input is calculated to lead to exceedance of a critical rate of nitrogen leaching. The mass balance approach is better suited to managed ecosystems of low biodiversity, in which inputs and outputs can be quantified with some confidence and in which the key concern is nitrate leaching. In the UK, this approach is applied to managed (productive) woodlands to ensure the long-term ecosystem function (eg, soils, soil biological resources, trees and linked aquatic ecosystems) is protected.
- The empirical approach (Section 6.2), in which critical loads are estimated, rather than calculated, for different ecosystems based on experimental or field evidence of thresholds for

changes in species composition, plant vitality or soil processes. The empirical approach is better suited to semi-natural communities for which the long-term protection of biodiversity and/or ecosystem function is the key concern. The UK applies the empirical approach to natural and semi-natural habitats, including unmanaged (non-productive) woodland.

6.2 Empirical critical loads of nutrient nitrogen

6.2.1 Introduction

Empirical critical loads of nutrient nitrogen were last updated for UK habitats in 2011 (Hall et al, 2011) following the CLRTAP workshop held in Noordwijkerhout (NL) in June 2010 (Bobbink & Hettelingh, 2011). The aim of this workshop was to review and revise the ranges of empirical critical loads of nitrogen for natural and semi-natural ecosystems, on the basis of additional scientific information available for the period from late 2002 to 2010. A number of UK experts participated in this and previous workshops (Achermann & Bobbink, 2003; Bobbink et al, 1996; Bobbink et al, 1992).

The critical loads from these workshops are presented as ranges rather than single values for each ecosystem. This range indicates the variation in sensitivity within a particular ecosystem, for example, because of differences in nutrient status or management etc. It is left to individual countries to decide where within these ranges the critical loads should be set for the purposes of national mapping; these values are referred to in this document for the UK as the “mapping values”. Environmental factors, for example, precipitation, base cation availability, or management, may influence where within a range the critical load should be set for some habitats. The decision of whether (and how) to apply these modifying factors is also left up to individual countries. UK experts agreed not to apply modifying factors in national-scale applications, with the exception of a precipitation modifier for the bog habitat (Section 6.2.3.3), but noted the use of such modifiers for site-specific applications could be very important. Some site-specific applications may use a different part of the critical load range, depending on the site and policy context, compared to the values given in this report for national mapping. Assessment of site management practices is also not possible in a national context.

The mapping values for each habitat are based on the following general principles (Hall et al, 2011), also used in 2003 (Hall et al, 2003):

- For those critical loads based on “expert judgement” a mapping value was not recommended unless there was specific evidence of relevance to the UK and to a significant UK plant community.
- When there was no specific UK evidence to suggest otherwise, the middle of the range was recommended for UK mapping.
- UK mapping values, which were not in the middle of the range were recommended where field or experimental evidence from the UK specifically suggested that the mid-range value was not appropriate.
- Values other than the mid-range were in some cases recommended where knowledge of UK ecosystems suggests they were more or less sensitive than the median for this ecosystem across Europe.

Where no new evidence had become available for a particular habitat, the previous (2003) mapping value was retained.

In addition to the UK and European evidence presented at the Noordwijkerhout workshop in June 2010, UK evidence collated under contract to JNCC and partners (Emmett et al, 2011; Stevens et al, 2011) was used in reviewing the UK mapping values for four habitats: acid grassland, calcareous grassland, heathland and bogs. The JNCC Project had two objectives:

(i) Analysis of broad scale datasets to generate nitrogen response curves for species and summary response variables for habitat function indices, such as Ellenberg N.

(ii) Interpretation of (i) and other research (eg, summarised in RoTAP, 2012) in respect of the implications for "conservation policy commitments" and surveillance requirements.

6.2.2 Results of the Noordwijkerhout workshop and UK mapping values

Critical loads of nitrogen (Bobbink & Hettelingh, 2011) are assigned to habitats of the European Nature Information System (EUNIS, http://eunis.eea.europa.eu/) habitat classification. This is a hierarchical classification that can be translated into other habitat classification systems, using tools such as the National Biodiversity Network (NBN) habitats dictionary (http://habitats.nbn.org.uk/), or for the UK, using a spreadsheet created by JNCC (based on the NBN dictionary) and downloadable from their website (http://www.jncc.gov.uk/default.aspx?page=1425).

The Noordwijkerhout workshop report (Bobbink & Hettelingh, 2011) provides ranges of nitrogen critical loads for 47 different EUNIS habitat classes, including a number of different woodland types. This report focuses on (a) the habitats mapped nationally for critical loads research in the UK, and (b) additional habitat types of conservation interest in the UK, but not mapped nationally due to a lack of appropriate data. Table 6.1 presents the critical load ranges for the habitats currently mapped nationally and includes the agreed UK mapping values; the evidence and rationale for the mapping values is given in the sections that follow. Table 6.2 gives the critical load ranges for sensitive habitats not mapped nationally, but of high conservation value in the UK and for which critical loads are available; please refer to Part III of this report for further information on applying critical loads to features of designated sites. The critical loads given in Tables 6.1 and 6.2 refer to natural and semi-natural ecosystems; mass balance critical loads are calculated for UK managed (productive) coniferous woodland and managed (productive) broadleaved woodland (Section 6.3).

Table 6.1. Critical loads of nutrient nitrogen for habitats currently mapped nationally in the UK.

Habitat type	**EUNIS code**	**Critical load range (kg N ha^{-1} year^{-1})**	**UK Mapping Value (kg N ha^{-1} year^{-1})**	**Indication of exceedance**
Marine habitats				
Mid-upper saltmarshes	A2.53	20-30 (#)	25	Increase in dominance of graminoids
Pioneer & low saltmarshes	A2.54/55	20-30 (#)	25	Increase in late-successional species, increase in productivity
Coastal habitats				
Coastal stable dune grasslands	B1.4[a]	8-15 #	9 acid dunes 12 non-acid dunes	Increase tall graminoids, decrease in prostrate plants, increased N leaching, soil acidification, loss of typical lichen species.
Mire, bog & fen habitats				
Raised & blanket bogs	D1[b]	5-10 ##	8,9,10 depending on rainfall	Increase in vascular plants, altered growth & species composition of bryophytes, increased N in peat and peat water.
Grasslands & tall forb habitats				
Semi-dry calcareous grassland	E1.26	15-25 ##	15	Increase in tall grasses, decline in diversity, increased mineralization, N leaching; surface acidification.
Dry acid and neutral closed grassland	E1.7[c]	10-15 ##	10	Increase in graminoids, decline in typical species, decrease in total species richness.
Juncus meadows & *Nardus stricta* swards	E3.52	10-20 #	15	Increase in tall graminoids, decreased diversity, decrease in bryophytes.
Moss & lichen dominated mountain summits	E4.2	5-10 #	7	Effects upon bryophytes and/or lichens.

Habitat type	**EUNIS code**	**Critical load range (kg N ha^{-1} $year^{-1}$)**	**UK Mapping Value (kg N ha^{-1} $year^{-1}$)**	**Indication of exceedance**
Heathland habitats				
Northern wet heaths:				
- *Calluna* dominated (upland)	F4.11[b,d]	10-20 #	10	Decreased heather dominance, decline in lichens and mosses, increase N leaching.
- *Erica tetralix* dominated (lowland)	F4.11[b,d]	10-20 (#)	10	Transition from heather to grass dominance.
Dry heaths	F4.2[b,d]	10-20 ##	10	Transition from heather to grass dominance, decline in lichens, changes in plant biochemistry, increased sensitivity to abiotic stress.
Forest habitats				
Beech woodland	G1.6	10-20 (#)	15	Changes in ground vegetation & mycorrhiza, nutrient imbalance, changes in soil fauna.
Acidophilous oak-dominated woodland	G1.8	10-15 (#)	10	Decrease in mycorrhiza, loss of epiphytic lichens and bryophytes, changes in ground vegetation.
Scots Pine woodland	G3.4	5-15 #	12	Changes in ground vegetation & mycorrhiza, nutrient imbalances, increased N_2O & NO emissions.

Habitat type	**EUNIS code**	**Critical load range (kg N ha^{-1} $year^{-1}$)**	**UK Mapping Value (kg N ha^{-1} $year^{-1}$)**	**Indication of exceedance**
Forest habitats overall				
All forests: ground flora	G	See G1 & G3		Changed species composition, increase of nitrophilous species, increased susceptibility to parasites.
Broadleaved woodland	G1	10-20 ##	See G4 below	Changes in soil processes, nutrient imbalance, altered composition of mycorrhiza & ground vegetation.
Coniferous woodland	G3	5-15 ##	See G4 below	Changes in soil processes, nutrient imbalance, altered composition of mycorrhiza & ground vegetation.
Mixed woodland	G4		12	This is the mapping value used in 2003 for all unmanaged woodland (see G). This is within the ranges for G1 & G3 and is applied to all unmanaged woodland in the UK not included in G1.6, G1.8 or G3.4 (see section 6.2.3.11)

Reliability scores assigned at Noordijkerhout workshop in 2010 (Bobbink & Hettelingh, 2011):

##	reliable: when a number of published papers of various studies showed comparable results.
#	quite reliable: when the results of some studies were comparable.
(#)	expert judgement: when no empirical data were available for the ecosystem; critical load based upon expert judgement and knowledge of ecosystems which were likely to be comparable with this ecosystem.

Footnotes (Bobbink & Hettelingh, 2011):

[a] For acidic dunes, the 8-10 kg N ha^{-1} $year^{-1}$ range should be applied; for calcareous dunes the 10-15 kg N ha^{-1} $year^{-1}$ range should be applied.

[b] Apply the high end of the range to areas with high levels of precipitation and the low end of the range to areas with low levels of precipitation; apply the low end of the range to systems with a low water table, and the high end of the range to systems with a high water table. Note that water tables can be modified by management.

[c] Apply the lower end of the range to habitats with low base availability, and the higher end of the range to those with high base availability.

[d] Apply the high end of the range to areas where sod cutting has been practiced; apply the lower end of the range to areas with low-intensity management.

Table 6.2. Critical loads of nutrient nitrogen for habitats not mapped nationally, but of high conservation value (taken from Bobbink & Hettelingh, 2011); refer to Part III of this report for further information on applying critical loads to habitat features of sites of high conservation value.

Habitat type	**EUNIS code**	**Critical load range (kg N ha^{-1} year^{-1})**	**Indication of exceedance**
Coastal habitats			
Shifting coastal dunes	B1.3	10-20 (#)	Biomass increase, increased N leaching.
Coastal dune heaths	B1.5	10-20 (#)	Increase in plant production, increased N leaching, accelerated succession.
Moist to wet dune slacks	B1.8[c]	10-20 (#)	Increased biomass of tall graminoids.
Inland surface water habitats			
Softwater lakes (permanent oligotrophic waters)	C1.1[e]	3-10 ##	Changes in species composition of macrophyte communities, increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P.
Permanent dystrophic lakes, ponds, pools.	C1.4[f]	3-10 (#)	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P.
Mire, bog & fen habitats			
Valley mires, poor fens & transition mires	D2[g]	10-15 #	Increase in sedges & vascular plants, negative effects on bryophytes.
Rich fens	D4.1	15-30 (#)	Increase in tall graminoids, decrease in bryophytes.
Montane rich fens	D4.2	15-25 (#)	Increase in vascular plants, decrease in bryophytes.
Grasslands & tall forb habitats			
Inland dune pioneer grassland	E1.94[c]	8-15 (#)	Decrease in lichens, increase in biomass.
Inland dune siliceous grassland	E1.95[c]	8-15 (#)	Decrease in lichens, increase in biomass, increased succession.
Low & medium altitude hay meadows	E2.2	20-30 (#)	Increase in tall grasses, decrease in diversity.
Mountain hay meadows	E2.3	10-20 (#)	Increase in nitrophilous graminoids, changes in diversity.
Molinia caerulea meadows	E3.51	15-25 (#)	Increase in tall graminoids, decreased diversity, decreased bryophytes.
Alpine & subalpine acid grassland	E4.3	5-10 #	Changes in species composition, increase in plant production.
Alpine & subalpine calcareous grassland	E4.4	5-10 #	Changes in species composition, increase in plant production.

Habitat type	EUNIS code	Critical load range (kg N ha^{-1} $year^{-1}$)	Indication of exceedance
Heathland, scrub & tundra habitats Arctic, alpine & subalpine scrub habitats	F2	5-15 #	Decline in lichens, bryophytes & evergreen shrubs.
Forest habitats Meso- & eutrophic oak woodland	G1.A	15-20 (#)	Changes in ground vegetation.

Reliability scores assigned at Noordijkerhout workshop in 2010 (Bobbink & Hettelingh, 2011):

##	reliable: when a number of published papers of various studies showed comparable results.
#	quite reliable: when the results of some studies were comparable.
(#)	expert judgement: when no empirical data were available for the ecosystem; critical load based upon expert judgement and knowledge of ecosystems which were likely to be comparable with this ecosystem.

Footnotes (Bobbink & Hettelingh, 2011):

[a] For acidic dunes, the 8-10 kg N ha^{-1} $year^{-1}$ range should be applied; for calcareous dunes the 10-15 kg N ha^{-1} $year^{-1}$ range should be applied.

[b] Apply the high end of the range to areas with high levels of precipitation and the low end of the range to areas with low levels of precipitation; apply the low end of the range to systems with a low water table, and the high end of the range to systems with a high water table. Note that water tables can be modified by management.

[c] Apply the lower end of the range to habitats with low base availability, and the higher end of the range to those with high base availability.

[d] Apply the high end of the range to areas where sod cutting has been practiced; apply the lower end of the range to areas with low-intensity management.

[e] This critical load should only be applied to oligotrophic waters with low alkalinity with no significant agricultural or other human inputs. Apply the lower end of the range to boreal, sub-Arctic and alpine dystrophic lakes, and the higher end of the range to Atlantic soft waters. See Curtis & Simpson (2011) for discussion on this issue.

[f] This critical load should only be applied to waters with low alkalinity with no significant agricultural or other direct human inputs. Apply the lower end of the range to boreal, sub-Arctic and alpine dystrophic lakes.

[g] For EUNIS category D2.1 (valley mires) use the lower end of the range (#).

6.2.3 Evidence for setting UK mapping values

This section provides the rationale and evidence to support the UK mapping values for empirical nitrogen critical loads for each habitat mapped nationally. Field evidence of the impacts of nitrogen deposition provides important support for the significance of exceedance of nitrogen critical loads. However, the lack of such evidence does not invalidate the critical loads because:

- The study design may not be adequate to detect the effects of nitrogen deposition.
- The long-term nature of responses to deposited nitrogen means that adverse effects may occur at some point in the future.
- Local modifying factors may reduce the impacts of nitrogen deposition at a specific location.

Three types of field evidence exist:

(i) Evidence of changes in species composition, growth or vitality through time. Key issues in the interpretation of such evidence are the continuity in location of the plots, the measurement methods, and the role of other factors such as site management, in causing the observed change.

(ii) Evidence of spatial associations between nitrogen deposition and species composition and other responses. A key issue in the interpretation of such evidence will be the confounding effects of factors such as climate. The strongest evidence of cause-effect relationships from spatial associations will be close to point sources of pollution. For example, Pitcairn *et al.* (1998) reported a gradient study of ground flora composition in an acid woodland away from an intensive livestock unit and found a greater frequency of nitrophilic species above an estimated deposition rate of 15-20 kg ha^{-1} yr^{-1}.

(iii) Evidence that the nitrogen content of foliage has increased over time in areas with high levels of nitrogen deposition. There is evidence of increases in the nitrogen content of mosses and heather in many areas of the UK over the last few decades, which is consistent with a cumulative effect of nitrogen deposition (e.g. Pitcairn *et al.*, 1995).

6.2.3.1 Saltmarshes (EUNIS classes A2.53/4/5)

Critical loads for saltmarshes were not mapped for the UK prior to 2011, despite there being a critical load range, and mapping of the habitat possible. Part of the reason for this was that the critical load range was so high (30-40 kg N ha-1 year-1) that there would be very limited, if any, exceedance around the UK. Another reason was the lack of UK studies to corroborate continental research.

However, in the 2010 revisions at Noordwijkerhout (Bobbink & Hettelingh, 2011), it was proposed to reduce the critical load range to 20-30 kg N ha^{-1} $year^{-1}$, based on the following evidence. It is generally accepted that saltmarsh vegetation is primarily N limited (Mitsch and Gosselink 2000) and N limitation has been demonstrated in European saltmarshes at the island of Schiermonnikoog in the Netherlands (Kiehl et al. 1997) and in Norfolk, UK (Jefferies and Perkins 1977). A previous experiment in the Netherlands used high deposition rates (50 and 100 kg N ha^{-1} $year^{-1}$), but saw effects of increased biomass in the first growing season, repeated each year for the three years of the experiment, on the young saltmarsh (Van Wijnen & Bakker, 1999), and accelerated succession of the plant communities towards older stages. More recently, repeat vegetation survey analysis showed significant correlations with N deposition and vegetation change (de Vries, unpublished data) in a barrier island saltmarsh in the Netherlands. By extrapolation to these continental systems, it can be assumed that UK saltmarshes will behave in a similar manner, although field experiments are still needed in the UK at lower N deposition rates to verify this proposed range. Therefore it was proposed that UK saltmarshes are assigned a mapping value of the mid-point of the range: 25 kg N ha^{-1} year^{-1}.

6.2.3.2 Dune grassland (EUNIS class B1.4)

Critical loads for dune grasslands are based on the recommendations from the Noordwijkerhout meeting (Bobbink & Hettelingh, 2011) and the evidence below.

Research by Remke et al. (2009a) in Baltic dunes showed changes in *Cladonia portentosa* tissue N content, soil acidification, and greater mineralisation rates in acidic dune systems above 5 kg N ha^{-1} year^{-1} wet deposition. These changes were associated with greater cover of *Carex arenaria* in acidic dunes, but no clear changes in soil properties or species composition in calcareous dunes in the same deposition range (Remke et al. 2009b). As dry deposition in the Baltic is relatively low this probably relates to ~ 8 kg N ha^{-1} year^{-1} total N deposition. This was proposed to be the new lower end of the critical load range at Noordwijkerhout.

UK research by Plassmann et al. (2009) in a nitrogen manipulation experiment on fixed dune grassland at Newborough Warren in north Wales showed significantly increased N pools in moss in the low N treatment of 7.5 kg N ha^{-1} year^{-1} on top of a background of 10 – 12 kg N ha^{-1} year^{-1} . These changes occurred despite P co-limitation and heavy grazing, both previously considered as factors likely to minimise adverse effects of N. However, no effects on species composition were observed. More recent work in the UK on the same experiment has shown roughly linear increases in leaching fluxes with N additions above the background (Laurence Jones, CEH, unpublished data, Figure 6.1). Therefore adverse effects on N leaching and N storage have been observed somewhere within the deposition range 12 - 19 kg N ha^{-1} year^{-1}.

A recent survey in the UK and four other European countries on de-calcified dune grasslands showed adverse effects on plant species richness occurring somewhere between 5 and 10 kg N ha^{-1} year^{-1} (unpublished data, Figure 6.2). However, there is insufficient evidence to define precisely the minimum load at which damage might occur and hence for the UK situation we have applied values at the mid-point of the ranges for acidic and calcareous grassland.

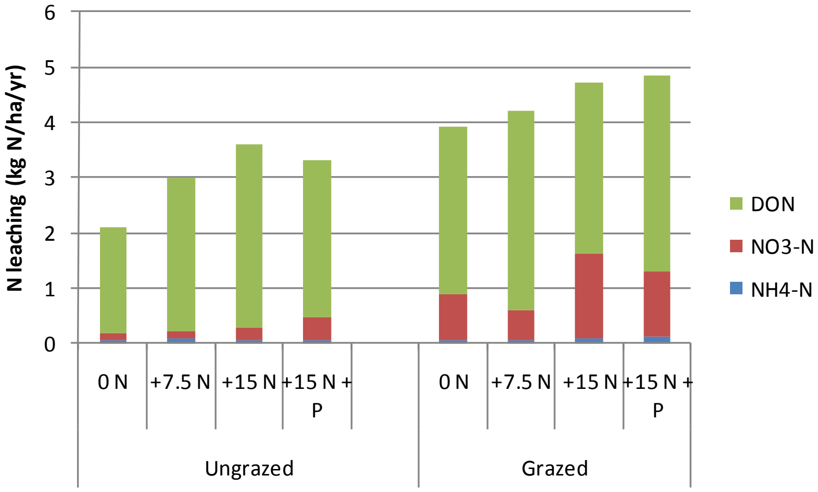


Figure 6.1. Increased leaching of inorganic and organic N with N additions (kg N ha^{-1} year^{-1}) above a background of 10-12 kg N ha^{-1} year^{-1} under two grazing regimes on a partially de-calcified calcareous fixed dune grassland at Newborough Warren, N. Wales. (DON = dissolved organic nitrogen)

Together this evidence supports the recommendations from Noordwijkerhout for the critical load range of 8 – 15 kg N ha^{-1} year^{-1}; and that acidic dunes are more sensitive than calcareous dunes and the range 8 – 10 kg N ha^{-1} year^{-1} be applied to acidic dunes, and 10 – 15 kg N ha^{-1} year^{-1} to calcareous dunes. Applying the mid-point of each range for national mapping purposes gives 9 kg N ha^{-1} year^{-1} for acidic and 12 kg N ha^{-1} year^{-1} for calcareous dune grassland; see Figure 2.4a for mapped areas of acid and calcareous dunes in the UK.

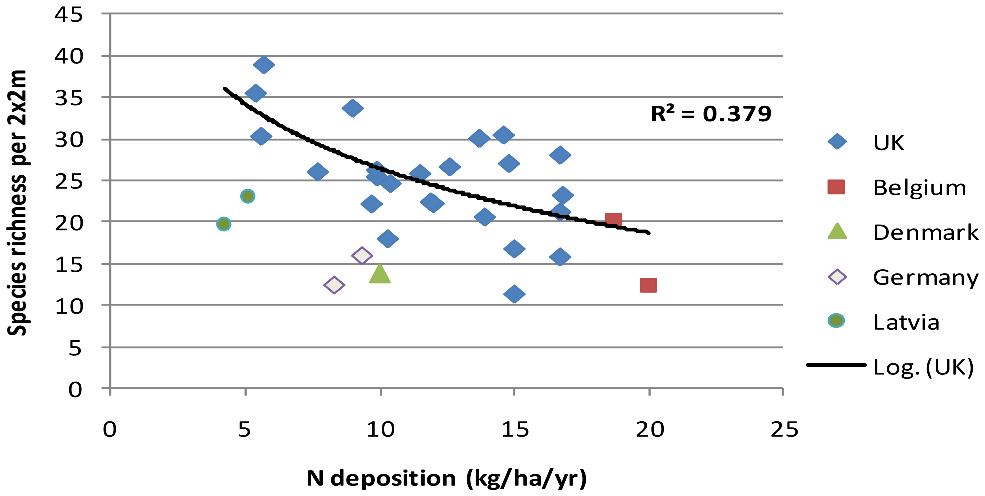


Figure 6.2. Species richness in de-calcified dune grasslands (NVC SD12), showing greatest species loss occurring somewhere between 5 and 10 kg N ha^{-1} year^{-1}.

6.2.3.3 Raised and blanket bogs (EUNIS class D1)

The critical load range for this habitat (5-10 kg N ha^{-1} year^{-1}) was not changed at the Noordwijkerhout workshop (Bobbink & Hettelingh, 2011). However, this workshop proposed that the critical load should be set at the high end of the range in areas of high precipitation and at the low end of the range in areas of low precipitation. This is based upon expert judgement from observations that responses to nitrogen are smaller in wetter areas where bogs receive higher effective precipitation than those in drier areas (eg, Sweden: Gunnarson 2002).

In 2003 the UK mapping value was set at the upper end of this range (ie, 10 kg N ha^{-1} year^{-1}) to take into account the higher precipitation in the UK (Hall et al, 2003) compared to other regions of Europe where much of the evidence for the critical load range originates. Concern was raised at the November 2010 workshop in the UK (Hall et al, 2011) that this value may not adequately protect bogs in drier regions of the UK, which could require a lower critical load. The examination of bog habitat data (Table 6.3) by Stevens et al (2011) and Emmett et al (2011) did not provide sufficient new UK evidence to recommend lowering the critical load for the bog below the current value of 10 kg N ha^{-1} year^{-1}.

Table 6.3 Extract of Table 2.5 from Emmett et al (2011) showing impacts of N deposition on bog species, ecosystem function and processes. (This extract only shows the results for N deposition covering the critical load range for this habitat).

N deposition range (kg N ha^{-1} year^{-1})	**Species distribution inhibited[#] by N deposition as determined by Stevens et al (2011)**	**Species distribution strongly inhibited[##] by N deposition as determined by Stevens et al (2011)**	**Evidence of change including impacts on ecosystem functions and soil processes**
0-5			No evidence of impact on indices of ecological function below 10 kg N ha^{-1} year^{-1} identified in new analyses (Stevens et al, 2011).
5-10	*Odontoschisma denudatum* *Anastrophyllum minutum*		

[#] species distribution inhibited = species occurrence fell by 20% relative to occurrence at the lowest N deposition levels

[##] species distribution strongly inhibited = species occurrence fell by 50% relative to occurrence at the lowest N deposition levels

However, examining long-term average rainfall data across the geographic range of UK bogs (as determined by the bog habitat distribution map; see Section 2.6.5, Figure 2.3d) showed their occurrence from the east of England with average rainfall of ~550 mm per annum to those in the north-west with average rainfall above 3000mm per annum. It was concluded that the impacts of nitrogen to drier areas could have been considered when setting the mapping value for bogs in 2003. Despite the lack of UK-specific evidence of higher sensitivity of drier bogs to nitrogen, it was agreed that a precipitation modifier should be used in setting the mapping value for bogs in the 2011 update, although scientific evidence from UK studies should still be sought to underpin this decision.

The CCE proposed a method for applying a modifying factor for rainfall at the national and/or European scale (Slootweg et al, 2008, modified and extended), that would take account of the variability in precipitation across the geographic range of each habitat across Europe (or the EMEP grid region). The CCE provided cumulative distribution functions (CDFs) of rainfall vs percentage habitat area across Europe; these provide 1-percentiles values that can be applied to national scale rainfall to determine the critical load:

$$\mathrm{CLempN} = \mathrm{CL}_{lo} + \mathrm{fmod} * (\mathrm{CL}_{up} - \mathrm{CL}_{lo})$$

Where:
CL_{lo} = critical load at the lower end of the range
CL_{up} = critical load at the upper end of the range
fmod = modifying factor from the CDF (ie, percentile value divided by 100 to give values 0-1)

For example, Figure 6.3a below shows the CDF from the CCE for rainfall vs the area of bog (D1) across Europe. Table 6.4 shows selected percentiles from the CDF for bog provided by the CCE, and corresponding fmod values. The full list of percentile values is used as a look-up table to generate fmod vaues for each 1km habitat square for the UK, based on UK rainfall data (annual average 1961-90).

Table 6.4: Look-up table of selected CDF percentiles and fmod values for bog

Rainfall (mm) for bog habitat across Europe	**Percentiles of percentage bog across Europe**	**fmod (percentile / 100)**
380.8	0	0
408.1	1	0.01
416.1	2	0.02
425.0	3	0.03
432.2	4	0.04
437.7	5	0.05
441.1	6	0.06
443.6	7	0.07
445.5	8	0.08
448.0	9	0.09
451.6	10	0.10

This means that all 1km bog habitat squares with UK rainfall <=380.8 mm could be assigned an fmod value of zero; squares with rainfall >380.8 and <=408.1 mm are assigned an fmod value of 0.01, and so on for all one hundred 1-percentiles. These fmod values can then be used to calculate the nitrogen critical loads using the equation above. However, this method was rejected at the UK experts workshop (November 2010: Hall et al, 2011) as it was considered that it implied greater knowledge of the spatial variability in habitat sensitivity to nitrogen than actually exists. This does not mean that such modifying factors should not be applied (they may be very important for site-specific applications), but alternative methods of applying them may be needed. In the case of the precipitation modifier for bog critical loads, the data collated were valuable for informing a simpler approach for applying rainfall thresholds for setting the mapping values for bogs. The data are summarised in Figure 6.3 as follows:

- Figure 6.3a: CDF of data on the percentage area of bog vs annual average rainfall for 1961-90 across the European region (data from CCE);
- Figure 6.3b: CDF of the percentage area of the UK bog habitat vs UK annual average rainfall 1961-90.
- Figure 6.3c: Histogram of the number of UK bog habitat squares by rainfall category; this shows that the majority of bog habitat squares receive an average of 1000-1500mm rainfall per annum.
- Figure 6.3d: Histogram of the number of UK bog habitat squares by nitrogen critical load category, based on spatial values calculated using the equation above; this shows that the

calculated critical load for the majority of UK bog habitat squares would be above 8.5 kg N ha^{-1} year^{-1}. The median critical load for all bog habitats squares using this approach is 9.5 kg N ha^{-1} year^{-1}.

Using the available data it was decided to calculate the rainfall ranges that would give specified median nitrogen critical load values as shown in Table 6.5, and use this information to apply these mapping values to areas of bog habitat across the UK (Figure 6.4).

Table 6.5: Ranges of UK average annual rainfall used to determine median nitrogen critical loads for bog habitats.

Annual average rainfall range (mm year^{-1})	**Median nitrogen critical load (kg N ha^{-1} year^{-1})**
548-758	8
759-1285	9
>1285	10

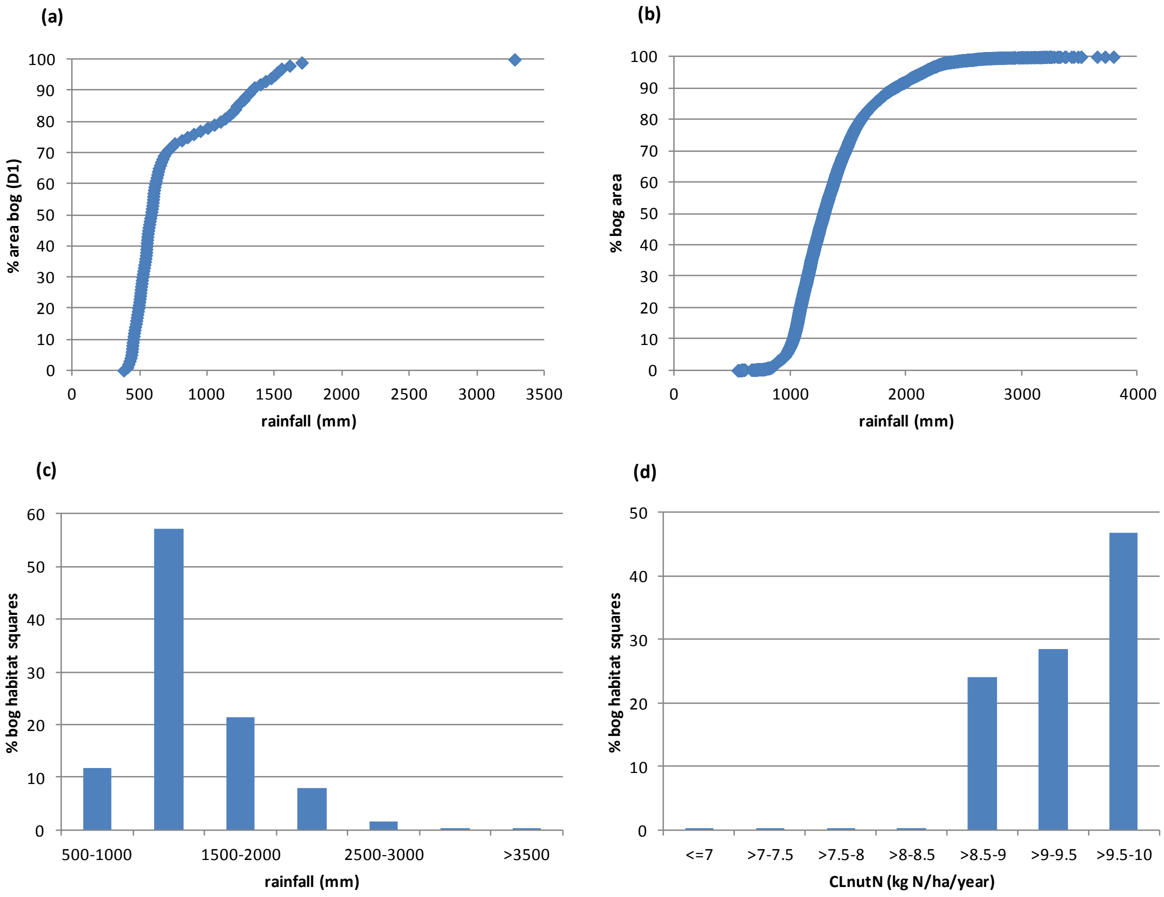


Figure 6.3: (a) CDF of percentage of bog (D1) vs annual average rainfall 1961-90 across the European region (data from CCE); (b) CDF of percentage area of UK bog habitat vs UK annual average rainfall 1961-90; (c) Histogram of the number of UK bog 1km squares vs annual average rainfall (1961-90) categories; (d) Histogram of the number of UK bog 1km squares vs nitrogen critical load calculated by using (a) to derive fmod values applied to the data in (b).

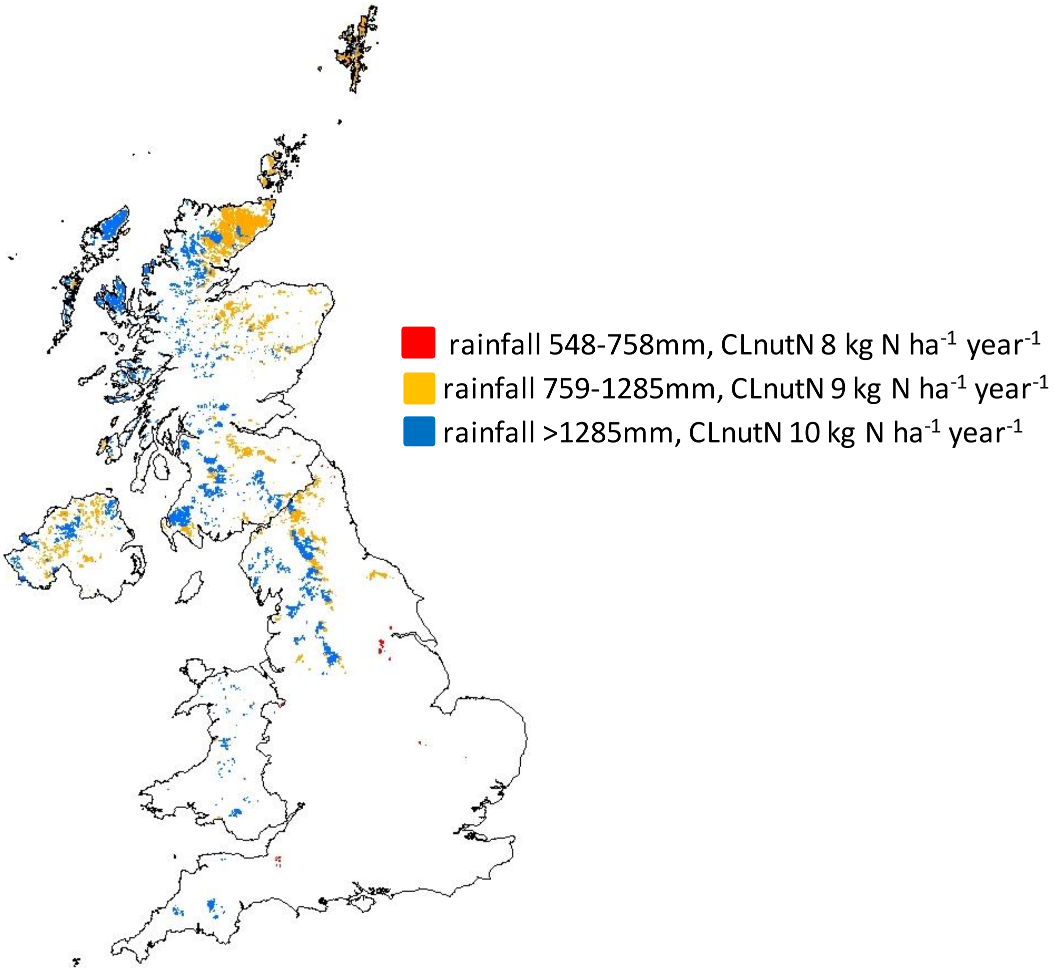


Figure 6.4: Three categories of rainfall and empirical nitrogen mapping values for the UK bog habitat.

6.2.3.4 Calcareous grassland (EUNIS class E1.26)

The critical load range (15-25 kg N ha^{-1} year^{-1}) for this habitat was not changed at Noordjikerhout (Bobbink & Hettelingh, 2011). However, new UK evidence was available in 2011 to enable the mapping value for this habitat to be reviewed. Van den Berg et al (2010) analysed permanent quadrat data from 106 plots (56 sites) on calcareous grassland in nature reserves across the UK that were surveyed between 1990 and 1993, and compared them with a re-survey of 48 of the plots (35 sites) carried out between 2006 and 2009. Their results provided evidence of a decrease in species diversity and evenness, a decline in the frequency of characteristic species, and a lower number of rare and scarce species, when nitrogen deposition exceeds the critical load range (15-25 kg N ha^{-1} year^{-1}).

An extract of Table 2.3 from Emmett et al (2011) is given in Table 6.6 below. This shows the species inhibited by N deposition and evidence of other impacts on ecosystem functions and soil processes. The extract only shows the results for N deposition covering the critical load range for this habitat.

Based on the evidence for impacts on species, on mean Ellenberg N scores and on canopy height (including impacts at N deposition levels below the minima of the critical load range), Emmett et al

(2011) proposed a new UK mapping value at the lower end of the range for calcareous grassland (15 kg N ha^{-1} year^{-1}) and this has been applied.

Table 6.6: Extract of Table 2.3 from Emmett et al (2011) showing impacts of N deposition on calcareous grassland species, ecosystem function and processes.

N deposition range (kg N ha^{-1} year^{-1})	**Species distribution inhibited[#] by N deposition as determined by Stevens et al (2011)**	**Species distribution strongly inhibited[##] by N deposition as determined by Stevens et al (2011)**	**Evidence of change including impacts on ecosystem functions and soil processes**
0-5			
5-10	*Spiranthes spiralis* *Bromopsis erecta* *Allium vineale* *Geranium columbinum* *Centaurea scabiosa* *Daucus carota*	*Spiranthes spiralis* *Bromopsis erecta* *Centaurea scabiosa*	Reduced presence of *Bromopsis erecta* below 2003 critical load mapping value (20 kg N ha^{-1} year^{-1}) identified in Stevens et al (2011) may have important implications as it is usually a dominant species when present. Changes in productivity and nutrient cycling may then follow.
10-15	Species above plus: *Carex spicata* *Ononis repens* *Carlina vulgaris*	Species above plus: *Daucus carota* *Ononis repens* *Carex spicata*	A 20% increase in Ellenberg N at 10-15 kg N ha^{-1} year^{-1} identified in new analyses (Stevens et al, 2011). Canopy height increases by 20% at 5-10 kg N ha^{-1} year^{-1} and 50% at 15-20 kg N ha^{-1} year^{-1} identified in new analysis of one dataset (Stevens et al, 2011).
15-20	Species above plus: *Echium vulgare* *Rosa micrantha* *Cynoglossum officinale* *Cladonia foliacea* *Melica nutans*	Species above plus: *Allium vineale* *Geranium columbinum*	
20-25	Species above plus: *Campanula glomerata*	Species above plus: *Carlina vulgaris* *Echium vulgare* *Rosa micrantha* *Cynoglossum officinale* *Cladonia foliacea* *Melica nutans*	Altered species composition previously reported both in Stevens et al (2011) and RoTAP (2011). Increase in competitive species and plant productivity as indicated by increased canopy height and specific leaf area by Stevens et al (2011). Increased Ellenberg N value with N deposition indicating shift to more nutrient-loving species in Stevens et al (2011). A 20% change at 10-15 kg N ha^{-1} year^{-1} and a 50% change at 35-40 kg N ha^{-1} year^{-1} in one dataset. Evidence of further increases in nitrate leaching, loss of forb species and overall plant species richness (RoTAP, 2011).

[#] species distribution inhibited = species occurrence fell by 20% relative to occurrence at the lowest N deposition levels

[##] species distribution strongly inhibited = species occurrence fell by 50% relative to occurrence at the lowest N deposition levels

6.2.3.5 Wet and dry acid grassland (EUNIS classes E3.52 & E1.7)

The critical load range (10-20 kg N ha^{-1} year^{-1}) for wet acid grassland (E3.52) was not changed at Noordwijkerhout (Bobbink & Hettelingh), but the range for dry acid grassland (E1.7) was reduced from 10-20 kg N ha^{-1} year^{-1} to 10 to 15 kg N ha^{-1} year^{-1}. The UK mapping value in 2003 was 15 kg N ha^{-1} year^{-1} for both wet and dry acid grassland.

Base cation availability may affect the sensitivity of dry acid grassland to nitrogen and the Noordwijkerhout workshop (Bobbink & Hettelingh, 2011) recommended the use of the lower end of the range in areas of low base availability and the higher end of the range in areas of high base availability. However, it was agreed at the UK experts meeting in November 2010 (Hall et al, 2011) not to apply a base cation availability modifier (using a CDF of base cation availability vs habitat area) in national scale applications, on the basis that: (a) it implies a greater knowledge of the habitat response spatially than exists; (b) the guidance only applies to dry acid grassland.

New evidence for lowering the UK mapping value for dry acid grassland is provided by Hicks & Ashmore (2010) who used UK field survey data to examine (a) the relationship between nitrogen deposition and species richness ratio, and (b) the relationship between critical load exceedance and species richness ratio, using critical loads at the minimum (10kg N ha^{-1} year^{-1}) and former maximum (20kg N ha^{-1} year^{-1}) of the range for E1.7. Regression equations showed a worse fit to the exceedance data based on the maximum critical load, and a reduction in the number of species between the minimum and maximum of the critical load range. The regression (Figure 6.5) showed there is a significant effect on the species richness ratio when the minimum critical load (10kg N ha^{-1} year^{-1}) is exceeded by 20% (ie 2kg N ha^{-1} year^{-1}). Hicks & Ashmore (2010) concluded that the threshold for site integrity should therefore be based on the minimum of the critical load range (10 kg N ha^{-1} year^{-1}).

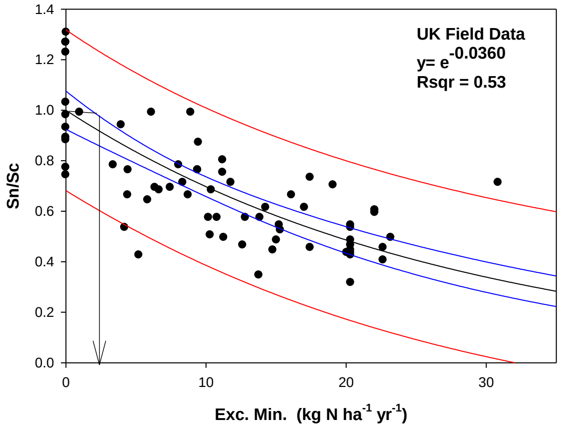


Figure 6.5: (from Hicks & Ashmore 2010): Relationship between the species richness ratio (Sn/Sc) and N exceedance calculated using modelled N deposition values minus the minimum critical load (10kg N ha^{-1} year^{-1}) for unfertilized plots of dry acid grassland at 68 sites across the UK. Sn/Sc = species richness ratio where Sn = number of species in a treatment and Sc = number of species in the control.

Emmett et al (2011) indicate the acid grassland species likely to be inhibited at different N deposition levels and the impacts on ecosystem function and soil processes. The evidence is summarised in the extract of Table 2.2 of Emmett et al (2011) in Table 6.7 below, which presents the information for N deposition levels encompassing the critical load range. Based on the evidence for the impacts on species and on changes in Ellenberg N (including changes at N deposition levels below the minima of the critical load range), Emmett et al (2011) support setting the mapping value for **dry** acid grassland (E1.7) to the lower end of the range at 10 kg N ha^{-1} year^{-1}. However, it was felt there was insufficient evidence to support a change to the mapping value for wet acid grassland (E3.5) and that the previous mapping value of 15 kg N ha^{-1} year^{-1} should be retained for this habitat.

Table 6.7: Extract of Table 2.2 from Emmett et al (2011) showing impacts of N deposition on acid grassland species, ecosystem function and processes.

N deposition range (kg N ha^{-1} year^{-1})	**Species distribution inhibited[#] by N deposition as determined by Stevens et al (2011)**	**Species distribution strongly inhibited[##] by N deposition as determined by Stevens et al (2011)**	**Evidence of change including impacts on ecosystem functions and soil processes**
0-5			
5-10	*Cerastium arvense* *Vicia lathyroides* *Trifolium arvense* *Peltigera didactyla* *Cetraria aculeate* *Cerastium semidecandrum*		20% increase in Ellenberg N at 5-10 kg N ha^{-1} year^{-1} and 50% increase at 10-15 kg N ha^{-1} year^{-1} in analysis of one dataset suggests a major change in N availability and nutrient cycling rates (Stevens et al, 2011). Plant canopy height found to be positively related to N deposition in one dataset at 5-10 kg N ha^{-1} year^{-1} and negatively in another in new analyses. Suggests sensitivity of habitat to change with direction of change dependent on site factors (Stevens et al, 2011). Decline of *Cerastium arvense* identified in new analyses (Stevens et al, 2011) unlikely to have major functional implications but together with evidence from Stevens et al (2004) indicates species change starts to occur below 2003 mapping value in dry acidic grasslands (15 kg N ha^{-1} year^{-1}).
10-15	Species above plus: *Viola canina* *Scapania gracilis* *Racomitrium lanuginosum*	*Cerastium arvense* *Vicia lathyroides* *Trifolium arvense* *Cetraria aculeate* *Cerastium semidecandrum*	
15-20	Species above plus: *Frullania tamarisci*	Species above plus: *Peltigera didactyla* *Viola canina* *Scapania gracilis*	Reduced retention of deposited N in soils with increased nitrate leaching to freshwaters (RoTAP, 2011). Altered species composition both in Stevens et al (2011) and RoTAP (2011). Risk of increased fungal pathogen damage to sensitive species such as *Vaccinium myrtillus* (Strengbom et al, 2002). Increased Ellenberg N value with N deposition indicating shift to more nutrient-loving species in Stevens et al (2011) but no change in Ellenberg R (acidity) value. Evidence that species are differentially sensitive to forms of N deposited (UKREATE, 2010).

[#] species distribution inhibited = species occurrence fell by 20% relative to occurrence at the lowest N deposition levels

[##] species distribution strongly inhibited = species occurrence fell by 50% relative to occurrence at the lowest N deposition levels

6.2.3.6 Montane: moss & lichen dominated mountain summits (EUNIS class 4.2)

The critical load range agreed at Noordwijkerhout (Bobbink & Hettelingh, 2011) for this habitat remained unchanged at 5-10 kg N ha^{-1} year^{-1}. Since 2003 the UK mapping value has been 7 kg N ha^{-1} year^{-1}. Montane habitat experts in the UK have studied the available evidence and concluded that although chemical changes may occur below 7 kg N ha^{-1} year^{-1}, habitat degradation is not seen below this threshold, and therefore the mapping value should also remain unchanged. This decision is supported by evidence from Armitage (2010) that was presented and discussed at the Noordwijkerhout workshop.

The study by Armitage (2010) surveyed *Racomitrium lanuginosum* – *Carex bigelowii* ("alpine moss heath") on the mountain summits at 38 sites in the UK, plus additional sites in Norway, the Faroes and Iceland. Moss tissue N increases with N deposition (CBED 2004-06: CEH Edinburgh) (Figure 6.6), as does shoot growth. Despite the increased shoot growth however, the depth of the moss layer decreases with increased N deposition, and this is due to increased shoot turnover (ie higher ratio of decomposition at the bottom of the shoot to growth at the top). Sites with a high rate of moss shoot turnover have lower moss cover. There is no clear threshold of effect, but shoot turnover begins to increase at tissue N of c. 0.5 %, which corresponds to total N deposition of 7 kg ha^{-1} year^{-1}, supporting the use of 7 kg N ha^{-1} year^{-1} as the mapping value for this habitat in the UK. It should be noted that the interpretation of these data is not completely straightforward as the N gradient corresponds with a climatic gradient. Nevertheless N deposition accounts for more of the patterns than the climate variables.

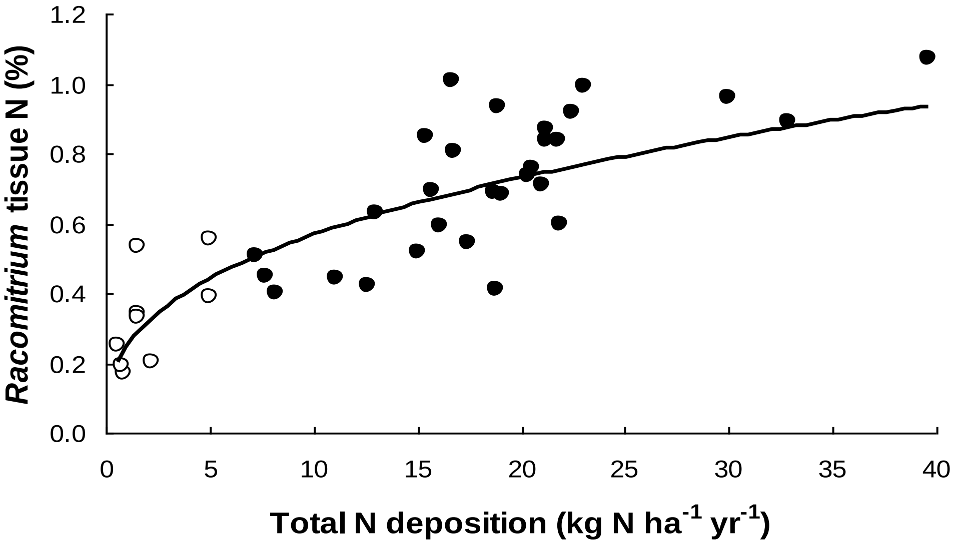


Figure 6.6: Relationship between mean *R. lanuginosum* tissue N content (%) at 38 sites (filled circles – UK, open circles - Europe) and total N deposition, R^2 = 73%; $P < 0.001$; $\log y = 0.364(\log x) - 0.61$. Each point is the mean of 8 samples.

6.2.3.7 Dwarf shrub heath (EUNIS classes F4.11 & F4.2)

The Noordwijkerhout workshop (Bobbink & Hettelingh, 2011) recommended applying the high end of the critical load ranges for these heathland classes in areas with high precipitation, or for systems with a high water table, and the low end of the range in areas of low precipitation or for systems with a low water table. They also recommend using the low end of the range where management intensity is low. The application of these modifying factors was discussed between UK experts in November 2010 (Hall et al, 2011) and it was agreed not to apply them in national-scale applications, but noted it could be important to apply these for site-specific applications where local knowledge on management practice, water table height etc is available.

Upland and lowland wet heath (F4.11)

In 2003 the critical load range for lowland wet heath was 10-25 kg N ha^{-1} year^{-1}; at the Noordwijkerhout workshop (Bobbink & Hettelingh, 2011) the upper end of this range was reduced to 20 kg N ha^{-1} year^{-1}. This results in the same overall range (10-20 kg N ha^{-1} year^{-1}) being applicable to both upland and lowland wet heaths. In 2003 the UK mapping value for both was set at 15 kg N ha^{-1} year^{-1} (Hall et al, 2003), but this was reviewed and updated in 2011 (see below).

Dry heaths (F4.2)

The critical load range agreed at Noordwijkerhout (Bobbink & Hettelingh, 2011) for this habitat remained unchanged at 10-20 kg N ha^{-1} year^{-1}. In 2003 the UK mapping value for this habitat was set to 12 kg N ha^{-1} year^{-1} (Hall et al, 2003), but this was reviewed and updated in 2011 (see below).

New mapping value for wet heaths (F4.11) and dry heaths (F4.2)

No new evidence was available at the November 2010 UK experts meeting (Hall et al, 2011) to suggest altering the UK mapping values for wet or dry heaths. However, Stevens et al (2011) and Emmett et al (2011) provided new evidence of impacts of N deposition to heathlands in the UK. Table 6.8 below presents an extract of Table 2.4 of Emmett et al (2011) showing the impacts of N deposition on heathland species and ecosystem function at N deposition levels encompassing the critical load range. Note that the evidence does not distinguish between wet and dry heathland habitats. Based on the evidence of impacts on species and the increase in Ellenberg N (including impacts at N deposition values below the minima of the critical load range), Emmett et al (2011) support the use of a new mapping value at the lower end of the range (10 kg N ha^{-1} year^{-1}) for both wet (F4.11) and dry (F4.2) heathland.

Table 6.8: Extract of Table 2.4 from Emmett et al (2011) showing impacts of N deposition on heathland species, ecosystem function and processes.

N deposition range (kg N ha^{-1} year^{-1})	**Species distribution inhibited[#] by N deposition as determined by Stevens et al (2011)**	**Species distribution strongly inhibited[##] by N deposition as determined by Stevens et al (2011)**	**Evidence of change including impacts on ecosystem functions and soil processes**
0-5			
5-10	*Fossombronia wondraczekii* *Cladoia cervicornis verticillata* *Cladonia strepsilis* *Arctostaphylos uva-ursi* *Anastrophyllum minutum* *Lepidozia pearsonii* *Cetraria aculeate* *Cetraria uncialis biuncialis* *Lichenomphalia umbellifera* *Microlejeunea ulicina* *Cladonia cervicornis cervicornis* *Cladonia subulata* *Leucobryum glaucum*	*Fossombronia wondraczekii* *Cladonia strepsilis* *Arctostaphylos uva-ursi*	A 20% increase in Ellenberg N at 5-10 kg N ha^{-1} year^{-1} relative to lowest levels of N deposition according to one dataset (BSBI LCS) (Stevens et al, 2011).
10-15	Species above plus: *Cladonia portentosa* *Vaccinium vitis-idaea*	Species above plus: *Cladonia cervicornis verticillata* *Anastrophyllum minutum* *Lepidozia pearsonii* *Cetraria aculeate* *Cetraria muricata* *Cladonia uncialis biuncialis* *Microlejeunea ulicina*	
15-20	Species above plus: *Viola canina* *Dibaeis baeomyces* *Cladonia glauca*	Species above plus: *Lichenomphalia umbellifera* *Cladonia cervicornis cervicornis* *Cladonia subulata* *Leucobryum glaucum* *Cladonia portentosa* *Vaccinium vitis-idaea* *Viola canina*	Altered species composition both in Stevens et al (2011) and RoTAP (2011). A 20% increase in Ellenberg N value at 5-20 kg N ha^{-1} year^{-1} relative to lowest levels of N deposition for both upland and lowland heathland indicating shift to more nutrient-loving species in Stevens et al (2011). A 20% reduction in Ellenberg R value at 15-20 kg N ha^{-1} year^{-1} relative to lowest levels of N deposition (Stevens et al, 2011). Conflicting evidence of change in canopy height with both positive and negative relationships described. Suggests sensitivity of habitat to change with direction of change dependent on site factors (Stevens et al, 2011).

[#] species distribution inhibited = species occurrence fell by 20% relative to occurrence at the lowest N deposition levels

[##] species distribution strongly inhibited = species occurrence fell by 50% relative to occurrence at the lowest N deposition levels

6.2.3.8 Beech (*Fagus*) woodland (EUNIS class G1.6)

The critical load range set for this habitat at Noordwijkerhout (Bobbink & Hettelingh, 2011) was 10-20 kg N ha^{-1} $year^{-1}$. Within that range a UK mapping value of 15 kg N ha^{-1} $year^{-1}$ has been agreed based on evidence available from: (a) a long term nitrogen gradient experiment on a small scale (Thetford gradient study) and (b) a regional scale comparison from high (Thetford: 15-35 kg N ha^{-1} $year^{-1}$) and low (Alice Holt: 8-12 kg N ha^{-1} $year^{-1}$) N deposition beech forests (Vanguelova and Pitman, 2009). At Thetford impacts have been observed (at N deposition >15 kg N ha^{-1} $year^{-1}$) on soil NO_3 availability, foliar N and K, beech flowering patterns and seed and litterfall production (e.g. double leaf biomass at high N) (Vanguelova and Pitman, 2009). Increased soil nitrification rates and reduced soil microbial diversity seen at Thetford were not observed at Alice Holt (Emma Thorpe, PhD study, http://www.forestry.gov.uk/fr/INFD-8DPG55).

6.2.3.9 Acidophilous oak (*Quercus*) dominated woodland (EUNIS class G1.8)

The critical load range set for this habitat at Noordwijkerhout (Bobbink & Hettelingh, 2011) was 10-15 kg N ha^{-1} $year^{-1}$ and within that range the agreed UK mapping value is 10 kg N ha^{-1} $year^{-1}$. This mapping value is supported by evidence from a typical acidophilous (Atlantic) Oak (*Quercus petraea*) woodland at Grizedale, part of the Level II Forest Intensive Monitoring network. The range of N deposition at this site for the last 15 years has been between 9 and 20 kg N ha^{-1} $year^{-1}$. Increasing N leaching, in the form of NO_3 and DON, has been measured at this site for the last 15 years, in addition to soil acidification (Vanguelova et al, 2010). Oak crown condition has also deteriorated with time (Vanguelova et al., 2007) with increased susceptibility to insect attacks. An insect infestation during 2004 to 2005 added an extra 4-5 kg N ha^{-1} y^{-1} to the N deposition at Grizedale (Pitman et al., 2010). Soil NO_3-N leaching significantly increased and ground vegetation composition response was subsequently observed at the site together with a significant increase in Ellenberg scores at N deposition exceeding 10 kg ha^{-1} $year^{-1}$ (Figure 6.7). The lag effect between N input and plant response is between one to two years which is illustrated in Figure 6.7. The mapping value for this habitat is the same as the mapping value used for Atlantic oak woodlands in 2003 to protect epiphytic lichens (Hall et al, 2003).

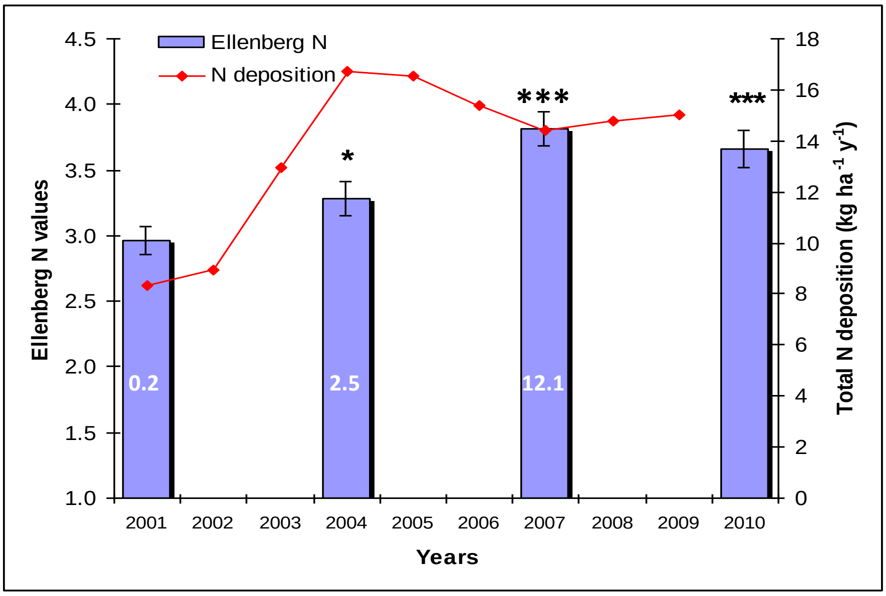


Figure 6.7: Change in Ellenberg N scores derived from repeated ground flora surveys at Grizedale acidophilous *Quercus* dominated forest with measured temporal total N deposition to the site and NO_3 leaching fluxes from deep soil from 2001 to 2010. Blue bars are mean Ellenberg values from 10 replicates, vertical bars are *se* of the mean and stars indicate significant difference of Ellenberg score away from 2001 baseline at $p<0.05$ (*) and $p<0.001$ (***). Red line is the total annual N deposition and white values within bars are the deep soil NO_3 leaching flux in kg ha^{-1} year^{-1}.

6.2.3.10 Scots pine (*Pinus sylvestris*) woodland (EUNIS class G3.4)

The critical load range set for this habitat at Noordwijkerhout (Bobbink & Hettelingh, 2011) was 5-15 kg N ha^{-1} year^{-1} and within that range the agreed UK mapping value is 12 kg N ha^{-1} year^{-1}. This mapping value is based on evidence from large scale UK Level I forest monitoring which suggests that Scots pine needle N concentrations go above the critical threshold of 1.7% (Taylor, 1991, Gundersen, 1999) when N deposition is higher than 12 kg ha^{-1} year^{-1} (Figure 6.8; Kennedy, 2003). This is further supported by evidence of N recovery at the Level II Scots pine Intensive Forest Monitoring plot at Thetford, where N deposition values of 17-19 kg N ha^{-1} year^{-1} in 1995 have fallen to an average of 10-12 kg N ha^{-1} year^{-1} in recent years. This decrease in N deposition has been accompanied by a significant decrease in soil NO_3 leaching in winter drainage (Vanguelova et al, 2010) and a temporal response of ground flora to N deposition and soil NO_3 changes have been observed using Ellenberg scores.

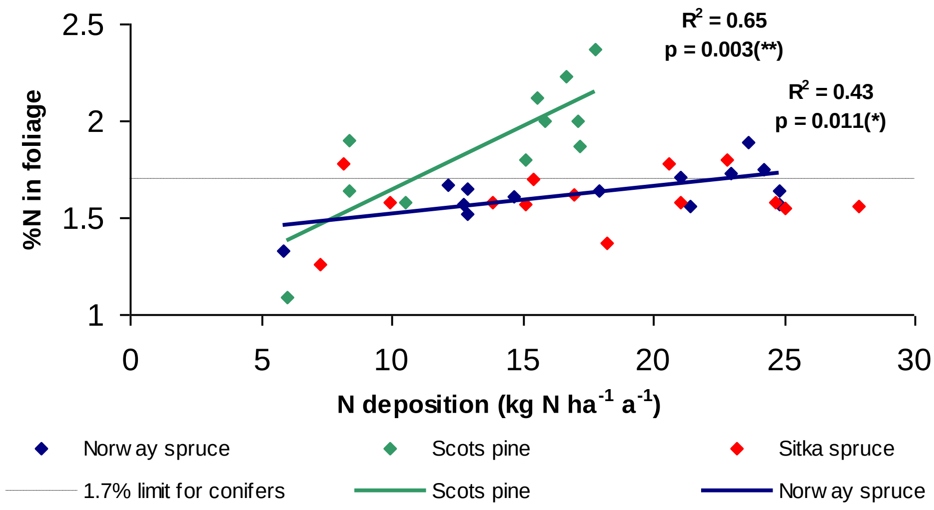


Figure 6.8: Relationship between nitrogen deposition and foliar nitrogen in three conifer species in Great Britain (Kennedy, 2003).

6.2.3.11 Remaining unmanaged coniferous and broadleaved woodland (EUNIS class G4)

The Noordwijkerhout workshop (Bobbink & Hettelingh, 2011) gave ranges of critical loads for broadleaved woodland (G1: 10-20 kg N ha^{-1} year^{-1}) and for coniferous woodland (G3: 5-15 kg N ha^{-1} year^{-1}) for application at broad geographical scales. The data the UK hold on the distribution of managed and unmanaged woodland does not allow for the differentiation between unmanaged conifer and unmanaged broadleaf woodland. In 2003 all UK unmanaged coniferous and broadleaved woodland (except Atlantic oak woodland) was assigned a mapping value of 12 kg N ha^{-1} year^{-1} to protect the woodland ground flora, based on the range for all forests of 10-15 kg N ha^{-1} year^{-1} (Achermann & Bobbink, 2003). Without additional evidence available it was agreed that the mapping value for all remaining areas of unmanaged woodland (see Figure 2.2b), that are not included within the distributions for the above three categories (G1.6, G1.8, G3.4), should be kept at 12 kg N ha^{-1} year^{-1}; this value falls within the new ranges for G1 and G3.

6.3 Steady state mass balance critical loads of nutrient nitrogen for managed woodlands

In the steady state mass balance approach the long-term inputs and outputs of nitrogen from the system are calculated, with the critical load being exceeded when any excess nitrogen input is calculated to lead to exceedance of a critical rate of nitrogen leaching. The steady state mass balance for nutrient nitrogen is calculated as:

$$CLnutN = N_u + N_i + N_{de} + N_{le(acc)}$$

where:

N_u = nitrogen uptake (removal by harvesting of trees)
N_i = nitrogen immobilisation
N_{de} = denitrification
$N_{le(acc)}$ = acceptable level of nitrogen leaching

This equation is applied in the UK to managed (productive) woodlands to ensure the long-term ecosystem function (eg, soils, soil biological resources, trees and linked aquatic ecosystems) is protected. The data for N_u, N_i and N_{de} are the same as those used in the derivation of CLminN for managed woodlands and are described in Section 4.3. The value for the acceptable leaching of nitrogen depends on the “harmful effects” to be avoided. In general it is not the leaching flux itself that is harmful, but the concentration of N in the leaching flux (CLRTAP, 2013), hence $N_{le(acc)}$ can be calculated as:

$N_{le(acc)} = Q * [N]_{acc}$
Where:
Q = precipitation surplus (m^3 ha^{-1} $year^{-1}$)
$[N]_{acc}$ = acceptable N concentration (eq m^{-3})
(dividing the result by 1000 will give the $N_{le(acc)}$ in keq ha^{-1} $year^{-1}$)

However, in the UK values for $[N]_{acc}$ have not been derived for woodlands (or other habitat types). Instead fixed values for $N_{le(acc)}$ have been defined for application to managed conifers and managed broadleaved woodland: a range of 1-5 kg N ha^{-1} $year^{-1}$ was considered for managed conifers, with a single value of 4 kg N ha^{-1} $year^{-1}$ selected based on Emmett et al (1993) and Emmett & Reynolds (1996) and applied to all 1km squares containing this habitat. For managed broadleaved woodland a $N_{le(acc)}$ range of 1-3 kg N ha^{-1} $year^{-1}$ was considered and the upper value of 3 kg N ha^{-1} $year^{-1}$ used based on Williams et al (2000), again applied to all 1km squares for this habitat.

PART 2: CRITICAL LOAD EXCEEDANCES

7. Introduction to critical load exceedances

The exceedance is the amount of deposition (of acidity or nitrogen) above the critical load. By overlaying maps of acid or nitrogen deposition on critical load maps, "exceedance" maps can be generated. These maps highlight the areas receiving excess deposition, and the amount of deposition above the critical load. In addition, simple statistics are generated to quantify the area of sensitive habitats associated with critical load exceedances. These exceedance maps and statistics are used by Defra and other bodies to guide policy development on the control of air pollutants. The statistics are also used by Defra, the Devolved Administrations and JNCC in environmental statistics publications such as a UK biodiversity indicator (eg, http://jncc.defra.gov.uk/page-4229). Reducing the area and amount of critical load exceedance continues to be a driver of Government policy on reducing emissions of acidic and nitrogen-containing air pollutants (sulphur dioxide, nitrogen oxides and ammonia).

Exceedances are calculated separately for each habitat type using habitat-specific deposition values: mean deposition to moorland (ie, low-growing vegetation) is applied to the coastal, grassland, heathland and montane habitats; mean deposition to forests is applied to all woodland habitats. Critical loads for terrestrial habitats are mapped at 1km resolution and national deposition data are currently available on a 5km grid. Exceedances for these habitats are calculated at 1km resolution by assuming that deposition values remain constant across each 5km grid square. Exceedances for freshwaters use catchment-weighted deposition values (see Section 10.2).

It should be noted that reports presenting European-scale exceedance maps (eg, CCE Status Reports, CLRTAP documents) are usually based on the European EMEP deposition data which until recently has been mapped on a 50km grid. Differences in the spatial resolution and patterns of deposition from national (5km) data sets and EMEP lead to substantial differences in estimates of the area where critical loads are exceeded, with EMEP deposition suggesting smaller exceedances than those calculated using the higher resolution data. Such differences are likely to occur with models/methods designed for different spatial scales and application. This report focuses on exceedances calculated using the national 5km deposition data (Section 9).

The calculation of exceedances is carried out via a suite of Python scripts developed and written to automate the spatial processes involved (within a GIS framework) and generate summary statistics (Section 11) and exceedance maps (Section 12).

8. Exceedance and damage

The critical loads data on which exceedance calculations are based are derived from empirical or steady-state mass balance methods, which are used to define critical loads for the *long-term* (see Section 1). Therefore, exceedance is an indication of the *potential* for harmful effects to systems at steady-state, or in the long-term, and a habitat that is currently exceeding its critical load is not necessarily already showing the signs of damage. In addition, reducing deposition to below the critical load does not mean the ecosystems immediately recover. There are time lags before chemical recovery takes place, and further delays before biological recovery. The timescales, for both chemical and biological recovery, could be very long, particularly for the most sensitive ecosystems; dynamic models can be applied to estimate the timescales involved but these are not discussed in this report.

9. Concentration Based Estimated Deposition (CBED)

The deposition data used in the UK calculations of acidity critical loads (Sections 3.4 and 4.2) and exceedances of acidity and nitrogen critical loads are based on the CBED methodology. CBED generates 5km resolution maps of wet and dry deposition of sulphur, oxidised and reduced nitrogen, and base cations using measurements of air concentrations of gases and aerosols as well as concentrations in precipitation from the UK Eutrophying and Acidifying Pollutants (UKEAP) network.

The site-based measurements are interpolated to generate maps of concentrations for the UK. The ion concentrations in precipitation are combined with the UK Met Office annual precipitation map to generate wet deposition. Gas and particulate concentration maps are combined with spatially distributed estimates of vegetation-specific deposition velocities (Smith *et al.*, 2000) to generate dry deposition. The land cover types include forest, moorland, grassland (agricultural/improved), arable, urban and water. The vegetation specific dry deposition rates are combined, depending on the relative proportion of different land cover, to generate values for grid square average dry deposition. Dry deposition includes deposition of gases and vapours (SO_2, HNO_3, NO_2 and NH_3) and particles (sulphate, nitrate, ammonium, calcium and magnesium) to vegetation. This process enables separate values to be derived for deposition to different land cover types; for critical loads exceedances, deposition values for moorland are applied to all non-woodland habitats, and deposition values for forest applied to all woodland habitats.

The map of SO_2 concentration is calculated from rural measurements of SO_2 and uses an urban enhancement factor. For oxidised nitrogen dry deposition, nitric acid concentrations are calculated by interpolation of measurements from 30 sites. NO_2 concentrations are taken for the Pollution Concentration Mapping (PCM) model (ie, Stedman et al., 2007). This includes a combination of interpolation of measurements from rural sites combined with modelling concentrations from point sources and line sources. Ammonia concentrations are taken from the FRAME atmospheric chemical transport model (Hallsworth et al., 2010) with concentrations corrected for the modelled bias when compared with measurements.

Wet deposition includes deposition from precipitation as well as direct deposition of cloud droplets to vegetation (known as 'occult' deposition) and is mapped for anthropogenic and total calcium, chloride, magnesium, and sulphate, and for (total) acidity (hydrogen ion), sodium, ammonium and nitrate. The separation of anthropogenic (non-seasalt) and total components is calculated using ion ratios relative to sodium in sea water.

Mapping wet deposition includes an orographic enhancement factor for the concentration of precipitation in upland regions due to the seeder-feeder effect. The enhancement factor is taken from observations of the increase in ion concentrations with altitude observed at Great Dun Fell in the Northern Pennines (Fowler et al., 1988) and subsequently confirmed by measurements at Holme Moss in the southern Pennines (Dore et al., 2001 ; Beswick et al., 2003).

Significant inter-annual variations in deposition can occur due to the natural variability in annual precipitation (which influences wet deposition) as well as the general circulation of air (ie, leading to increased or decreased import of polluted air from the European continent). The CBED deposition data used to calculate the exceedance of critical loads is therefore averaged over a three year period. This has been demonstrated to be a suitable time period to smooth out inter-annual variations in deposition.

The CBED maps of total nitrogen (oxidised + reduced) and total acid (total nitrogen + non-marine sulphur) deposition, to moorland and to woodland, for 2011-13 are shown in Figure 9.1. These clearly show the enhanced deposition to woodland due to the higher dry deposition velocity for this habitat type.

Future deposition scenarios (or hindcast scenarios) can be generated using a long-range atmospheric dispersion model, such as the UK FRAME model (Fournier et al, 2004; Dore et al, 2007; Vieno et al, 2010) calibrated to the current CBED data.

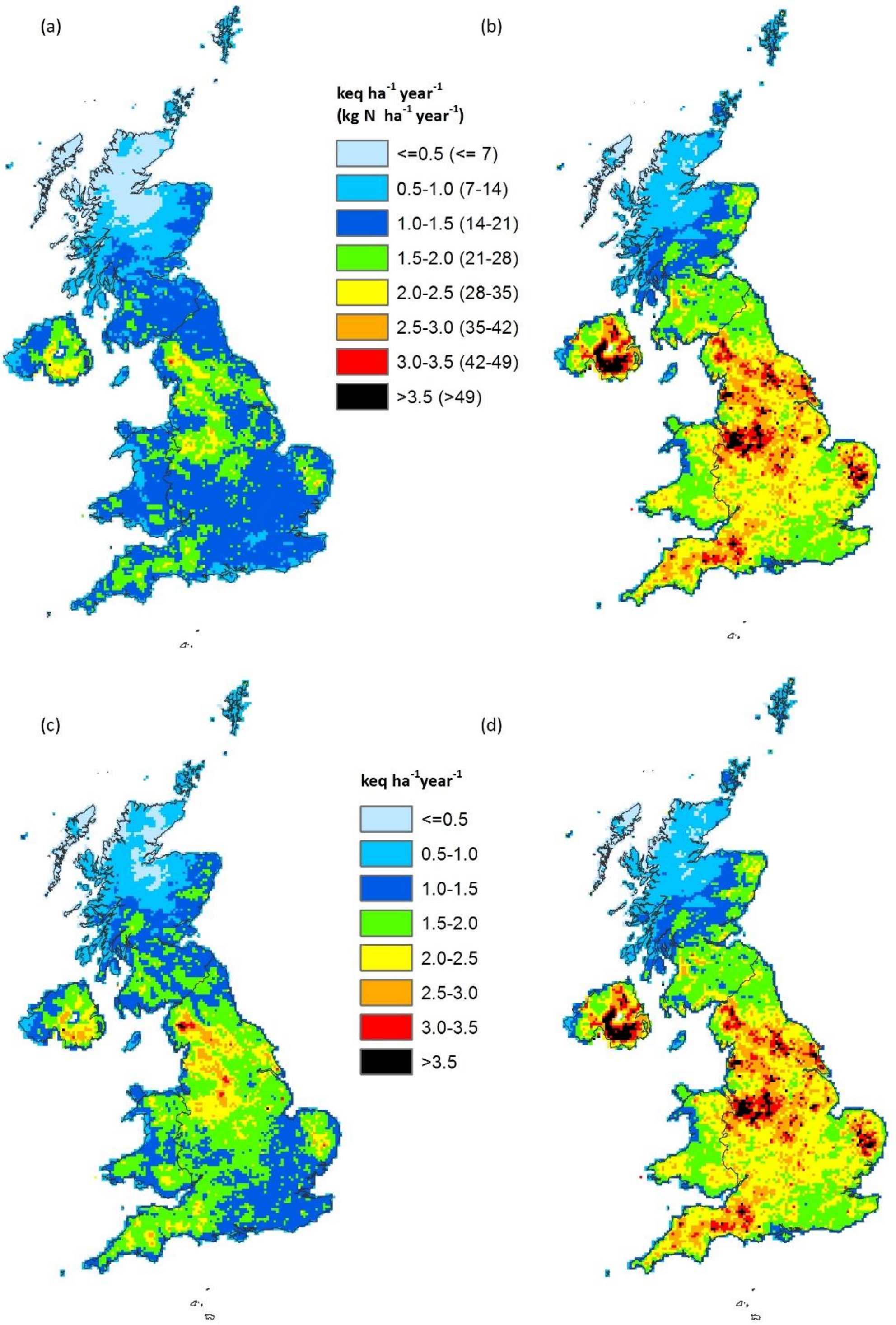


Figure 9.1: CBED 2011-13 total nitrogen deposition assuming (a) moorland everywhere, and (b) woodland everywhere, and total acid deposition assuming (c) moorland everywhere, and (d) woodland everywhere.

10. Calculating exceedance of nitrogen critical loads

For eutrophication, the exceedance is calculated using total nitrogen deposition, derived from nitrogen oxides and ammonia, ie, exceedance = nitrogen deposition – nitrogen critical load.

11. Calculating exceedance of acidity critical loads

For acidification the contribution of both sulphur and nitrogen deposition needs to be taken into account, and this is done using the acidity critical loads CLmaxS, CLminN and CLmaxN that define the Critical Loads Function (CLF: see Section 4). Figure 11.1 shows there are different options for reducing sulphur and nitrogen deposition, depending on where these values lie in relation to the CLF. Only in zone 1 can non-exceedance be achieved by reducing sulphur deposition alone. In zone 3 both sulphur and nitrogen deposition must be reduced before there are options to reduce either pollutant further to achieve non-exceedance. Although being able to examine the CLF and pollutant reduction options in this way can be useful, this is not the focus of the national calculations, which aim to calculate the "shortest distance" exceedance and identify the areas of habitat at risk. The calculations differ for terrestrial and freshwater habitats and these are described separately below. Note that the Henriksen and Posch (2001) formulation of FAB for lakes allows for direct deposition to the lake surface. This results in a different shape for the CLF for lake sites; for streams the CLF below applies.

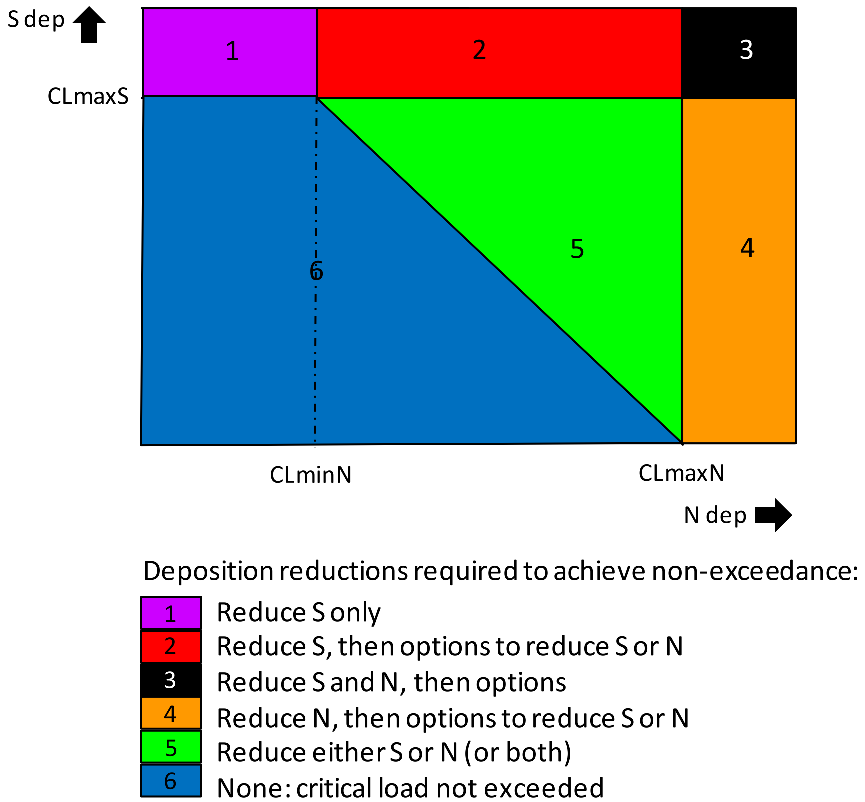


Figure 11.1: Schematic showing deposition reductions required to achieve non-exceedance of critical loads, depending on where the deposition values lie in relation to the CLF.

11.1 Exceedance of acidity critical loads for terrestrial habitats

This is calculated by comparing the values of CLmaxS, CLminN and CLmaxN to the values of sulphur and nitrogen (oxidised + reduced) deposition. For this five regions of the CLF can be defined (Figure

11.2a), which differ from those in Figure 11.1. Different calculations are applied to calculate exceedance depending on which region the sulphur and nitrogen deposition values lie in, in relation to the CLF (Figure 11.2b). The value “ycrit” (Figure 11.2 c) is determined by drawing a perpendicular line from the point of sulphur and nitrogen deposition to the CLF line. Exceedance is defined by the amount of sulphur and nitrogen deposition as shown by the red arrows (Figure 11.1c); this is what is referred to as the “shortest distance” exceedance, not the length of the diagonal line. Exceedances for the five regions of the CLF are calculated as follows:

Region 1:

Condition: Sdep > CLmaxS and Ndep < CLminN
Exceedance = Sdep – CLmaxS

Region 2:
Condition: S2 > CLmaxS
Exceedance = (Sdep – CLmaxS) + (Ndep – CLminN)

Region 3:
Condition: N2 > CLmaxN
Exceedance = Sdep + (Ndep – ClmaxN)

Region 4:
Condition: Sdep > ycrit and S2 <= CLmaxS and N2 <= CLmaxN
Exceedance = (Sdep – S2) + (Ndep – N2)

Region 5:
Condition: Sdep <= ycrit and Sdep <= CLmaxS and Ndep <= CLmaxN
Critical load not exceeded

Exceedances are calculated for every 1km square for each habitat type; from these results the exceedance metrics described in Section 12 are calculated.

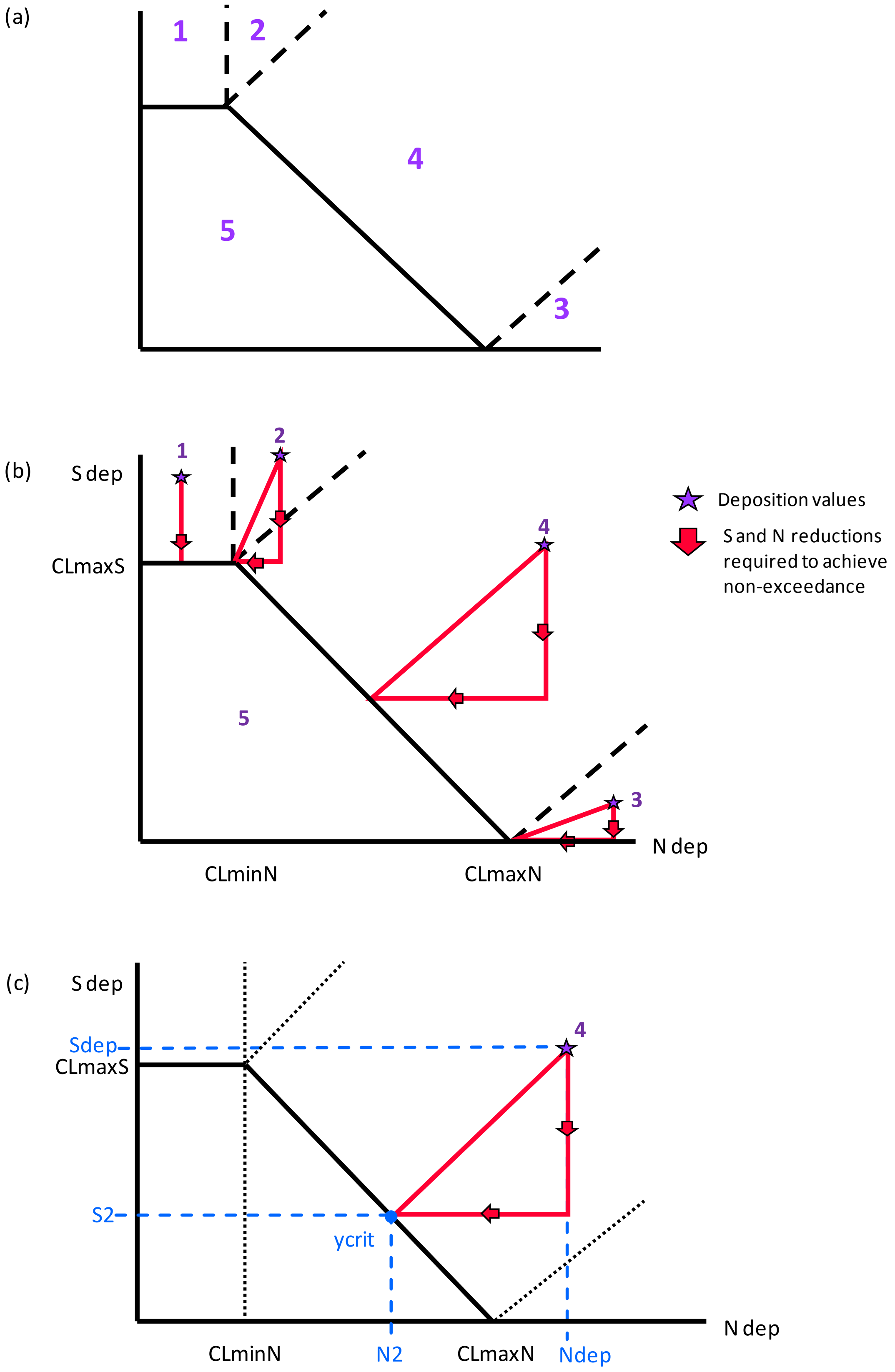


Figure 11.1: Calculating exceedances using the acidity CLF: (a) five regions of the CLF; (b) example S and N deposition reductions required depending on region of CLF; (c) example of parameters needed to calculate exceedance where S and N deposition falls in region 4. S2 = intercept on Sdep-axis from ycrit, N2 = intercept on Ndep-axis from ycrit, ycrit = intercept of sulphur and nitrogen deposition on CLF.

11.2 Exceedance of acidity critical loads for freshwaters

The first step in the calculation of exceedances for freshwaters is to calculate catchment-weighted deposition values. Unlike the critical loads for terrestrial habitats, the freshwater critical loads are based on parameters for each catchment (ie, the total land area draining into the lake or stream at the sampling point). The catchments contain a mixture of land cover types and therefore deposition values need to take this into account. Using LCM2000 data (Fuller et al, 2002a; 2002b) the spatial coverage of woodland and non-woodland habitat within each catchment has been derived. These maps are overlaid on the 5km sulphur and nitrogen deposition data for woodland and for moorland (ie, to represent the non-woodland areas), and area-weighted mean sulphur and nitrogen deposition values calculated for each catchment.

The calculation of exceedances of freshwater critical loads is based on the export of sulphur and nitrogen from the catchment:

Exceedance = $S_{export} + N_{export} - L_{crit}$

where L_{crit} = critical ANC leaching (ie, acidity critical load)

The export of sulphur and nitrogen take account of the in-lake retention of sulphur and nitrogen (Box 2, Section 5.6). The export of sulphur is calculated as:

$S_{export} = (1 - \rho_S) * S_{dep}$

where ρ_S is the in-lake retention fraction for sulphur

For stream sites ρ_S will be zero.

The calculation of the export of nitrogen depends on the following:

Case 1:

Ndep < CLminN (No terrestrial nitrate leaching occurs)

$N_{export} = (1 - \rho_N) * (LC_{ratio} * \text{Ndep})$

where ρ_N = in-lake retention fraction for nitrogen

LC_{ratio} is the lake:catchment ratio.

Case 2:

Ndep > CLminN (terrestrial nitrate leaching occurs)

$N_{export} = (1 - \rho_N) * (\text{Ndep} - \text{CLminN})$

Both ρ_N and LC_{ratio} are zero for stream sites.

The exceedance metrics in Section 12 are calculated from the exceedance results for each site catchment.

12. Summary exceedance statistics by habitat and country

Sections 10 and 11 describe the exceedance calculations for acidity and nutrient nitrogen. Once these exceedance values have been derived additional exceedance metrics can be calculated and then summarised by habitat and country (England, Wales, Scotland, Northern Ireland, UK). The exceedance metrics are:

(i) Area of habitat exceeded.

This is derived from the habitat distribution maps described in Section 2. For terrestrial habitats the area values are based on the LCM2000 data (Section 2). If the critical load for any individual habitat is exceeded, the exceeded area is set to the habitat area within the 1km square for that particular habitat. For the freshwater habitats, if the FAB critical load is exceeded, the whole catchment is assumed to be exceeded and the exceeded area set to the catchment area. The exceeded areas for individual habitats are then summarised by country.

(ii) Percentage area of habitat exceeded.

This is calculated from the exceeded areas derived in (i) and the total area of each habitat mapped in each country, according to the habitat distribution maps in Section 2. While this is a useful metric, it does have its limitations, for example, when comparing exceedance results from one year to another (or one deposition scenario to another), there may very small (or no) changes in the percentage area of habitat exceeded. This is because the magnitude of the exceedance may have reduced, but the area exceeding the critical load remains the same; the area exceeded will only reduce when the critical load is no longer exceeded.

(iii) Accumulated Exceedance (AE) is a metric which takes into account both the area exceeded and the magnitude of exceedance:

$$\text{AE (keq year}^{-1}\text{)} = \text{exceedance (keq ha}^{-1}\text{ year}^{-1}\text{)} * \text{exceeded area (ha)}$$

AE is calculated for each 1km square for each habitat and then summarised by habitat and country. AE is set to zero where critical loads are not exceeded. This metric can be useful for comparing results for different years or scenarios, but because the results are expressed in keq year^{-1} they tend to be very large numbers and not intuitive to understand. It should also be noted that the same AE can arise from a large exceedance and small exceeded area, or a small exceedance and a large area.

(iv) Average Accumulated Exceedance (AAE) which averages the AE across the entire sensitive habitat area:

$$\text{AAE (keq ha}^{-1}\text{ year}^{-1}\text{)} = \text{AE (keq year}^{-1}\text{)} / \text{total habitat area (ha)}$$

This metric provides an exceedance value averaged across the whole habitat area. It is based on the AE for the habitat (by country) divided by the total habitat area. AAE is set to zero where critical loads are not exceeded. This metric provides a more intuitive value for comparing the exceedance results for different years or scenarios, and gives an indication of the reduction in the magnitude of exceedance even if there is no change in the percentage area of habitat exceeded.

Tables 12.1 and 12.2 provide examples of the summary exceedance statistics by habitat for the UK based on CBED deposition data for 2011-13; data for individual countries are also generated. Section 14 uses some of the exceedance metrics to show the trends in exceedance over time.

Table 12.1: Summary acidity exceedance statistics for the UK based on deposition data for 2011-13

Habitat	**EUNIS class(es)**	**Habitat area (km^2)[#]**	**Exceeded area (km^2)**	**Percentage area exceeded**	**Accumulated Exceedance (keq $year^{-1}$)**	**Average Accumulated Exceedance (keq ha^{-1} $year^{-1}$)**
Acid grassland	E1.7 & E3.52	15336	11254	73.4	775286	0.51
Calcareous grassland	E1.26	1808	0	0.0	0	0
Dwarf shrub heath	F4.11 & F4.2	24705	7046	28.5	319432	0.13
Bog	D1	5454	2732	50.1	186729	0.34
Montane	E4.2	3054	1903	62.3	75908	0.25
Managed coniferous woodland	G3	8374	4709	56.2	349016	0.42
Managed broadleaved woodland	G1	7452	3987	53.5	352120	0.47
Unmanaged woodland	G4	4011	1623	40.5	120259	0.30
Freshwaters[##]	C1 & C2	7857	1478	18.8	92582	0.12
All habitats		78051	34732	44.5	2271332	0.29

[#] Habitat areas are based on the distribution maps in Section 2. Note these maps only include areas where there are also data available to map the critical loads, and therefore they may differ from other national habitat distribution maps, and the total areas mapped for acidity and for nitrogen also differ for some habitats.

[##] The results for freshwaters are based on the data for 1752 lake or stream catchments across the UK (see Sections 2 and 5).

Table 12.2: Summary nutrient nitrogen exceedance statistics for the UK based on deposition data for 2011-13.

Habitat	**EUNIS class(es)**	**Habitat area (km^2)[#]**	**Exceeded area (km^2)**	**Percentage area exceeded**	**Accumulated Exceedance (keq $year^{-1}$)**	**Average Accumulated Exceedance[##] (keq ha^{-1} $year^{-1}$)**	**Average Accumulated Exceedance[##] (kg N ha^{-1} $year^{-1}$)**
Acid grassland	E1.7 & E3.52	15235	9256	60.8	398520	0.26	3.7
Calcareous grassland	E1.26	3578	3135	87.6	124998	0.35	4.9
Dwarf shrub heath	F4.11 & F4.2	24826	10322	41.6	490673	0.20	2.8
Bog	D1	5526	2380	43.1	146672	0.27	3.7
Montane	E4.2	3129	2228	71.2	64255	0.21	2.9
Managed coniferous woodland	G3	8383	7239	86.4	657438	0.78	11.0
Managed broadleaved woodland	G1	7482	7240	96.8	923878	1.23	17.3
Beech woodland (unmanaged)	G1.6	719	719	100.0	68281	0.95	13.3
Acidophilous oak woodland (unmanaged)	G1.8	1434	1270	88.6	137719	0.96	13.5
Scots pine (unmanaged)	G3.4	204	49	24.2	2214	0.11	1.5
Other unmanaged woodland	G4	1761	1673	95.0	219651	1.25	17.5
Dune grassland	B1.4	323	94	29.2	1749	0.05	0.8
Saltmarsh	A2.5	427	3	0.8	100	0.002	0.03
All habitats		73027	45608	62.5	3236148	0.44	6.2

[#] Habitat areas are based on the distribution maps in Section 2. Note these maps only include areas where there are also data available to map the critical loads, and therefore they may differ from other national habitat distribution maps, and the total areas mapped for acidity and for nitrogen also differ for some habitats.

[##] Results for AAE are given in both keq ha^{-1} $year^{-1}$ (for comparison with acidity) and in kg N ha^{-1} $year^{-1}$ as this unit is more commonly recognised for nitrogen.

13. Mapping critical load exceedances

Exceedance maps show the spatial patterns of exceedance across the country, and can be generated for individual habitats (Section 13.1) or for all terrestrial habitats combined (Section 13.2).

13.1 Exceedance maps for individual habitats

Exceedances can be mapped for the individual habitats listed in Tables 12.1 and 12.2. However, as there are a total of 9 habitats for acidity and 13 habitats for nutrient nitrogen, these individual maps are rarely used routinely, but can be useful for studies examining specific habitats. Examples of the exceedance maps for dwarf shrub heath show that, for acidity (Figure 13.1a), the highest exceedances are largely confined to the Pennines, Lake District, Snowdonia and parts of Northern Ireland. The map for nutrient nitrogen (Figure 13.1b) also has high exceedances in the same regions, but the areas exceeded are larger and more extensive, indicating that eutrophication is a greater risk for this habitat than acidification.

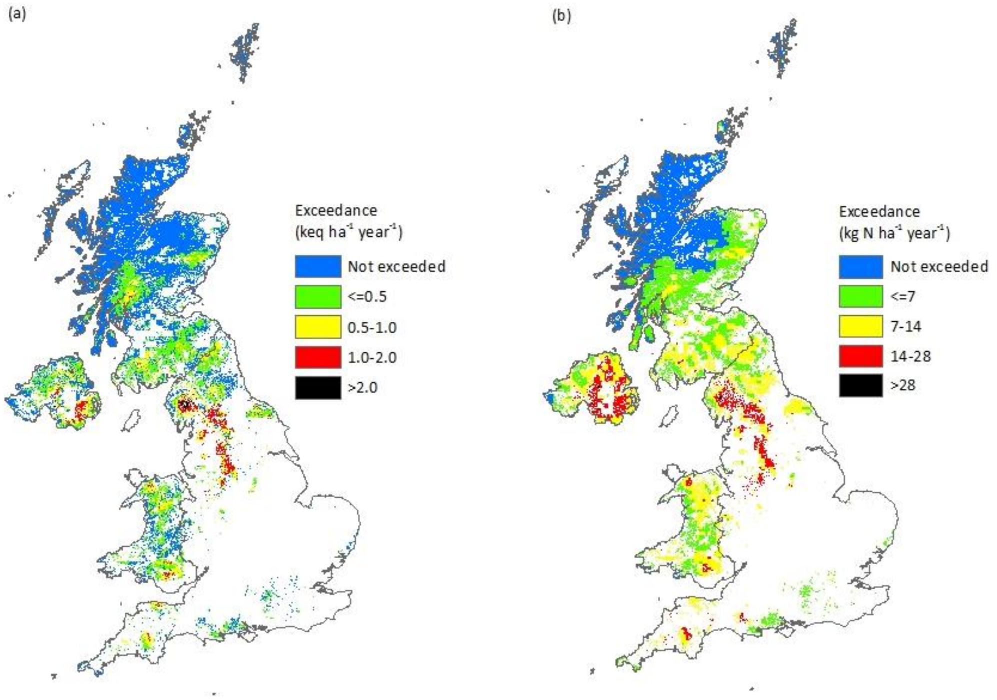


Figure 13.1: Exceedance of critical loads for dwarf shrub heath for (a) acidity and (b) nutrient nitrogen by ecosystem-specific deposition (acidity and nitrogen respectively) for 2011-13. Note that although the two legends are in different units, they are mapped in equivalent class intervals so the maps can be directly compared.

For freshwaters the critical loads data refer to 1752 sites sampled across the UK (Sections 2 & 5). The exceedance data for this habitat can either be mapped to show the area of each catchment (Figure 13.2a) or as point data (Figure 13.2b). The results are clearer when mapped as points, as the smaller sites are then easier to see, even then some sites become "lost" on the map due to the large number of sites in some regions (eg, North Wales, Cumbria, North York Moors). The areas with the highest exceedances are in the Pennines, Lake District, North York Moors, and south-west England.

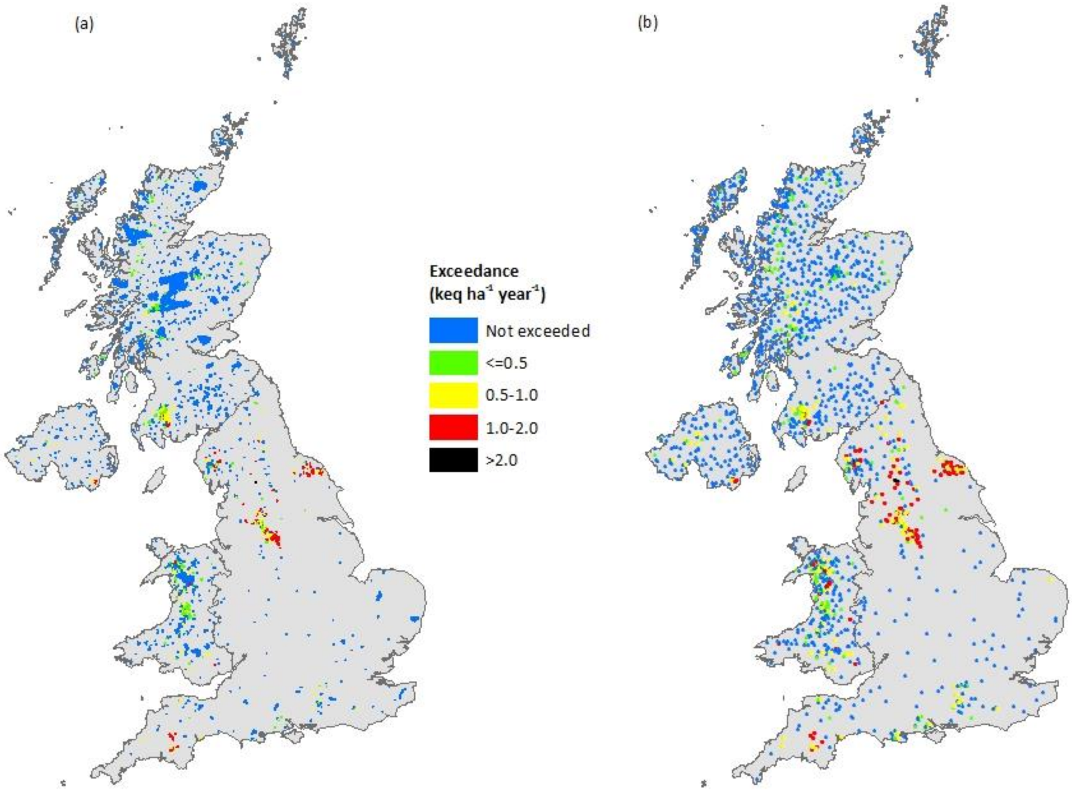


Figure 13.2: Exceedances of acidity critical loads for 1752 lake and stream sites across the UK by acid deposition for 2011-13 mapped (a) by site catchment; and (b) mapped as points.

13.2 Exceedance maps for all terrestrial habitats combined

To provide an overview of the spatial pattern of exceedance for all habitats, there are two different methods that can be used: the first uses a statistic of the habitat-specific critical loads data to calculate critical loads to protect a chosen percentage of the total area of habitat; the second calculates the Average Accumulate Exceedance (AAE) for all habitats. Both of these methods can be applied to the 1km data for the terrestrial habitats; the freshwater exceedance results are not included in these maps because the data are catchment based rather than for 1km squares, and as such may overlap with other habitat data.

13.2.1 Exceedance maps based on 5th-percentile critical loads

This is an approach that was used by the CCE in the 1990s for summarising the critical loads data for different habitats and presenting critical load and exceedance maps at the European scale (Hettelingh et al, 1991; Posch et al, 1999); the CCE are now reporting exceedances using AAE maps (Section 13.2.2 below). At the UK scale a statistic of the critical load values of CLmaxS, CLminN, CLmaxN and CLnutN is calculated from the 1km data for all the terrestrial habitats. The statistic used is the 5th-percentile; this is the critical load that will protect 95% of the sensitive habitat area in each 1km grid square. The 5th-percentile critical loads are calculated by ranking all the habitat critical load values within a grid square from low to high, together with their associated habitat area values. The areas are then summed until they reach 5% of the total sensitive habitat area within each square, and the critical load set to the corresponding value. For example, if a grid square contained the habitat and critical load data shown in Table 13.1 below, then:

- The total habitat area is 90 ha

- 5% of the total habitat area is 4.5 ha
- The critical load corresponding to the cumulative habitat area of 4.5 ha, is 0.5 keq ha^{-1} year^{-1}; this is the 5th-percentile critical load to protect 95% of the habitat area within this square.

Table 13.1 Example data for 1km square for the calculation of the 5th-percentile critical load

Sensitive habitats with critical load values	**Critical load (keq ha^{-1} year^{-1}) (ranked from low to high)**	**Habitat area (ha)**	**Cumulative habitat area (ha)**
Bog	0.2	3	3
Dwarf shrub heath	0.5	15	18
Coniferous wood	1.0	30	48
Broadleaf wood	2.0	42	90

This method is used to derive 5th-percentile values of CLmaxS, CLminN, CLmaxN, CLnutN for all habitats combined. These data are used to calculate exceedances using the methodology in Section 11.1 (acidity) and Section 10 (nutrient nitrogen). The only difference here is that grid-average deposition (ie, average deposition to all habitat types) is used instead of habitat-specific deposition because the input critical loads to an individual grid square may be defined by different habitats. For example, the habitat defining the 5th-percentile value for CLmaxS may be different to the habitat defining the 5th-percentile CLminN. Therefore these maps (Figure 13.3) may underestimate the exceedance to some habitat types, and in particular, woodlands which receive higher deposition. The maps show that a much larger area of habitats are exceeded for nutrient nitrogen than for acidity.

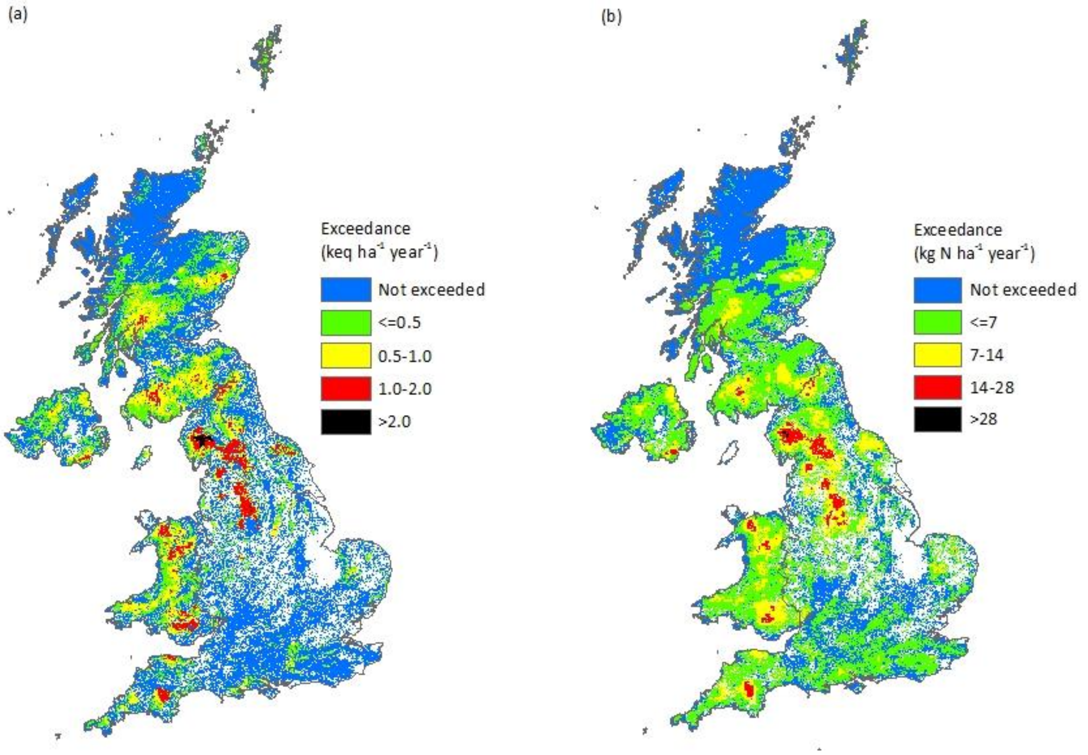


Figure 13.3: Exceedance of 5th-percentile critical loads of (a) acidity; (b) nutrient nitrogen by grid-average deposition (acidity and nitrogen respectively) for 2011-13. Note that although the two legends are in different units, they are mapped in equivalent class intervals so the maps can be directly compared.

13.2.2 Exceedance maps based on Average Accumulated Exceedance (AAE)

Maps of AAE replaced those based on 5th-percentile critical loads in reporting exceedance results at the European scale (Posch et al, 2001; Posch et al, 2012). For the UK maps of AAE for all terrestrial habitats combined (Figure 13.4) provide a better representation of the summary critical load exceedance statistics (Section 12), than the maps based on the 5th-percentile critical loads. This is because both the summary statistics and the AAE maps are based on the critical loads and area data for all habitats (except freshwaters), and on habitat-specific deposition. However, this also means that the magnitude of exceedance and the area exceeded shown on these maps is greater than on the maps based on the percentile critical loads. The AAE for all (terrestrial) habitats combined is calculated for each 1km square as:

$$\text{AAE} = \sum(\text{AE for all habitats})/\sum(\text{area for all habitats})$$

AE (and AAE) is set to zero where the critical loads are not exceeded.

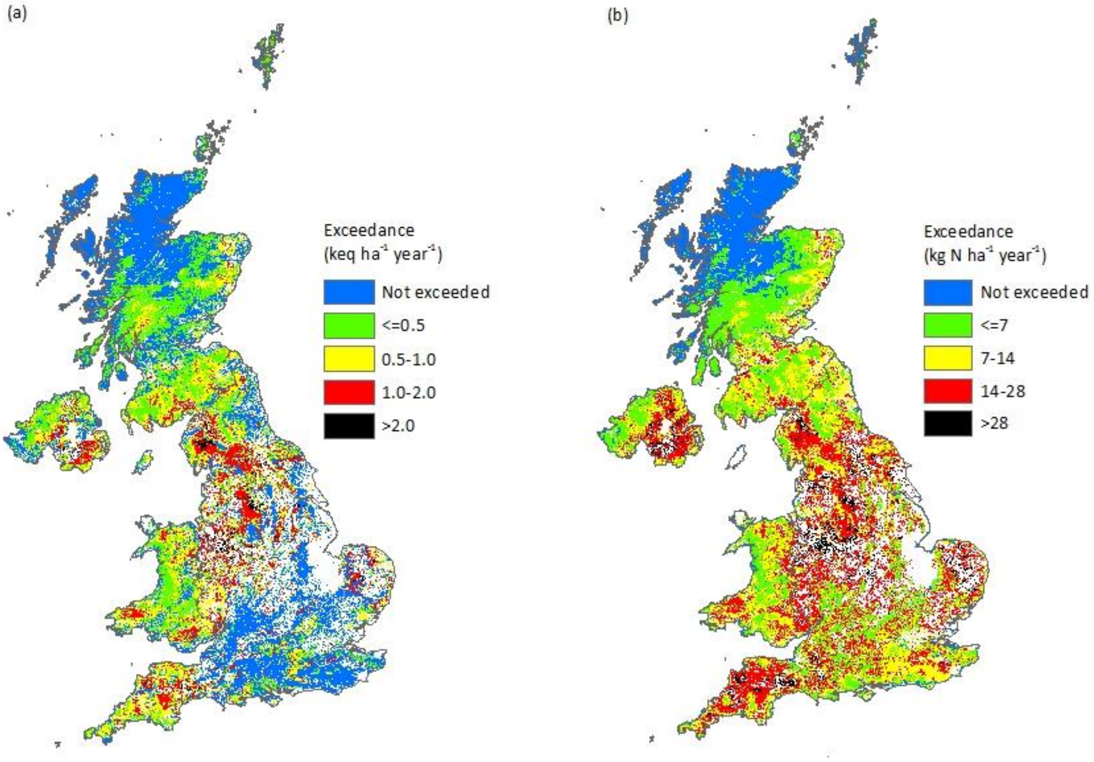


Figure 13.4: Average Accumulated Exceedance for (a) acidity; (b) nutrient nitrogen, based on all habitat critical loads and ecosystem-specific deposition (for acidity and nitrogen respectively) for 2011-13. Note that although the two legends are in different units, they are mapped in equivalent class intervals so the maps can be directly compared.

PART III: SITE RELEVANT CRITICAL LOADS

14. Introduction

Site relevant critical loads (SRCL) have been applied to three types of statutory protected sites:

- Special Areas of Conservation (SACs) are protected sites designated under the EC Habitats Directive. Annexes I and II of the Directive identify the habitats and species (excluding birds) to be protected; 78 Annex I habitat types and 41 species are believed to occur in, or be native to the UK.
- Special Protected Areas (SPAs) are sites classified under the EC Birds Directive to protect rare and vulnerable birds (as listed in an Annex to the Directive) and regularly occurring migratory species.
- Sites of Special Scientific Interest (SSSIs in England, Wales and Scotland) and Areas of Special Scientific Interest (ASSIs in Northern Ireland) provide statutory protection to the UK's flora and fauna. There are additional SSSIs designated for geological or physiographic features but these are not included in the SRCL assessments.

This report describes the national SRCL database. It has been set up to enable UK wide assessments of designated sites at risk from the adverse impacts from excess acid or nitrogen deposition. The national SRCL may differ from critical load values that would be set in site-specific applications where additional information on site characteristics or management may be available. For site-specific applications further guidance should be sought from the Air Pollution Information System (APIS: www.apis.ac.uk) and the statutory nature conservation bodies (SNCBs).

Digital boundaries for all sites in the UK have been collated by JNCC, together with tables identifying the designated feature habitats and species associated with each site, but no digital information is currently available on the spatial area of each feature within each site. ***Therefore, for the purposes of the national SRCL work described here, it is assumed that all features recorded for a site, occur across the entire site area. To avoid double (or triple or more) counting the area exceeding critical loads for sites with more than one designated feature, the maximum area exceeded for any feature is used when summarising results to the site and country levels (see Section 16).***

To assign SRCL, the first step is to consider if the interest feature is potentially sensitive to acidification and/or eutrophication. Specialists within Natural England, Scottish Natural Heritage and CEH have used expert judgement to determine this (SNIFFER, 2007). For SPAs where the features are bird species, the broad habitats the birds depend upon for feeding, breeding and roosting are considered.

To assign critical loads to the habitat features of designated sites it is necessary to link the different habitat classifications used. Acidity critical loads are mapped by broad habitat and empirical critical loads of nitrogen are based on the EUNIS (European Nature Information System; Davies & Moss, 2002) habitat classification. Look-up tables developed by Davies & Moss (2002) and published in the National Biodiversity Network (NBN) Habitats Dictionary (http://habitats.nbn.org.uk/) and available from the JNCC website (http://jncc.defra.gov.uk/page-1425) enable linkages to be made between:

- Annex I habitats and EUNIS classes
- Annex I habitats and broad habitats

- EUNIS habitats and broad habitats

Using the look up tables the most appropriate EUNIS class and broad habitat class can be assigned to each interest feature.

The conservation agencies use a number of different reporting categories; site assessments may be reported by interest feature (Annex I habitats are the interest feature for habitat features of SACs), or by "NCLCode" for nitrogen and "ACCode" for acidity. The NCLCode and ACCode have been defined by the conservation agencies and linked to EUNIS classes for nitrogen purposes, and to broad habitats for acidity purposes. NCLCodes and ACCodes have been assigned to each interest feature of each SAC, SPA and SSSI. Table 14.1 lists the NCLCodes and class name, the corresponding EUNIS class(es), range of nitrogen critical loads, and the "Recommended" critical load value for Article 17 reporting (for more information refer to http://www.apis.ac.uk/indicative-critical-load-values). Table 14.2 lists the ACCodes; the class name here is the broad habitat determining which habitat critical load values should be applied to interest features this code is assigned to.

Table 14.1: NCLCodes and corresponding EUNIS classes and nitrogen critical loads

NCLCode	NCLClass	Nearest EUNIS code with CLnutN	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)
NCL000	No comparable habitat with established critical load estimate available			
NCL001	Alpine and subalpine grasslands	E4.3; E4.4	5-10	5
NCL002	Arctic, alpine and subalpine scrub habitats	F2	5-15	5
NCL003	Coastal dune heaths	B1.5	10-20	10
NCL004	Coastal stable dune grasslands	B1.4	8-15	8
NCL005	Dry heaths	F4.2	10-20	10
NCL006	Inland dune pioneer grasslands	E1.94	8-15	8
NCL007	Low and medium altitude hay meadows	E2.2	20-30	20
NCL008	Moist and wet oligotrophic grasslands: Heath (Juncus) meadows and	E3.52	10-20	10
NCL009	Moist and wet oligotrophic grasslands: Molinia caerulea meadows	E3.51	15-25	15
NCL010	Moist to wet dune slacks	B1.8	10-20	10
NCL011	Moss and lichen dominated mountain summits	E4.2	5-10	7
NCL012	Mountain hay meadows	E2.3	10-20	10
NCL013	Mountain rich fens	D4.2	15-25	15
NCL014	Non-mediterranean dry acid and neutral closed grassland	E1.7	10-15	10
NCL015	Northern wet heath: Calluna-dominated wet heath (upland moorland)	F4.11	10-20	10
NCL016	Northern wet heath: Erica tetralix dominated wet heath	F4.11	10-20	10
NCL017	Pioneer, low-mid, mid-upper saltmarshes	A2.54; A2.55; A2.53	20-30	20
NCL018	Valley mires, poor fens and transition mires	D2	10-15	10
NCL019	Raised and blanket bogs	D1	5-10	5
NCL020	Rich fens	D4.1	15-30	15
NCL021	Shifting coastal dunes	B1.3	10-20	10
NCL023	Permanent oligotrophic waters: Softwater lakes	C1.1	3-10	3
NCL024	Sub-atlantic semi-dry calcareous grassland	E1.26	15-25	15
NCL031	Inland dune siliceous grasslands	E1.95	8-15	8
NCL038	Broadleaved deciduous woodland	G1	10-20	10
NCL039	Coniferous woodland	G3	5-15	10
NCL040	Fagus woodland	G1.6	10-20	15
NCL041	Acidophilous Quercus-dominated woodland	G1.8	10-15	10
NCL042	Meso- and eutrophic Quercus woodland	G1.A	15-20	15
NCL043	Pinus sylvestris woodland south of taiga	G3.4	5-15	12
NCL044	Permanent dystrophic lakes, ponds and pools	C1.4	3-10	3
NCL045	Coastal stable dune grasslands	B1.4	8-10	8
NCL046	Coastal stable dune grasslands	B1.4	10-15	10
NCL047	Moist to wet dune slacks	B1.8	10-20	10
NCL048	Moist to wet dune slacks	B1.8	10-20	15
NCL049	Permanent oligotrophic waters: Softwater lakes	C1.1	5-10	5
NCL101	Designated feature/feature habitat not sensitive to eutrophication			
NCL102	Specie's broad habitat not sensitive to eutrophication			

Table 14.2: ACCodes denoting broad habitat critical loads to be applied to an interest feature.

ACCode	AcidityClass
ACG	Acid grassland
BGP	Bogs
CG4	Calcareous grassland
DSH	Dwarf shrub heath
FW	Freshwater
MON	Montane
NSH	Habitat not sensitive to acidification
NSS	Specie's habitat not sensitive to acidification
UMW	Broadleafed/Coniferous unmanaged woodland

The SRCL database tables document the habitat classification relationships and rationale for the linkages for each feature, as well as noting where appropriate linkages are not available. Extracts of the SRCL tables for SACs and SSSIs are given in Tables 14.3 and 14.4 respectively. These show the linkages between the different habitat classifications and the habitat categories used for reporting purposes. Table 14.5 summarises the number of unique interest feature habitats or species that SRCL have been assigned to for UK SACs, SPAs and SSSIs.

Table 14.3: Extract of SRCL database for SACs showing linkages between habitat classifications for features with nitrogen critical loads assigned

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
H1130	Estuaries	A2.54; A2.55; A2.53	Littoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H1150	Coastal lagoons	A2.54; A2.55; A2.53	Inshore sublittoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H1220	Perennial vegetation of stony banks	B1.4	Supralittoral sediment	NCL004	Coastal stable dune grasslands	8-15	8	ACG	Acid grassland
H1310	Salicornia & other annuals colonising mud & sand	A2.54; A2.55; A2.53	Littoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H1320	Spartina swards	A2.54; A2.55; A2.53	Littoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H1330	Atlantic salt meadows	A2.54; A2.55; A2.53	Littoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H1420	Halophilous scrubs	A2.54; A2.55; A2.53	Littoral sediment	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
H2110	Embryonic shifting dunes	B1.3	Supralittoral sediment	NCL021	Shifting coastal dunes	10-20	10	NSH	Not sensitive to acidification
H2120	Shifting white dunes	B1.3	Supralittoral sediment	NCL021	Shifting coastal dunes	10-20	10	NSH	Not sensitive to acidification
H2130	Fixed grey dunes	B1.4	Supralittoral sediment	NCL045	Coastal stable dune grasslands	8-10	8	ACG	Acid grassland
H2130	Fixed grey dunes	B1.4	Supralittoral sediment	NCL046	Coastal stable dune grasslands	10-15	10	CG4	Calcareous grassland
H2140	Decalcified fixed dunes	B1.5	Supralittoral sediment	NCL003	Coastal dune heaths	10-20	10	DSH	Dwarf shrub heath
H2150	Atlantic decalcified fixed dunes	B1.5	Supralittoral sediment	NCL003	Coastal dune heaths	10-20	10	DSH	Dwarf shrub heath
H2170	Dunes with Salix	B1.8	Supralittoral sediment	NCL010	Moist to wet dune slacks	10-20	10	ACG	Acid grassland
H2190	Humid dune slacks	B1.8	Supralittoral sediment	NCL047	Moist to wet dune slacks	10-20	10	ACG	Acid grassland
H2190	Humid dune slacks	B1.8	Supralittoral sediment	NCL048	Moist to wet dune slacks	10-20	15	CG4	Calcareous grassland
H21A0	Machairs	B1.4	Supralittoral sediment	NCL046	Coastal stable dune grasslands	10-15	10	CG4	Calcareous grassland
H2250	Coastal dunes with Juniperus spp.	B1.5	Supralittoral sediment	NCL003	Coastal dune heaths	10-20	10	DSH	Dwarf shrub heath
H2330	Inland dunes & grass	E1.94	Acid grassland	NCL006	Inland dune pioneer grasslands	8-15	8	ACG	Acid grassland
H3110	Oligotrophic waters	C1.1	Standing open water and canals	NCL049	Permanent oligotrophic waters	5-10	5	FW	Freshwater
H3130	Oligotrophic to mesotrophic standing waters	C1.1	Standing open water and canals	NCL023	Permanent oligotrophic waters	3-10	3	FW	Freshwater
H3160	Natural dystrophic lakes & ponds	C1.4	Standing open water and canals	NCL044	Permanent dystrophic waters	3-10	3	FW	Freshwater
H4010	Wet heaths with Erica tetralix	F4.11	Dwarf shrub heath	NCL016	Erica tetralix dominated wet heath	10-20	10	DSH	Dwarf shrub heath
H4020	Wet heaths with Erica ciliaris & Erica tetralix	F4.11	Dwarf shrub heath	NCL016	Erica tetralix dominated wet heath	10-20	10	DSH	Dwarf shrub heath
H4030	Dry heaths	F4.2	Dwarf shrub heath	NCL005	Dry heaths	10-20	10	DSH	Dwarf shrub heath
H4040	Dry Atlantic coastal heaths	F4.2	Dwarf shrub heath	NCL005	Dry heaths	10-20	10	DSH	Dwarf shrub heath
H4060	Alpine & Boreal heaths	F2	Montane habitats	NCL002	Alpine & subalpine scrub habitats	5-15	5	MON	Montane
H4080	Sub-Arctic Salix spp. scrub	F2	Montane habitats	NCL002	Alpine & subalpine scrub habitats	5-15	5	MON	Montane
H5110	Stable xerothermophilous formations	E1.26	Broadleaved, mixed and yew woodland	NCL024	Semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
H5130	Juniperus communis formations (heath)	F4.2	Broadleaved, mixed and yew woodland	NCL005	Dry heaths	10-20	10	DSH	Dwarf shrub heath
H5130	Juniperus communis formations (calcareous grass)	E1.26	Broadleaved, mixed and yew woodland	NCL024	Semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
H6130	Calaminarian(acid) grasslands	E1.7	Inland rock	NCL014	Dry acid & neutral closed grassland	10-15	10	ACG	Acid grassland
H6130	Calaminarian (calcareous) grasslands	E1.26	Inland rock	NCL024	Semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
H6150	Siliceous alpine & boreal grasslands	E4.3; E4.4	Montane habitats	NCL001	Alpine & subalpine grasslands	5-10	5	MON	Montane
H6170	Alpine & subalpine calcareous grasslands	E4.3; E4.4	Calcareous grassland	NCL001	Alpine & subalpine grasslands	5-10	5	CG4	Calcareous grassland
H6210	Semi-natural dry grasslands	E1.26	Calcareous grassland	NCL024	Semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
H6211	Semi-natural dry grasslands (orchids)	E1.26	Calcareous grassland	NCL024	Semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
H6230	Species-rich Nardus grassland	E1.7	Calcareous grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	ACG	Acid grassland
H6410	Molinia meadows	E3.51	Fen, marsh and swamp	NCL009	Molinia caerulea meadows	15-25	15	ACG	Acid grassland
H6430	Hydrophilous tall herb fringe	E2.3	Inland rock	NCL012	Mountain hay meadows	10-20	10	ACG	Montane
H6510	Lowland hay meadows (acid)	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	ACG	Acid grassland
H6510	Lowland hay meadows (calcareous)	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	CG4	Calcareous grassland
H6520	Mountain hay meadows (acid)	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	ACG	Acid grassland
H6520	Mountain hay meadows (calcareous)	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	CG4	Calcareous grassland
H7110	Active raised bogs	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BGP	Bogs
H7120	Degraded raised bogs	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BGP	Bogs
H7130	Blanket bogs	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BGP	Bogs
H7140	Transition mires & quaking bogs	D2	Fen, marsh and swamp	NCL018	Valley mires, poor fens & transition	10-15	10	BGP	Bogs
H7150	Depressions on peat substrates	D2	Bogs	NCL018	Valley mires, poor fens & transition	10-15	10	BGP	Bogs
H7210	Calcareous fens	D4.1	Fen, marsh and swamp	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification

Table 14.3 continued

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
H7220	Petrifying springs with tufa formation	D4.2	Fen, marsh and swamp	NCL013	Mountain rich fens	15-25	15	NSH	Not sensitive to acidification
H7220	Petrifying springs with tufa formation	D4.1	Fen, marsh and swamp	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
H7230	Alkaline fens	D4.1	Fen, marsh and swamp	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
H7240	Alpine pioneer formations	D4.2	Fen, marsh and swamp	NCL013	Mountain rich fens	15-25	15	NSH	Not sensitive to acidification
H8110	Siliceous scree	F2	Inland rock	NCL002	Alpine & subalpine scrub habitats	5-15	5	MON	Montane
H8120	Calcareous & calcshist screes	F2	Inland rock	NCL002	Alpine & subalpine scrub habitats	5-15	5	MON	Montane
H8210	Calcareous rocky slopes	E4.3; E4.4	Inland rock	NCL001	Alpine & subalpine grasslands	5-10	5	MON	Montane
H8220	Siliceous rocky slopes	F2	Inland rock	NCL002	Alpine & subalpine scrub habitats	5-15	5	MON	Montane
H8240	Limestone pavements	E4.3; E4.4	Inland rock	NCL001	Alpine & subalpine grasslands	5-10	5	CG4	Calcareous grassland
H9120	Atlantic acidophilous beech forests	G1.6	Broadleaved, mixed and yew woodland	NCL040	Fagus woodland	10-20	15	UMW	Broadleaf/Conifer unmanaged woodland
H9130	Asperulo-Fagetum beech forests	G1.6	Broadleaved, mixed and yew woodland	NCL040	Fagus woodland	10-20	15	UMW	Broadleaf/Conifer unmanaged woodland
H9160	Oak or oak-hornbeam forests	G1.A	Broadleaved, mixed and yew woodland	NCL042	Meso- & eutrophic Quercus woodland	15-20	15	UMW	Broadleaf/Conifer unmanaged woodland
H9180	Tilio-Acerion forests	G1.A	Broadleaved, mixed and yew woodland	NCL042	Meso- & eutrophic Quercus woodland	15-20	15	UMW	Broadleaf/Conifer unmanaged woodland
H9190	Old acidophilous oak woods	G1.8	Broadleaved, mixed and yew woodland	NCL041	Acidophilous Quercus woodland	10-15	10	UMW	Broadleaf/Conifer unmanaged woodland
H91A0	Old sessile oak woods	G1.8	Broadleaved, mixed and yew woodland	NCL041	Acidophilous Quercus woodland	10-15	10	UMW	Broadleaf/Conifer unmanaged woodland
H91C0	Caledonian forest	G3.4	Coniferous woodland	NCL043	Pinus sylvestris woodland	5-15	12	UMW	Broadleaf/Conifer unmanaged woodland
H91D0	Bog woodland	D1	Broadleaved, mixed and yew woodland	NCL019	Raised & blanket bogs	5-10	5	BGP	Bogs
H91J0	Taxus baccata woods	G3	Broadleaved, mixed and yew woodland	NCL039	Coniferous woodland	5-15	10	UMW	Broadleaf/Conifer unmanaged woodland

Notes:

- Interest Codes are Annex I Habitat Codes: National and international reporting categories.
- NCLCode/NCLClass: category for nutrient nitrogen critical loads for reporting results to JNCC and Defra; note, more than one NCLCode can be assigned to each Interest Code.
- EUNIS code: European habitat class assigned to the NCLClass and used for assigning the nitrogen critical loads (CLnutN).
- CLnutN range: the published critical load range for the EUNIS Code.
- Recommended CLnutN: the “Recommended values” for Article 17 reporting (for further information refer to: http://www.apis.ac.uk/indicative-critical-load-values); where no “Recommended value” has been set for an Interest Code, the minimum value of the range will be applied.
- ACCode/AcidityClass: category for acidity critical loads for reporting results to JNCC and Defra; note, more than one ACCode can be assigned to each Interest Code.

Table 14.4: Extract of SRCL database for SSSIs showing linkages between habitat classifications for features with nitrogen critical loads assigned

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
BOGLOW	Bog - lowland	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGLOW	Bog - lowland	D1	Lowland Raised Bog	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGS	Bogs	D1	Lowland Raised Bog	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGS	Bogs	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGS	Bogs	D1	Blanket bog	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGUP	Bog - upland	D1	Bogs	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
BOGUP	Bog - upland	D1	Blanket bog	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
FENLOW	Fen marsh & swamp - lowland	E3.51	Purple Moor Grass and Rush Pastures	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	E3.51	Fen, marsh and swamp	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	D2	Lowland Fens	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	D2	Fen, marsh and swamp	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	D2	Lowland Fens	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	D2	Lowland Fens	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENLOW	Fen marsh & swamp - lowland	D4.1	Lowland Fens	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENLOW	Fen marsh & swamp - lowland	D4.1	Fen, marsh and swamp	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENLOW	Fen marsh & swamp - lowland	D4.1	Lowland Fens	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENMARSH	Fen, marsh & swamp	E3.51	Purple Moor Grass and Rush Pastures	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	E3.51	Fen, marsh and swamp	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D4.2	Upland Flushes Fens and Swamps	NCL013	Mountain rich fens	15-25	15	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D4.2	Fen, marsh and swamp	NCL013	Mountain rich fens	15-25	15	NSH	Not sensitive to acidification
FENMARSH	Fen, marsh & swamp	D2	Lowland Fens	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D2	Upland Flushes Fens and Swamps	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D2	Fen, marsh and swamp	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D2	Upland Flushes Fens and Swamps	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENMARSH	Fen, marsh & swamp	D4.1	Upland Flushes Fens and Swamps	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENMARSH	Fen, marsh & swamp	D4.1	Lowland Fens	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENMARSH	Fen, marsh & swamp	D4.1	Fen, marsh and swamp	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
FENUP	Fen marsh & swamp - upland	E3.51	Purple Moor Grass and Rush Pastures	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENUP	Fen marsh & swamp - upland	E3.51	Fen, marsh and swamp	NCL009	Molinia caerulea meadows	15-25	15	AG	Acid grassland
FENUP	Fen marsh & swamp - upland	D4.2	Upland Flushes Fens and Swamps	NCL013	Mountain rich fens	15-25	15	NSH	Not sensitive to acidification
FENUP	Fen marsh & swamp - upland	D4.2	Fen, marsh and swamp	NCL013	Mountain rich fens	15-25	15	NSH	Not sensitive to acidification
FENUP	Fen marsh & swamp - upland	D2	Upland Flushes Fens and Swamps	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENUP	Fen marsh & swamp - upland	D2	Fen, marsh and swamp	NCL018	Valley mires, poor fens & transition mires	10-15	10	AG	Acid grassland
FENUP	Fen marsh & swamp - upland	D4.1	Upland Flushes Fens and Swamps	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
GRASAC	Acid grassland	E1.94	Acid grassland	NCL006	Inland dune pioneer grasslands	8-15	8	AG	Acid grassland
GRASAC	Acid grassland	E3.52	Acid grassland	NCL008	Moist & wet oligotrophic grasslands	10-20	10	AG	Acid grassland
GRASAC	Acid grassland	E1.7	Acid grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	AG	Acid grassland
GRASAC	Acid grassland	E1.95	Acid grassland	NCL031	Inland dune siliceous grasslands	8-15	8	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.94	Lowland dry acid grassland	NCL006	Inland dune pioneer grasslands	8-15	8	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.94	Acid grassland	NCL006	Inland dune pioneer grasslands	8-15	8	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.7	Acid grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.7	Lowland dry acid grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.95	Acid grassland	NCL031	Inland dune siliceous grasslands	8-15	8	AG	Acid grassland
GRASACLO	Acid grassland lowland	E1.95	Lowland dry acid grassland	NCL031	Inland dune siliceous grasslands	8-15	8	AG	Acid grassland
GRASACUP	Acid grassland upland	E1.94	Acid grassland	NCL006	Inland dune pioneer grasslands	8-15	8	AG	Acid grassland
GRASACUP	Acid grassland upland	E3.52	Acid grassland	NCL008	Moist & wet oligotrophic grasslands	10-20	10	AG	Acid grassland
GRASACUP	Acid grassland upland	E1.7	Acid grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	AG	Acid grassland
GRASACUP	Acid grassland upland	E1.95	Acid grassland	NCL031	Inland dune siliceous grasslands	8-15	8	AG	Acid grassland

Table 14.4 continued

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
GRASCA	Calcareous grassland	E1.7	Calcareous grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	CG4	Calcareous grassland
GRASCA	Calcareous grassland	E1.26	Calcareous grassland	NCL024	Sub-atlantic semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
GRASCA	Calcareous grassland	E1.26	Calcareous grassland	NCL024	Sub-atlantic semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
GRASCALO	Calcareous grassland lowland	E1.26	Lowland Calcareous Grassland	NCL024	Sub-atlantic semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
GRASCALO	Calcareous grassland lowland	E1.26	Calcareous grassland	NCL024	Sub-atlantic semi-dry calcareous grassland	15-25	15	CG4	Calcareous grassland
GRASCAUP	Calcareous grassland upland	E1.7	Upland Calcareous Grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	CG4	Calcareous grassland
GRASCAUP	Calcareous grassland upland	E1.7	Calcareous grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	CG4	Calcareous grassland
GRASCAUP	Calcareous grassland upland	E1.7	Calcareous grassland	NCL014	Dry acid & neutral closed grassland	10-15	10	CG4	Calcareous grassland
GRASNELO	Neutral grassland lowland	E2.2	Lowland Meadows	NCL007	Low & medium altitude hay meadows	20-30	20	AG	Acid grassland
GRASNELO	Neutral grassland lowland	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	CG4	Calcareous grassland
GRASNELO	Neutral grassland lowland	E2.2	Lowland Meadows	NCL007	Low & medium altitude hay meadows	20-30	20	CG4	Calcareous grassland
GRASNELO	Neutral grassland lowland	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	AG	Acid grassland
GRASNELOUP	Neutral grassland	E2.2	Lowland Meadows	NCL007	Low & medium altitude hay meadows	20-30	20	AG	Acid grassland
GRASNELOUP	Neutral grassland	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	AG	Acid grassland
GRASNELOUP	Neutral grassland	E2.2	Lowland Meadows	NCL007	Low & medium altitude hay meadows	20-30	20	CG4	Calcareous grassland
GRASNELOUP	Neutral grassland	E2.2	Neutral grassland	NCL007	Low & medium altitude hay meadows	20-30	20	CG4	Calcareous grassland
GRASNELOUP	Neutral grassland	E2.3	Upland hay meadows	NCL012	Mountain hay meadows	10-20	10	CG4	Calcareous grassland
GRASNELOUP	Neutral grassland	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	CG4	Calcareous grassland
GRASNELOUP	Neutral grassland	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	AG	Acid grassland
GRASNELOUP	Neutral grassland	E2.3	Upland hay meadows	NCL012	Mountain hay meadows	10-20	10	AG	Acid grassland
GRASNEUP	Neutral grassland upland	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	CG4	Calcareous grassland
GRASNEUP	Neutral grassland upland	E2.3	Upland hay meadows	NCL012	Mountain hay meadows	10-20	10	CG4	Calcareous grassland
GRASNEUP	Neutral grassland upland	E2.3	Neutral grassland	NCL012	Mountain hay meadows	10-20	10	AG	Acid grassland
GRASNEUP	Neutral grassland upland	E2.3	Upland hay meadows	NCL012	Mountain hay meadows	10-20	10	AG	Acid grassland
HEATH	Dwarf shrub heath	F4.2	Lowland Heathland	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.2	Dwarf shrub heath	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.2	Lowland Heathland	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.11	Dwarf shrub heath	NCL015	Northern wet heath (Calluna)	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.11	Upland heathland	NCL015	Northern wet heath (Calluna)	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.11	Lowland Heathland	NCL016	Northern wet heath (Erica tetralix)	10-20	10	CA	Dwarf shrub heath
HEATH	Dwarf shrub heath	F4.11	Dwarf shrub heath	NCL016	Northern wet heath (Erica tetralix)	10-20	10	CA	Dwarf shrub heath
HEATHLOW	Dwarf shrub heath - lowland	F4.2	Lowland Heathland	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATHLOW	Dwarf shrub heath - lowland	F4.2	Lowland Heathland	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATHLOW	Dwarf shrub heath - lowland	F4.2	Dwarf shrub heath	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
HEATHLOW	Dwarf shrub heath - lowland	F4.11	Dwarf shrub heath	NCL016	Northern wet heath (Erica tetralix)	10-20	10	CA	Dwarf shrub heath
HEATHLOW	Dwarf shrub heath - lowland	F4.11	Lowland Heathland	NCL016	Northern wet heath (Erica tetralix)	10-20	10	CA	Dwarf shrub heath
HEATHUP	Dwarf shrub heath - upland	F4.11	Upland heathland	NCL015	Northern wet heath (Calluna)	10-20	10	CA	Dwarf shrub heath
HEATHUP	Dwarf shrub heath - upland	F4.11	Dwarf shrub heath	NCL015	Northern wet heath (Calluna)	10-20	10	CA	Dwarf shrub heath
MONTANE	Montane habitats	E4.3; E4.4	Mountain heaths and willow scrub	NCL001	Alpine & subalpine grasslands	5-10	5	MO	Montane
MONTANE	Montane habitats	E4.3; E4.4	Montane habitats	NCL001	Alpine & subalpine grasslands	5-10	5	MO	Montane
MONTANE	Montane habitats	F2	Mountain heaths and willow scrub	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
MONTANE	Montane habitats	F2	Montane habitats	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
MONTANE	Montane habitats	F2	Mountain heaths and willow scrub	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
MONTANE	Montane habitats	F2	Mountain heaths and willow scrub	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
MONTANE	Montane habitats	F2	Montane habitats	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
MONTANE	Montane habitats	E4.2	Montane habitats	NCL011	Moss & lichen mountain summits	5-10	7	MO	Montane
MONTANE	Montane habitats	E4.2	Mountain heaths and willow scrub	NCL011	Moss & lichen mountain summits	5-10	7	MO	Montane

Table 14.4 continued

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
MOSAIC	Mosaic	F4.2	Various Habitats (site specific)	NCL005	Dry heaths	10-20	10	CA	Dwarf shrub heath
MOSAIC	Mosaic	E4.2	Various Habitats (site specific)	NCL011	Moss & lichen mountain summits	5-10	7	MO	Montane
MOSAIC	Mosaic	F4.11	Various Habitats (site specific)	NCL015	Northern wet heath (Calluna)	10-20	10	CA	Dwarf shrub heath
MOSAIC	Mosaic	D1	Various Habitats (site specific)	NCL019	Raised & blanket bogs	5-10	5	BO	Bogs
MOSAIC	Mosaic	D4.1	Various Habitats (site specific)	NCL020	Rich fens	15-30	15	NSH	Not sensitive to acidification
ROCKINLD	Inland rock	E4.3; E4.4	Limestone Pavements	NCL001	Alpine & subalpine grasslands	5-10	5	NSH	Not sensitive to acidification
ROCKINLD	Inland rock	F2	Inland Rock Outcrop and Scree Habitats	NCL002	Arctic, alpine & subalpine scrub habitats	5-15	5	MO	Montane
SALTMARS	Saltmarsh	A2.54; A2.55; A2.53	Coastal saltmarsh	NCL017	Pioneer, low-mid, mid-upper saltmarsh	20-30	20	NSH	Not sensitive to acidification
SEDMTSUP	Supralittoral sediment	B1.5	Supralittoral sediment	NCL003	Coastal dune heaths	10-20	10	CA	Dwarf shrub heath
SEDMTSUP	Supralittoral sediment	B1.5	Coastal Sand Dunes	NCL003	Coastal dune heaths	10-20	10	CA	Dwarf shrub heath
SEDMTSUP	Supralittoral sediment	B1.4	Coastal Vegetated Shingle	NCL004	Coastal stable dune grasslands	8-15	8	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.4	Coastal Vegetated Shingle	NCL004	Coastal stable dune grasslands	8-15	8	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.4	Coastal Sand Dunes	NCL004	Coastal stable dune grasslands	8-15	8	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.4	Supralittoral sediment	NCL004	Coastal stable dune grasslands	8-15	8	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.8	Supralittoral sediment	NCL010	Moist to wet dune slacks	10-20	10	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.8	Coastal Sand Dunes	NCL010	Moist to wet dune slacks	10-20	10	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.3	Supralittoral sediment	NCL021	Shifting coastal dunes	10-20	10	AG	Acid grassland
SEDMTSUP	Supralittoral sediment	B1.3	Coastal Sand Dunes	NCL021	Shifting coastal dunes	10-20	10	AG	Acid grassland
SOW_D_O	Dystrophic loch	C1.4	Oligotrophic and Dystrophic Lakes	NCL044	Permanent dystrophic waters	3-10	3	FW	Freshwater
SOW_D_O	Dystrophic loch	C1.4	Standing open water and canals	NCL044	Permanent dystrophic waters	3-10	3	FW	Freshwater
SOW_OLI	Standing open water - oligotrophic	C1.1	Oligotrophic and Dystrophic Lakes	NCL023	Permanent oligotrophic waters	3-10	3	FW	Freshwater
SOW_OLI	Standing open water - oligotrophic	C1.1	Standing open water and canals	NCL023	Permanent oligotrophic waters	3-10	3	FW	Freshwater
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wood-Pasture & Parkland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wet Woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Lowland Mixed Deciduous Woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wet Woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wet Woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Broadleaved, mixed and yew woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wood-Pasture & Parkland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wood-Pasture & Parkland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wood-Pasture & Parkland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wood-Pasture & Parkland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1	Wet Woodland	NCL038	Broadleaved deciduous woodland	10-20	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G3	Lowland Beech and Yew Woodland	NCL039	Coniferous woodland	5-15	10	UMW	Broadleaf/Conifer unmanaged woodland

Table 14.4 continued

Interest Code	Interest Name	Nearest EUNIS code with CLnutN	Broad Habitat	NCLCode	NCLClass	CLnutN range (kg N/ha/year)	Recommended CLnutN (kg N/ha/year)	ACCode	AcidityClass
WOODBL	Broad-leaved, mixed & yew woodland	G3	Broadleaved, mixed and yew woodland	NCL039	Coniferous woodland	5-15	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1.6	Lowland Beech and Yew Woodland	NCL040	Fagus woodland	10-20	15	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1.8	Upland Oakwood	NCL041	Acidophilous Quercus woodland	10-15	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1.8	Upland Birchwoods	NCL041	Acidophilous Quercus woodland	10-15	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1.A	Upland Mixed Ashwoods	NCL042	Meso- & eutrophic Quercus woodland	15-20	15	UMW	Broadleaf/Conifer unmanaged woodland
WOODBL	Broad-leaved, mixed & yew woodland	G1.A	Upland Oakwood	NCL042	Meso- & eutrophic Quercus woodland	15-20	15	UMW	Broadleaf/Conifer unmanaged woodland
WOODCON	Coniferous woodland	G3	Coniferous woodland	NCL039	Coniferous woodland	5-15	10	UMW	Broadleaf/Conifer unmanaged woodland
WOODCON	Coniferous woodland	G3.4	Native pine woodlands	NCL043	Pinus sylvestris woodland	5-15	12	UMW	Broadleaf/Conifer unmanaged woodland

Notes:

- Interest Code/Interest Name = Reporting category used by Conservation Agencies and reporting results to JNCC and Defra.
- NCLCode/NCLClass = reporting category for nutrient nitrogen critical loads for reporting results to JNCC and Defra; note, more than one NCLCode can be assigned to each Interest Code.
- EUNIS code: European habitat class assigned to the NCLClass and used for assigning the nitrogen critical loads (CLnutN).
- CLnutN range = the published critical load range for the EUNIS Code.
- Recommended CLnutN: the “Recommended values” for Article 17 reporting (for further information refer to: http://www.apis.ac.uk/indicative-critical-load-values); where no “Recommended value” has been set for an Interest Code, the minimum value of the range will be applied.
- ACCode/AcidityClass = Category for acidity critical loads for reporting to JNCC and Defra; note, more than one ACCode assigned to each Interest Code.

Table 14.5: Summary of unique interest features by designated site type together with number of features with acidity or nitrogen SRCL assigned.

Counts	SACs	SPAs	SSSIs
Total number sites in UK	621	257	6876
Number unique interest features*	119	128	45
Number of these that are habitat features	78	0	45
Number of these that are species features	41	128	0
Number unique interest features with acidity CL	64	56	24
Number of these that are habitat features	47	0	24
Number of these that are species features	17	56	0
Number unique interest features with nitrogen CL	83	96	27
Number of these that are habitat features	61	0	27
Number of these that are species features	22	96	0

*This is the number of unique "Interest Codes" (eg. see Tables 14.3 & 14.4).

15. Assigning critical loads to interest features

The sections below outline how the acidity and nitrogen critical loads are assigned to the interest features of designated sites.

15.1 Assigning nutrient nitrogen critical loads

Empirical critical loads for nitrogen were assigned to EUNIS habitat classes at international workshops, most recently in 2010 (Hettelingh & Bobbink, 2011). The critical loads are published as a range of values because of (a) variations in ecosystem response within regions where those ecosystems have been studied; (b) the finite intervals in nitrogen deposition used in experimental studies; (c) uncertainties in the estimated total nitrogen deposition values from the studies (Achermann & Bobbink, 2003). For the SRCL database critical loads have been applied to each interest feature based on the corresponding EUNIS class(es); in some cases critical loads are not available for a EUNIS class corresponding with the habitat, and if appropriate critical loads have been assigned for the EUNIS class that most closely resembles the feature habitat; for some feature habitats no appropriate critical loads are available.

Tables 14.3 and 14.4 show the critical load ranges for the habitat interest features of UK SACs and SSSIs. They also show the "recommended" nutrient nitrogen critical loads; these are the result of a JNCC report (JNCC, 2013) on the UK approach to assessing conservation status, in which they defined "recommended" values for Annex I habitats (based on Hettelingh & Bobbink, 2011) for use in Article 17 reporting under the Habitats Directive. The SRCL database has been updated so that all national critical load exceedance assessments (for SACs, SPAs, and SSSIs) for Defra and JNCC use these "recommended" values.

15.2 Assigning acidity critical loads

In the UK acidity critical loads are calculated and applied to nine habitat types sensitive to acidification: acid grassland, calcareous grassland, dwarf shrub heath, bog, montane, managed (productive) coniferous woodland, managed (productive) broadleaved woodland, unmanaged (non-productive) coniferous and broadleaved woodland, and freshwaters. The critical loads for terrestrial habitats are mapped nationally for the areas shown in the 1km habitat distribution maps (see Part I).

These maps are based on national scale data sets appropriate for national scale critical load and critical level assessments; however this means they may not include all small areas of sensitive habitats or some coastal habitats. Therefore some designated sites and/or feature habitats may not be included in the areas mapped nationally for critical loads. To overcome this, for SRCL a separate database of national critical loads for terrestrial habitats has been created, that provides critical loads for every 1km square in the UK whether the habitat is known to exist there or not. These SRCL values are based on the same methods and data as the national habitat critical loads database. The appropriate SRCL can then be extracted for the features of each designated site. Woodland areas within designated sites are assumed to be non-productive and therefore in assigning SRCL only the acidity critical loads for non-productive woodland are used. The extracts of the SAC and SSSI SRCL databases (Tables 14.3 and 14.4) show which habitat acidity critical loads are applied to each feature.

The national acidity critical loads for freshwaters are based on the water chemistry data for 1752 selected sites across the UK, mainly upland lakes and streams. Because these depend on site-specific water chemistry they cannot be extrapolated to other sites. For this reason, the SRCL database notes where freshwater critical loads would be appropriate for the feature, but does not include any critical load values.

15.3 Summary of national SRCL database

Tables 14.1-14.4 summarise the reporting categories used and the relationships between interest features, broad habitats, EUNIS classes and NCLCodes and ACCodes. Table 14.5 summarises the number of unique interest features (habitats or species) associated with SACs, SPAs and SSSIs, and the number of interest features that have critical loads assigned to them; and as seen in Tables 14.3 and 14.4 some interest features can be related to more than one NCLCode or ACCode.

Exceedances of SRCL are calculated for each NCLCode and ACCode for each interest feature for each site and then summarised by interest feature, site and country (Section 16). Table 15.1 provides a more summary of the SRCL database at NCLCode and ACCode level by country. It shows:

(a) the number of SACs, SPAS and SSSIs by country
(b) the total number of NCLCodes and ACCodes assigned to all the interest features (including the codes that denote if a feature is not sensitive to acidification and/or eutrophication; see Tables 14.1 and 14.2) for all the sites within a country.
(c) the number of NCLCodes and ACCodes assigned to interest features that also have SRCL values.

Table 15.1: Summary of the SRCL database by country. Features are represented by ACCodes for acidity and NCLCodes for nutrient nitrogen.

Site type	Country	Number sites	SRCL for acidity:		SRCL for nutrient N	
			Number sensitive ACCodes	Number ACCodes with SRCL	Number sensitive NCLCodes	Number NCLCodes with SRCL
SACs	England	231	616	546	777	691
	Wales	85	331	298	441	387
	Scotland	236	902	839	1160	1074
	NI	54	167	153	211	189
	Eng/Wales	7	26	24	42	40
	Eng/Scot	3	3	2	9	8
	UK	616	2045	1862	2640	2389
SPAs	England	78	522	264	877	482
	Wales	17	53	28	81	35
	Scotland	145	288	180	508	292
	NI	14	38	19	69	31
	Eng/Wales	3	22	10	40	27
	Eng/Scot	0	0	0	0	0
	UK	257	923	501	1575	867
SSSIs	England	4115	5419	4187	11286	4232
	Wales	1018	1721	1382	4874	1463
	Scotland	1451	1704	1264	4086	1385
	NI	291	278	232	686	252
	Eng/Wales	0	0	0	0	0
	Eng/Scot	0	0	0	0	0
	UK	6875	9122	7065	20932	7332

16. Calculating exceedances of SRCL

Exceedances are calculated for all site features (by ACCode and NCLCode) that critical loads and deposition data can be assigned to; two sets of metrics are calculated:

(i) Counts:
(ii) Exceeded areas and magnitude of exceedance:

To obtain the area of sites and features exceeding critical loads, the site boundaries have been spatially overlaid on a 1km grid, to generate tables that provide the area of each site within each 1km grid square of the UK; with a unique identifier assigned to each 1km square nationally. These 1km tables are then linked to the SRCL tables of critical loads by designated feature, and finally linked to tables of deposition values. As the deposition data used to date are on a 5km grid, the deposition values are assumed to be constant for all 1km squares within each 5km grid. The SRCL tables define whether the grid-average, moorland or woodland deposition values (Section 9) should be applied to each feature in the critical load exceedance calculations. A linked suite of Python scripts calculate the exceedances for each feature for each 1km square of each site and summarise the data to provide the following metrics (remembering that more than one NCLCode or ACCode can be associated with an individual designated feature):

(a) By site:

- Total number of designated features with SRCL
- Total number of NCLCodes and ACCodes with SRCL
- Number of designated features exceeding SRCL

- Number of NCLCodes and ACCodes exceeding SRCL
- Maximum exceedance for any NCLCode and ACCode; this is the maximum value of positive exceedance for any feature (NCLCode and ACCode) within a site.
- Maximum area exceeded for any NCLCode and ACCode; if the critical load is exceeded and the deposition values are constant across the whole site, the exceeded area would equal the site area; if the deposition values vary across the site (eg, as a result of the site crossing the boundaries between different 5km grid squares with different deposition values) then the exceeded area will be the sum of the 1km portions of the site where deposition exceeds the critical loads.
- Maximum Accumulated Exceedance (AE); this is the sum of the maximum exceedance multiplied by the maximum area exceeded.

(b) By country:

- Total number of sites
- Total number and % of sites with SRCL for one or more designated features
- Total number of designated features with SRCL
- Total number of NCLCodes and ACCodes
- Total number of NCLCodes and ACCodes with SRCL
- Total number and % of sites with exceedance of SRCL for one or more features
- Total number and % of features with exceedance of SRCL
- Total number and % of NCLCodes and ACCodes with exceedance of SRCL
- Total area of all sites
- Total area of all sites with SRCL
- Maximum exceeded area
- Maximum AE
- Maximum Average Accumulated Exceedance (AAE): this is calculated as the maximum AE for the country, divided by the total area of sites with SRCL for the country.

An example of the summary results for nutrient nitrogen by country for SACs, based on CBED nitrogen deposition for 2011-13, is given in Tables 16.1 to 16.4.

By linking the tables of results by site with the spatial site boundary data two types of exceedance map are generated:

(i) Identifying sites with one or more feature exceeded
(ii) Showing the maximum AAE per site

An example of these maps for nutrient nitrogen exceedance for SACs is given in Figure 16.1.

Table 16.1: SAC count results for nutrient nitrogen

Country	**CountryCode**	**Total number of sites**	**Total number of sites with CL values**	**Total number of site features with CL values**	**Total number of NCLCodes**	**Number of sites with any feature exceeded**	**Number of features exceeded**	**Number of NCLCodes exceeded**
England	1	231	197	691	777	185	634	716
Wales	2	85	79	387	441	74	343	381
Scotland	3	236	201	1074	1160	166	677	697
Northern Ireland	4	54	50	189	211	49	173	190
Eng/Wales border	12	7	7	40	42	7	39	41
Eng/Scotland border	13	3	2	8	9	1	6	7
United Kingdom		616	536	2389	2640	482	1872	2032

Table 16.2: SAC count results (as percentages) for nutrient nitrogen

Country	**CountryCode**	**As % of ALL sites/features**	**As % of sites/features with CL**		
		% of sites with CL values	**% of sites with CL that have exceedance**	**% of features exceeded**	**% of NCLCodes exceeded**
England	1	85.3	93.9	91.8	92.1
Wales	2	92.9	93.7	88.6	86.4
Scotland	3	85.2	82.6	63.0	60.1
Northern Ireland	4	92.6	98.0	91.5	90.0
Eng/Wales border	12	100.0	100.0	97.5	97.6
Eng/Scotland border	13	66.7	50.0	75.0	77.8
United Kingdom		87.0	89.9	78.4	77.0

Table 16.3: SAC area results for nutrient nitrogen

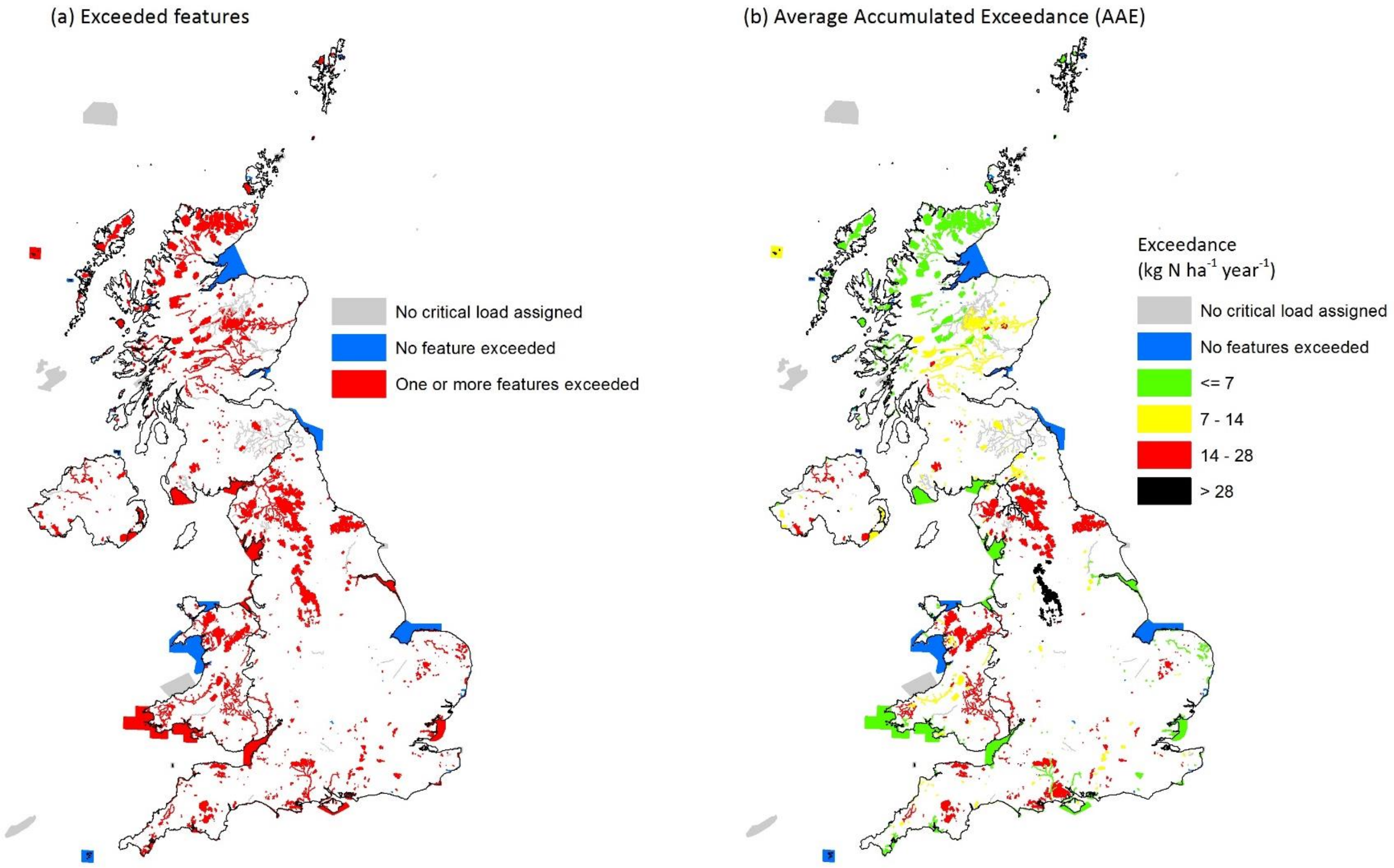
Country	CountryID	Total area of all sites (ha)	Total area of sites with CL values (ha)	Maximum exceeded area (ha)	Maximum AE (keq/year)	Maximum AAE (keq/ha/yr)	Maximum AAE (kg N/ha/yr)
England	1	846008	778240	667780	774015	0.99	13.9
Wales	2	591040	283955	173037	166200	0.59	8.2
Scotland	3	921241	743452	634396	235673	0.32	4.4
Northern Ireland	4	66650	60171	56833	52543	0.87	12.2
Eng/Wales border	12	95072	0	0			
Eng/Scotland border	13	112492	0	0			
United Kingdom		2632503	1865818	1532045	1228431	0.66	9.2

Note: There are zeros in the above table for cross-border regions because the area calculations are based on data for 1km squares and the entire 1km square is assigned to a single country.

Table 16.4: SAC area results (as percentages) for nutrient nitrogen

Country	CountryID	As % of ALL sites	% area of sites with CL that have exceedance
		% area of sites with CL values	
England	1	92.0	85.8
Wales	2	48.0	60.9
Scotland	3	80.7	85.3
Northern Ireland	4	90.3	94.5
Eng/Wales border	12	0.0	
Eng/Scotland border	13	0.0	
United Kingdom		70.9	82.1

Note: There are zeros in the above table for cross-border regions because the area calculations are based on data for 1km squares and the entire 1km square is assigned to a single country.



(a) Exceeded features

(b) Average Accumulated Exceedance (AAE)

Figure 16.1: Exceedance of nutrient nitrogen critical loads for SAC features by CBED deposition for 2011-13.

References

Achermann, B. & Bobbink, R. (eds.) 2003. Empirical critical loads for nitrogen. Environmental Documentation No. 164 Air. Swiss Agency for Environment, Forest and Landscape SAEFL, Berne, Switzerland.

Allen, S.E. 1964. Chemical aspects of heather burning. Journal of Applied Ecology, 1, 347-367.

Allen, S.E., Grimshaw, M., Parkinson, J.A. & Quarmby, C. 1974. Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford.

Armitage, H.F. 2010. Assessing the influence of environmental drivers on the current condition and recovery potential of *Racomitrium* heath. PhD thesis, University of Aberdeen. (also in preparation for submission to GCB).

Batey, T. 1982. Nitrogen cycling in upland pastures of the UK. Philosophical Transactions of the Royal Society of London, B 296, 551-556.

Batterby. R.W. 1994. Critical loads and acid deposition for UK freshwaters. A report of the Critical Loads Advisory Group (Freshwaters sub-group). ECRC Research Paper No. 11, ECRC, University College London, London, UK, 139pp.

Beswick, K.M., Choularton, T.W., Inglis, D.W.F., Dore, A.J. & Fowler, D. 2003. Influences on long-term trends in ion concentration and deposition at Holme Moss. Atmospheric Environment, 37 (14), 1927-1940.

Bobbink, R. & Hettelingh, J.P. (eds) 2011. Review and revision of empirical critical loads and dose-response relationships. Coordination Centre for Effects, National Institute for Public Health and the Environment (RIVM). http://wge-cce.org

Bobbink, R., Boxman, D., Fremstad, E., Heil, G., Houdijk, A. & Roelofs, J. 1992. Critical loads for nitrogen eutrophication of terrestrial and wetland ecosystems based on changes in vegetation and fauna. In: Grennfelt, P. & Thornelof, E. (eds.), Critical loads for nitrogen, Nord 41, Nordic Council of Ministers, Copenhagen, pp. 111.

Bobbink, R., Hornung, M. & Roelofs, J.G.M. 1996. Empirical nitrogen critical loads for natural and semi-natural ecosystems. In: Manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. Texte 71/96, III-1-54, Federal Environmental Agency, Berlin.

Boorman, D.B., Hollis, J.M. & Lilly, A. 1995. Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology Report No.126.

Calver, L. 2003. A suggested improved method for the quantification of critical loads of acidity for peat soils. PhD Thesis, University of York.

Calver, L.J., Cresser, M.S. & Smart, R.P. 2004. Tolerance of *Calluna vulgaris* and peatland plant communities to sulphuric acid deposition. Chemistry and Ecology, 20, 309-320.

Charman, D. 2002. Peatlands and Environmental Change, Wiley, New York.

CLRTAP, 2013. Manual on methodologies and criteria for Modelling and Mapping Critical Loads & Levels and Air Pollution Effects, Risks and Trends. [Access latest version of all chapters via the web version: http://wge-cce.org/Pubications/Mapping_Manual]

COM(2005)446. 2005. Communication from the Commission to the Council and the European Parliament: Thematic Strategy on air pollution:

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0446:FIN:EN:PDF

Cresser, M.S. 2000. The critical loads concept: milestone or millstone for hte new millennium? The Science of the Total Environment, 249, 51-62.

Cresser, M.S., Yesmin, L., Gammack, S.M., Dawod, A., Billett, M.F. 1997. The physical and chemical “stability” of ombrogenous mires in response to changes in precipitation chemistry, Blanket Mire Degradation: Causes, Consequences and Challenges, British Ecological Society Mires Discussion Group Special Publication, 153-159, MLURI, Aberdeen.

Curtis, C.J., Allott, T.E.H., Battarbee, R.W., Harriman, R. & Hall, J. 1996. Screening and validation of the empirical maps of UK freshwater critical loads. ECRC Research Paper No. 12, ECRC, University College London, London, UK, 121pp.

Curtis, C.J., Emmett, B.A., Reynolds, B. & Shilland, J. 2006. How important is N_2O production in removing atmospherically deposited nitrogen from UK moorland catchments? Soil Biology and Biochemistry, 38, 2081-2091.

Curtis, C. & Simpson, G. (eds.) 2004. Summary of research under Defra contract “Recovery of acidified freshwaters in the UK”, EPG/1/3/183. ECRC Research Report No. 98, Environmental Change Research Centre, University College London.

Curtis, C. & Simpson, G. (eds.) 2007. Freshwater Umbrella: The effects of nitrogen deposition and climate change on freshwaters in the UK. Report to Defra under contract CPEA17, July 2007. ECRC Research Report No. 115, Environmental Change Research Centre, University College London, London, 205pp.

Curtis, C. & Simpson, G. (eds.) 2011. Freshwater Umbrella: The effects of nitrogen deposition on freshwaters in the UK. Report to Defra under Contract AQ0803. ECRC Research Report No. 152, University College London, London, UK, 204pp.

Davies, C.E. & Moss, D. 1999. EUNIS Habitat Classification. Draft final report to the European Environment Agency European Topic Centre on Nature Conservation. 1999 Work Programme: Task 4.3. Institute of Terrestrial Ecology, November 1999.

Davies, C.E. & Moss. D. 2002. EUNIS Habitat Classification. 2001 Work Programme, Final Report to the European Environment Agency European Topic Centre on Nature Protection and Biodiversity. Centre for Ecology and Hydrology, February 2002.

Dawod, A.M. 1996. The effect of acidifying pollutant deposition on organic upland soils in the UK. PhD Thesis. University of Aberdeen.

Dore, A.J., Choularton, T.W. & Inglis, D.W.F. 2001. Monitoring studies of precipitation and cap cloud chemistry at Holme Moss in the Southern Pennines. Water, Air and Soil Pollution: Focus 1; 381-390.

Dore, A.J., Vieno, M., Tang, Y.S., Dragosits, U., Dosio, A., Weston, K.J. & Sutton, M.A. 2007. Modelling the atmospheric transport and deposition of sulphur and nitrogen over the United Kingdom and assessment of the influence of SO_2 emissions from international shipping. Atmospheric Environment, 41, 2355-2367.

Edwards, P.N. & Christie, T.M. 1981. Yield models for forest management. Booklet No. 48. Forestry Commission, Edinburgh.

Emmett, B.A. & Reynolds, B. 1996. Nitrogen critical loads for spruce plantations in Wales: is there too much nitrogen? Forestry, 69, 205-214.

Emmett, B.A., Reynolds, B., Stevens, P.A., Norris, D.A., Hughes, S., Gorres, J. & Lubrecht, I. 1993. Nitrate leaching from afforested Welsh catchments – Interactions between stand age and nitrogen deposition. Ambio, 22, 386-394.

Emmett, B.A., Stevens, C.J., Rowe, E.C., Smart, S.M., Henrys, P.A., Maskell, L.C. & Gowing, D.J. 2011. Interpretation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. JNCC Report No. 449, JNCC, Peterborough, UK.

FC. 2001. National inventory of woodland and trees: England. Inventory Report. Forestry Commission, Edinburgh.

FC. 2002a. National inventory of woodland and trees: Scotland. Inventory Report. Forestry Commission, Edinburgh.

FC. 2002b. National inventory of woodland and trees: Wales. Inventory Report. Forestry Commission, Edinburgh.

FC. 2003. National inventory of woodland and trees: Great Britain. Inventory Report. Forestry Commission, Edinburgh.

Fournier, N., Dore, A.J., Vieno, M., Weston, K.J., Dragosits, U. & Sutton, M.A. 2004. Modelling the deposition of atmospheric oxidised nitrogen and sulphur to the United Kingdom using a multi-layer long-range transport model. Atmospheric Environment, 38, 683-694.

Fowler, D., Cape, J.N., Leith, I.D., Choularton, T.W., Gay, M.J. & Jones, A. 1988. The influence of altitude on rainfall composition at Great Dun Fell. Atmospheric Environment, 22, 1355-1362.

Frissel, M.J. 1978. Cycling of mineral nutrients in agricultural ecosystems. Developments in Agricultural and Managed Forest Ecology, 3. Elsevier, Amsterdam, 356pp.

Fuller, R.M., Smith, G.M., Sanderson, J.M., Hill, R.A. & Thomson, A.G. 2002a. The UK Land Cover Map 2000: construction of a parcel based vector map from satellite images. Cartographic Journal, 39, 115-25.

Fuller, R.M., Smith, G.M., Sanderson, J.M., Hill, R.A., Thomson, A.G., Cox, R., Brown, N.J. & Gerard, F. 2002b. Countryside Survey 2000 Module 7: Land Cover Map 2000. Final Report, CSLCM Final CEH report to Defra.

Gammack, S.M., Smith, C.M.S. and Cresser, M.S. 1995. The approach used for mapping critical loads for ombrotrophic peats in Great Britain, Proceedings of a Conference on: Acid Rain and its Impact: The Critical Loads Debate, R.W. Battarbee (Ed.), 180-183, Ensis Publishing, London.

Gordon, C., Emmett, B.A., Jones, M.L.M., Barden, T., Wildig, J., Williams, D.L., Woods, C., Bell, S.A., Norris, D.A., Ashenden, T.W., Rushton, S.P. & Sanderson, R.A. 2001. Grazing/nitrogen deposition interactions in upland acid moorland. Welsh Office, Countryside Council for Wales, National Power, Powergen, Eastern Generation Joint Environment Programme, 83pp.

Gundersen, P. 1999. Nitrogen status and impact of nitrogen input in forests – indicators and their possible use in critical load assessment. Conference on Critical Loads, Copenhagen 1999.

Haines-Young, R., Barr, C.J., Black, H.I.J., Briggs, D.J., Bunce, R.G.H., Clarke, R.T., Cooper, A., Dawson, F.H., Firbank, L.G., Fuller, R.M., Furse, M.T., Gillespie, M.K., Hill, R., Hornung, M., Howard, D.C., McCann, T., Morecroft, M., Petit, S., Sier, A.R.J., Smart, S.M., Smith, G.M., Stott, A., Stuart, R.C. & Watkins, J.W. 2000. Accounting for nature: assessing habitats in the UK countryside. London: CEH/DETR.

Hall, J., 2001. Harmonising of ecosystem definitions. In: Modelling and Mapping of Critical Thresholds in Europe. Status Report 2001, Coordination Centre for Effects. Eds: M. Posch, P.A.M. de Smet, J.P.Hettelingh & R.J. Downing. RIVM Report No. 259101010.

Hall, J., Emmett, B., Garbutt, A., Jones, L., Rowe, E., Sheppard, L., Vanguelova, E., Pitman, R., Britton, A., Hester, A., Ashmore, M., Power, S. & Caporn, S. 2011. UK Status Report July 2011: Update to empirical critical loads of nitrogen. Report to Defra under contract AQ801 Critical Loads and Dynamic Modelling. http://cldm.defra.gov.uk

Hall, J., Ullyett, J., Heywood, L., Broughton, R., Fawehinmi, J. & 31 UK experts. 2003. Status of UK critical loads: Critical loads methods, data and maps. February 2003. Report to Defra (Contract EPG 1/3/185). http://cldm.defra.gov.uk

Hall, J., Ullyett, J., Heywood, L., Broughton, R. & 12 UK experts. 2004. Update to: The Status of UK Critical Loads – Critical Loads Methods, Data and Maps. February 2004. Report to Defra (Contract EPG 1/3/185). http://cldm.defra.gov.uk

Hallsworth, S., Sutton, M.A., Dore, A.J., Dragosits, U., Tang, Y.S. & Vieno, M. 2010. The role of the indicator choice in quantifying the ammonia threat to the Natura 2000 network. Environmental Science & Policy, 13, 671-687.

Hamilton, G.L. 1975. Forest Mensuration Handbook. Forestry Commission Booklet 39. HMSO, London.

Henriksen, A. & Posch, M. 2001. Steady-state models for calculating critical loads of acidity for surface waters. Water, Air and Soil Pollution: Focus 1, 375-398.

Hettelingh, J.-P., Downing, R.J. & Smet, P.A.M. (eds.) 1991. Mapping critical loads for Europe: CCE Technical Report No. 1, July 1991. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. http://wge-cce.org/

Hettelingh, J.-P., Posch, M., de Smet, P.A.M. & Downing, R.J. 1995. The use of critical loads in emission reduction agreements in Europe. Water, Air and Soil Pollution, 85, 2381-2388.

Hettelingh, J.-P., Posch, M. & Slootweg, J. (eds.) 2009. Progress in the modelling of critical thresholds, impacts to plant species diversity and ecosystem services in Europe. CCE Status Report 2009, Coordination Centre for Effects, RIVM, Bilthoven, Netherlands http://wge-cce.org/

Hicks, K. & Ashmore, M.R. 2010. Dose-response relationships in air pollution and implications for current permitting approach. Natural England Project Reference Number: 09-002.

Hornung, M., Sutton, M.A. & Wilson, R.B. 1995a. Mapping and modelling of critical loads of nitrogen – a workshop report. Report of a workshop held at Grange-over-Sands, Cumbria, UK, under the auspices of the UNECE Convention on Long-Range Transboundary Air Pollution, Working Group on Effects, 24-26 October 1994. Institute of Terrestrial Ecology, Edinburgh.

Hornung, M., Bull, K.R., Cresser, M., Ullyett, J., Hall, J.R., Langan, S.J., Loveland, P.J. & Wilson, M.J. 1995b. The sensitivity of surface waters in Great Britain to acidification predicted from catchment characteristics. Environmental Pollution, 87, 207-214.

Hornung, M., Bull, K., Cresser, M., Hall, J., Langan, S., Loveland, P. and Smith, C. 1995c. An empirical map of critical loads for soils in Great Britain, Environmental Pollution, **90**, 301-310.

Hornung, M., Bull, K., Cresser, M., Hall, J., Loveland, P., Langan, S., Reynolds, B. and Robertson, W.H. 1995d. Mapping critical loads for the soils of Great Britain, Proceedings of a conference on: Acid Rain and its Impact: The Critical Loads Debate, 43-51, Ensis Publishing, London.

Jefferies, R.L. & Perkins, N. 1977. The effects on the vegetation of the additions of inorganic nutrients to salt march soils at Stiffkey, Norfolk. Journal of Ecology 65, 867-882.

JNCC, 2013. The UK Approach to Assessing Conservation Status for the 2013 EU Habitats Directive Article 17 Reporting. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6563

Kennedy, F. 2003. How extensive are the impacts of nitrogen pollution in Great Britain's forests? Forest Research Annual Report and Accounts, 2001-2002, pp. 66-75.

Kiehl, K., Esselink, P. and Bakker, J.P. 1997. Nutrient limitation and plant species composition in temperate salt marches. Oecologia 111, 325-330.

Langan, S.J., Sverdrup, H.U. & Coull, M. 1995. The calculation of base cation release from the chemical weathering of Scottish soils using the PROFILE model. Water, Air and Soil Pollution, 85, 2497-2502.

Lavers, G.M. 1969. The strength properties of timbers. Forest Products Research Bulletin No. 50. HMSO, London.

Morton, D., Rowland, C., Wood, C., Meek, L., Marston, C., Smith, G., Wadsworth, R. & Simpson, I.C. 2011. Final Report for LCM2007 – the new UK Land Cover Map. CS Technical Report No. 11/07. Centre for Ecology & Hydrology.

Mitsch, W.J. & Gosselink, J.P. 2000. Wetlands, 3rd edn. Wiley, New York.

NEGTAP. 2001. Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK. Report prepared by the National Expert Group on Transboundary Air Pollution on behalf of the UK Department of the Environment, Food and Rural Affairs (Defra) and the Devolved Administrations. http://pollutantdeposition.defra.gov.uk/reports

Nilsson, J. (ed.) 1986. Critical loads for sulphur and nitrogen. Report 1986:11. Nordic Council of Ministers, Copenhagen, Denmark.

Nilsson, J. & Grennfelt, P. 1988, Critical loads for sulphur and nitrogen. Report 1988:15. UNECE/Nordic Council of Ministers, Copenhagen, Denmark.

Parveen, Z., Smart, R., White, C., Gammack S., Deacon, C. and Cresser, M. 2001. Effects of simulated H_2SO_4 deposition on *Calluna vulgaris*/peat microcosms and associated soil solutions, Chemistry and Ecology, 17, 293-314.

Perkins, D.F. 1978. The distribution and transfer of energy and nutrients in the Agrostis-Festuca grassland ecosystem. In: Production Ecology of British Moors and Montane Grasslands (eds. O.W. Heal & D.F. Perkins), Ecological Studies 27, 374-495, Springer-Verlag, Berlin.

Pitman, R.M., Vanguelova, E.I. and Benham, S.E. 2010. The effects of phytophagous insects on water and soil nutrient concentrations and fluxes through forest stands of the Level II monitoring network in the UK. Science of the Total Environment, 409, 169-181.

Plassmann, K., Edwards-Jones, G., Jones, M.L.M. 2009. The effects of low levels of nitrogen deposition and grazing on dune grassland. Science of the Total Environment 407, 1391-1404.

Posch, M., de Smet, P.A.M., Hettelingh, J.-P. & Downing, R.J. (eds.) 2001. Modelling and mapping of critical thresholds in Europe. Status Report 2001: Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. http://wge-cce.org/

Posch, M., de Smet, P.A.M., Hettelingh, J.-P. & Downing, R.J. (Eds.) 1999. Calculation and Mapping of Critical Thresholds in Europe: Status Report 1999. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. http://wge-cce.org/

Posch, M., de Smet, P.A.M. & Hettelingh, J.-P. 1999. Critical loads and their exceedances in Europe: an overview. In: Posch, M., de Smet, P.A.M., Hettelingh, J.-P. & Downing, R.J. (Eds.), Calculation and Mapping of Critical Thresholds in Europe: Status Report 1999. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. pp 3-11. http://wge-cce.org/

Posch, M., de Vries, W. & Hettelingh, J.-P. 1995. Critical loads of sulphur and nitrogen. In: Posch, M., de Smet, P.A.M., Hettelingh, J.-P. & Downing, R.J. (Eds.), Calculation and Mapping of Critical Thresholds in Europe: Status Report 1995. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. pp 31-41. http://wge-cce.org/

Posch, M. & Hettelingh, J.-P. 1997. Remarks on critical load calculations. In: Posch, M., de Smet, P.A.M., Hettelingh, J.-P. & Downing, R.J. (Eds.), Calculation and Mapping of Critical Thresholds in Europe: Status Report 1997. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. pp 25-28. http://wge-cce.org/

Posch, M., Kamari, J., Forsius, M., Henriksen, A. & Wilander, A. 1997. Exceedance of critical loads for lakes in Finland, Norway and Sweden: Reduction requirements for acidifying nitrogen and sulphur deposition. Environmental Management, 21(2), 291-304.

Posch, M., Slootweg, J. & Hettelingh, J.-P. (eds) 2012. Modelling and mapping of atmospherically induced ecosystem impacts in Europe. CCE Status Report 2012. Coordination Centre for Effects, RIVM, Bilthoven, Netherlands. http://wge-cce.org/

Power, S.A., Ashmore, M.R., Terry, A.C., Caporn, S.J.M., Pilkington, M.G., Wilson, D.B., Barker, C.G., Carroll, J.A., Cresswell, N., Green, E.R. & Heil, G.W. 2004. Linking field experiments to long-term simulation of impacts of nitrogen deposition on heathlands and moorlands. Water, Air and Soil Pollution: Focus 4, 259-267.

Preston, C.D., Pearman, D.A. & Dines, T.D. (eds.) 2002. New Atlas of the British and Irish Flora. Oxford: Oxford University Press.

Preston, C.D., Telfer, M.G., Roy, D.B., Carey, P.D., Hill, M.O., Meek, W.R., Rothery, P., Smart, S.M., Smith, G.M., Walker, K.J. & Pearman, D.A. 2003. The changing distribution of the flora of the United Kingdom: technical report. Report to DEFRA on CEH project C01093. CEH Monks Wood, Huntingdon.

Proctor, M.C.F. and Maltby, E. 1998. Relations between acid atmospheric deposition and the surface pH of some ombrotrophic bogs in Britain, *Journal of Ecology*, **86**, 329-340.

Rawes, M. & Heal, O.W. 1978. The blanket bog as part of a Pennine moorland. In: Production ecology of British moors and montane grasslands (eds. O.W. Heal & D.F. Perkins), Ecological Studies 27, 224-243. Springer-Verlag, Berlin.

Remke, E., Brouwer, E., Kooijman, A.M., Blindow, I., Esselink, H. & Roelefs, J.G.M. 2009a. Even low to medium nitrogen deposition impacts vegetation of dry, coastal dunes around the Baltic Sea. Environmental Pollution 157: 792–800.

Remke, E., Brouwer, E., Kooijman, A., Blindow, I. and Roelofs, J.G.M. 2009b. Low atmospheric nitrogen loads lead to grass encroachment in Coastal Dunes, but only on acid soils. Ecosystems 12, 1173-1188.

Reynolds, B., Hornung, M. & Stevens, P.A. 1987. Solute budgets and denudation rate estimates for a mid-Wales catchment. Catena, 14, 13-23.

Rodwell, J. S. 1991(a). British plant communities. Vol. 1. Woodlands and scrub. Cambridge: Cambridge University Press.

Rodwell, J. S. 1991(b). British plant communities. Vol. 2. Mires and heaths. Cambridge: Cambridge University Press.

Rodwell, J. S. 1992. British plant communities. Vol. 3. Grasslands and montane communities. Cambridge: Cambridge University Press.

Rodwell, J. S. 1995. British plant communities. Vol. 4. Aquatic communities, swamps and tall-herb fens. Cambridge: Cambridge University Press.

Rodwell, J. S. 2000. British plant communities. Vol. 5. Maritime communities and vegetation of open habitats. Cambridge: Cambridge University Press.

RoTAP. 2012. Review of Transboundary Air Pollution: Acidifcation, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Contract Report to the Department for Environment, Food and Rural Affairs. Centre for Ecology and Hydrology. www.rotap.ceh.ac.uk

Sanger, L.J., Billett, M.F. and Cresser, M.S. 1996. The effect of precipitation chemistry upon anion and cation fluxes from ombrotrophic peat in the UK, *Journal of Applied Ecology*, **33**, 754-772.

Skiba, U. & Cresser, M. 1989. Prediction of long-term effects of rainwater acidity on peat and associated drainage water chemistry in upland areas. Water Research, 23, 1477-1482.

Slootweg, J., Posch, M. & Hettelingh, J-P. 2008. Summary of National Data. In: Hettelingh, J-P. Hettelingh, M.Posch & Slootweg, J (eds.), Critical Load, Dynamic Modelling and Impact Assessment in Europe. CCE Status Report 2008, Coordination Centre for Effects, Bilthoven, Netherlands. http://wge-cce.org/.

Smith, C.M.S., Cresser, M.S. and Mitchell, R.D.J. 1992. Sensitivity to acid deposition of dystrophic peat in Great Britain, Ambio, **22**, 22-26.

Smith, R.I., Fowler, D., Sutton, M.A., Flechard, C. & Coyle, M. 2000. Regional estimation of pollutant gas deposition in the UK: model description, sensitivity analyses and outputs. Atmospheric Environment, 34, 3757-3777.

Smith, R.I. & Fowler, D. 2001. Uncertainty in wet deposition of sulphur. Water, Air and Soil Pollution: Focus 1: 341-354.

Stedman, J.R., Kent, A.J., Grice, S., Bush, T.J. & Derwent, R.G. 2007. A consistent method for modelling PM10 and PM2.5 concentrations across the United Kingdom in 2004 for air quality assessment. Atmospheric Environment, 41, 161-172.

Stevens, C.J., Dise, N.B., Mountford, J.O. & Gowing, D.J. 2004. Impact of nitrogen deposition on the species richness of grasslands. Science, 303 (5665), 1876-1879.

Stevens, C.J., Smart, S.M., Henrys, P., Maskell, L.C., Walker, K.J., Preston, C.D., Crowe, A., Rowe, E., Gowing, D.J. & Emmett, B.A. 2011. Collation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives. JNCC Report No. 447 , JNCC, Peterborough, UK.

Strengbom, J., Nordin, A., Nasholm, T. & Ericson, L. 2002. Parasitic fungus mediates change in nitrogen-exposed boreal forest vegetation. Journal of Ecology, 90, 61-67.

Sverdrup, H., de Vries, W. & Henriksen, A. 1990. Mapping critical loads. Guidance to criteria, methods and examples for mapping critical loads and areas where they have been exceeded. Annex to the UNECE Task Force on Mapping manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. Report 1990: 14, Nord 1990: 98. Copenhagen: Nordic Council of Ministers.

Taylor, C.M.A. 1991. Forest fertilisation in Britain. Bulletin 95. Forestry Commission, Edinburgh.

Terry, A.C., Ashmore, M.R., Power, S.A., Allchin, L. & Heil, G.W. 2004. Modellilng of impacts of elevated atmospheric nitrogen deposition on Calluna dominated ecosystems in the UK. Journal of Applied Ecology, 41, 897-909.

UBA, 1996. Manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. UNECE Convention on Long-Range Transboundary Air Pollution. Federal Environmental Agency (Umweltbundesamt), Berlin. [NB. For latest version of manual see reference for CLRTAP 2013]

UKREATE. 2010. Terrestrial Umbrella: Effects of Eutrophication and Acidification on Terrestrial Ecosystems. CEH Contract Report NEC03425. Defra Contract No. AQ0802.

Van den Berg, L.J.L., Vergeer, P., Rich, T.C.G., Smart, S.M., Guest, D. & Ashmore, M.R. 2010. Direct and indirect effects of nitrogen deposition on species composition change in calcareous grasslands. Global Change Biology, doi: 10.1111/j.1365-2486.2010.02345.x

Van Wijnen, H.J. and Bakker, J.P. 1999. Nitrogen and phosphorus limitation in a coastal barrier salt marsh: the implications for vegetation succession. Journal of Ecology 87, 265-272.

Vanguelova, E.I., Barsoum, N., Benham, S., Broadmeadow, M., Moffat, A., Nisbet, T., Pitman, R., 2007. Ten Years of Intensive Environmental Monitoring of British Forests. Forestry Commission Information Note 88, Edinburgh.

Vanguelova, E.I., Pitman, R. 2009. Impact of N deposition on soil and tree biochemistry in both broadleaved and coniferous stands in the UK. In "6th International Symposium on Ecosystem Behaviour BIOGEOMON 2009", Liisa Ukonmaanoho, Tiina M. Nieminen and Mike Starr (eds.), ISSN 1795-150X, pp.184

Vanguelova, E.I., Benham, S., Pitman, R., Moffat, A., Broadmeadow, M., Nisbet, T., Durrant, D., Barsoum, N., Wilkinson, M., Bochereau, F., Broadmeadow, S., Hutchings, T., Crow, P., Durrant-Houston, T., Taylor, P. 2010. Chemical fluxes in time through forest ecosystems in the UK – soil response to pollution recovery. Environmental Pollution, 158: 1857-1869.

Vieno, M., Dore, A.J., Bealey, W.J., Stevenson, D.S. & Sutton, M.A. 2010. The importance of source configuration in quantifying footprints of regional atmospheric sulphur deposition. Science of the Total Environment, 408, 985-995.

Williams, D.L., Emmett, B.A., Brittain, S.A., Pugh, B., Hughes, S., Norris, D., Meadows, K., Richardson, C., & Bell, S. 2000. Influence of forest type, structure and management on nitrate leaching. Contract report (Project C00521) by the Centre for Ecology and Hydrology to National Power/Powergen/Eastern Power Joint Environment Programme (GT00233), pp56.

Yesmin, L., Gammack, S.M. and Cresser, M.S. 1996. Effects of atmospheric nitrogen deposition on ericoid mycorrhizal infection of *Calluna vulgaris* growing in peat soils, *Applied Soil Ecology*, **4**, 49-60.