STATUS OF UK CRITICAL LOADS AND EXCEEDANCES

PART 1 – CRITICAL LOADS AND CRITICAL LOADS MAPS

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1 INTRODUCTION

The UK National Focal Centre (NFC) at CEH (previously ITE) Monks Wood is responsible for co-ordinating critical loads mapping activities in the UK and compiling national critical loads data sets and maps from data supplied by UK experts. In 1998 the UK NFC produced the report "Status of UK Critical Loads and Exceedances, Part 1 – Critical Loads and Critical Loads maps" (Hall *et al.*, 1998). This report documented the methods used to calculate national critical loads and the critical load values based on these methods were submitted to the Coordination Centre for Effects (CCE) in the Netherlands in January 1998. The CCE are responsible for compiling critical loads data sets and maps at the European scale from national contributions.

Since the 1998 report was published, research by UK experts has lead to changes in some of the data sets used to calculate critical loads. However, much of the information given in the 1998 report (Hall *et al.*, 1998) remains relevant today. This document highlights the changes that have been made to national critical loads calculations since that time. It should be noted that the methods applied in the UK for calculating acidity and nutrient nitrogen critical loads continue to conform to the methods recommended by the International Cooperative Programme on Mapping and Modelling (UBA, 1996), under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP).

Acidity critical loads for non-woodland ecosystems (ie, acid grassland, calcareous grassland and heathland) are still based on the empirical acidity critical loads map for soils. The Simple Mass Balance (SMB) equation continues to be applied to woodland (coniferous and deciduous) ecosystems, though changes have been made to some of the input parameters and a new criterion has been used to determine acidity critical loads for organic forested soils. The methods for deriving empirical acidity critical loads for freshwaters remain unchanged. However, new data on base cation deposition, base cation uptake and nitrogen uptake, have led to new values for the maximum critical loads for sulphur and nitrogen for all ecosystems; these critical loads are used in the calculation of critical load exceedances.

The methods and values used to define empirical critical loads for nutrient nitrogen for terrestrial ecosystems remain the same as in the 1998 report (Hall *et al.*, 1998). The nutrient nitrogen mass balance equation for woodland ecosystems now includes revised values for nitrogen uptake. However, the critical loads for woodland ecosystems are based on the minimum of empirical and mass balance values.

National critical loads data, taking these revisions into account, were submitted to the CCE in February 2001.

A summary of the changes made to critical load calculations and the minimum and maximum values across the UK are summarised (Appendix 3) and maps of the old (1998) versus new (2001) calculations presented (Appendix 4).

2 CRITICAL LOADS OF ACIDITY - TERRESTRIAL ECOSYSTEMS

Two methods are used in the UK for calculating acidity critical loads for terrestrial ecosystems: the empirical approach is applied to non-woodland ecosystems and the Simple Mass Balance (SMB) equation to woodland ecosystems.

2.1 Empirical – soil-vegetation systems: acid grassland, calcareous grassland and heathland

The empirical acidity critical loads for soils continue to be used for the non-woodland ecosystems (i.e. acid grassland, calcareous grassland and heathland). The methods used to define the ecosystem areas and assign critical loads is unchanged from 1998 (Hall *et al.*, 1998). The current form of the SMB equation is only suitable for woodland ecosystems; further work on parameterisation and testing of the equation would be required to apply the SMB to non-woodland ecosystems in the UK.

2.2 Simple Mass Balance (SMB) equation

The SMB equation is the most commonly used model in Europe for the calculation of acidity critical loads for forest ecosystems. In the UK we apply this method to coniferous and deciduous woodland ecosystems, except for wooded areas on peat soils, where the SMB is inappropriate; in such areas empirical critical loads of acidity are applied (Smith *et. al*., 1993).). The SMB equations used are given in Appendices 1 and 2.

Chemical criteria and limits

In 1998, the critical chemical criterion used in the SMB for all soil types (other than peats) was a critical molar Ca:Al ratio of one. However, recent work (Hall *et al.*, 2001a & 2001b) has highlighted that the Ca:Al ratio is more appropriate for mineral soils than organic soils; for the latter a critical pH is considered to be more suitable. This finding was confirmed at the recent UNECE Workshop on Chemical Criteria and Critical Limits, held in York 19-21 March 2001, where one of the recommendations was that critical pH was the preferred criterion for organic soils. Therefore, in preparing critical loads for the February 2001 data submission to the CCE, a Ca:Al ratio of one was applied to forested mineral soils and a critical pH of 4.0 to forested organic soils, with the exception of peat soils, where empirical critical loads continue to be used. The pH value of 4.0 is recommended in the UNECE Mapping Manual (UBA, 1996).

Gibbsite equilibrium constant

The values for the gibbsite equilibrium constant (K_{gibb}), which simulate the relationship between aluminium and hydrogen ions in soil solution, have been set separately for mineral and organic soils. The value now applied to mineral soils (950 m^6/eq^2) was previously applied to all soil types. For organic soils, a value of 9.5 m^6/eq^2 has been used. These values are based on the percentage of organic matter in the soil and are recommended in the UNECE Mapping Manual (UBA, 1996).

Calcium deposition inputs to the SMB

When using the Ca:Al criterion in the SMB, values for total (wet plus dry, marine plus non-marine) calcium deposition to woodland need to be included in the critical load calculations (Appendix 1). Previously the 20km data for 1992-94 had been used. This has now been updated to the 5km resolution data for 1995-97, provided by CEH Edinburgh (Smith *et al*., 2000; Smith & Fowler, 2001).

Base cation, calcium and nitrogen uptake

The methods used to estimate base cation, calcium and nitrogen losses by the uptake and removal through the harvesting of forests and woodlands, are unchanged from those given in the 1998 report (Hall *et al.*, 1998). The uptake values used still represent the theoretical maximum removal, which assume that potential timber yields are achieved, ie, no correction is made for the "best guess" of the actual timber yield. As this method can overestimate timber removal, it represents a "worst case" for base cation removal and a "best case" for nitrogen removal (Hall *et al.*, 1998).

Calcium uptake values are required for the SMB equation, when using the Ca:Al criterion. Base cation uptake values for are needed in the calculation of the maximum critical load of sulphur (CLmaxS), and nitrogen uptake values for deriving the minimum critical load of nitrogen (CLminN) and mass balance critical loads of nutrient nitrogen.

Since 1998, further research has been carried out by Forest Research to improve the estimates of uptake values for coniferous and deciduous trees. They concluded that the 1998 values were too low because: (a) they excluded biomass removal during forest thinning; (b) they used very low wood nitrogen concentrations due to measurements on linear cores, which underestimate the contribution from sap wood. Therefore, Forest Research investigated the effect of adding thinnings into the uptake estimates for their Forestry Level II sites. The new uptake values provided by Forest Research are given in Table 1; the values are based on results for three Level II oak sites for deciduous woodland and four Level II sitka spruce sites for coniferous woodland. The oak sites are all on calcium-rich soils, so uptake values for deciduous trees on calcium-poor soils were derived empirically. The average values for the coniferous and deciduous sites are used in the national critical loads mapping exercise. However, it should be recognised that there are still uncertainties with this approach, since this provides only:

(i) three default values for calcium and base cation uptake (coniferous on all soil types, deciduous on calcium-poor soils, deciduous on calcium-rich soils);
(ii) two default values for nitrogen uptake (ie, no separation for calcium-rich and calcium-poor soils necessary for nitrogen);

These default values are then applied to appropriate areas (see below) at the national scale. A range of uptake values for coniferous and deciduous woodland, for more sites of different soil types across the UK would improve the critical load calculations further.

Forest Research will recommend further revisions to these figures in the future when they have improved nutrient concentration data available for all 10 Level II sites.

We have also changed the method used to identify areas of calcium-rich and calcium-poor soils. In 1998, we used a 1km map, which divided soils into three sensitivity classes depending on their base saturation and pH (Hall *et al.*, 1998). However, we were concerned that this did not accurately reflect the calcium richness of the soils across the UK, leading to uptake values being inappropriately assigned in some areas. Therefore, for the 2001 data submission, we used the 1km map of calcium weathering rates (also used in the SMB equation), assigning those grid squares with a low weathering rate (ie, <= 0.5 keq ha^{-1} $year^{-1}$) the calcium-poor uptake value, and squares with a higher weathering rate the calcium-rich uptake value. We believe this gives a better representation of areas of calcium-rich and calcium-poor soils at the national scale.

Table 1.
Base cation, calcium and nitrogen uptake values for coniferous and deciduous woods.

Woodland Type	Uptake Values (keq ha^{-1} $year^{-1}$) January 1998			Uptake Values (keq ha^{-1} $year^{-1}$) February 2001		
	base cations	calcium	nitrogen	base cations	calcium	nitrogen
Conifers	0.253	0.117	0.279	0.25	0.12	0.5
Deciduous Ca-rich soils	0.613	0.516	0.278	0.85	0.7	0.5
Deciduous Ca-poor soils	0.171	0.076	0.278	0.4	0.33	0.5

3 CRITICAL LOADS OF ACIDITY – FRESHWATER ECOSYSTEMS

Two empirical models have been used in the UK to calculate sulphur and acidity critical loads for freshwaters: the Diatom model and the Steady-State Water Chemistry (SSWC) model. In addition, to provide the critical loads needed for the calculation of exceedances (ie the minimum and maximum critical loads of sulphur and nitrogen) for work under the CLRTAP, the First-order Acidity Balance (FAB) model has been used.

3.1 Empirical models

The methods for calculating empirical acidity critical loads for freshwaters (ie, the Diatom model and the SSWC model) remain unchanged. However, the number of sites to which the models have been applied has increased, with an extra 25 sites in Great Britain, bringing the total to 1470, plus 140 sites in Northern Ireland, giving a total of 1610 sites in the UK.

3.2 First-order Acidity Balance model

FAB is a catchment-based model and therefore takes into account catchment specific data such as deposition, forest areas and lake to catchment ratios. To derive these parameters the catchment boundaries and areas are required. The boundaries for the additional 25 sites in Great Britain have been defined on Ordnance Survey maps and digitised under the DETR Freshwater Umbrella contract at University College London (UCL). The grid references for the 140 sites in Northern Ireland were provided to the Department of the Environment in Northern Ireland (DOE NI), whose GIS staff used an Ordnance Survey Northern Ireland digital elevation model (DEM) to define the catchment boundaries and calculate the catchment areas. However, for 36 of these sites it was not possible to determine the catchment boundaries from the DEM, so these were defined and digitised manually at UCL.

Many of the input parameters to FAB (eg, catchment-weighted estimates of nitrogen immobilisation and denitrification) remain the same as those used in 1988. The catchment-weighted runoff values for Great Britain are still based on the 1941-60 data set. However, for the sites in Northern Ireland catchment-weighted values based on 1961-90 runoff data were provided by DOE NI. The areas of forestry in the catchments in Northern Ireland were determined from the CORINE land cover map (CORINE, 1994).

4 Critical Loads of Nutrient Nitrogen

Critical loads for nutrient nitrogen ($CL_{nut}N$) can be calculated using two different methods, empirical and mass balance (UBA, 1996). In the UK the empirical, mass balance, or both of these approaches, have been used to calculate nutrient nitrogen critical loads for the same terrestrial ecosystems for which acidity critical loads are determined. Nutrient nitrogen critical loads have not been calculated for UK freshwaters. The small, upland catchments selected for the calculation of acidity critical loads are not considered to be at risk from eutrophication (ie excess nitrogen as a nutrient), since they are more likely to be phosphorous, rather than nitrogen limited systems.

4.1 Empirical critical loads of nutrient nitrogen

The empirical critical loads of nutrient nitrogen applied to terrestrial in the UK (Hall *et al.*, 1998), have not changed since 1998. In addition to the values previously agreed upon in the UK for acid grassland, calcareous grassland, heathland and deciduous woodland, an empirical value (13 kg N ha^{-1} $year^{-1}$) has now been assigned to coniferous woodland ecosystems, on the basis of changes in ground flora. This value has been assigned to areas of coniferous woodland by selecting those 1km squares where the coniferous woodland class (ie, class 16) on the combined CEH Land Cover Map of Great Britain and the CORINE land cover map covering Northern Ireland (Hall *et al.*, 1998), occupies >5% of a grid square.

However, following the UNECE Workshop on Chemical Criteria and Critical Limits (York, March 2001), it has been agreed that there will be a UNECE Workshop in Autumn 2002 (probably November) to review the empirical critical loads for nutrient nitrogen. This will incorporate the results of recent research on the effects of excess nitrogen deposition on plants and habitats, to review and revise the values where necessary. Following this workshop the UK will revise its empirical nutrient nitrogen values accordingly.

4.2 Mass balance critical loads for nutrient nitrogen

The mass balance approach has been used to calculate critical loads for coniferous and deciduous woodland ecosystems. In 1998, for deciduous woodland, the minimum value from the empirical or mass balance approaches was used to set the critical load for each 1km square of this woodland ecosystem. In 2001, it was agreed that the same approach should be applied to coniferous woodland ecosystems, hence, the assignment of an empirical critical load as described above. This means that national maps of nutrient nitrogen critical loads for woodland ecosystems are set to protect either changes in ground flora or excess nitrogen leaching, depending on which method gives the lowest critical load value in any grid square.

The mass balance equation for $CL_{nut}N$ is:

$$CL_{nut}N = N_u + N_i + N_{le(acc)} + N_{de}$$

Where N_u = nitrogen uptake

N_i = nitrogen immobilisation

$N_{le(acc)}$ = acceptable level of nitrogen leaching

N_{de} = denitrification

The derivation of, and values for N_i, N_{de} and $N_{le(acc)}$ remain unchanged from the 1998 report (Hall *et al.*, 1998). The nitrogen uptake values for the woodland ecosystems have been revised as described in Section 2.2 above, while the values for other ecosystems have not been changed.

5 Critical Loads Function

The Executive Body of the CLRTAP adopted the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Gothenburg (Sweden) on 30 November 1999. The Protocol sets emission ceilings for 2010 for four pollutants: sulphur, oxidised nitrogen, ammonia and Volatile Organic Compounds (VOCs). Consequently, in addition to examining the impact of excess nitrogen as a nutrient (ie, eutrophication), it became necessary to consider the combined acidifying effects of both sulphur and nitrogen deposition. To examine these effects, the so-called "Critical Loads Function" (CLF) was developed in Europe (Posch *et al.*, 1999; Posch & Hettelingh, 1997; Posch *et al.*, 1995; Hettelingh *et al.*, 1995). The CLF defines separate acidity critical loads in terms of sulphur and nitrogen, referred to as the "minimum" and "maximum" critical loads of sulphur and nitrogen. These "new" acidity critical loads can be compared with sulphur and nitrogen deposition using the CLF (Hall *et al.* 1998, Hall *et al.*, 2001c). The effects of excess nitrogen as a nutrient are considered separately. The sections below describe any changes made to the calculations of these "new" acidity critical loads in preparation for the data submission in February 2001.

5.1 Maximum Critical Load of Sulphur ($CL_{max}S$)

For terrestrial ecosystems, $CL_{max}S$ 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:

$$CL_{max}S = CL(A) + BC_{dep} - BC_u$$

Where $CL(A)$ = acidity critical load (empirical or SMB)
BC_{dep}^* = non-marine base cation less non-marine chloride deposition
BC_u = base cation uptake by vegetation

The acidity critical loads used in this calculation are those described in Section 2 above.

For the calculations of $CL_{max}S$ for the 1998 data submission we used 20km non-marine base cation values for 1992-94 minus a modelled estimate of non-marine chloride for 2010 (Hall *et al.*, 1998). However, since other countries in Europe use present day values only, this was discussed with UK experts and we agreed to compare longer-term mean values of BC_{dep}, with those for 2-3 years and the values previously used. The latest available deposition data are for 1995-97 at 5km resolution; however, problems were identified in the non-marine deposition values in this data set, which have been reported back to NETCEN (via CEH Edinburgh) for clarification, hence these data have not been used. Comparisons of BC_{dep} values for 1986-91 (5km resolution data) with those previously used (ie, based on non-marine base cations for 1992-94 and modelled non-marine chloride for 2010) showed that although the maximum values for 1986-91 were higher, the mean values across the country were lower than those previously used. However, we decided to use the 1986-91 5km data as longer-term mean values, rather than continue to include a modelled estimate of non-marine chloride for 2010.

Values for BC_u remain unchanged for acid grassland, calcareous grassland and heathland. For the woodland ecosystems the new BC_u values described in Section 2.2 and listed in Table 1, were used.

The calculation of $CL_{max}S$ for freshwater ecosystems remains unchanged since 1998 (Hall *et al.*, 1998).

5.2 Minimum Critical Load of Nitrogen ($CL_{min}N$)

The calculation of $CL_{min}N$ for terrestrial ecosystems has been changed since that used in the UK in 1998 (which excluded denitrification), so it is now consistent with the UNECE Mapping Manual (UBA, 1996):

$$CL_{min}N = N_u+N_i+N_{de}$$

Where N_u = nitrogen uptake
N_i = nitrogen immobilisation
N_{de} = denitrification

N_i data are the same as in 1998, based on soil type. Uptake values for woodland ecosystems have been modified according to Section 2.2 and Table 1 of this report. Uptake values for other ecosystems remain unchanged. Values for N_{de} are based on soil type (Hall *et al.*, 1998). The inclusion of N_{de} in the equation and revised nitrogen uptake values for woodland ecosystems have led to increased $CL_{min}N$ values

The calculations of $CL_{min}N$ for freshwater ecosystems remain unchanged since 1998 (Hall *et al.*, 1998).

5.3 Maximum Critical Load of Nitrogen ($CL_{max}N$)

$CL_{max}N$ is calculated for terrestrial ecosystems as:

$$CL_{max}N = CL_{min}N + CL_{max}S$$

Changes to the input data used in the calculations of $CL_{min}N$ and $CL_{max}S$ have led to changes in the values of $CL_{max}N$. However, for most ecosystems the changes are very small (less than 0.1 keq ha^{-1} $year^{-1}$ for mean values).

The calculation of $CL_{max}N$ for freshwater ecosystems remains unchanged since 1998 (Hall *et al.*, 1998).

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Appendix 1

SMB equation using Ca:Al ratio as chemical criterion (mineral soils).

NB. Base cation (BC) terms here only relate to calcium.

$CL(A) = ANC_w – ANC_{le(crit)}$

Where:

$CL(A)$	= critical loads of acidity (calculated in eq ha^{-1} $year^{-1}$) [using units given here divide $CL(A)$ by 1000 to give keq ha^{-1} $year^{-1}$]
ANC_w	= Acid Neutralising Capacity produced by weathering (eq ha^{-1} $year^{-1}$)
$ANC_{le(crit)}$	= 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} $year^{-1}$) = minimum (u, BC_a)
u	= calcium uptake (keq ha^{-1} $year^{-1}$), see values in Table 2.
BC_a	= calcium availability (keq ha^{-1} $year^{-1}$) = 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 for woodland 1995-97 (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 (mineral soils: 950 [m^6/eq^2])
$Ca{:}Al$	= Calcium:Aluminium ratio = 1

Appendix 2

SMB equation using critical pH as chemical criterion (organic soils).

$CL(A) = ANC_w - ANC_{le(crit)}$

Where:

$CL(A)$	= critical loads of acidity (calculated in eq ha^{-1} $year^{-1}$) [using units given here divide $CL(A)$ by 1000 to give keq ha^{-1} $year^{-1}$]
ANC_w	= Acid Neutralising Capacity produced by weathering (eq ha^{-1} $year^{-1}$)
$ANC_{le(crit)}$	= critical leaching of ANC (eq ha^{-1} $year^{-1}$) $= Q * ([H] + [Al])$
Q	= runoff (m^3 ha^{-1} = mm runoff * 10)
$[H]$	= hydrogen ion concentration (eq m^{-3}) $= 10^{(-pH)} * 1000$
pH	= critical pH (4.0)
$[Al]$	= aluminium concentration (eq m^{-3}) $= K_{gibb} * H^3$
K_{gibb}	= gibbsite equilibrium constant (organic soils: 9.5 [m^6/eq^2])

Appendix 3.
Summary of UK critical load values and the justification for their use

Critical loads parameter	Ecosystem code[#]	Minimum value	Maximum value	Data sources/methods used	Justification
$CL_{max}(S)$ Eq/ha/year	AG	130	5030	$= CLA + (BC_{dep}* - Cl_{dep}*) - BC_u$ CLA = empirical soil critical loads (based on weathering rate & mineralology of dominant soil type) for AG, CG & H, and SMB equation for C & D. See *BCdep*, *Cldep* and *BCu* comments below.	Mapping Manual (UBA, 1996)
	CG	598	4798		
	H	130	5010		
	C	10	11732		
	D	4	11108		
	W	0	36900	$= L_{crit} / (1 - \rho_S)$	
$CL_{min}(N)$ Eq/ha/year	AG	213	570	$= N_u + N_i + N_{de}$ See *Nu*, *Ni*, & *Nde* comments below.	Mapping Manual.
	CG	857	1214		
	H	433	790		
	C	643	1000		
	D	643	1000		
	W	15	638	$= fN_u + (1 - r)(N_i + N_{de})$	Mapping Manual. N_{de} values catchment-weighted according to area of different soils present in catchment.
$CL_{max}(N)$ Eq/ha/year	AG	363	5550	$= CL_{max}(S) + CL_{min}(N)$	Mapping Manual
	CG	1455	5972		
	H	583	5466		
	C	733	12651		
	D	647	11751		
	W	143	201500	$= CL_{min}N + (L_{crit} / 1 - \rho N)$	Mapping Manual.
$CL_{nut}(N)$ Eq/ha/year	AG	714	1786	Empirical values applied: Acid grassland: 10, 12.5, 25 kg N/ha/year depending on species present.	Mapping Manual. Empirical values recommended by UK experts (Hall *et al.* 1998). However, the UK will review these after the UNECE workshop in 2002 to review empirical critical loads for nutrient nitrogen.
	CG	3571	3571	Empirical value applied: 50 kg N/ha/year	
	H	714	1214	Empirical values applied: 10, 15, 17 kg N/ha/year depending on species present.	

	C	928	928	Minimum of empirical value (13 kg N/ha/year) or mass balance value (where $CL_{nut}(N) = N_u + N_i + N_{le(acc)} + N_{de}$). N_i & N_{de} values between 1 & 4 kg N/ha/year depending on soil type. Previously only mass balance used for conifers.	Mass balance equation and empirical value as recommended in Mapping Manual. Input values recommended by UK experts (Hall *et al.* 1998). Empirical value lower everywhere.
	D	1071	1214	Minimum of empirical value (17kg N/ha/year) or mass balance value (where $CL_{nut}(N) = N_u + N_i + N_{le(acc)} + N_{de}$). N_i & N_{de} values between 1 & 4 kg N/ha/year depending on soil type.	Mapping Manual. Empirical values recommended by UK experts. Input values to mass balance equation recommended by UK experts (Hall *et al.* 1998).
	W	-	-	Not calculated.	
$BC_{dep}* - Cl_{dep}*$ Eq/ha/year	AG	0	1150	$BC_{dep}*$ and $Cl_{dep}*$ = changed to measured mean data 1986-91 for low vegetation.	Mapping Manual.
	CG	0	1150		
	H	0	1150		
	C	0	1850	$BC_{dep}*$ and $Cl_{dep}*$ = changed to measured mean data 1986-91 for woodland ecosystems.	
	D	0	1850		
	W	-	-	Not used.	
BC_u Eq/ha/year	AG	0	0	Set to zero - uptake negligible for acid grassland.	Based on published data by UK experts.
	CG	222	222	Includes removal via sheep.	Based on published data by UK experts.
	H	0	0	No uptake for heathland.	
	C	250	250	New values. Calculated from: average volume increment * basic wood density * concentration in wood and assuming potential yields achieved. Values based on data for Sitka Spruce.	Based on published data. Single value for UK for each of the following: coniferous woodland (all soils), deciduous woodland (Ca-poor soils), deciduous woodland (Ca-rich soils). Regional and species specific volume increment and concentration in wood to be incorporated in future. NB. These used in CLmaxS calculations only, estimates of calcium uptake only used in SMB for mineral soils.
	D	400	850	New values. Calculated from: average volume increment * basic wood density * concentration in wood and assuming potential yields achieved. Values based on data for Oak. Minimum value for Ca-poor soils and maximum value for Ca-rich soils.	
	W	-	-	Not used.	
ANC_w Eq/ha/year	AG	-	-	SMB not used: empirical critical loads of acidity for soils applied, therefore ANCw not assigned.	Methods agreed by UK experts (Hall *et al.* 1998). (SMB only applied to woodland ecosystems in UK).
	CG	-	-		
	H	-	-		
	C	0	4000	Set to zero for peat soils	Recommended in Mapping Manual. See Hornung *et*

	D	0	4000		*al.*, 1995. Assigned values checked against application of PROFILE for limited number of sites.
	W	-	-	Not used.	
$ANC_{le(crit)}$ Eq/ha/year	AG	-	-	SMB not used: empirical critical loads of acidity for soils applied, therefore ANCle(crit) not calculated.	Methods agreed by UK experts (Hall *et al.* 1998). (SMB only applied to woodland ecosystems in UK).
	CG	-	-		
	H	-	-		
	C	0.1	7734	Calculated via SMB equation with ratio of Ca:Al = 1 as chemical criterion for mineral soils and critical pH 4.0 for organic soils. Empirical acidity critical loads applied to peat soils.	SMB with BC:Al ratio and base cation deposition produced unrealistically high critical loads. Ca:Al ratio recommended in paper by Cronan & Grigel (1995).
	D	0	7067		
	W	-	-	For freshwaters the ANC_{limit} is set at zero μeq/l.	Value selected for 50% probability of damage to brown trout populations.
N_u Eq/ha/year	AG	70	70	Equivalent to 1kg N/ha/year	Based on published data by UK experts
	CG	714	714	Equivalent to 10kg N/ha/year	
	H	290	290	Equivalent to 4kg N/ha/year	
	C	500	500	New values. Methods as for BC_u.	Based on published data – one value for whole of UK: regional growth values to be incorporated in future.
	D	500	500		
	W	0	279	= fN_u. Uses N_u value of 279 eq/ha/year for all coniferous forest multiplied by percentage forest in catchment.	Based on published data. Curtis et al (1998).
N_i Eq/ha/year	AG	71	214	Values dependant on soil type. Equivalent to 1 or 3 kg N/ha/year	Based on published data for long term sustainability.
	CG	71	214		
	H	71	214		
	C	71	214		
	D	71	214		
	W	7	214	N_i values catchment-weighted according to area of different soils present in catchment.	
$N_{le(acc)}$) Eq/ha/year	AG	-	-	Empirical nutrient nitrogen critical loads used, therefore Nle(acc) not assigned.	
	CG	-	-		
	H	-	-		
	C	428	428	Equivalent to 6kg N/ha/year.	Values based on data from a limited number of detailed site studies for GB plantations.
	D	428	428		
	W	-	-	Not used.	

N_{de} Eq/ha/year	AG	71	286	Used in CLminN only. (Empirical critical loads of nutrient nitrogen used). Values assigned according to soil type. Equivalent to 1, 2 or 4 kg N/ha/year.	
	CG	71	286		
	H	71	286		
	C	71	286	Used in CLminN and mass balance of CLnutN. Values assigned according to soil type.	
	D	71	286		
	W	7	285	Uses catchment-weighted N_{de} values (based on soil type) instead of f_{de}.	Use of f_{de} (0.1-0.8) as in Mapping Manual gives N_{de} values up to 25kg N/ha/year – much too high for UK (Curtis et al, 1998).
Precipitation surplus Q (m)	AG	-	-	SMB not used, therefore Q not assigned.	
	CG	-	-		
	H	-	-		
	C	0.057	3.876	1km runoff data based on 30-year (1941-1970) mean rainfall data.	Used in SMB equation for acidity critical loads.
	D	0.057	3.876		
	W	0.097	3.364	1km catchment-weighted runoff based on mean rainfall data for 1941-70 for GB and 1961-90 for NI.	Used in FAB.
k_{gibb} (m6/eq2)	AG	-	-	SMB not used (empirical acidity critical loads applied).	
	CG	-	-		
	H	-	-		
	C	9.5	950	Minimum value applied to organic soils and maximum value applied to mineral soils.	Mapping Manual.
	D	9.5	950		
	W	-	-	Not used.	

[#] Ecosystem Codes:
AG = acid grassland
CG = calcareous grassland
H = heathland
C = coniferous forest
D = deciduous forest
W = waters

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Cronan, C.S. & Grigal, D.F. 1995. Use of calcium/aluminium ratios as indicators of stress in forest ecosystems. Journal of Environmental Quality, 24:209-226.

Curtis, C.J., Allott, T.E.H., Bird, D., Hall, J., Harriman, R., Helliwell, R., Kernan, M., Reynolds, B. & Ullyett, J. 1998. Critical loads of sulphur and nitrogen for freshwaters in Great Britain and assessment of deposition reduction requirements with the First-order Acidity Balance (FAB) model. Research Paper No. 16. Environmental Change Research Centre, University College London.

Hall, J., Bull, K., Bradley, I., Curtis, C., Freer-Smith, P., Hornung, M., Howard, D., Langan, S., Loveland, P., Reynolds, B., Ullyett, J. & Warr, T. 1998. Status of UK critical loads and exceedances, January 1998. Part 1 – Critical loads and critical loads maps. Report prepared under DETR/NERC Contract EPG1/3/116. Also on the UK NFC web site: http://critloads.ceh.ac.uk

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

Posch, M., Hettelingh, J.-P., de Smet, P.A.M. & Downing, R.J. (eds.) 1997. Calculation and mapping of critical thresholds in Europe: CCE Status Report 1997. National Institute of Public Health and the Environment, Report 259101007, Bilthoven, Netherlands.

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 (Umweltbudesamt), Berlin.

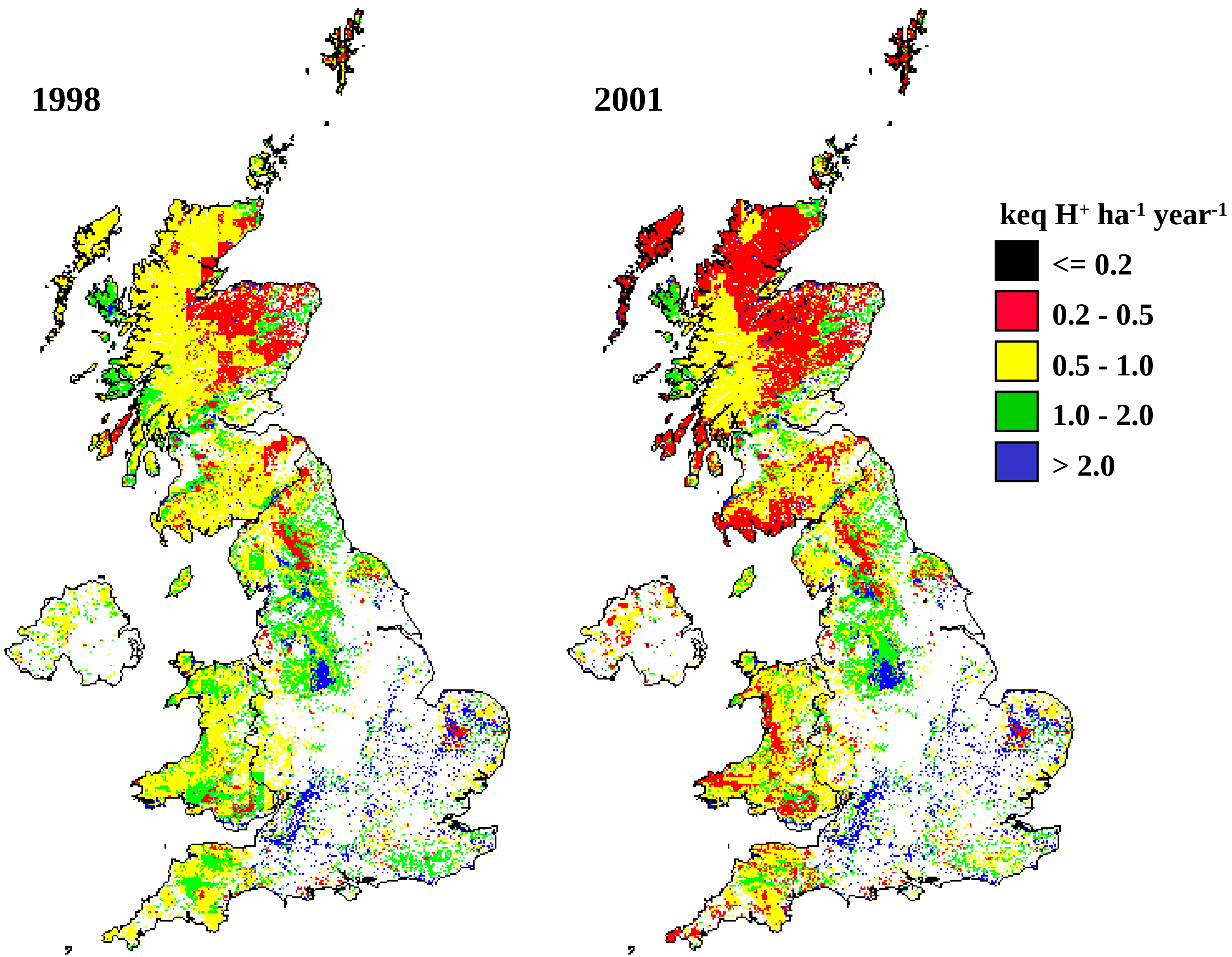
Appendix 4: Maps of critical loads based on the old (1998) versus the new (2001) calculations.

The following pages contain ecosystem maps of:

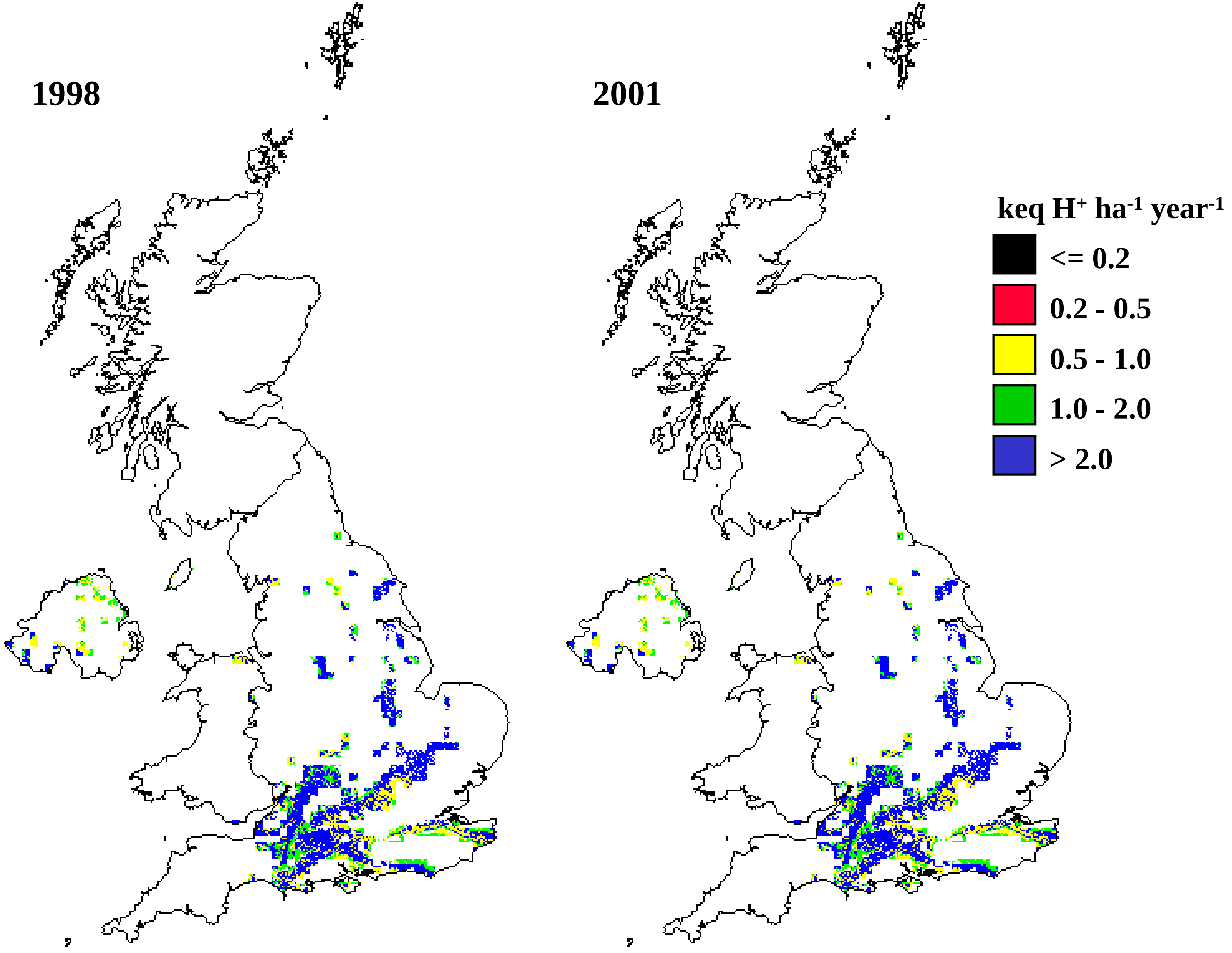
- The maximum critical loads of sulphur ($CL_{max}(S)$)
- The minimum critical loads of nitrogen ($CL_{min}(N)$)
- The maximum critical loads of nitrogen ($CL_{max}(N)$)
- Critical loads of nutrient nitrogen ($CL_{nut}(N)$)

The text in the main body of the report describes the derivation of these critical loads and should be read in conjunction with viewing these maps.

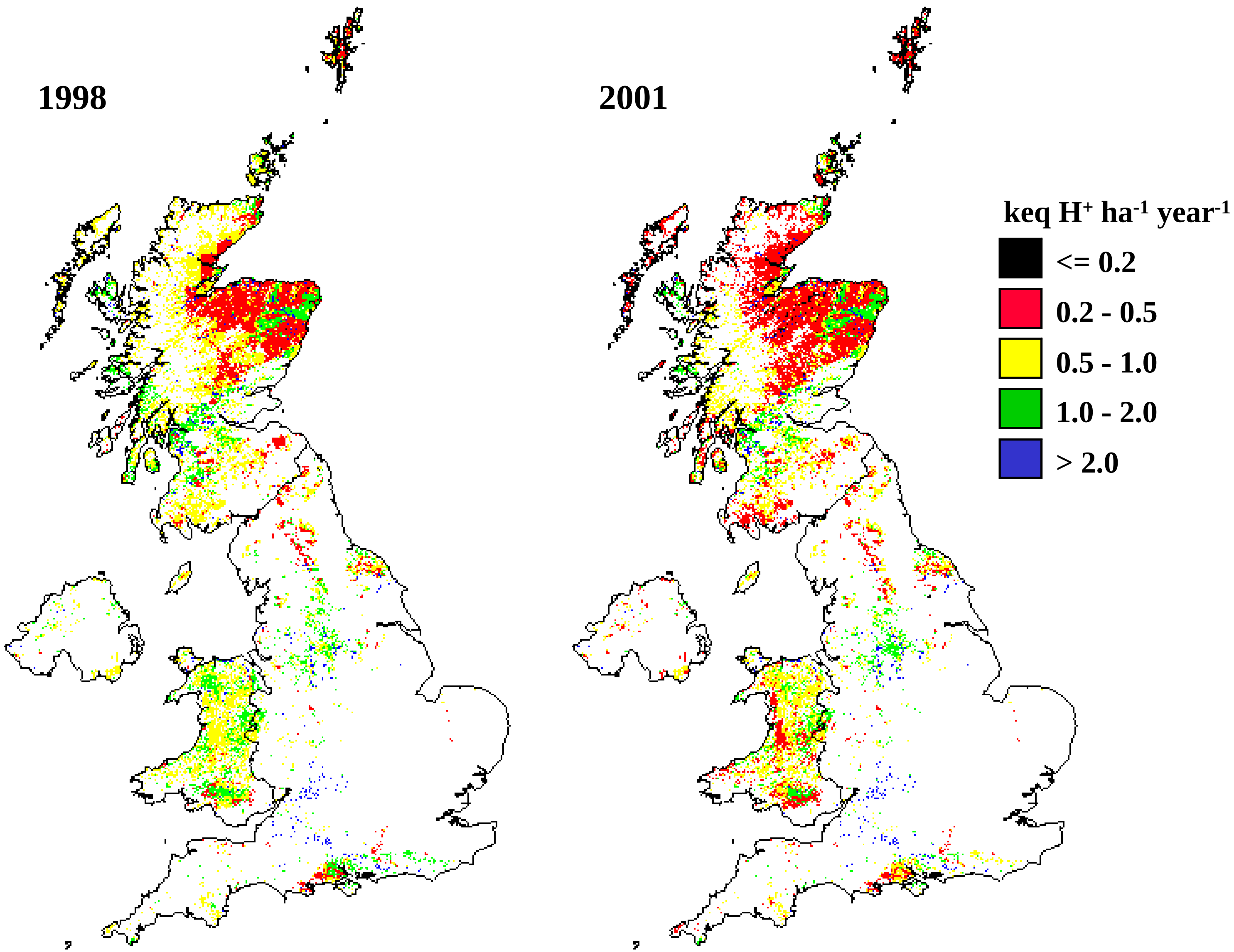
Maximum critical loads of Sulphur for acid grassland



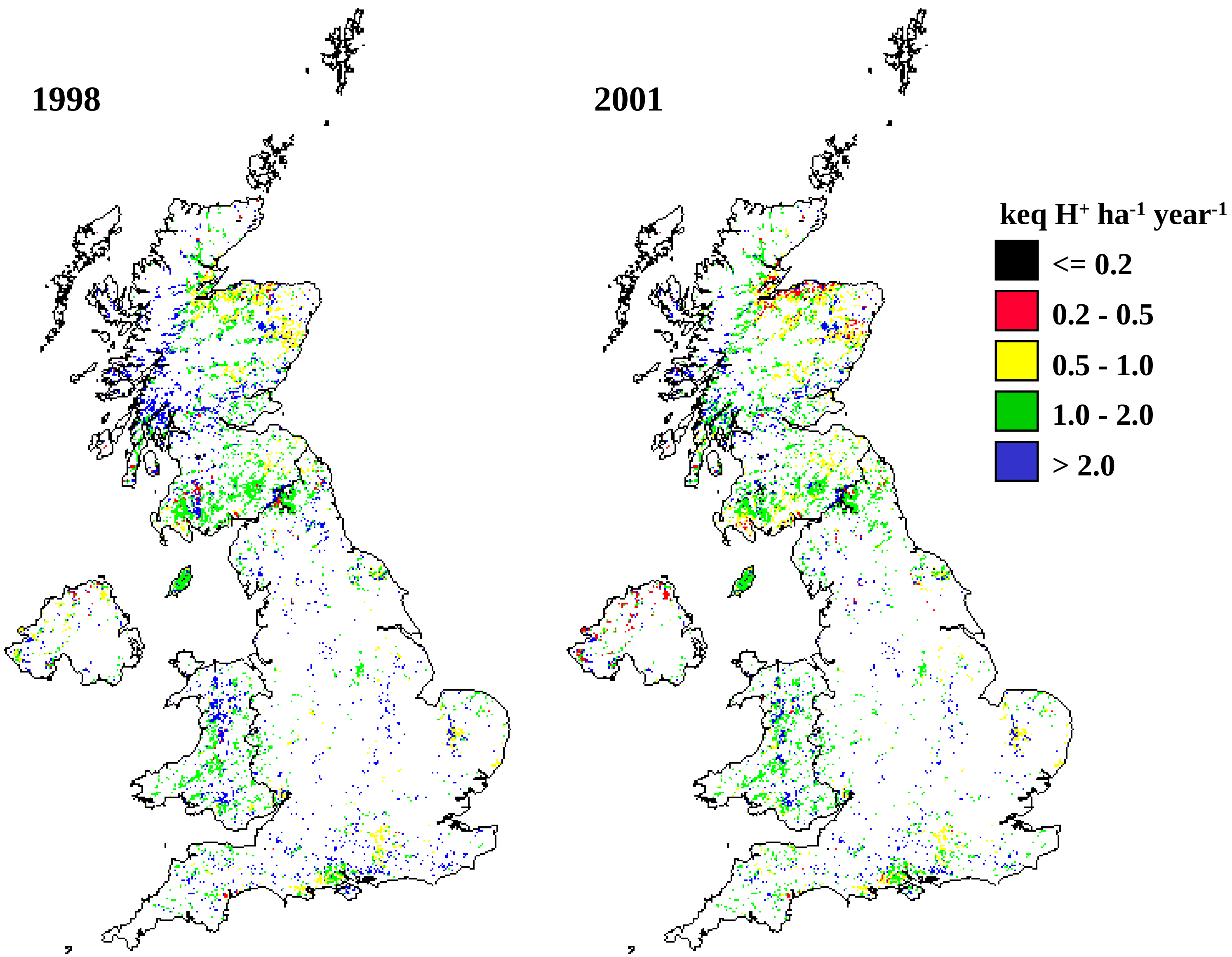
Maximum critical loads of Sulphur for calcareous grassland

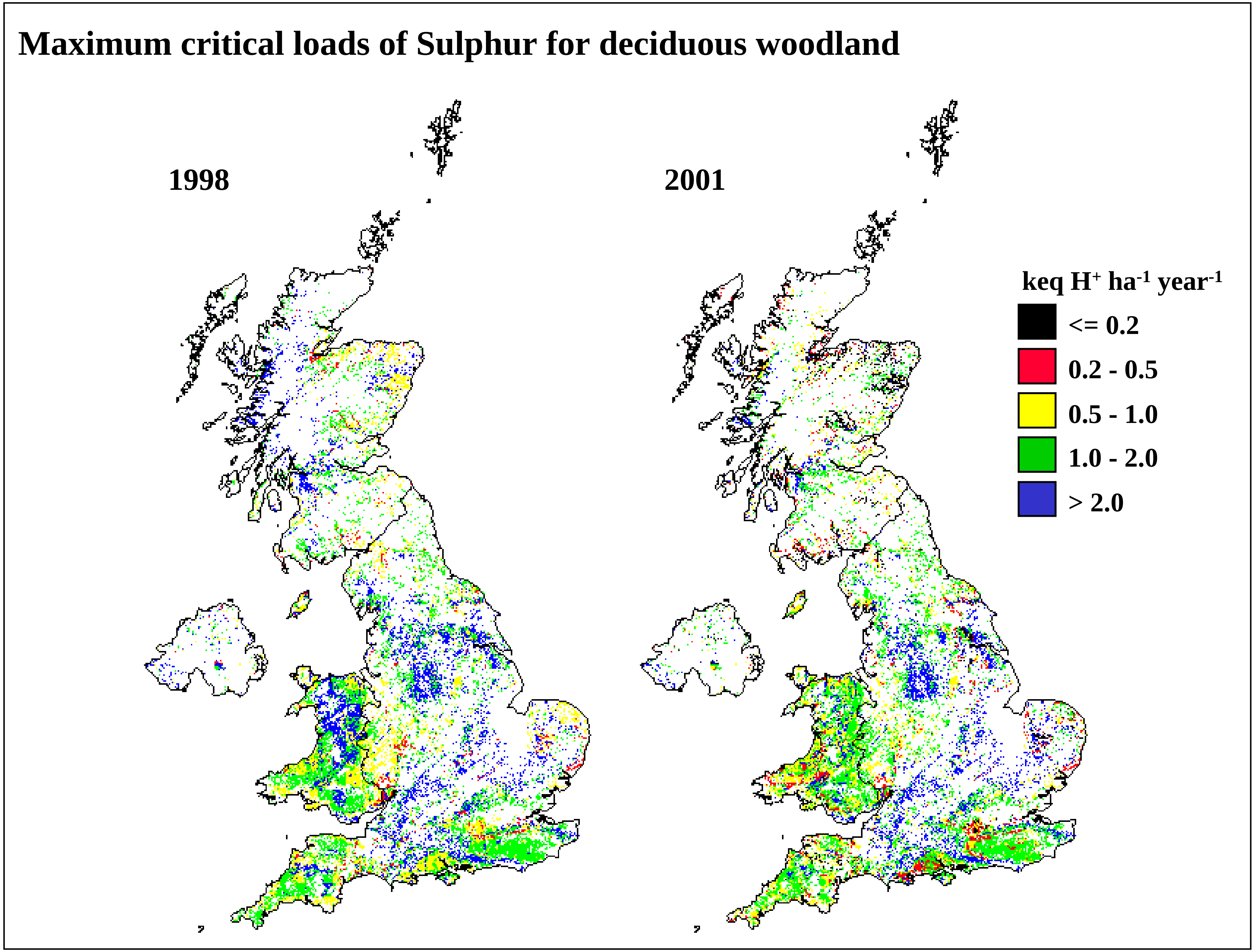


Maximum critical loads of Sulphur for heathland

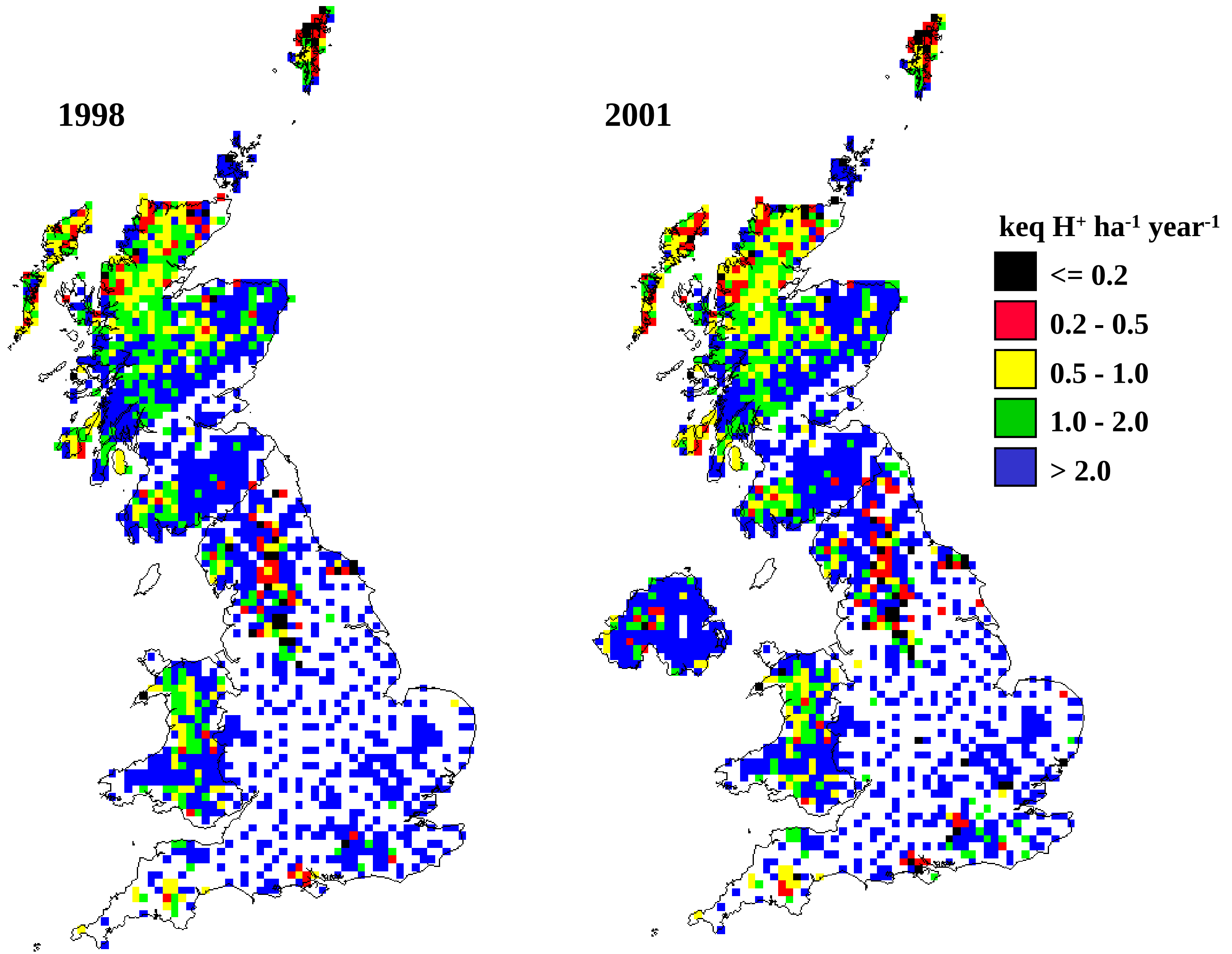


Maximum critical loads of Sulphur for coniferous woodland

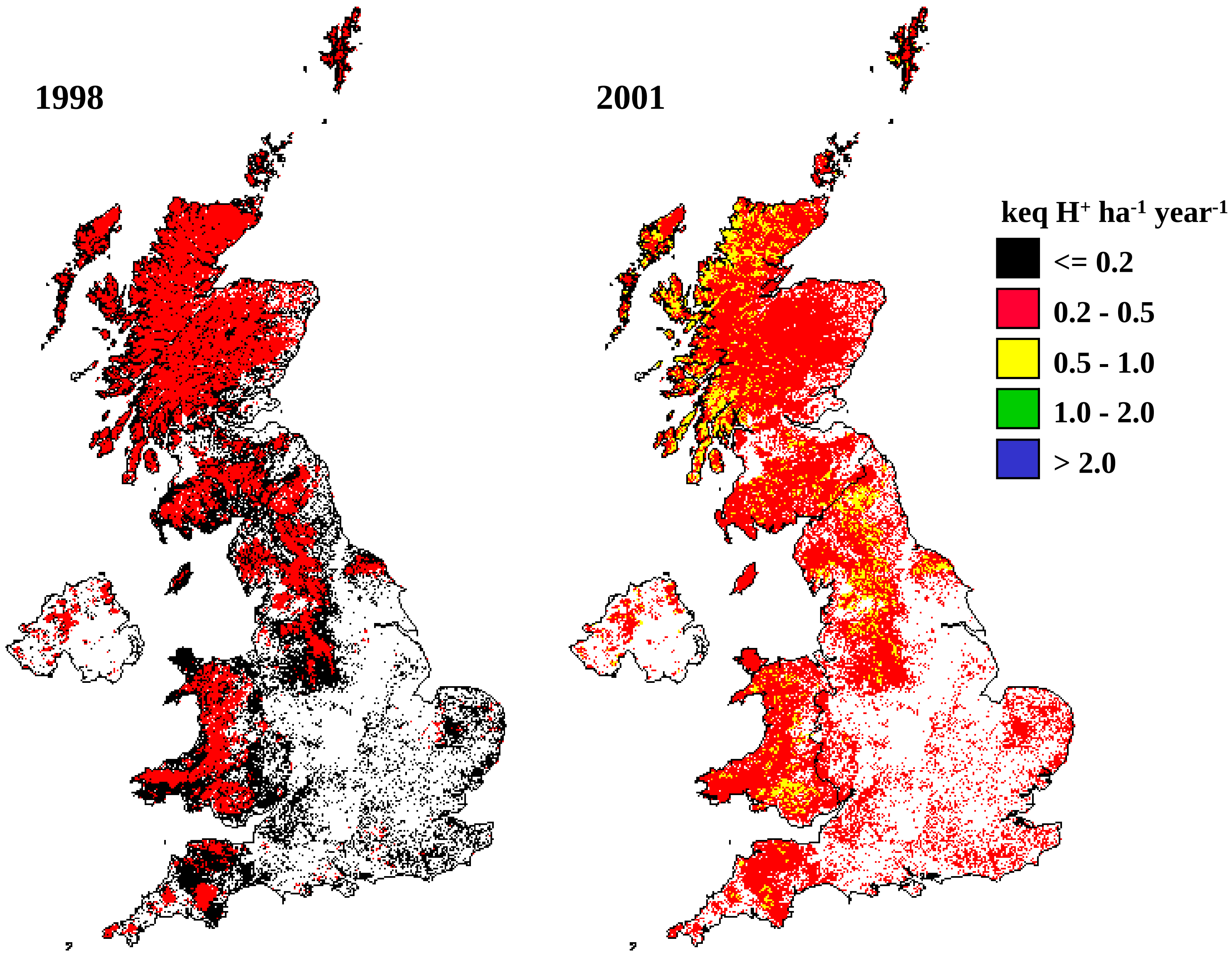



Maximum critical loads of Sulphur for deciduous woodland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

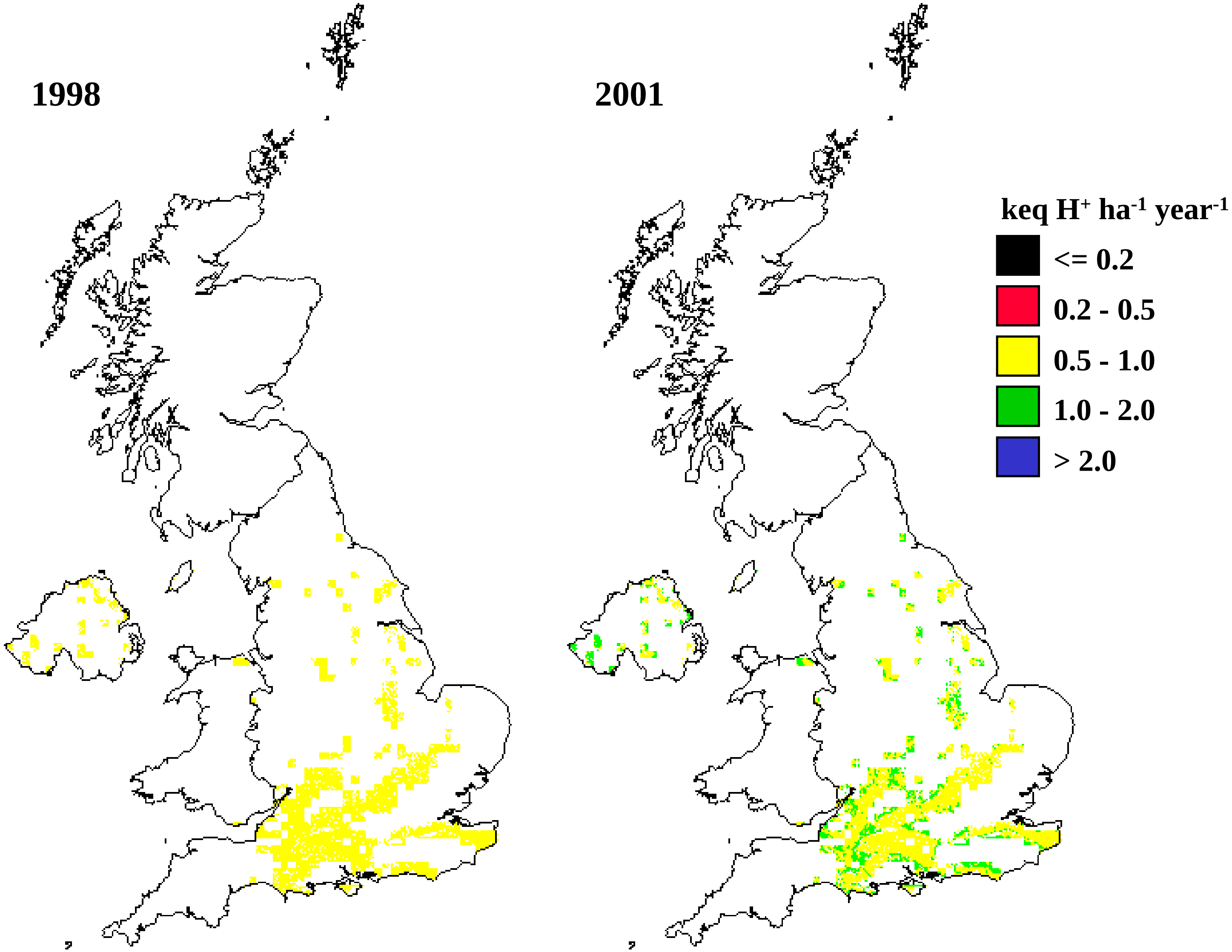
Maximum critical loads of Sulphur for freshwaters

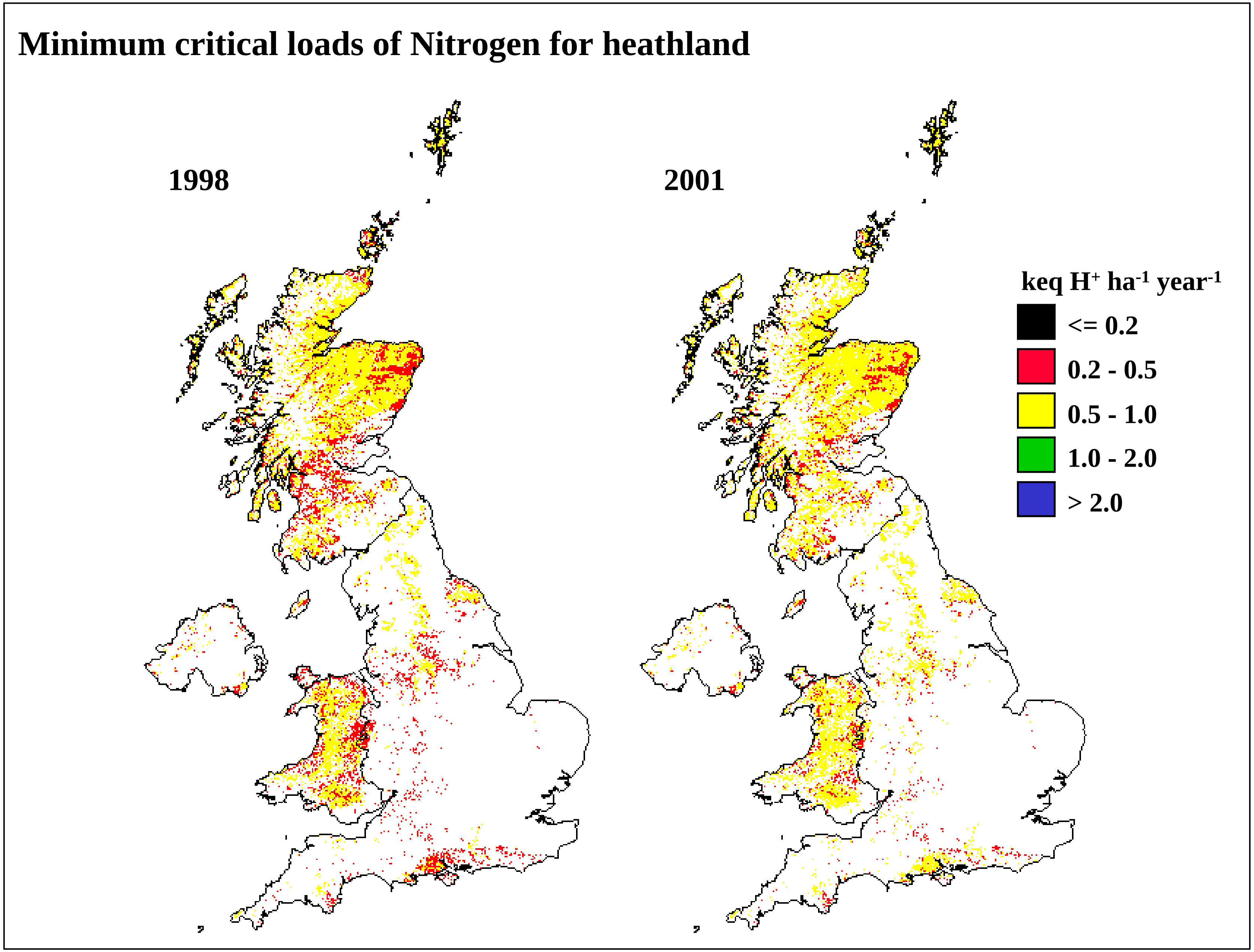


Minimum critical loads of Nitrogen for acid grassland

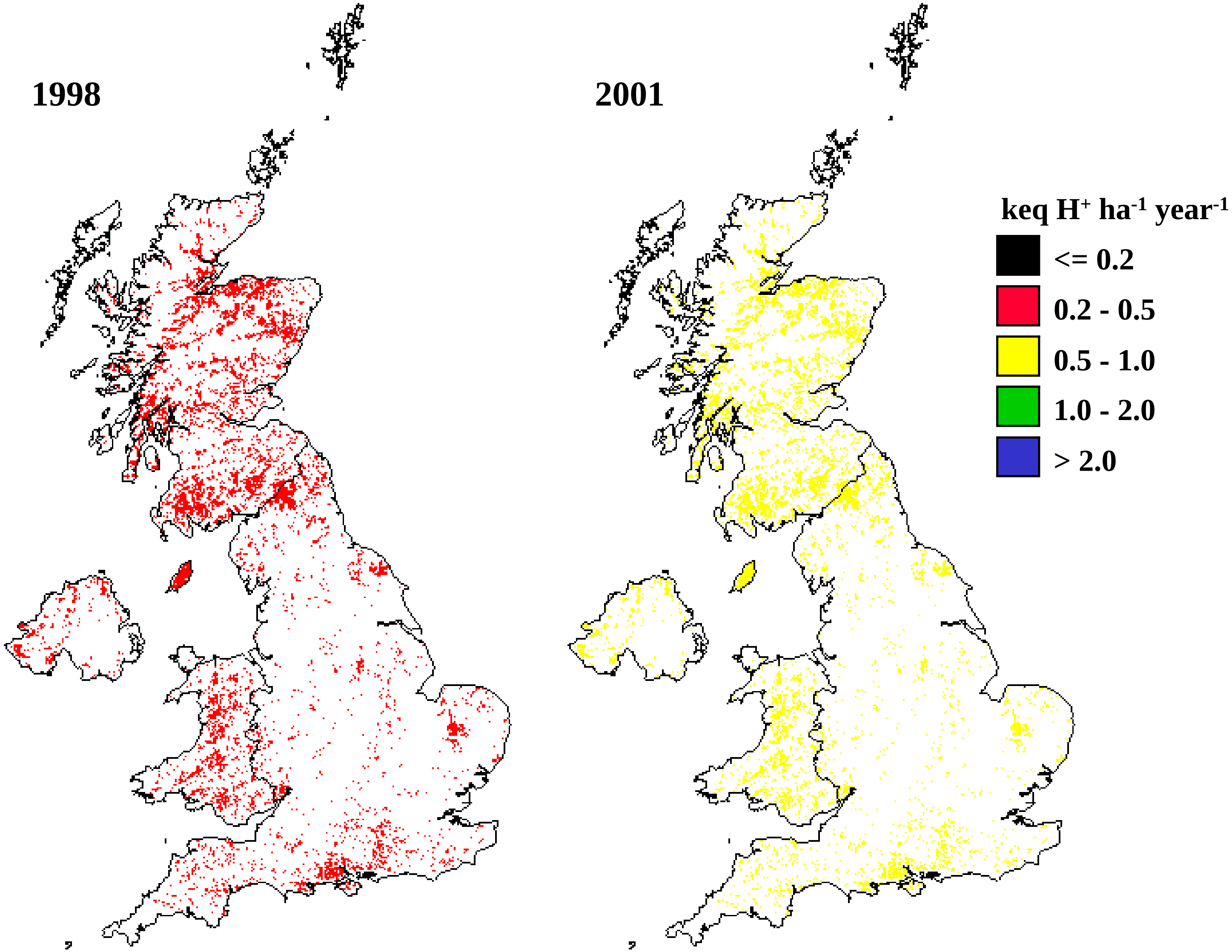


Minimum critical loads of Nitrogen for calcareous grassland

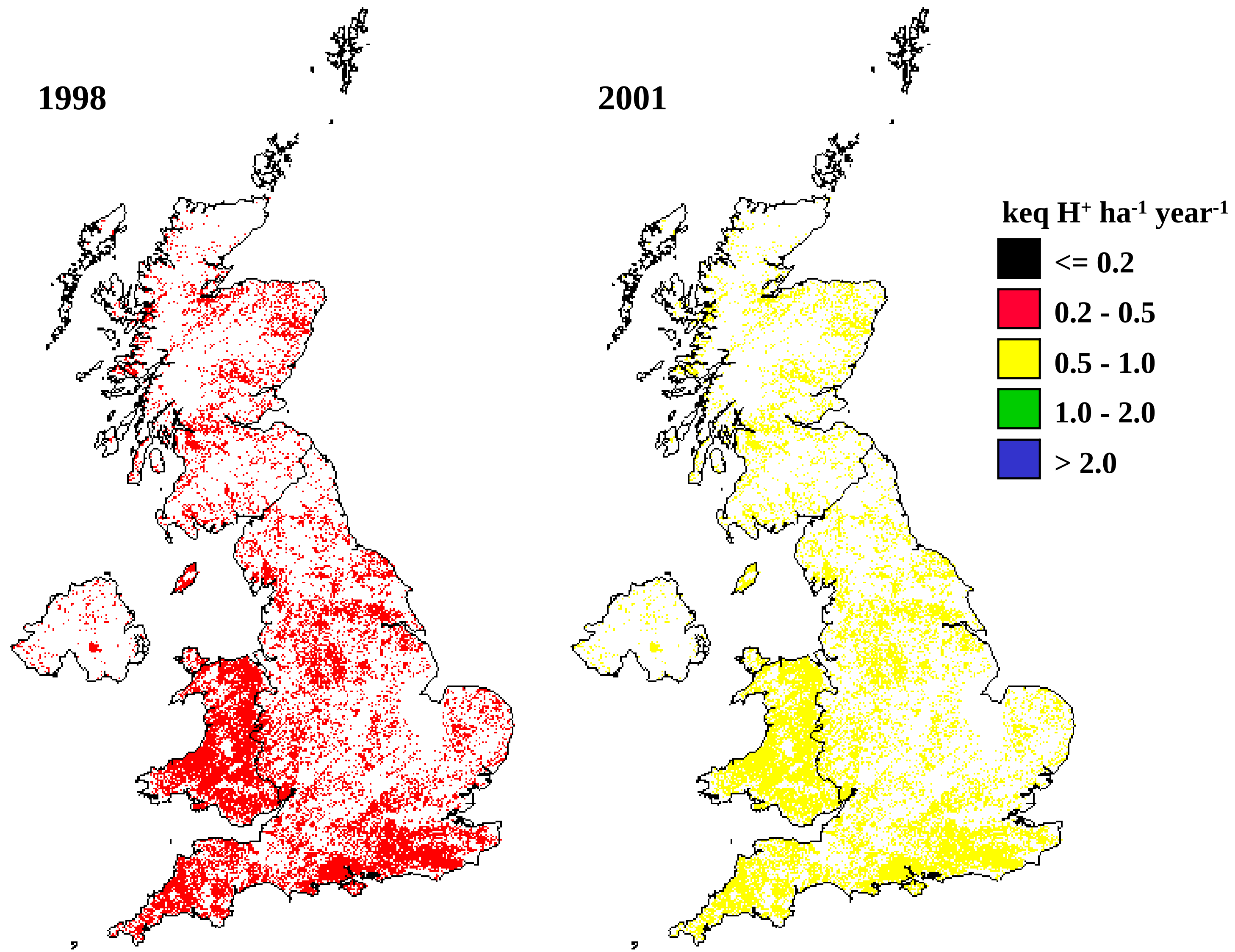



Minimum critical loads of Nitrogen for heathland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

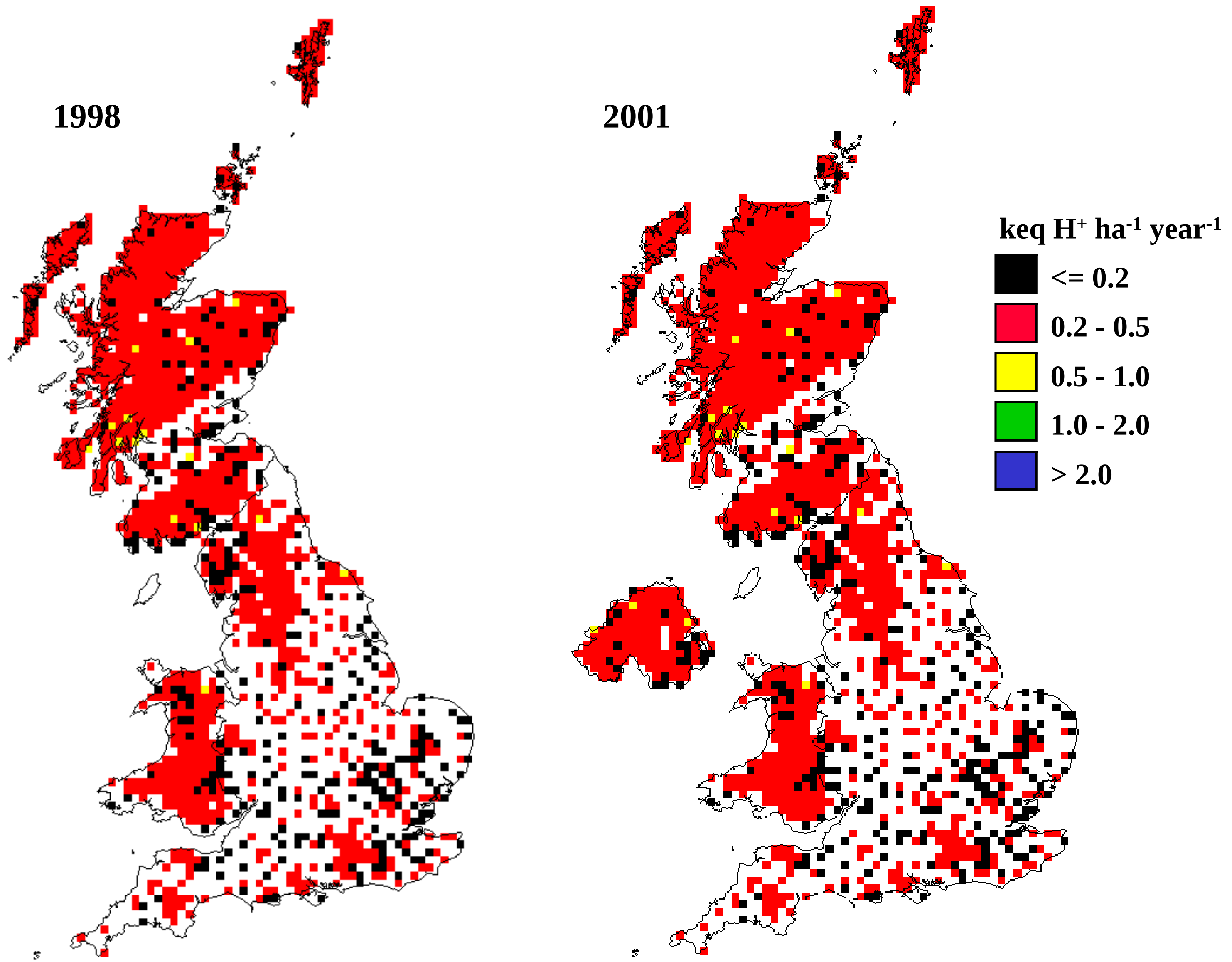
Minimum critical loads of Nitrogen for coniferous woodland



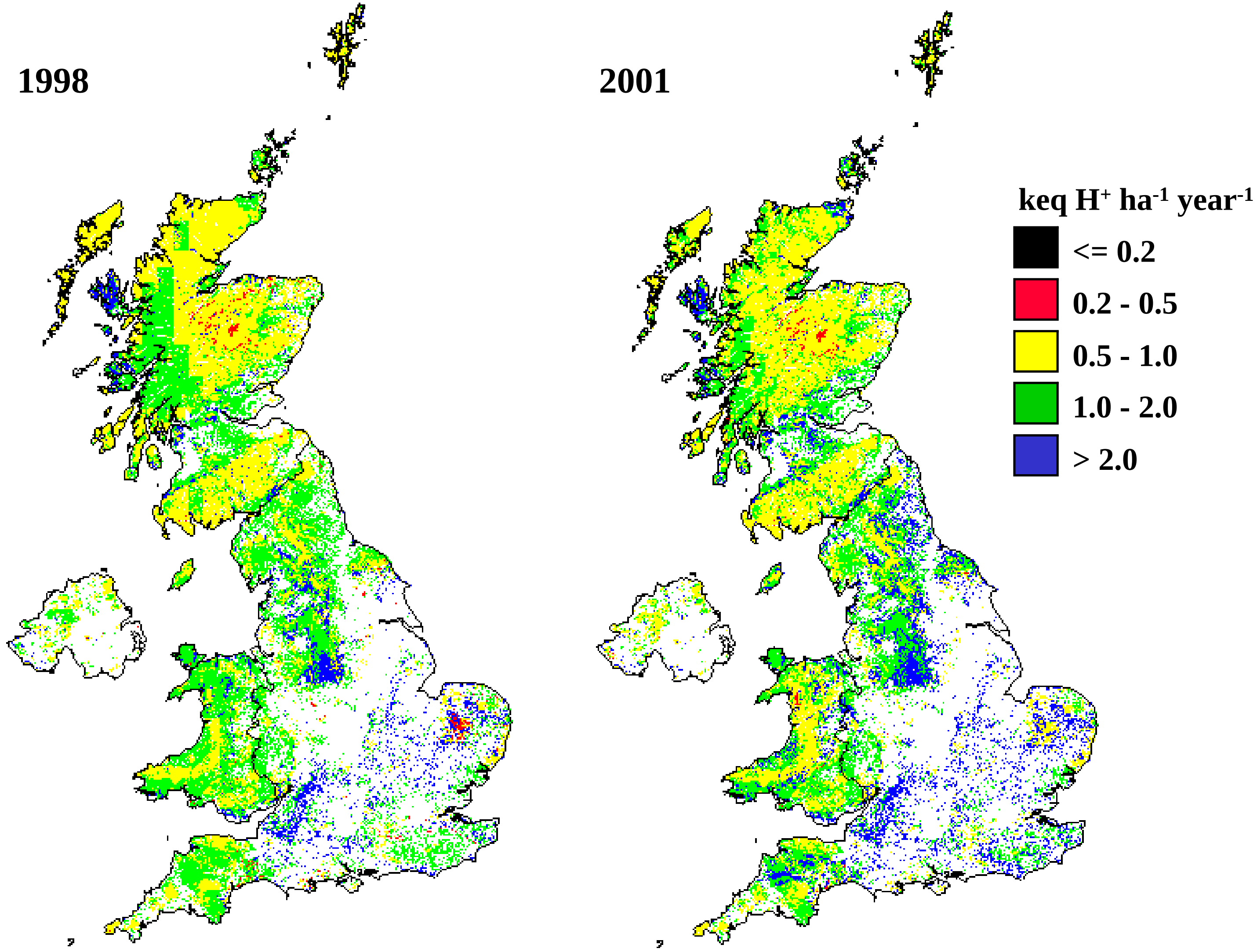
Minimum critical loads of Nitrogen for deciduous woodland



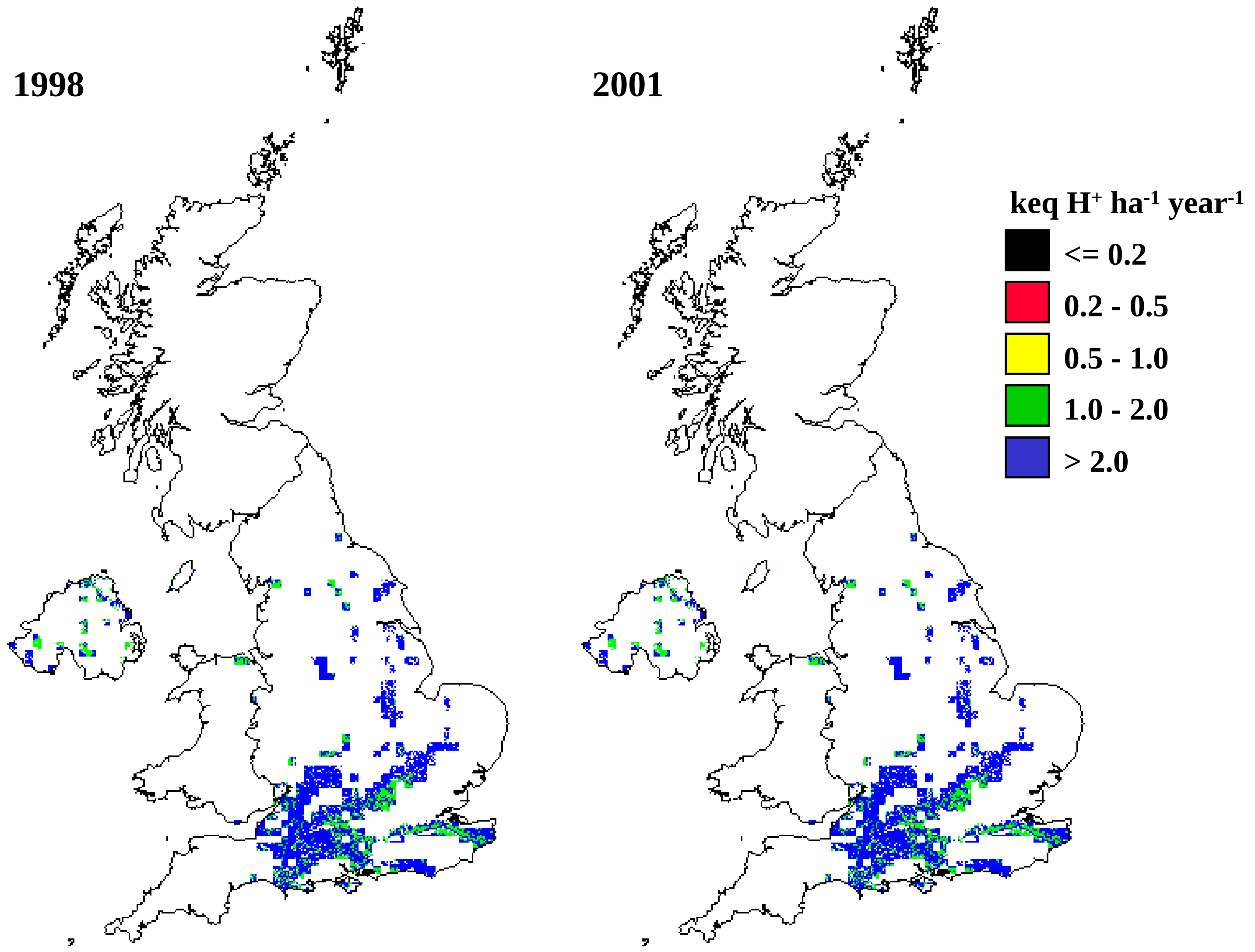
Minimum critical loads of Nitrogen for freshwaters

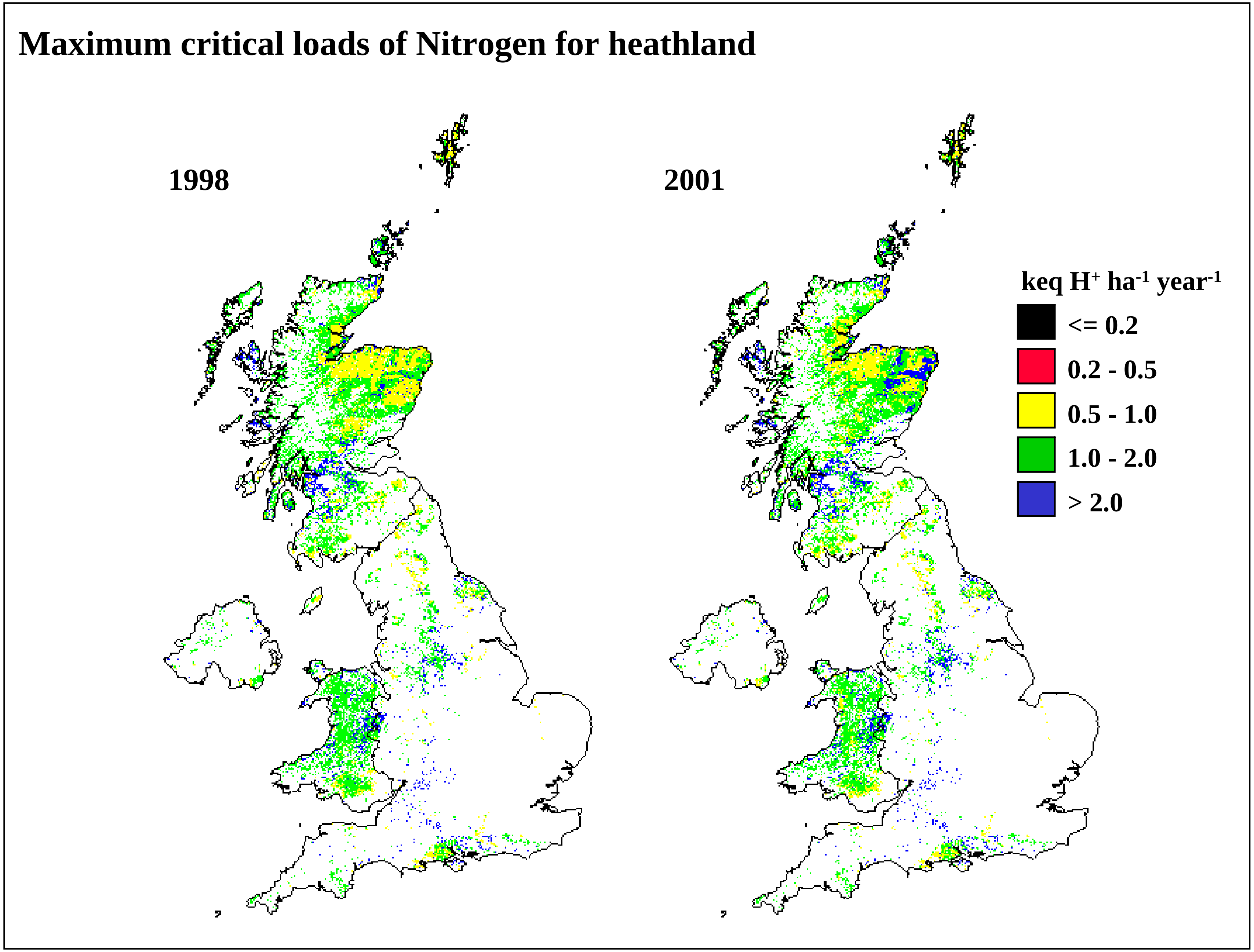


Maximum critical loads of Nitrogen for acid grassland

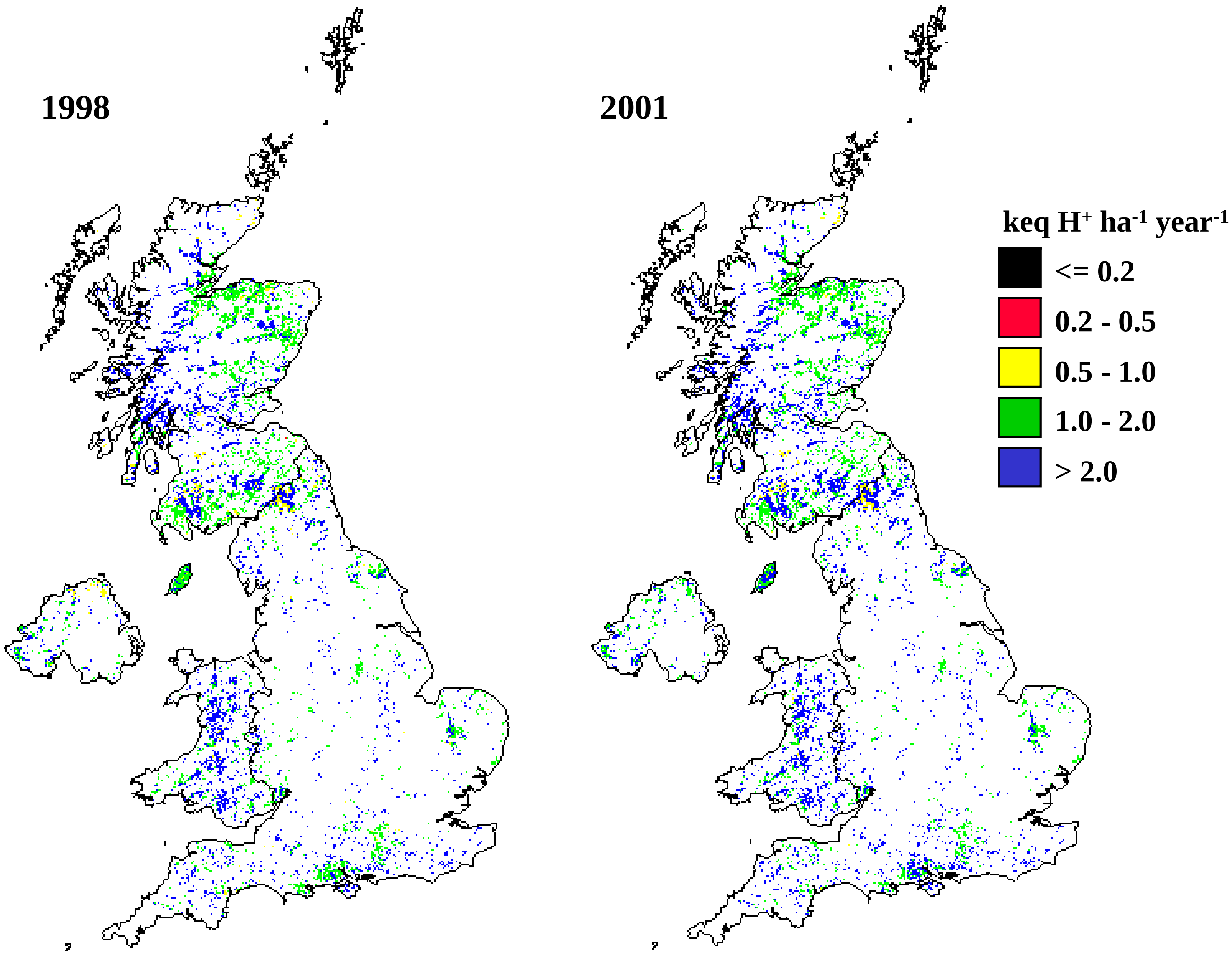


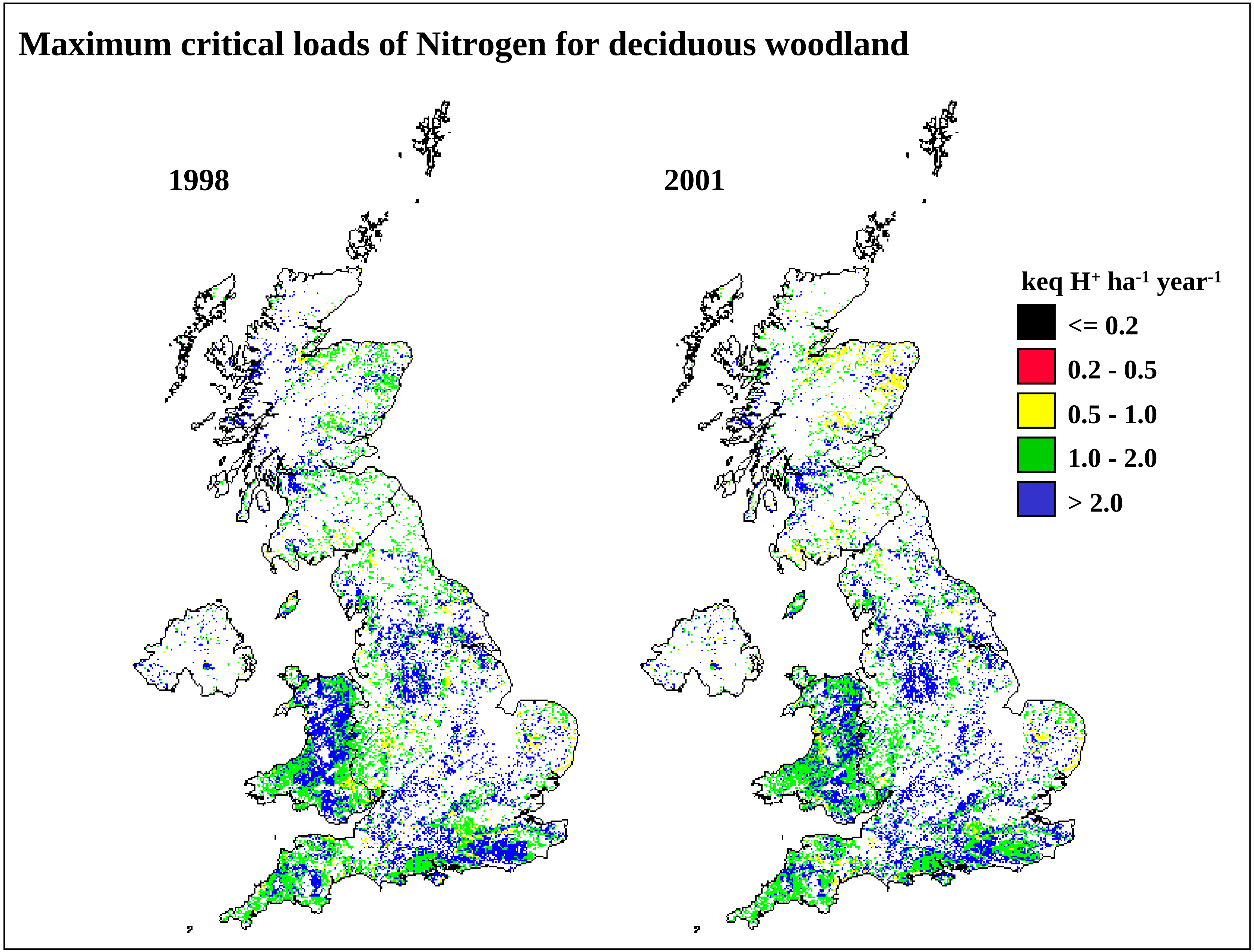
Maximum critical loads of Nitrogen for calcareous grassland



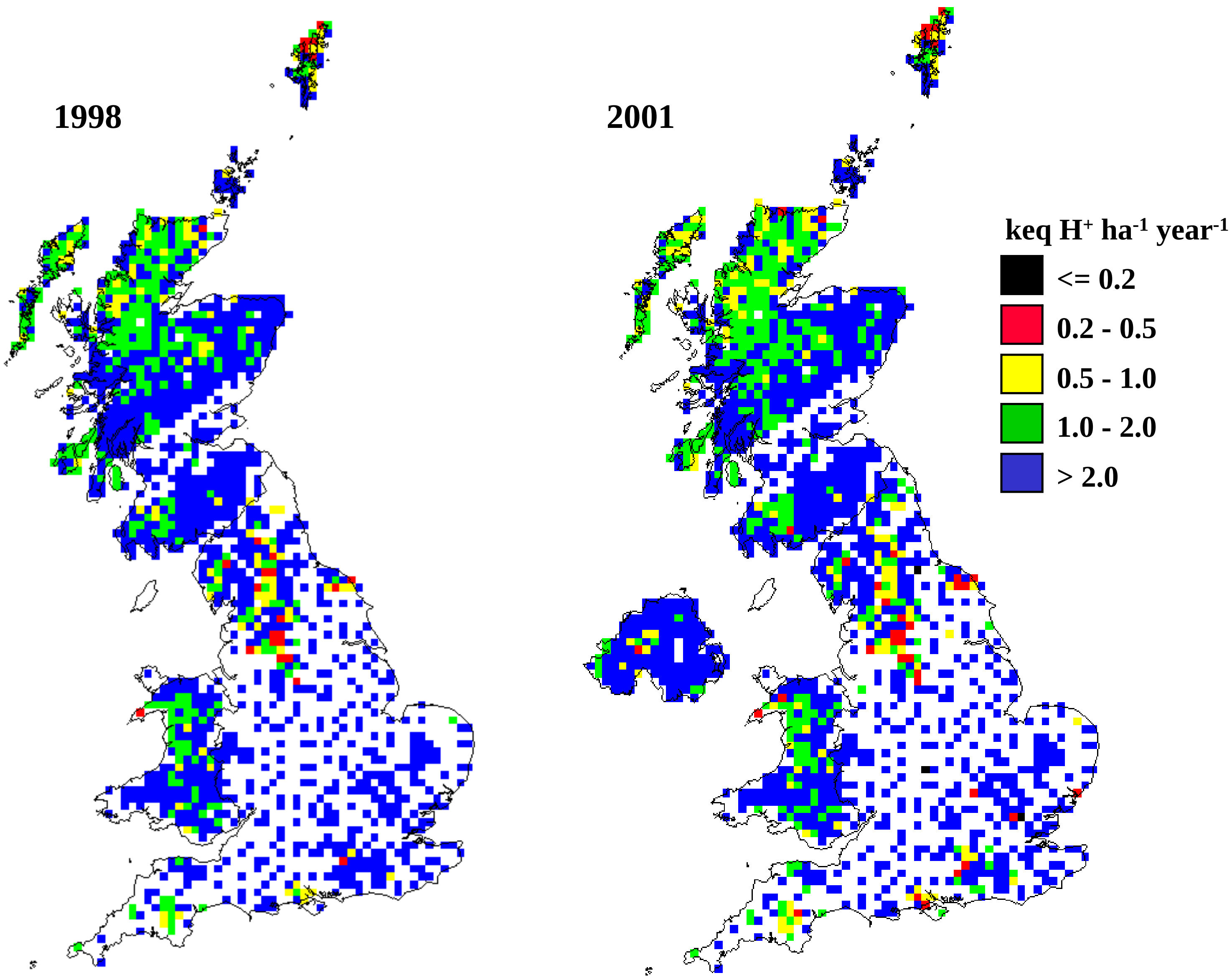

Maximum critical loads of Nitrogen for heathland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

Maximum critical loads of Nitrogen for coniferous woodland

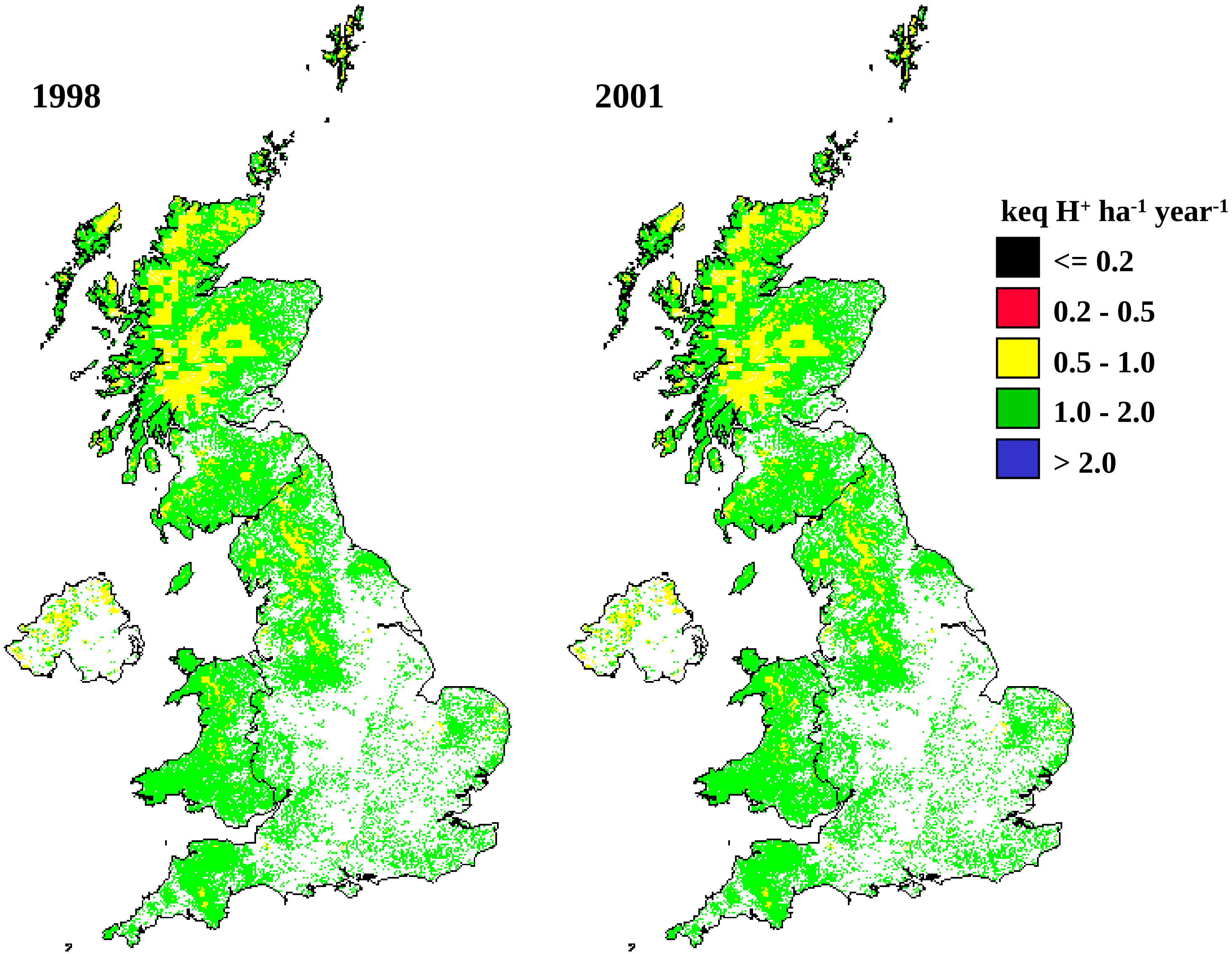


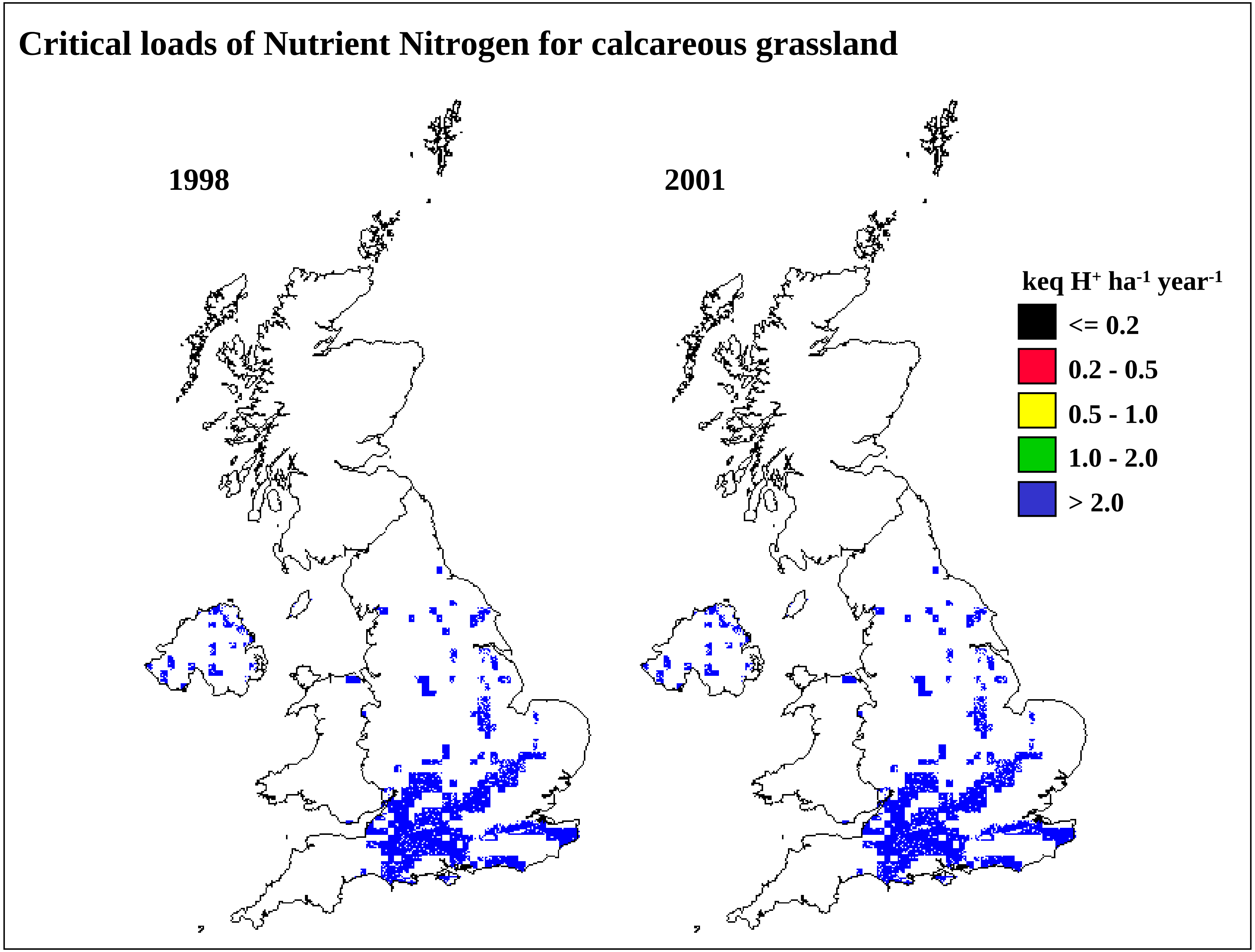

Maximum critical loads of Nitrogen for deciduous woodland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

Maximum critical loads of Nitrogen for freshwaters

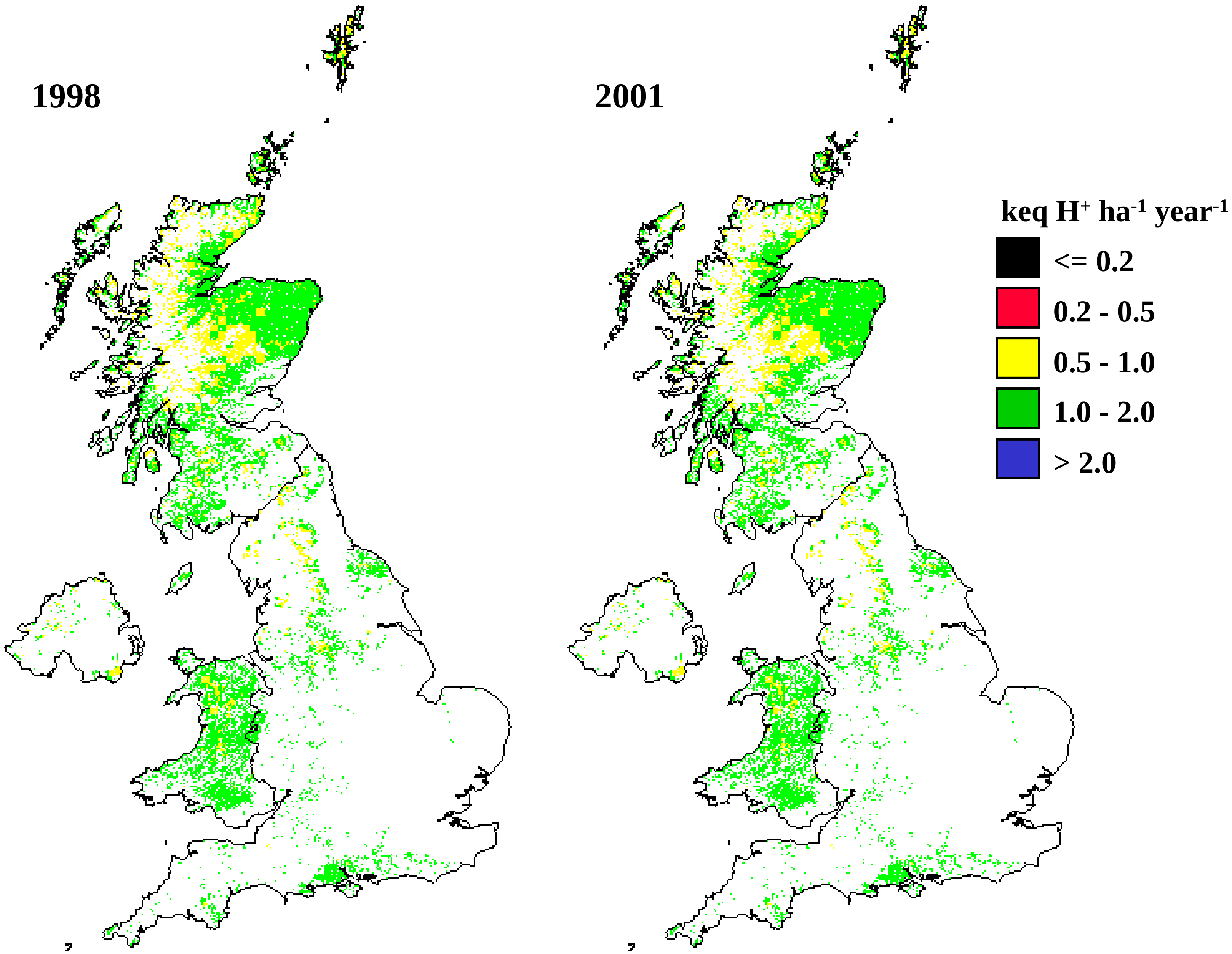


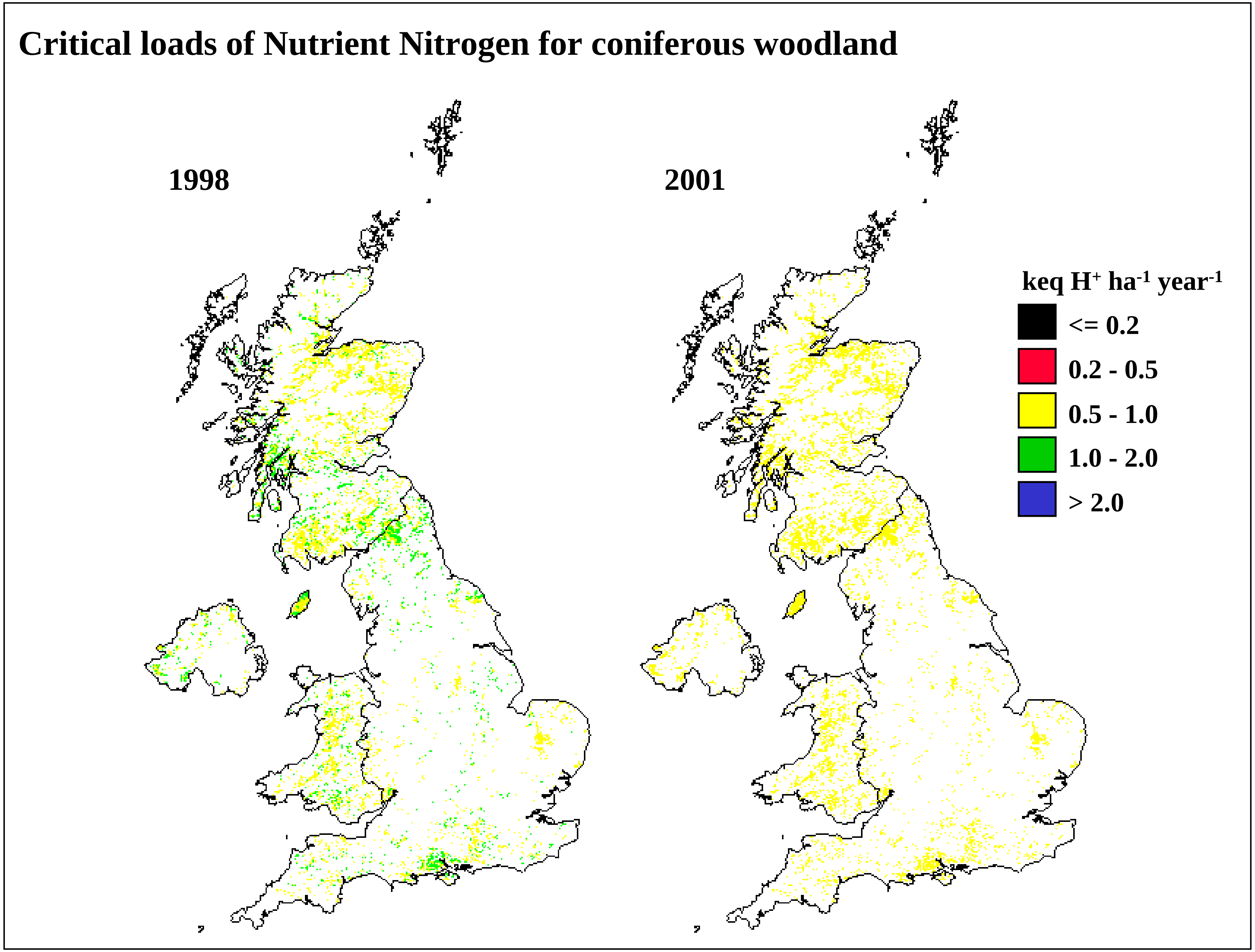
Critical loads of Nutrient Nitrogen for acid grassland




Critical loads of Nutrient Nitrogen for calcareous grassland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

Critical loads of Nutrient Nitrogen for heathland




Critical loads of Nutrient Nitrogen for coniferous woodland
1998
2001
keq H+ ha-1 year-1
<= 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

Critical loads of Nutrient Nitrogen for deciduous woodland