INSTITUTE OF TERRESTRIAL ECOLOGY
NATURAL ENVIRONMENT RESEARCH COUNCIL

COMPARISON OF MASS BALANCE CRITICAL LOADS AND EXCEEDANCES USING NON-MARINE AND TOTAL (NON-MARINE + MARINE) DEPOSITION

Helen Dyke, Jane Hall and Keith Bull

PLEASE TREAT IN CONFIDENCE UNTIL DISCUSSED IN SOILS SUB-GROUP

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1 Background

Over the years there have been many discussions in the CLAG soils sub-group regarding the use of "total" (ie. non-marine plus marine) base cations and sulphate for critical load and exceedance calculations. It has been argued that the inclusion of marine salts in the calculations resembles more closely the actual processes which occur in natural systems, particularly in regions, such as parts of the UK, where marine salts form a major component of the deposited ions.

Until now, marine ions have been omitted from all calculations both in the UK and in the UNECE. For the UK, this has made no practical difference to the estimation of exceedances using the empirically derived soil critical loads since the marine ions appear only in the deposition component of the calculation. For this, marine cations balance marine anions. The omission has been convenient in practice because marine salts cannot be included in modelled deposition estimates, either for the UK using HARM, or for Europe using the EMEP model. The difficulties of including marine salts in future exceedances and scenario development have therefore not arisen.

However, with the use of the recently developed Simple Mass Balance (SMB) equation for calculating critical loads, base cation deposition becomes a component of the critical loads calculation. Consequently, while marine salts in the deposition will "balance out", the changed critical loads values may have significant effects on the critical loads and exceedance maps.

Before the final datasets are sent to the CCE (in May 1995), it was deemed necessary to investigate the possible effects of the inclusion of sea salts in SMB calculations. This report describes the results of calculating critical loads of acidity and exceedances using non-marine and total (marine plus non-marine) deposition fields. The work will also influence which approach to deposition is used in UK critical loads calculations in the future.

The report that follows is divided into two sections. In section 2 the critical load of acidity is calculated and a simple exceedance derived by subtracting sulphur deposition; this is ignoring the neutralizing effect of base cations in an analogous fashion to past use of the empirical map for soils in the UK. In section 3, net base cation deposition is included by calculation of the term $CL_{max}(S)$ from the critical loads function. Northern Ireland mapped on the Irish grid and moved to an approximate position next to Great Britain is included on all maps.

2 Critical Load of Acidity (CL(A))

The Simple Mass Balance (SMB) model used for calculating the critical load of acidity (CL(A)) is summarized below using the standard UNECE notation, where possible:

$$CL(A) = ANC_w + \frac{1.5 * BCle}{BC : Al} + \left[\frac{1.5 * BCle}{BC : Al} \Big/ kgibb\right]^{1/3} * Q^{2/3}$$

Where:

ANC_w = Acid Neutralizing Capacity produced by weathering the middle of the Skokloster range values are used, peat squares are set to zero

BCle = base cation leaching

BCle = BCa - BCu

Where:

BCa = base cation availability

BCa = max ((0.8 * ANC_w + BCdep - BClemin) , 0)

Where:

BCdep = base cation deposition (wet + dry)

[1989-92 deposition values at 20km as supplied by NETCEN are used. For acid grassland and heathland the low vegetation deposition field is used, for woodland the woodland deposition field is used]

BClemin = minimum base cation leaching

BClemin = Q * BCl * 0.01

Where:

Q = 1km runoff data supplied by the Institute of Hydrology

BCl = limiting concentration for uptake of base cations (2 μeq/l)

BCu = net uptake of base cations

BCu = min (BCumax , BCa)

Where:

BCumax = maximum uptake of base cations

BCumax = (u * yc) / 8

Where:

u = base cation uptake ie 0.0 for acid grassland and heathland
0.278 for woodland

yc = yield class - this variable applies to woodland only. For acid grassland and heathland the class is set to zero; for woodland the Norway Spruce yield class of 10 is used

kgibb = gibbsite coefficient - this is set to 1 x $10^{8.5}$ for all soil-vegetation systems

BC : Al = base cation to aluminium ratio ie acid grassland = 1.0
heathland = 2.5
woodland = 1.4

The maps presented in this report are based on two versions of the Simple Mass Balance (SMB) model. Version SMB3/4 uses a new value for the limiting concentration for uptake of base cations - changed from 15μeq/l to 2μeq/l. Version SMB3/5 calculates the critical load for acidity using the same variables but with total (marine plus non-marine) base cation deposition. The base cation deposition contains calcium and magnesium only.

2.1 Critical load for acidity $CL(A)_{non-marine}$

The critical load for acidity calculated using version SMB3/4 of the model and based on non-marine base cation deposition for 1989-92 is shown in Figure 1. Acid grassland is seen to be the least sensitive soil-vegetation system, followed by heathland and then woodland. On the latter, small critical loads occur in Wales, Scotland and Northern Ireland. Table 1 lists the area of the country within the different critical load classes for each of the soil-vegetation systems.

2.2 Exceedance of $CL(A)_{non-marine}$ by non-marine sulphur deposition

The exceedance of the critical load of acidity for soils (SMB3/4) is based on non-marine (wet + dry) sulphur deposition for 1989-92 (Figure 2). Non-marine sulphur deposition for low vegetation is used to calculate exceedance of acid grassland and heathland critical loads. For woodland $CL(A)_{non-marine}$ exceedance is based on non-marine sulphur deposition for woodland. In all three cases (acid grassland, heathland and woodland), much of the Midlands and north of England are within exceeded areas as a result of high sulphur deposition in these areas. Overall, exceedance of the woodland $CL(A)_{non-marine}$ is the highest. For this soil-vegetation system, significant portions of the UK are exceeded (23.7 %), including the sensitive areas of Scotland and Wales. Table 2 lists the area within each exceedance class for acid grassland, heathland and woodland.

2.3 Critical load for acidity $CL(A)_{total}$

Re-calculation of the critical load for acidity with marine plus non-marine base cation deposition (1989-92) used version SMB3/5 of the model. For all three vegetation types, this greatly reduces the sensitivity of large parts of the UK (Figure 3). For example, in some 1km grid squares, the critical load for acidity for woodland increases from < 0.2 to > 2.0 keq H^+ ha^{-1} $year^{-1}$. The influence of the marine base cation deposition on $CL(A)_{total}$ are more significant in the western half of the UK reflecting the deposition pattern. A summary of the area within each critical load class is given in table 1 alongside the equivalent figures for $CL(A)_{non-marine}$.

2.4 Exceedance of $CL(A)_{total}$ by total (non-marine + marine) sulphur deposition

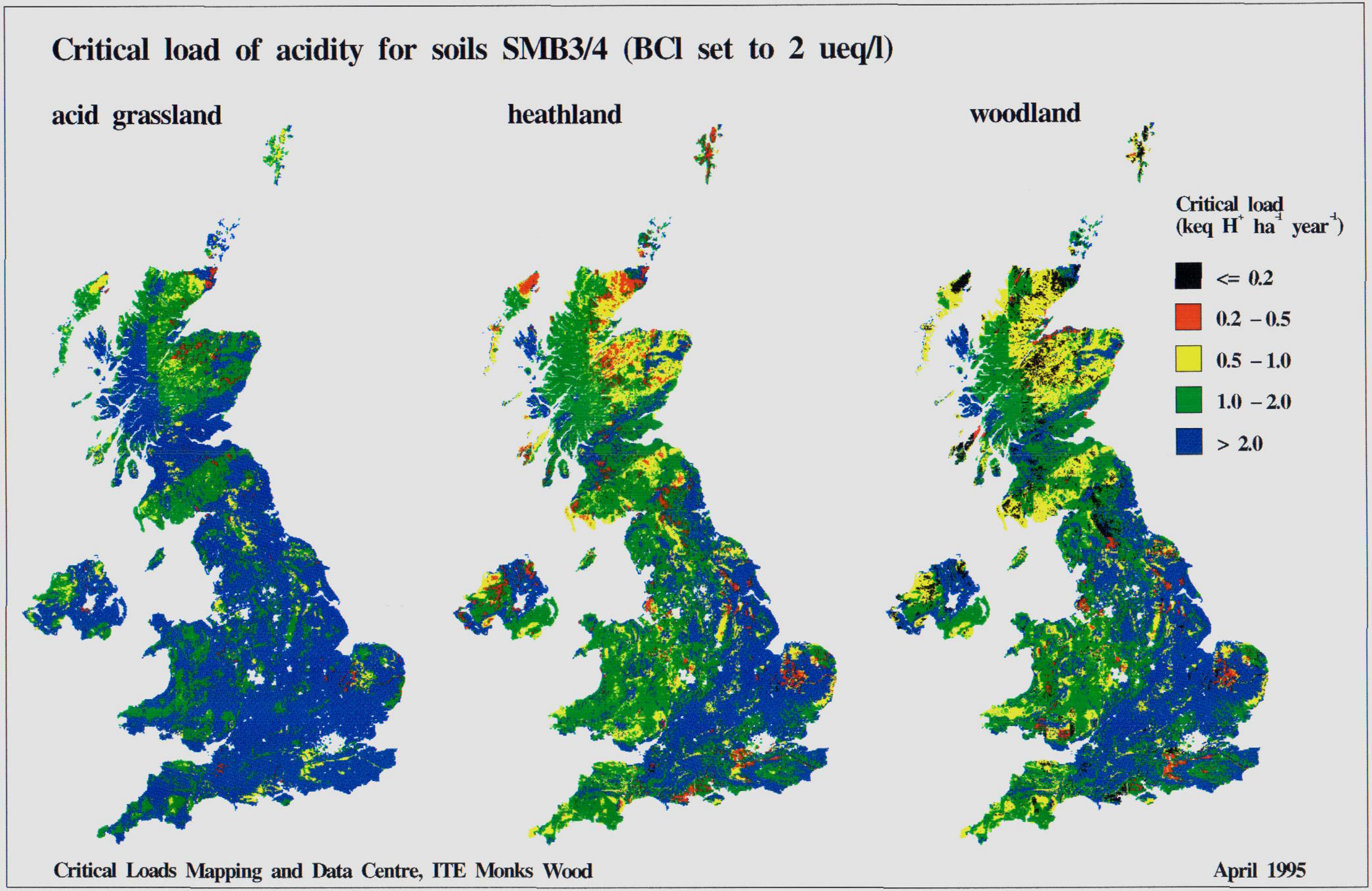
Calculations of exceedance of $CL(A)_{total}$ using non-marine + marine sulphur deposition result in reduced areas of exceedance for all three vegetation types (Figure 4). As in section 2.2, two different deposition fields are used in the calculation of these exceedance maps: for acid grassland and heathland non-marine + marine sulphur deposition over low vegetation is used, for woodland non-marine + marine sulphur deposition over woodland is used. The effects are particularly marked for woodland - there is almost no exceedance in Scotland, Wales or Northern Ireland using total sulphur deposition. The east-west division of the country produced by the $CL(A)_{total}$ calculations (section 2.3) has apparently been lost as a result of geographical variations in the sulphur deposition field. These effects are due to the distribution of marine + non-marine sulphur deposition and the pattern of the critical load obtained when calculating $CL(A)_{total}$ using marine + non-marine base cation deposition.

Table 1 **Area in critical load classes**

	$CL(A)_{non\ marine}$ (figure 1)						$CL(A)_{total}$ (figure 3)					
Critical load class (keq H^+ ha^{-1} $year^{-1}$)	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total
0.0 - 0.2	0	0.0	231	0.1	14910	6.3	0	0.0	0	0.0	14	0.0
0.2 - 0.5	2336	1.0	12759	5.3	4975	2.0	0	0.0	1218	0.5	1138	0.5
0.5 - 1.0	13990	5.9	39297	16.5	46047	19.3	1790	0.8	17206	7.2	7324	3.1
1.0 - 2.0	58754	24.6	99478	41.7	82640	34.6	26373	11.0	95807	40.1	60221	25.2
> 2.0	163600	68.5	86915	36.4	90108	37.8	210517	88.2	124449	52.2	169983	71.2

Table 2 **Area in exceedance classes**

	$CL(A)_{non\ marine}$ and non-marine sulphur deposition (figure 2)						$CL(A)_{total}$ and marine + non-marine deposition (figure 4)					
Exceedance (keq H^+ ha^{-1} $year^{-1}$)	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total
not exceeded	227959	95.5	208936	87.6	182069	76.3	236426	99.1	221010	92.6	222501	93.2
0.0 - 0.2	6268	2.6	11538	4.8	20125	8.4	1424	0.6	7649	3.2	4907	2.1
0.2 - 0.5	3502	1.5	11026	4.6	13612	5.7	706	0.3	4821	2.0	4956	2.1
0.5 - 1.0	948	0.4	5952	2.5	15251	6.4	124	0.0	4469	1.9	4801	2.0
> 1.0	3	0.0	1228	0.5	7623	3.2	0	0.0	731	0.3	1515	0.6
Total area exceeded	10721	4.5	29744	12.4	56611	23.7	2254	0.9	17670	7.4	16179	6.8

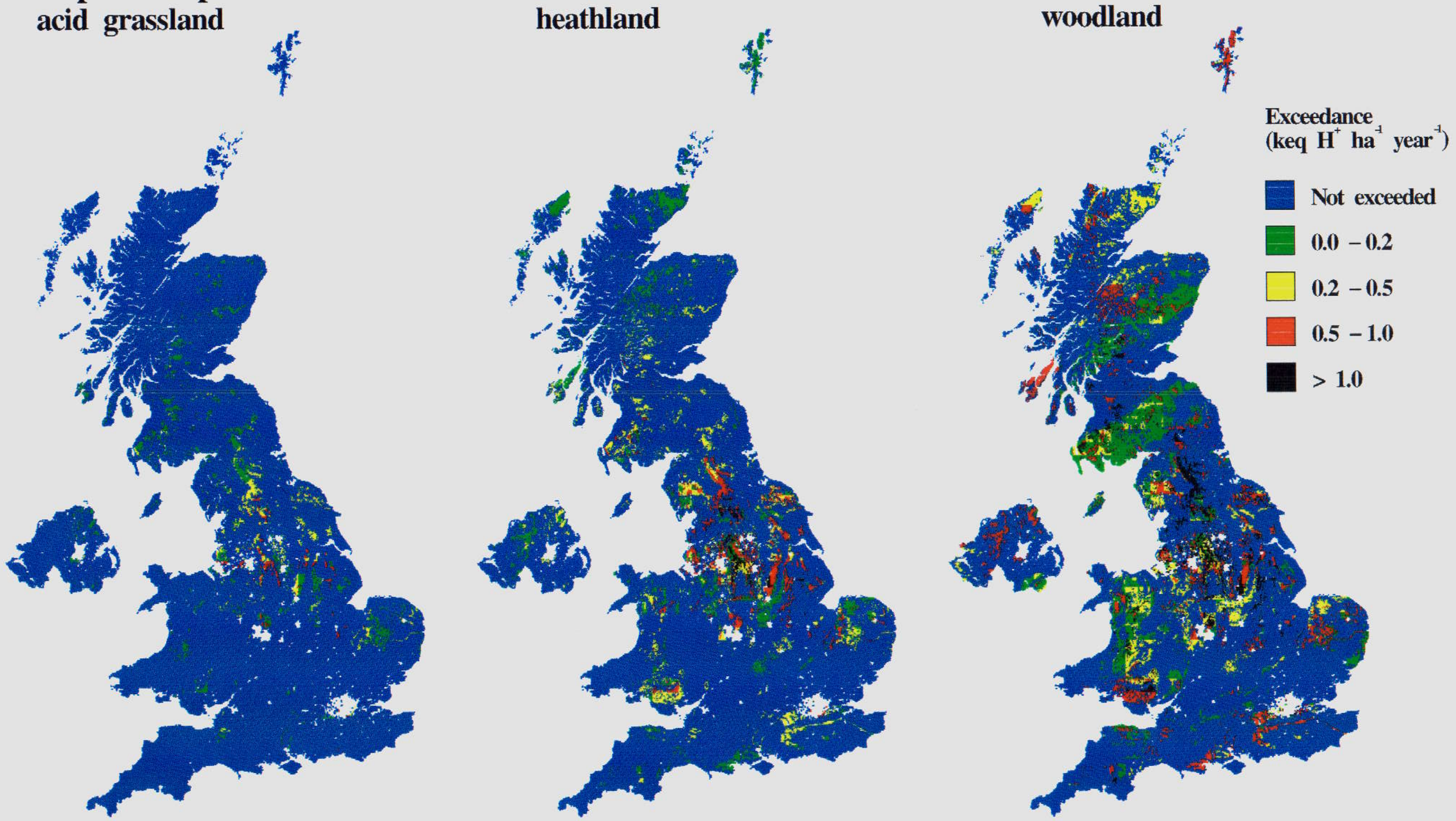


Data acknowledgement: CLAG soils sub-group, NETCEN (AEA Technology), ITE Bush, IH

NB. GB and Irish data are mapped on their national grids, however, the location of Northern Ireland with respect to GB is only approximate.

Figure 1

Exceedance of critical load of acidity for soils (SMB3/4) by non-marine (wet + dry) sulphur deposition 1989-92



Critical Loads Mapping and Data Centre, ITE Monks Wood

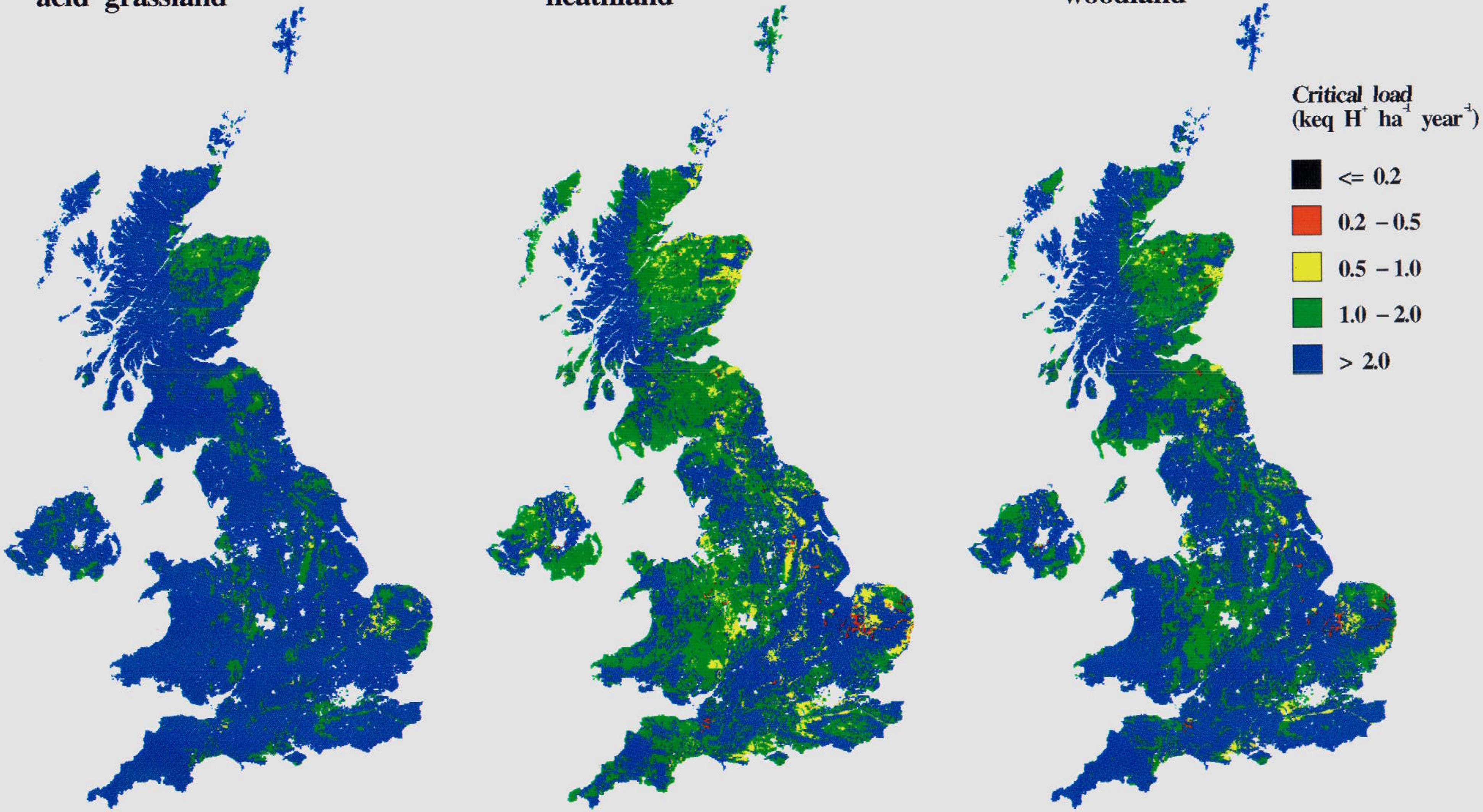
April 1995

Data acknowledgement: CLAG soils sub-group, NETCEN (AEA Technology), ITE Bush, IH

Figure 2

NB. GB and Irish data are mapped on their national grids, however, the location of Northern Ireland with respect to GB is only approximate.

Critical load of acidity for soils (SMB3/5) using total base cation deposition (marine + non-marine) 1989-92



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Data acknowledgement: CLAG soils sub-group, NETCEN (AEA Technology), ITE Bush, IH

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Figure 3

Exceedance of critical load of acidity for soils (SMB3/5) by total (marine + non-marine) (wet + dry) sulphur deposition 1989-92

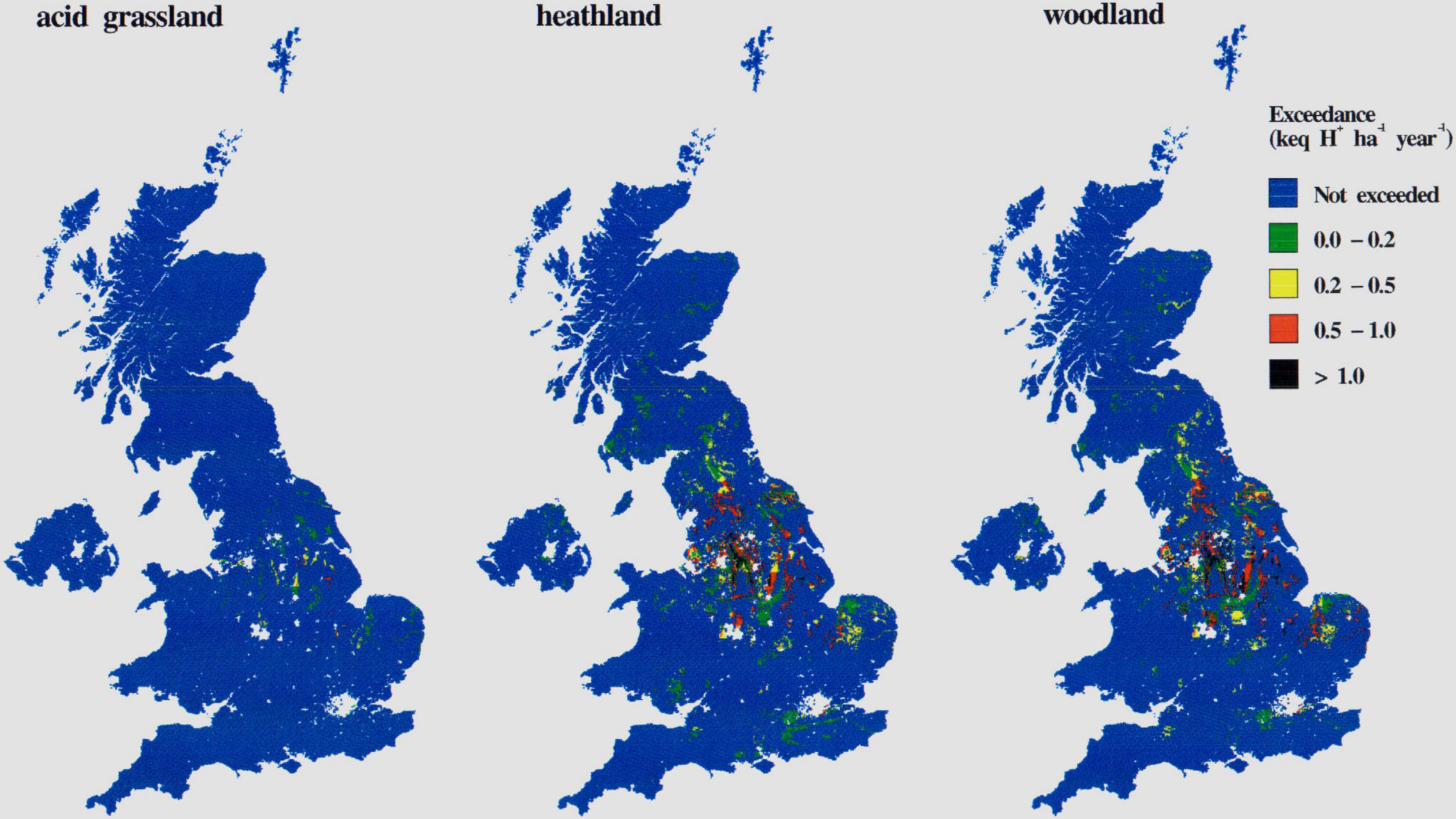

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Figure 4

3 Maximum Critical Load for Sulphur ($CL_{max}(S)$)

The equation for the calculation of the maximum critical load for sulphur is:

$$CL_{max}(S) = CL(A) + BCdep - BCu$$

Where:

CL(A) = critical load for acidity calculated in section 2 above

BCdep = base cation deposition (wet + dry)

[1989-92 deposition values at 20km as supplied by NETCEN are used. For acid grassland and heathland the low vegetation deposition field is used, for woodland the woodland deposition field is used]

BCu = net uptake of base cations

BCu = min (BCumax , BCa)

Where:

BCumax = maximum uptake of base cations

BCumax = (u * yc) / 8

Where:

u = base cation uptake ie 0.0 for acid grassland and heathland
0.278 for woodland

yc = yield class - this variable applies to woodland only. For acid grassland and heathland the class is set to zero; for woodland the Norway Spruce yield class of 10 is used

3.1 $CL_{max}(S)_{non\text{-}marine}$ ("maximum" critical load for sulphur) using non-marine base cation deposition

Using the equation detailed above, the maximum critical load for sulphur can be calculated for each soil-vegetation system. Figure 5 illustrates the results of calculating $CL_{max}(S)_{non\text{-}marine}$ from SMB3/4 using non-marine base cation deposition (1989-92). Critical loads are generally highest for acid grassland followed by heathland with woodland having the lowest values. Table 3 details the areas within each critical load class for the three soil-vegetation types.

3.2 Exceedance of $CL_{max}(S)_{non-marine}$ by non-marine sulphur deposition

Exceedance maps of $CL_{max}(S)_{non-marine}$ by non-marine sulphur deposition are shown in Figure 6. As in section 2.2, non-marine sulphur deposition for low vegetation is used to calculate exceedance of acid grassland and heathland critical loads. For woodland $CL_{max}(S)_{non-marine}$ exceedance is based on non-marine sulphur deposition for woodland. As for the $CL(A)_{non-marine}$ exceedance maps, there is a larger area and percentage area in excess of the critical load for woodland than for the less sensitive heathland or acid grassland. The areas of exceedance are recorded in table 4.

3.3 $CL_{max}(S)_{total}$ using non-marine + marine base cation deposition

When the calculation of $CL_{max}(S)_{total}$ is repeated using $CL(A)_{total}$ calculated with total (marine + non-marine) base cation deposition, the critical loads values are much higher (Figure 7) than those derived using non-marine data. The spatial distribution of critical load values is similar to that seen in the equivalent $CL(A)_{total}$ maps based on total deposition. The east-west division of the country is still evident although it is less marked. For all three soil-vegetation systems, $CL_{max}(S)_{total}$ falls into the two highest classes (ie 1.0 - 2.0 or > 2.0 keq H^+ ha^{-1} $year^{-1}$) for much of the country. The results are summarised in table 3. It can be seen from the maps and the tabulated results that differences between the non-marine and "total" calculations of $CL_{max}(S)$ are greatest for woodland soil systems.

3.4 Exceedance of $CL_{max}(S)_{total}$ by non-marine + marine sulphur deposition

There are virtually no areas of exceedance of $CL_{max}(S)_{total}$ by marine + non-marine sulphur deposition (Figure 8). Exceedances are calculated using the deposition data for low vegetation for acid grassland and heathland; for woodland $CL_{max}(S)_{total}$, deposition for woodland was used. As would be expected, the area of exceedance is largest for the most vegetation type with the lowest critical loads, ie for woodland. Differences between the two $CL_{max}(S)$ exceedance maps are particularly evident for woodland. Using marine + non-marine sulphur deposition, areas of exceedance are concentrated in the Midlands - the large areas of exceedance shown in figure 6, in Scotland and Wales in particular, are lost. The areas of exceedance for acid grassland, heathland and woodland are recorded in table 4.

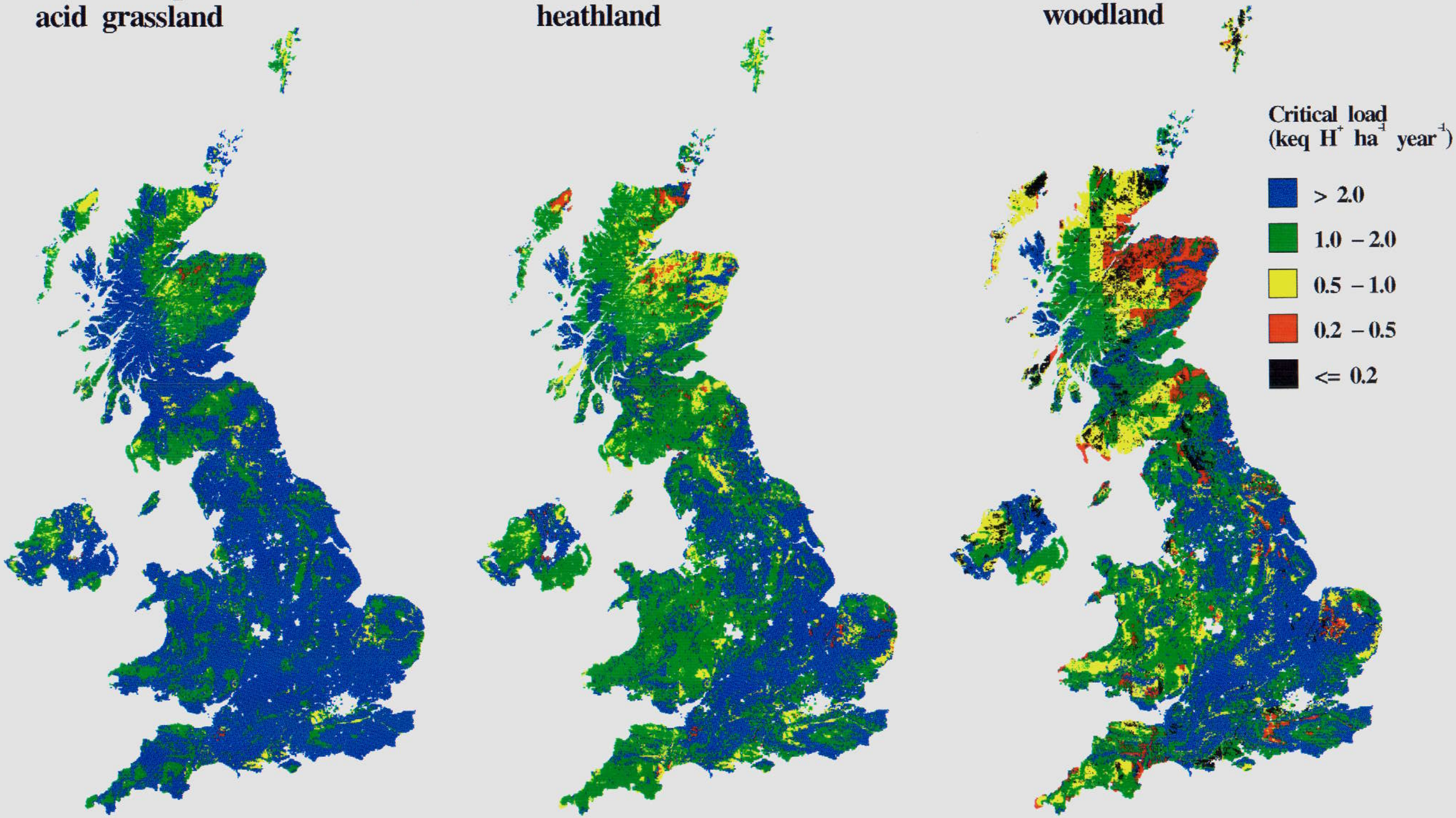
Table 3 **Area in critical load classes**

	$CL(A)_{non\ marine}$ (figure 5)						$CL(A)_{total}$ (figure 7)					
Critical load class (keq H^+ ha^{-1} $year^{-1}$)	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total
0.0 - 0.2	0	0.0	0	0.0	14994	6.3	0	0.0	0	0.0	1	0.0
0.2 - 0.5	572	0.2	4003	1.7	14787	6.2	0	0.0	0	0.0	308	0.1
0.5 - 1.0	10733	4.5	25323	10.6	36940	15.5	179	0.1	2987	1.3	3887	1.6
1.0 - 2.0	53596	22.5	113033	47.4	80274	33.6	11340	4.8	49000	20.5	33503	14.1
> 2.0	173779	72.8	96321	40.3	91685	38.4	227161	95.1	186693	78.2	200981	84.2

Table 4 **Area in exceedance classes**

	$CL(A)_{non\ marine}$ and non-marine sulphur deposition (figure 6)						$CL(A)_{total}$ and marine + non-marine sulphur deposition (figure 8)					
Exceedance (keq H^+ ha^{-1} $year^{-1}$)	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total	acid grassland (km^2)	% of total	heathland (km^2)	% of total	woodland (km^2)	% of total
not exceeded	235273	98.6	222813	93.4	174881	73.3	238382	99.9	234591	98.3	231433	97.0
0.0 - 0.2	2771	1.2	7574	3.2	18810	7.9	235	0.1	2311	1.0	2051	0.8
0.2 - 0.5	568	0.2	6339	2.6	23612	9.9	63	0.0	1431	0.6	3032	1.3
0.5 - 1.0	68	0.0	1942	0.8	15038	6.3	0	0.0	347	0.1	1905	0.8
> 1.0	0	0.0	12	0.0	6339	2.6	0	0.0	0	0.0	259	0.1
Total area exceeded	3407	1.4	15867	6.6	63799	26.7	298	0.1	4089	1.7	7247	3.0

Maximum critical load for sulphur (using CL(A) from SMB3/4 and non-marine base cation deposition 1989-92)



Critical Loads Mapping and Data Centre, ITE Monks Wood

April 1995

Data acknowledgement: CLAG soils sub-group, NETCEN (AEA Technology), ITE Bush

NB. GB and Irish data are mapped on their national grids, however, the location of Northern Ireland with respect to GB is only approximate.

Figure 5

Exceedance of maximum critical load for sulphur (using CL(A) from SMB3/4 and non-marine base cation deposition 1989-92) by non-marine sulphur deposition 1989-92

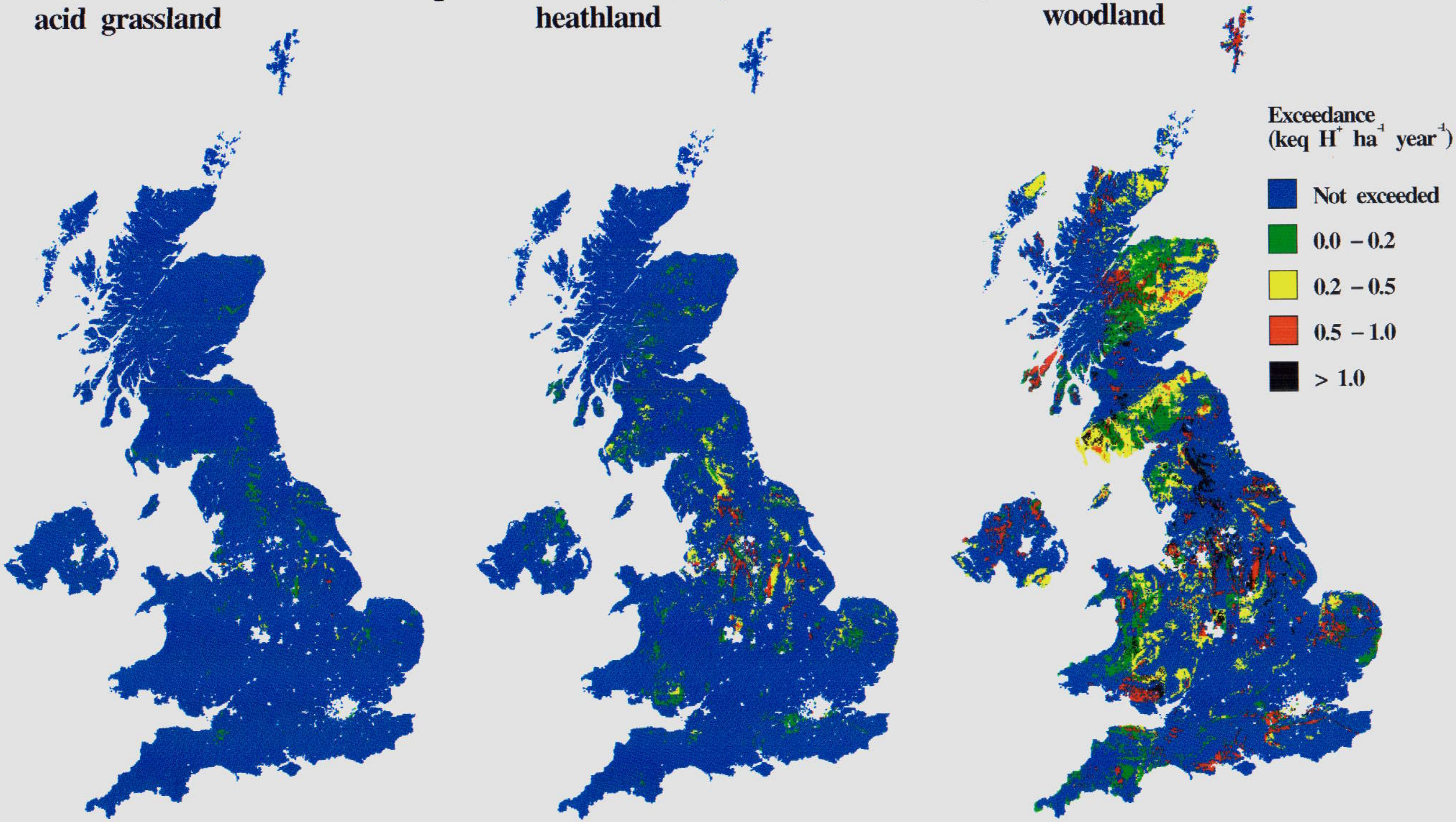


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Figure 6

Maximum critical load for sulphur (using CL(A) from SMB3/5 and total (marine + non-marine) base cation deposition 1989-92)

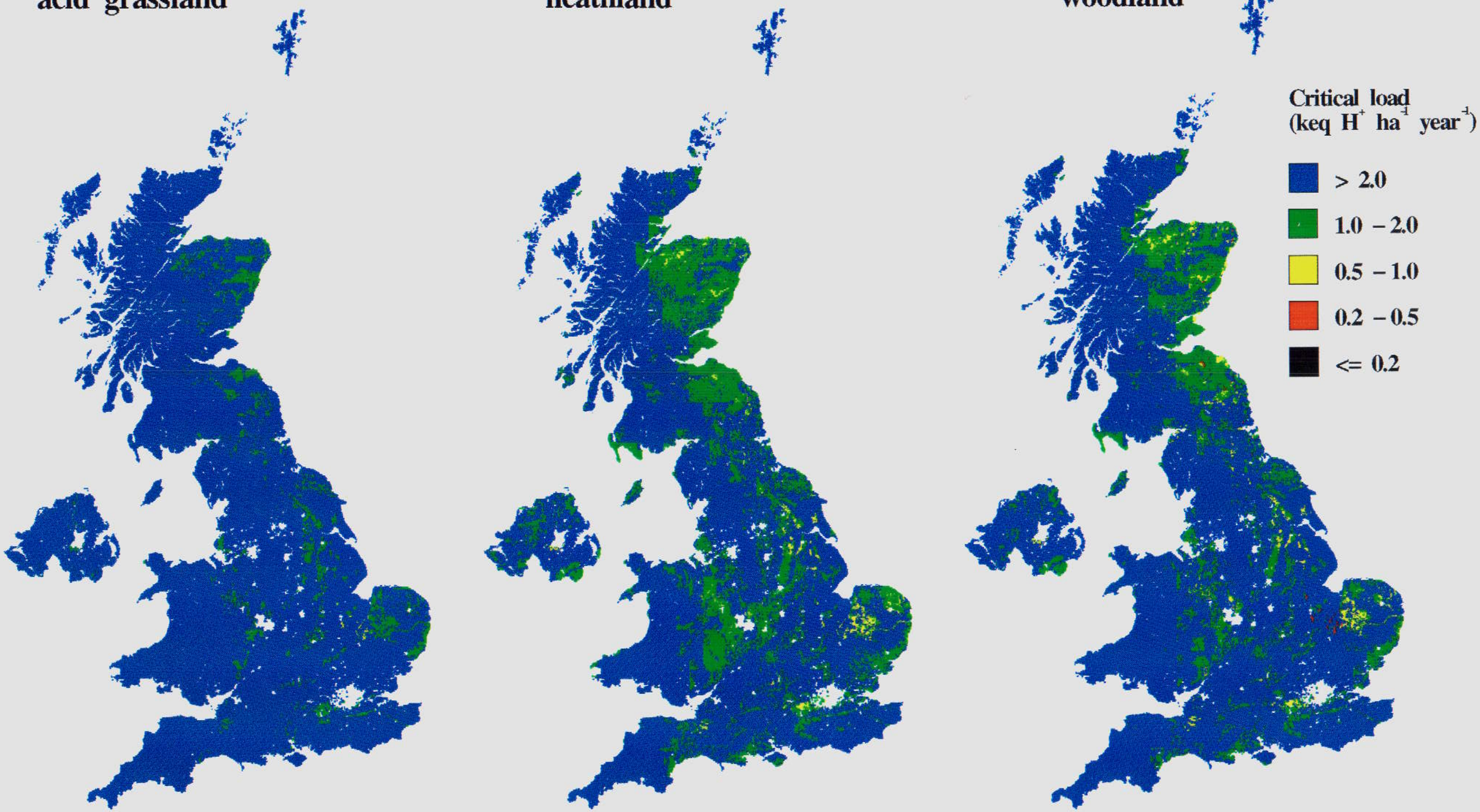

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Figure 7

Exceedance of maximum critical load for sulphur (using CL(A) from SMB3/5 and total (marine + non-marine) base cation deposition 1989-92) by total (marine + non-marine) sulphur deposition 1989-92

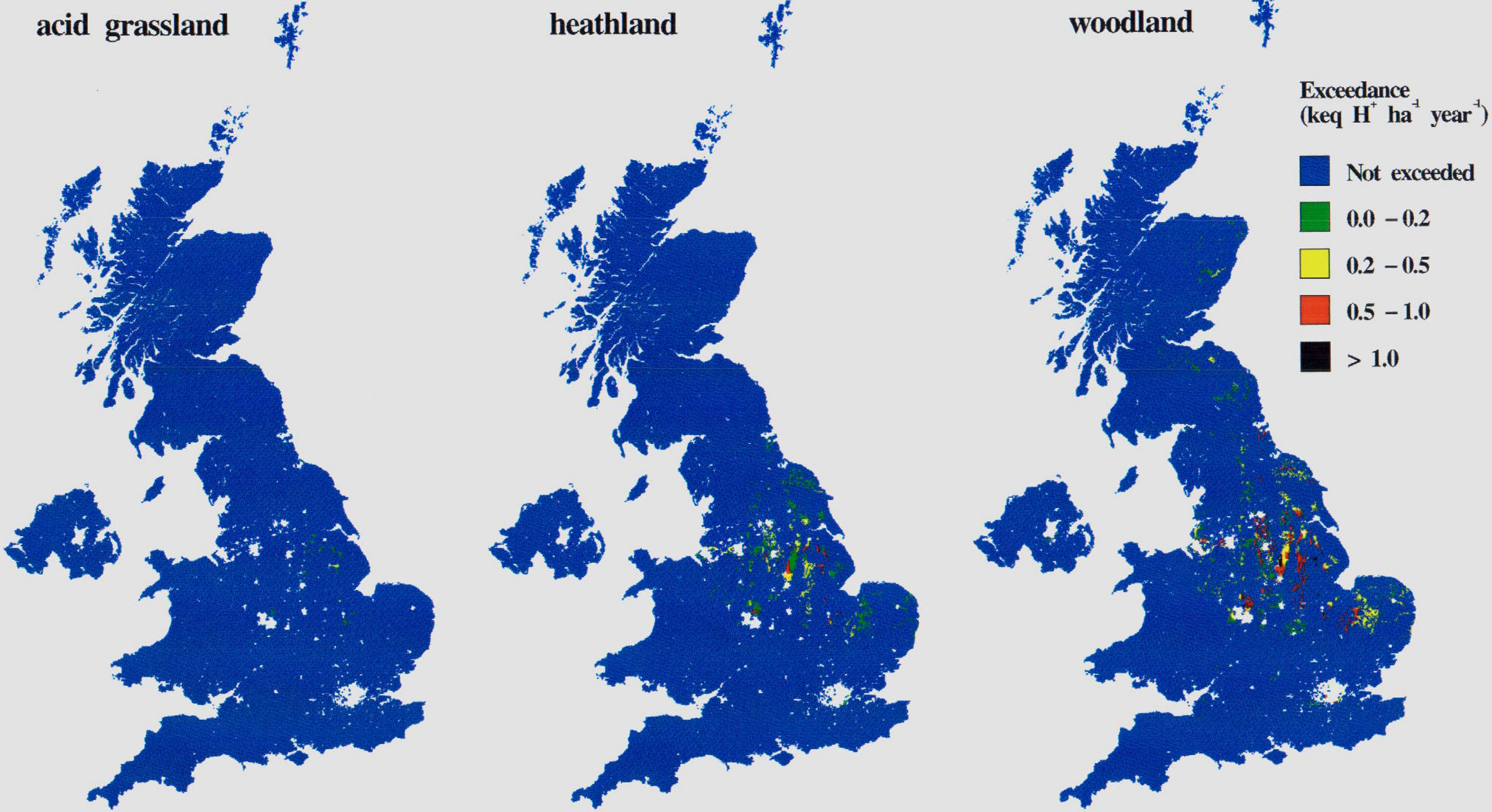

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Figure 8

4 Conclusions

This exercise illustrates the differences in critical loads and exceedances when using non-marine and "total" (marine + non-marine) deposition for the calculations. While it is to be expected that critical loads values will change by including marine base cations it is more surprising that exceedances are so different. It is clear that differences occur irrespective of whether a simple calculation is made of exceedances using CL(A) and sulphur deposition, or whether a net acidity calculation is made taking into account the neutralizing effect of base cations, ie using $CL_{max}(S)$.

For this report only calcium and magnesium have been included as base cations for calculation of both critical loads and exceedances, and only sulphate used as the acidifying anion. Further consideration might be given to the use of potassium, chloride and possibly sodium in the future.