SURVEY OF UK METAL CONTENT OF MOSSES 2000

PART II OF EPG 1/3/144 FINAL CONTRACT REPORT: DEVELOPMENT OF A CRITICAL LOAD METHODOLOGY FOR TOXIC METALS IN SOILS AND SURFACE WATERS: STAGE II

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Executive Summary

- This report presents the results of a national survey of metal contents of moss species, and uses them to derive estimates of U.K. metal deposition. The research forms part of a wider research programme on critical loads for metals.
- Surveys of moss metal content have been carried out in Nordic countries in 1980, 1985, 1990 and 1995, the U.K. participating in 1990 and 1995 (U.K. sampling done in 1996/97).
- *Pleurozium schreberi* and *Hylocomium splendens*, used in past surveys, along with *Hypnum cupressiforme* and *Rhytidiadelphus squarrosus* were sampled during summer 2000 across the U.K., with Northern Ireland sampled for the first time. Between June and September 2000 all 124 1995 survey sites were re-visited, and 86 new sites were added to improve coverage across the U.K..
- 35 sites had none of the four moss species, so the last three years' growth of 250 moss samples from 175 sites were analysed for calcium, potassium, magnesium, sodium, arsenic, cadmium, chromium, copper, nickel, lead, selenium, vanadium and zinc.
- Mean elemental concentrations varied between moss species sampled. This was partly due to the different locations from which they were sampled, and partly due to species differences in the rate of elemental uptake.
- Intercalibration between moss species at more than 60 sites where more than one moss was sampled enabled a '*Pleurozium* standardised' measure of element concentrations in mosses across the U.K. to be calculated and mapped.
- '*Pleurozium* standardised' moss concentrations of sodium and magnesium (derived mainly from sea salt) and selenium, are greatest in western coastal regions.
- '*Pleurozium* standardised' moss concentrations of potassium and calcium are lowest in northern Scotland.
- The majority of '*Pleurozium* standardised' moss concentrations of arsenic, chromium, nickel and vanadium are at, or below, background values. Larger concentrations in the Midlands, northern England, south Wales and the Severn Estuary probably all represent local emission sources.
- '*Pleurozium* standardised' moss concentrations of copper show relatively little structure although concentrations in north and central Scotland are generally much lower than in England and Wales. Clusters of high concentrations probably reflect contemporary emissions or historic mining activities.
- '*Pleurozium* standardised' moss concentrations of lead in Scotland, Northern Ireland and Wales are generally lower than in the more densely populated south and central England, presumably reflecting the combustion of leaded petrol.
- Most sites fall within or very close to '*Pleurozium* standardised' zinc baseline values, leaving a cluster of sites in central England and south Wales with larger values, probably reflecting local emission sources.

- '*Pleurozium* standardised' moss concentrations of cadmium are close to background for most of northern Scotland and Northern Ireland, whilst larger concentrations are associated with current and historical metal processing industries.

- Comparison of results with matched sites and moss species from the 1995 survey demonstrated significant reductions in concentrations of cadmium, copper, lead and zinc in the 2000 survey for both *Pleurozium schreberi* and *Hylocomium splendens*.

- Higher concentrations of sodium were found to be associated with lower concentrations of cadmium, copper, lead and zinc in *Pleurozium schreberi*, suggesting an effect of sea salt in reducing metal uptake. However, this relationship was much less clear in *Hylocomium splendens*.

- Local deposition rates were estimated from the moss concentrations, primarily using Scandinavian calibration relationships, and an inferential model was then used to derive the national deposition field based on the deposition estimates for the sample sites.

- National atmospheric deposition estimates of cadmium, copper lead and zinc derived from the 1995 and 2000 moss surveys were compared with deposition estimates obtained under the NERC-funded component of the overall research programme. This included deposition fields derived from the University of Reading's 'frisbee' collector network, and from an atmospheric transport model. There was a substantial difference between the estimates derived using the different methods.

- Although large particles do not contribute to long-range transport, the large deposition collected by the frisbees and some of the bulk deposition collectors raises the question of whether local cycling of earth-crust material should be considered in the calculation of critical loads exceedances for Cu and Zn.

- The weakest points identified in deposition estimates were the emission inventory for the modelling approach, the calibration for the moss approach, the capture efficiency of the frisbee collectors for the dry deposition of large particles and the U.K. bulk deposition measurements of metals.

- With the possible exception of Pb, the quality of the maps of heavy metal deposition to the U.K. is marginal for the mapping of critical load exceedances

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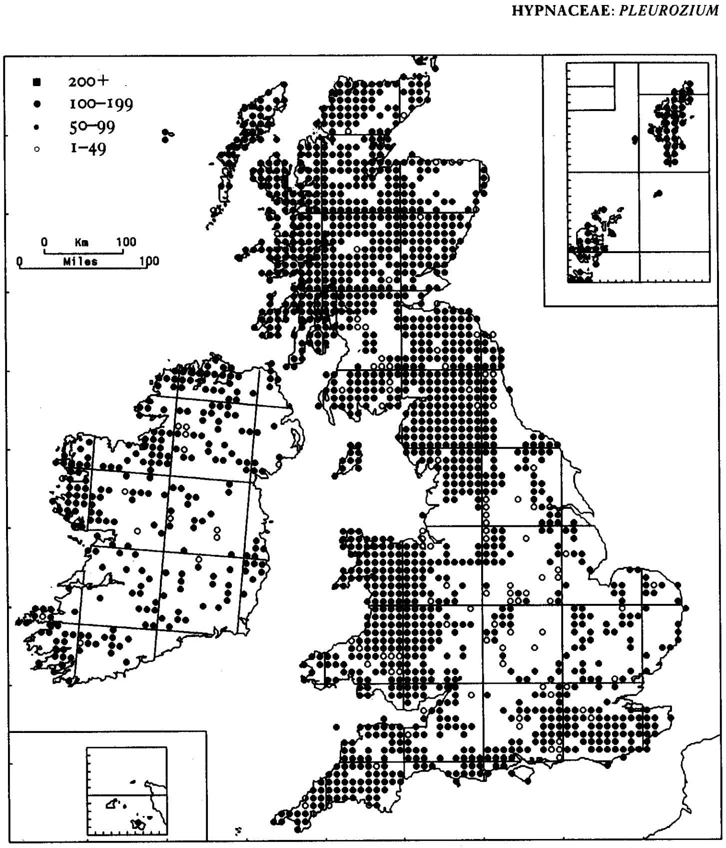
1. Introduction.

Many mosses, especially carpet forming species, obtain most of their nutrients directly from precipitation and dry deposition. The absence or strong reduction of the cuticle and thin leaves allows easy uptake from the atmosphere. Lack of an elaborate rooting system also means that uptake from the substrate is normally insignificant. These properties make mosses an ideal sampling medium for metals deposited from the atmosphere as the metals are accumulated by the moss, producing concentrations much higher than those in the original wet or dry deposition. This helps to reduce the risk of contamination during sampling and sample preparation whilst chemical analysis is more straightforward, because metal concentrations are much higher than those encountered in the analysis of precipitation samples

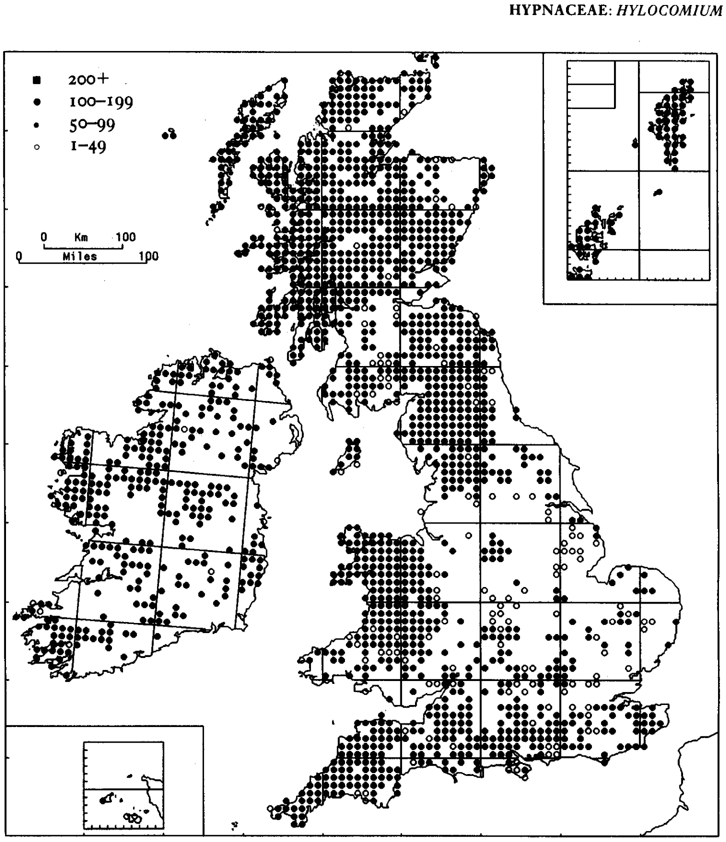
The idea of using mosses to measure atmospheric heavy metal deposition was first tested in the Nordic countries in 1980, having been developed in the late 1960s by Rühling and Tyler (Rühling and Tyler, 1968; Tyler, 1970). This lead to further surveys, involving ever increasing numbers of European countries, in 1985, 1990 and 1995 (Rühling 1992; 1994; Rühling and Steinnes 1998). The U.K. participated in the 1990 and 1995 surveys and contributed data to the European network.

Figure 1.1. Distribution map for *Pleurozium schreberi*



Pleurozium schreberi and *Hylocomium splendens*, the species selected for the early surveys, are found across northern Europe on acid substrates. Both can be abundant in coniferous forests, and also occur on acid heaths and moorlands. Annual growth increments can also be easily distinguished and separated for analysis. However, when the survey was extended to include the UK in 1990 and 1995 it proved impossible to gain complete coverage of the country using just these preferred species. *Pleurozium* and *Hylocomium* are fairly common in the wetter north and west of Britain (Figures 1.1 & 1.2) but become scarce towards the drier south and east, where acidic soils are also less common (Hill et al., 1994)

Figure 1.2. Distribution map for *Hylocomium splendens*



During the 1995 survey, two other species, *Rhytidiadelphus squarrosus* and *Pseudoscleropodium purum*, were collected in order to extend the spatial coverage. However, only at a few sites were samples representing more than one species collected, so that inter-calibration of metal concentrations between species was limited (Table1.1).

Table 1.1. Summary of the number of sites visited and moss species collected during the 1995 survey.

All sites (total = 124)	
Species	**No. of sites**
Pleurozium schreberi	78
Hylocomium splendens	57
Rhytidiadelphus squarrosus	8
Pseudoscleropodium purum	8

Sites with more than one species	
Species	**No. of sites**
Pleurozium schreberi & Hylocomium splendens	12
Pleurozium schreberi & Pseudoscleropodium purum	5
Pleurozium schreberi & Rhytidiadelphus squarrosus	4
Hylocomium splendens & Rhytidiadelphus squarrosus	2
Hylocomium splendens & Pseudoscleropodium purum	3

Section 2 of this report describes the site selection and sampling protocol for the 2000 survey (full protocol in Appendix 1), including the choice of supplementary moss species used to expand the survey's geographical cover. Analytical procedures, identical to those of the 1996/97 survey, are also described in Section 2. Metal concentrations in sampled moss species are summarised in Section 3.1 (full data in Appendix 2), and the method of intercalibration between moss species to give '*Pleurozium* standardised' concentrations is described in Section 3.2. Section 3.3 contains '*Pleurozium* standardised' maps of moss concentrations for all the metals analysed, with descriptions of those distributions. A comparison of moss concentrations in paired samples between the 1996/97 and 2000 surveys is made in Section 3.4, whilst Section 3.5 describes the relationship between concentrations of base cations derived from sea salt deposition and the metal concentrations in *Hylocomium splendens* and *Pleurozium schreberi*.

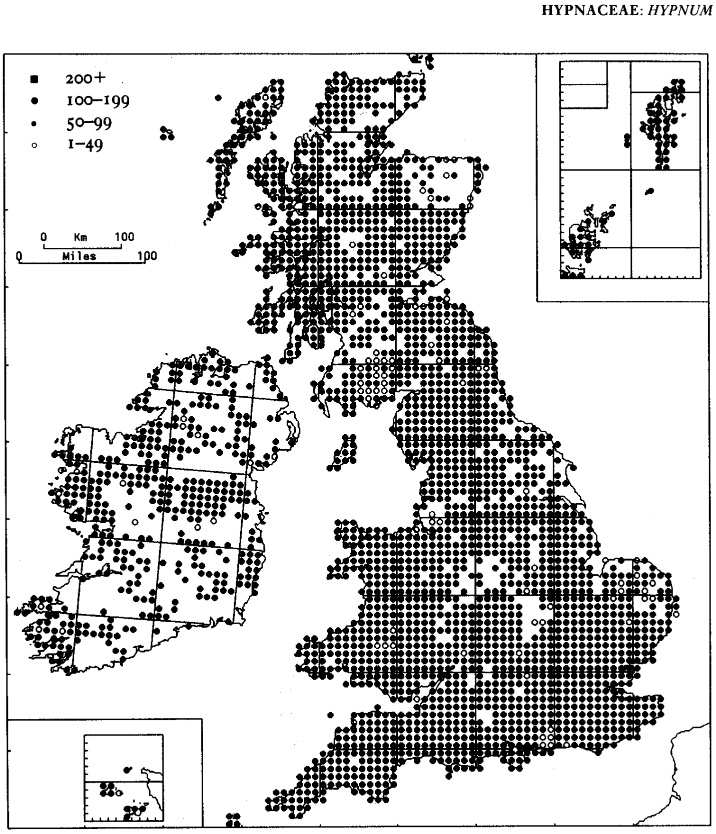
Calibration methods used to derive relationships between moss concentrations and deposition values for cadmium, copper, lead and zinc are presented in Section 4, with resulting deposition estimates for the four metals presented and compared in Section 5 with other methods for estimating metal deposition in the U.K., derived under a linked NERC-funded research project within the Environmental Diagnostics programme. Conclusions and recommendations on the moss concentrations and deposition estimates are presented in Sections 6 and 7.

2. Methods

2.1 Site selection and sampling protocol

A repeat of the 1995 survey was carried out between June and September 2000. All the 1995 survey sites were re-visited, and 86 new sites were added to improve coverage in Great Britain and to provide the first samples for Northern Ireland (Figure 2.2). All the landowners were contacted to obtain permission for access and moss collection. The survey focused on *Pleurozium schreberi* and *Hylocomium splendens* as the main species for collection, although *Hypnum cupressiforme* was also added to the list, as it occurs all over Britain (Figure 2.1), to give improved opportunities for sites in eastern England.

Figure 2.1. Distribution map for *Hypnum cupressiforme*



It is possible that some of the material collected was *Hypnum cupressiforme* var.*ericetorum* (now known as *H. jutlandicum*), but this is not likely to have affected the metal concentrations as the species are so closely related. In spite of this, it still proved impossible to collect any of the prescribed species at a surprisingly large number of sites (25), including some of those sampled in 1995. Therefore *Rhytidiadelphus squarrosus* was resorted to at some sites and a large number of inter species calibrations were carried out (Table 2.1). At a further 8 sites, *Pseudoscleropodium purum* was collected but as there were no samples of other species for inter-calibration, these were not analysed.

Figure 2.2 Location of sampling sites for the UK moss survey 2000

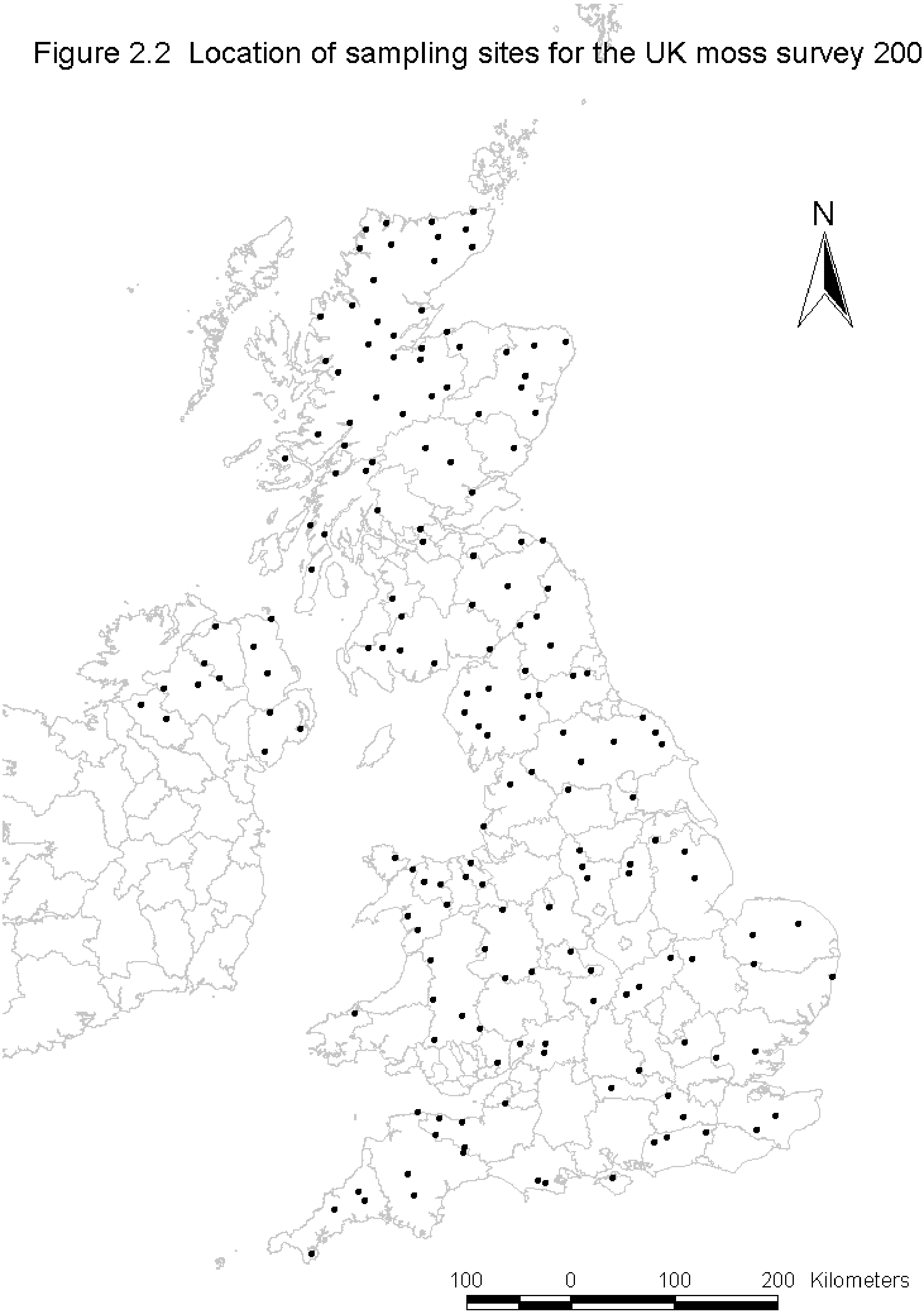


Table 2.1. Summary of the number of sites visited and moss species collected during the 2000 survey.

All sites (total = 210)	
Species	**No. of sites**
Pleurozium schreberi	91
Hylocomium splendens	80
Hypnum cupressiforme	39
Rhytidiadelphus squarrosus	40
Pseudoscleropodium purum	8
No moss present	25
Sites with more than one species	
Species	**No. of sites**
Pleurozium schreberi & Hylocomium splendens	31
Pleurozium schreberi & Hypnum cupressiforme	17
Pleurozium schreberi & Rhytidiadelphus squarrosus	17
Hylocomium splendens & Hypnum cupressiforme	5
Hylocomium splendens & Rhytidiadelphus squarrosus	8
Hypnum cupressiforme & Rhytidiadelphus squarrosus	9

The same protocols for site selection and collecting mosses were used as in the 1995 survey (Parry and Williams 1998) and these are summarised in Appendix 1. Essentially, these are a modified version of the protocol for the Nordic and European surveys. In the Nordic countries sampling points are placed at least 300m from main roads, villages and industries and at least 100m from smaller roads and single houses. These criteria were eased to 100m and 50m respectively for more densely populated countries such as Britain. The original requirement was for 2 litres of fresh moss, but in 1995 this was reduced to 1 litre to avoid depleting populations at individual sites. The minimum needed by the laboratory for analysis is 1 g dry weight of moss (last 3 years growth). Therefore, during summer 2000 we aimed to collect 2 small (23 x 15 cm) sealable polythene bags crammed full of the correct species not sorted according to age. On a number of occasions only 1 bag was collected as little moss could be found at a site, but even this proved enough for analysis.

Sampling in Northern Ireland was carried out by the Department of Agriculture and Rural Development Northern Ireland (DARDNI). The University of Bradford carried out sampling in Yorkshire. The Centre for Ecology and Hydrology, Bangor, sampled all other sites. Samples were sent to the NERC ICP-MS Facility at Kingston University, where they were prepared and analysed.

2.2 Analytical procedure

Analytical protocols were as for the previous UK moss survey (Parry & Williams, 1998). Whereas sampling for the previous survey occurred between October 1996 and April 1997, it has been referred to throughout this report as the 1995 survey. As soon as samples arrived they were logged with a unique identifier for analysis, together with details of their original label. The identification of the moss species was also checked. Between 15g and 20g of moss was placed in a paper drying bag and bar-coded with the corresponding sample number. Where original samples were significantly smaller than 50g, it was necessary to take slightly less than 15g to ensure some un-dried sample remained, in case the process needed to be repeated. Samples were then dried for 18-24 hours at 40°C. As the nature of the collection area varied considerably throughout each batch it was sometimes necessary to dry some of the more moist samples for a further 18-24 hour period (at 40°C) to ensure that they were completely dry. It was very important not to exceed this temperature, as above 40°C some of the more volatile metals may have been lost from the moss.

One gram of each dry moss then needed to be extracted from the sample for digestion. This corresponded to the last three years' growth of the moss so that there was consistency throughout the survey and any changes could be recorded in reference to the preceding survey carried out in 1996/1997. The four species of moss (*Hylocomium splendens*, *Pleurozium schreberi*, *Hypnum cupressiforme* and *Rhytidiadelphus squarrosus*) needed to be cut in different ways to remove three years growth. In the case of *Hylocomium splendens* a new shoot develops every year from older shoots, and therefore the four youngest shoots were used. In the case of *Pleurozium schreberi*, *Hypnum cupressiforme* and *Rhytidiadelphus squarrosus* three years growth corresponded to the top three centimetres of the youngest green/brown shoots. Each gram was weighed into a labelled PTFE beaker and covered with laboratory film to reduce the chances of contamination by any airborne particles or fragments of moss. For reference, moss material from the 1996/97 survey was prepared in the same way as the 2000 moss samples. A blank sample was also prepared along with each batch of digestions to monitor for contamination.

The extracted 1g samples were then digested by pipetting 5ml de-ionized water onto the sample followed by 10ml concentrated (69%) high purity (Aristar$^{®}$) nitric acid. The beakers were then covered with PTFE watch glasses so that no vapours were lost during the digestion. The samples were then heated on a hot plate at 140°C for three hours and allowed to reflux. After digestion the samples were removed from the hot plate and left to cool, still with their covers. The cool solutions were then filtered into cleaned 50ml volumetric flasks. Any residues in the beakers or on the lids were rinsed off with de-ionized water and added to the flask. The volume was made up to 50ml using more de-ionized water. The digested samples were then transferred to new, labeled, sample tubes and stored in a fridge to await analysis.

The samples were analysed for Ca, K, Mg & Na by inductively coupled plasma atomic emission spectrometry (ICP-AES) at this dilution. The elements As, Cd, Cr, Cu, Ni, Pb, Se, V & Zn were determined by inductively coupled plasma mass spectrometry. Just before analysis, the samples were further diluted by adding 2ml of the sample to 8ml de-ionized water. The mosses were analysed under normal operating conditions, with instrumentation optimized according to manufacturer's recommendations.

Analytical precision (i.e. the same sample solution analysed 3 times back to back) was between 1 and 6%, where concentrations were not close to the lower limits of detection (defined as 3x standard deviation of a blank). Sample preparation precision (i.e. the same sample prepared 5 times), was between 10 and 30%. Sampling precision (same species, same site, but different bags), was again between 10 and 30%.

A comparison of the measured data with the accepted value for the reference sample shows that at only 1 standard deviation their values are in agreement. Table 2.2 shows a comparison of analysis of the reference material in 1996/7 and in 2000. For all four metals, lower concentrations were recorded in 2000. It is difficult to interpret this apparent bias between 1996/97 and 2000 data, as t-tests on these data suggest that there is no significant difference between the values for each metal, at the 5% level. Also, as both the sampling and sample preparation precision can be up to 30% it is difficult to attach much importance to the bias. Nevertheless, the existence of this bias is of relevance to the interpretation of differences between the concentrations recorded in the field samples in 1996/97 and 2000 (see Section 3.4).

Table 2.2. Comparison of reference material analytical results (concs. in mg kg^{-1}) from 1996/97 and 2000.

Element	**1996/97 Mean**	**SD (n=5)**	**2000 Mean**	**SD (n=8)**	**Bias % (ref 1996)**
Cd	0.457	0.063	0.410	0.049	-10.4
Cu	66.2	8.12	57.9	5.99	-12.6
Pb	6.76	0.89	6.04	0.88	-10.7
Zn	31.3	4.39	29.6	3.06	-5.6

3. Results

3.1 Metal concentrations in mosses

Metal concentrations in the individual moss species are summarised in Tables 3.1 to 3.4 whilst the full data set is listed in Appendix 2.

Table 3.1. Summary statistics for metal concentrations (mg kg^{-1} dry wt.) in *Pleurozium schreberi* (n=91).

Metal	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**
Na	186.20	163.39	92.47	54.76	486.65
Mg	1127.3	1122.0	257.8	662.5	2037.9
K	3113.7	3013.2	860.2	1509.5	5641.1
Ca	2014	1819	1023	720	7680
V	1.367	1.091	1.108	0.342	8.253
Cr	1.358	1.427	0.703	0.106	3.677
Ni	0.965	0.756	0.984	0.051	8.043
Cu	4.597	4.460	1.668	1.440	10.000
Zn	28.40	25.00	17.72	7.64	122.00
As	0.347	0.159	0.7571	0.009	4.493
Se	0.356	0.332	0.182	0.058	0.917
Cd	0.165	0.123	0.176	0.025	1.197
Pb	4.734	2.887	5.221	0.688	34.483

Table 3.2 Summary statistics for metal concentrations (mg kg^{-1} dry wt.) in *Hylocomium splendens* (n=80).

Metal	**Mean**	**Median**	**Std. Dev.**	**Min**	**Max**
Na	228.6	231.6	90.2	35.5	501.0
Mg	1168.1	1172.0	234.6	498.7	1749.5
K	2431.5	2251.3	847.6	1187.0	5109.8
Ca	1901	1700	965	859	6665
V	1.005	0.799	0.672	0.141	3.007
Cr	1.246	1.233	0.521	0.160	3.400
Ni	0.831	0.634	0.726	0.014	3.827
Cu	3.734	3.515	1.258	1.580	7.420
Zn	22.20	17.75	22.08	8.03	195.00
As	0.157	0.092	0.193	0.009	1.034
Se	0.354	0.346	0.159	0.062	0.770
Cd	0.105	0.062	0.146	0.010	1.099
Pb	3.264	1.739	5.127	0.340	32.75

Table 3.3 Summary statistics for metal concentrations (mg kg^{-1} dry wt.) in *Hypnum cupressiforme* (n=39).

Metal	Mean	Median	Std. Dev.	Min	Max
Na	170.5	147.9	126.0	39.5	715.5
Mg	964.1	922.3	262.1	577.5	1649.0
K	2274	2116	677	1213	3792
Ca	2409	2371	798	1081	4982
V	1.568	1.455	0.947	0.321	4.577
Cr	1.687	1.812	0.714	0.160	3.103
Ni	1.547	1.247	1.086	0.014	5.670
Cu	4.507	4.270	1.448	0.868	8.000
Zn	27.06	23.30	13.43	7.36	74.70
As	0.358	0.259	0.365	0.017	2.153
Se	0.377	0.340	0.183	0.058	0.990
Cd	0.176	0.142	0.133	0.040	0.620
Pb	8.95	6.25	9.36	1.72	50.78

Table 3.4 Summary statistics for metal concentrations (mg kg^{-1} dry wt.) in *Rhytidiadelphus squarrosus* (n=40).

Metal	Mean	Median	Std. Dev.	Min	Max
Na	205.2	186.6	101.1	71.5	507.4
Mg	1095.2	1147.3	232.3	581.0	1471.1
K	4497	4252	1294	2652	7791
Ca	2589	2199	1362	1096	7120
V	1.658	1.141	1.402	0.381	6.190
Cr	2.012	1.760	0.881	0.760	4.800
Ni	1.253	1.060	0.738	0.183	3.207
Cu	5.383	5.180	1.406	2.680	8.720
Zn	34.40	27.25	18.72	17.90	112.00
As	0.508	0.242	0.658	0.028	3.057
Se	0.299	0.294	0.117	0.055	0.538
Cd	0.193	0.160	0.115	0.060	0.571
Pb	6.58	4.84	5.68	0.81	24.63

In only a very few cases were metal concentrations reported below the detection limit. Where this occurred, the result was set to a value of half the detection limit. Chromium had 20 cases, nickel 37, arsenic 9 and selenium 21, all other analyses were above the limit of detection. The data were generally log-normally distributed; thus the median values approximate to the geometric mean values and the arithmetic means are generally larger than the corresponding median values. The variability in the data is reflected in the range, which can span up to two orders of magnitude.

3.2 Intercalibration of metal concentrations between moss species

In order to extend the survey coverage beyond the regions where *Pleurozium* and *Hylocomium* commonly occur, *Hypnum* and *Rhytidiadelphus* were added to the list of species for collection. Simple linear regression was used to assess the relationship between metal concentrations in the different moss species. Due to the predominance of *Pleurozium,* regression relationships of the other species on *Pleurozium* were used to derive a metal concentration data set ‘standardised’ to *Pleurozium schreberi*. This data set was used to map the distribution of metal concentrations, as described in Section 3.3.

The regression relationships are summarised in Tables 3.5-3.7. In many cases, outlying data points were rejected following examination of the residuals around the best-fit line. In almost all cases, significant relationships were obtained between moss species although there were exceptions. These were for i) Ca, Cu and As for *Pleurozium* vs. *Hypnum* and ii) Na and Se for *Pleurozium* vs. *Rhytidiadelphus.* This meant that the standardised data set had 16 missing data points for Ca, Cu and As and 18 missing data for Na and Se. In most cases, the slopes of the regression lines between *Pleurozium* metal concentrations and those of the other mosses were close to unity, especially for the regressions against metal concentrations in *Hylocomium*. Deviations in slope from unity are indicative of the relative efficiency of the different moss species for capturing metals from the atmosphere. For the majority of regressions, the intercept was not significantly different from zero. Where significant non-zero intercepts exist, this may indicate differences in the background accumulation of metal in the different moss species. For example, previous work (Berg et al., 1995; Rühling and Steinnes 1998) suggests that *Pleurozium* and *Hylocomium* contain a background quantity of 20-30 mg kg^{-1} of Zn even at pristine sites. This is attributed to a nutrient function of Zn in the moss.

Table 3.5. Summary statistics for the regression of metal concentrations (mg kg^{-1}) in *Hylocomium splendens* and *Pleurozium schreberi.*

Metal	Constant[1]	Slope	r^2	n
Na	-5.102	1.005	0.750***	30
Mg	346.80	0.773	0.457***	28
K	1838	0.375	0.480***	24
Ca	95.62	0.934	0.912***	27
V	0.305	0.747	0.802***	26
Cr	0.258	0.840	0.799***	23
Ni	-0.024	1.026	0.908***	27
Cu	1.020	0.708	0.690***	26
Zn	9.342	0.601	0.529***	27
As	-0.017	1.243	0.919***	26
Se	0.059	0.832	0.735***	23
Cd	0.042	0.754	0.420***	25
Pb	0.503	0.933	0.669***	28

[1] All values not significantly different from zero

Table 3.6 Summary statistics for the regression of metal concentrations (mg kg^{-1}) in *Hypnum cupressiforme* and *Pleurozium schreberi.*

Metal	[1]Constant	Slope	r^2	n
Na	*86.278	0.807	0.747***	12
Mg	198.16	0.992	0.862***	12
K	**1869	0.640	0.423*	11
Ca	**1599	0.156	0.050	15
V	0.149	0.675	0.377*	14
Cr	0.153	0.795	0.939***	13
Ni	-0.110	0.905	0.822***	15
Cu	*3.129	0.293	0.072	17
Zn	***15.277	0.346	0.524**	12
As	0.127	0.231	0.044	13
Se	0.060	0.715	0.815***	13
Cd	**0.065	0.429	0.399**	15
Pb	*1.323	0.506	0.764***	13

*** significant at $p<0.001$; ** significant at $p<0.01$; * significant at $p<0.05$
[1] symbols denote significance of difference from zero

Table 3.7. Summary statistics for the regression of metal concentrations (mg kg^{-1}) in *Rhytidiadelphus squarrosus* and *Pleurozium schreberi.*

Metal	[1]Constant	Slope	r^2	n
Na	***120.78	0.142	0.082	17
Mg	496.87	0.477	0.298*	15
K	**924	0.610	0.931***	12
Ca	104.82	0.850	0.905***	15
V	**0.268	0.685	0.971***	13
Cr	0.208	0.838	0.845***	12
Ni	0.016	0.933	0.911***	14
Cu	-0.140	0.885	0.825***	13
Zn	***-28.275	2.119	0.907***	14
As	0.024	0.971	0.729***	12
Se	*0.249	0.113	0.009	17
Cd	**0.054	0.364	0.480**	14
Pb	**0.933	0.577	0.885***	12

*** significant at $p<0.001$; ** significant at $p<0.01$; * significant at $p<0.05$
[1] symbols denote significance of difference from zero

3.3 Spatial patterns of metal concentrations in mosses

Maps of the '*Pleurozium* standardised' data have been plotted as graduated symbols for the metal concentration at each site in Figures 3.3.1 to 3.3.13. With the exception of Cr and Ni which use a six interval scale, an eight interval scale has been used. The symbol maps are useful for identifying individual anomalies, whilst at the same time giving an overall impression of the metal distribution pattern across the country. A brief interpretation of the maps for each metal is provided in the following.

Sodium, potassium and magnesium (figures 3.3.1 - 3.3.3)

These metals were determined in order to identify those regions where uptake of heavy metals by the mosses could be suppressed by competition with Na and Mg derived from sea salt deposition (Gjengedal and Steinnes 1990; Berg and Steinnes 1997). The maps show strong gradients of sea salt deposition from west to east, with particularly high concentrations at many near-coastal sites particularly in northern Scotland. The areas most heavily influenced by sea salts are north west Scotland, Northern Ireland, the south west peninsular of England, the Lake District, northern Pennines and north and west Wales. There is evidence that sea salt deposition may reduce metal uptake by the mosses (Berg and Steinnes, 1997), and these maps provide a qualitative indication of where the effect must be considered when interpreting the concentration patterns for the heavy metals. Further analysis of this issue may be found in Section 3.5.

The maps also reveal a difference in the spatial concentration patterns between Na and Mg although these are both predominantly supplied from sea salt deposition. This has been noted elsewhere and attributed to relatively weak retention of Na by mosses so that it is readily exchanged for other cations such as K, Ca and Mg, particularly in areas where the concentration of these metals in precipitation is large (Steinnes et al., 1992). Potential enrichment of the mosses by Mg in canopy drip from higher plants (Berg et al., 1995) could be involved, although careful sampling should have minimised this effect.

The map for K shows much less structure in the data compared to Na and Mg, although concentrations are generally lower in northern Scotland compared to the rest of the UK. This may indicate competitive exchange with Mg which is present in relatively high concentrations in this region. Potassium is an essential nutrient, and thus relatively uniform concentrations might be expected. A few sites show very low levels of potassium. Although the reasons for this are not clear, one control on the amount of K held in moss tissue is the degree of desiccation it has experienced. This can lead to loss of intracellular K (Brown and Buck 1979; Brown and Brümelis 1996) and a reduction in total K content. There is also evidence that older segments of *Hylocomium splendens* contain less K than younger ones (Brown and Brümelis 1996).

Calcium (figure 3.3.4)

Concentrations are relatively low and uniform in Scotland and Northern Ireland compared to England and Wales, where more structure is apparent in the data. The principal sources of calcium are sea salts and windblown dust from soil, agricultural liming and quarrying. Thus broad regional patterns may simply reflect differing levels in the intensity of agricultural activity. Many of the anomalous sites (>5000 mg kg^{-1}) are located in regions of Carboniferous limestone (north Cumbria, Pennines, and Anglesey) and may be influenced by dust from quarrying in these regions. Other high values in the Cotswolds, and in central and eastern England may be due local point source inputs from agriculture.

Figure 3.3.1 'Pleurozium standardised' sodium concentrations in UK mosses 2000

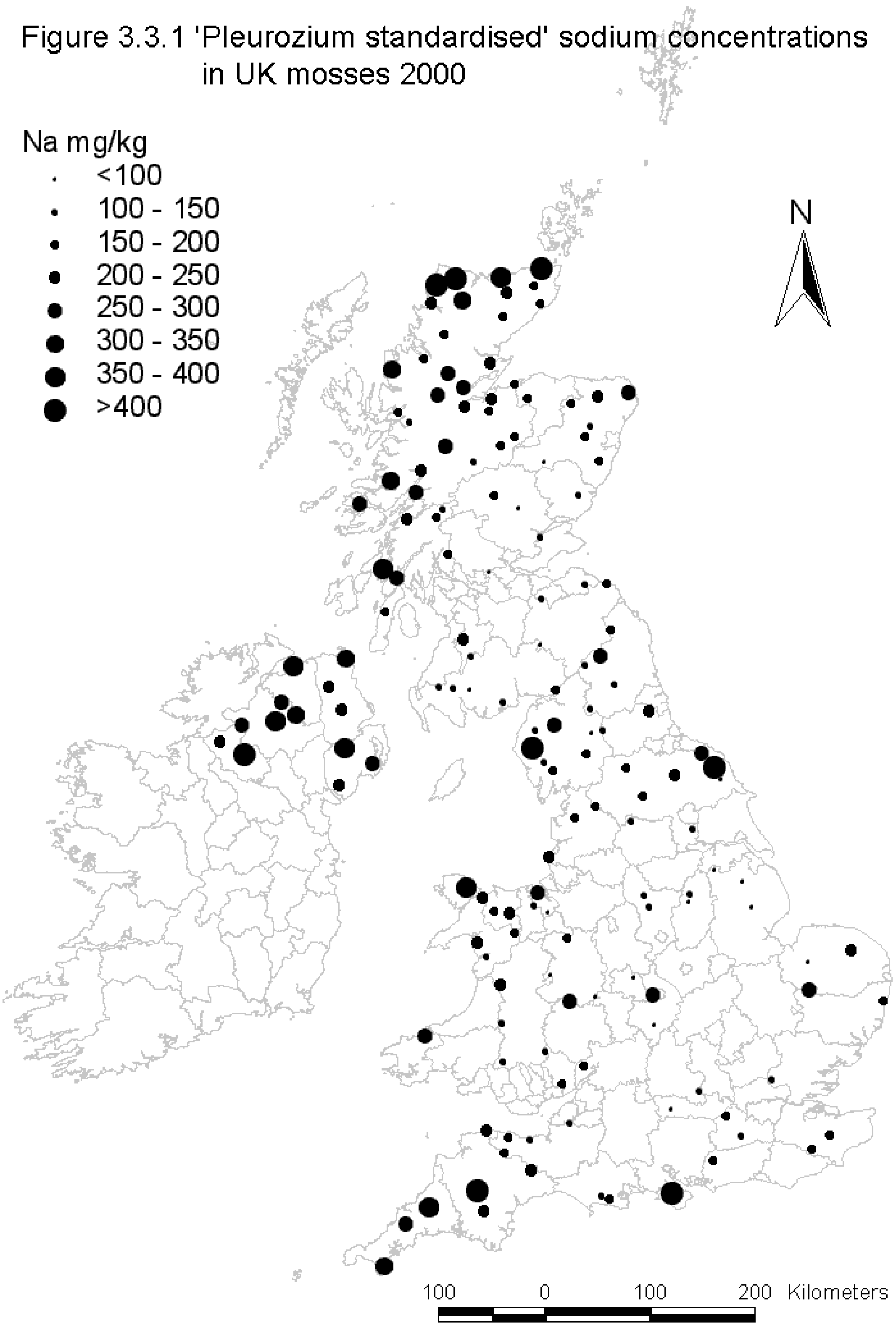


Figure 3.3.2 'Pleurozium standardised' potassium concentrations in UK mosses 2000

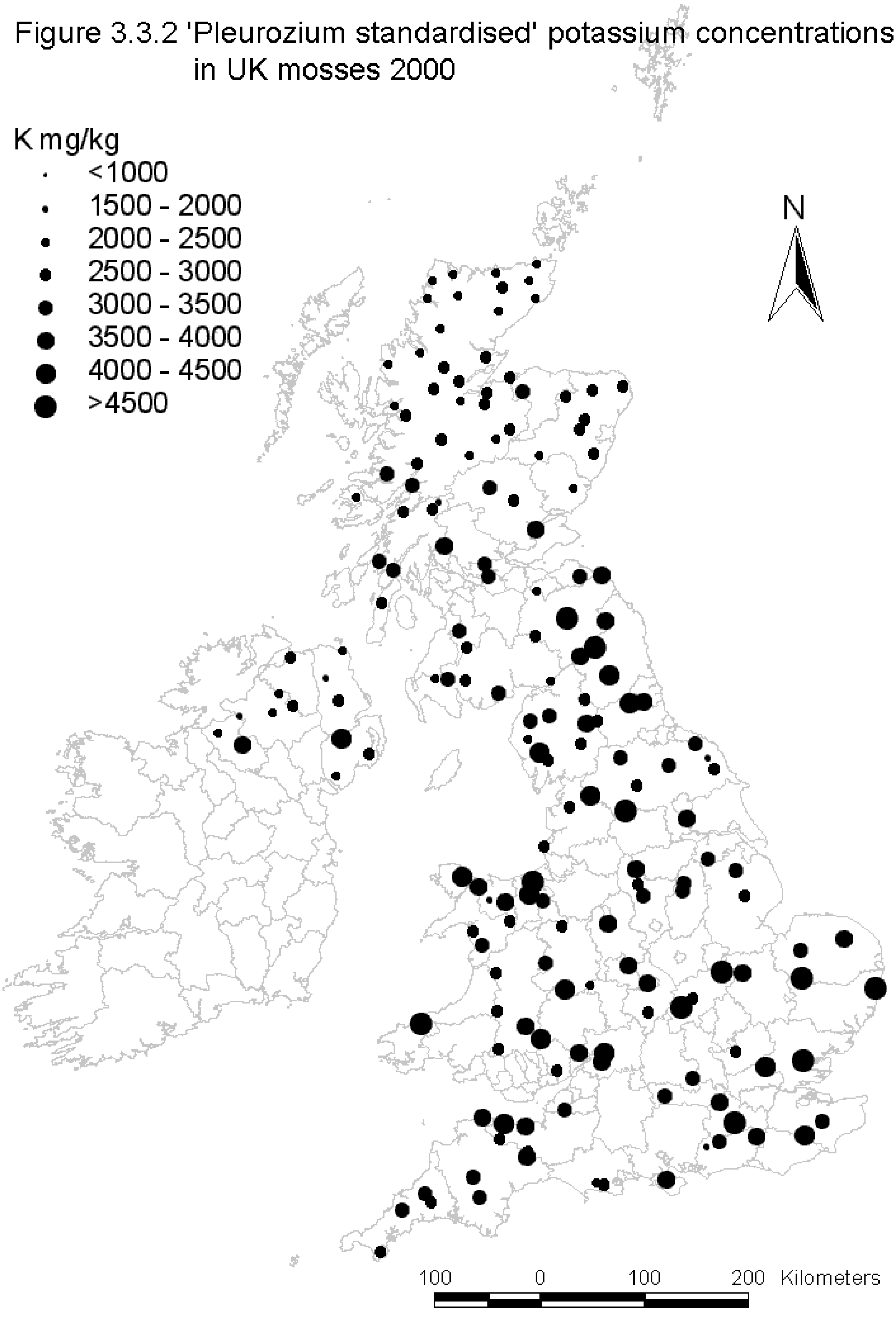


Figure 3.3.3 'Pleurozium standardised' magnesium concentrations in UK mosses 2000

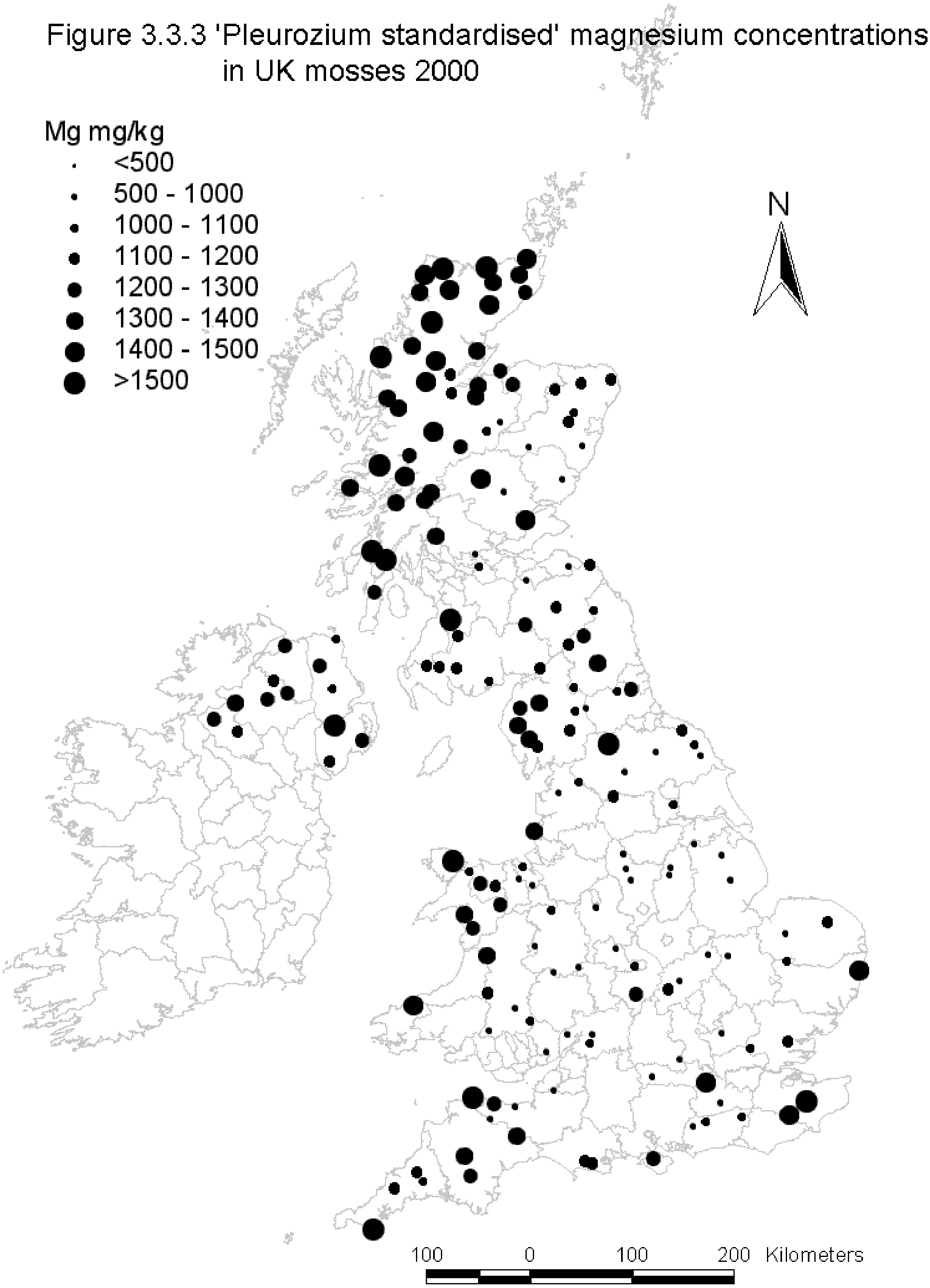
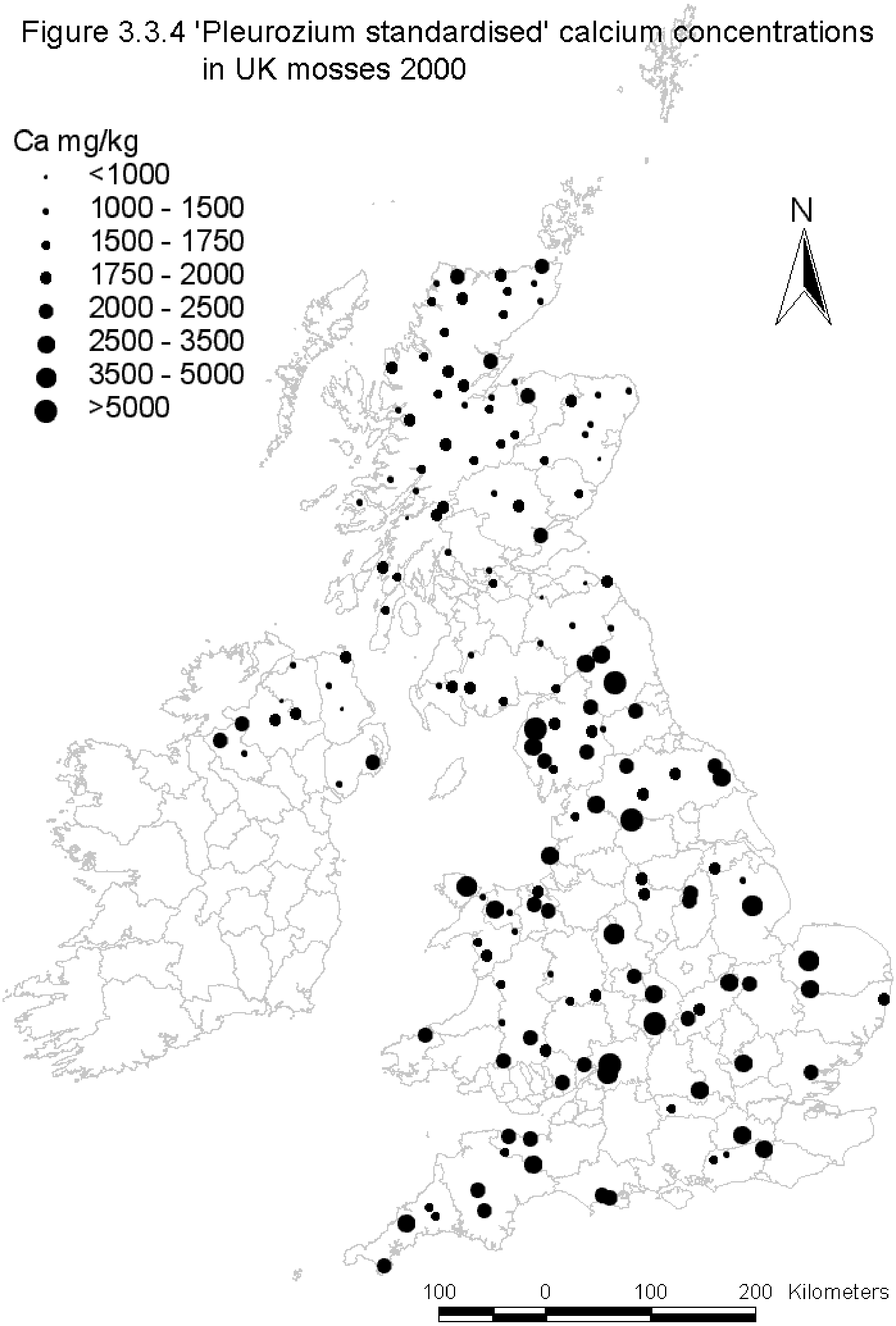


Figure 3.3.4 'Pleurozium standardised' calcium concentrations in UK mosses 2000



Selenium (figure 3.3.5)

The distribution of Se across the country is not dissimilar to that of Mg and Na, with enrichment in the western fringes of the UK, Scotland and Northern Ireland. This is due to the importance of the marine environment as a source of Se (Låg and Steinnes 1974) through enrichment of volatile dimethyl selenide compounds in the sea surface layer and marine aerosols (Cooke and Bruland 1987). Selenium was not reported in the 1995 European Survey (Rühling and Steinnes 1998); however from a survey in Norway (Steinnes et al., 1992), a background value of 0.2 mg kg^{-1} seems appropriate in areas away from marine influence.

Arsenic (figure 3.3.6)

From the 1995 European survey (Rühling and Steinnes 1998), background values of As can be less than 0.1 mg kg^{-1} in areas such as Iceland and northern Norway. Concentrations in Scotland, Northern Ireland and most of Wales are generally at, or close to, background and are generally low compared to England and southern parts of Wales. Arsenic is generally emitted to the atmosphere from coal combustion and more locally from mining sources. Several industrial processes provide minor sources. Overall these would account for the larger concentrations in central and southern England. In the south-west peninsular, large concentrations are probably associated with windblown dust from historic mining activities and there is also evidence of a point source effect in the vicinity of the Avonmouth smelter. The other anomalies are more difficult to assess without a much more detailed appraisal of potential point sources. For example, it is possible to speculate that those to the north of the Lake District may be associated with industrial emissions from Workington and possibly Barrow, whilst in north-central England there is an anomaly close to sources in the region of Bradford. The anomaly in west Sussex is downwind of the Fawley oil refinery and Southampton.

Copper (figure 3.3.7)

Local point sources from the metal industry and fossil fuel combustion are all-important contributors to emissions of Cu. From the 1995 European survey (Rühling and Steinnes 1998), the background concentration of Cu in mosses from areas without industrial emission sources is 4 to 8 mg kg^{-1}. This is partly attributed to a baseline concentration of the metal in mosses of between 3 and 5 mg kg^{-1} which is believed to reflect an essential nutrient function of Cu (Ross 1990; Berg et al., 1995). Thus, there is relatively little structure in the UK data although concentrations in north and central Scotland are generally much lower than in England and Wales. There are clusters of high concentrations in the Midlands, south Wales and northern Cumbria, which probably reflect contemporary emissions. However those occurring in Cornwall and north Wales may be due to dust from historic mining activities.

Figure 3.3.5 'Pleurozium standardised' selenium concentrations in UK mosses 2000

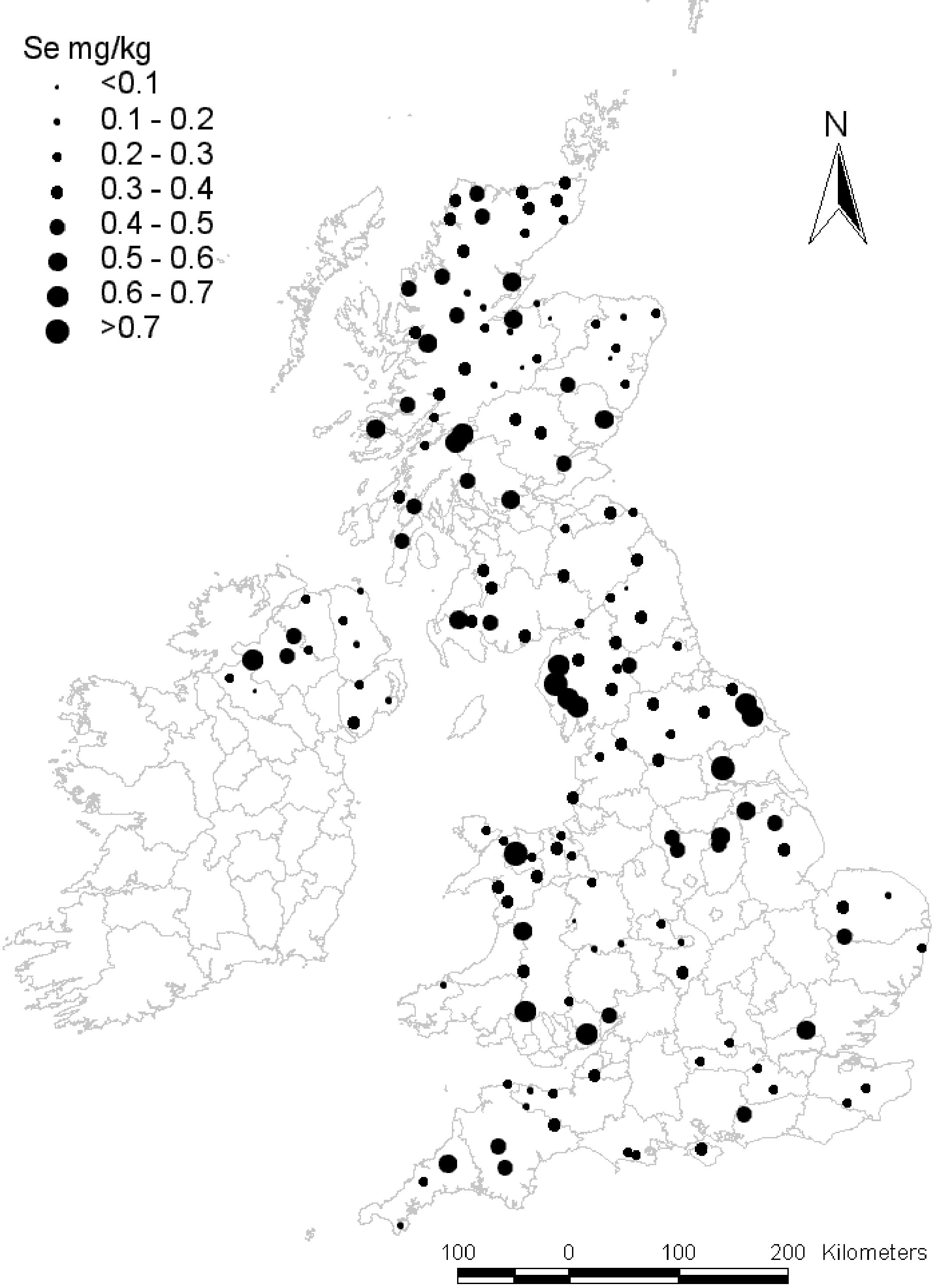


Figure 3.3.6 'Pleurozium standardised' arsenic concentrations in UK mosses 2000

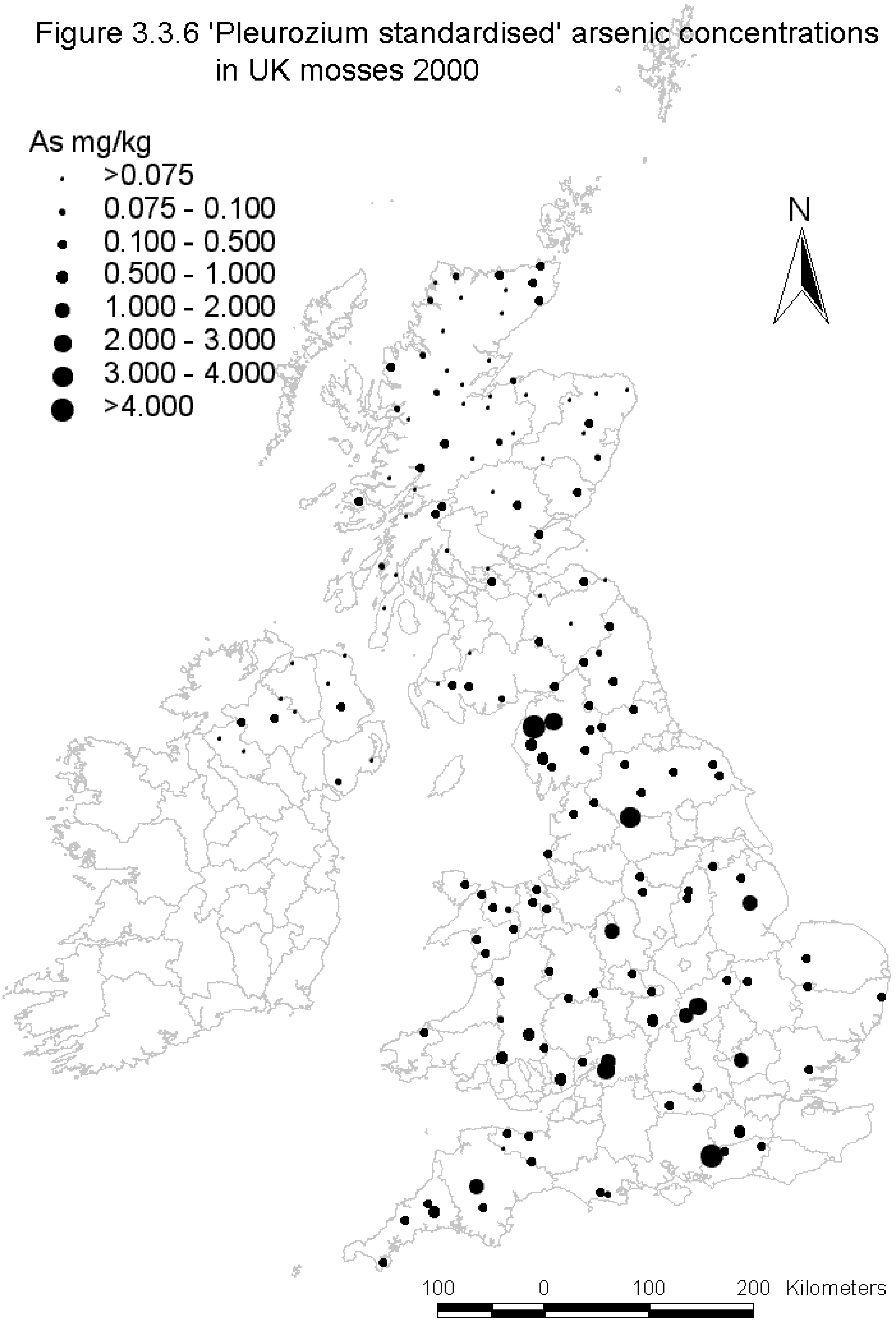
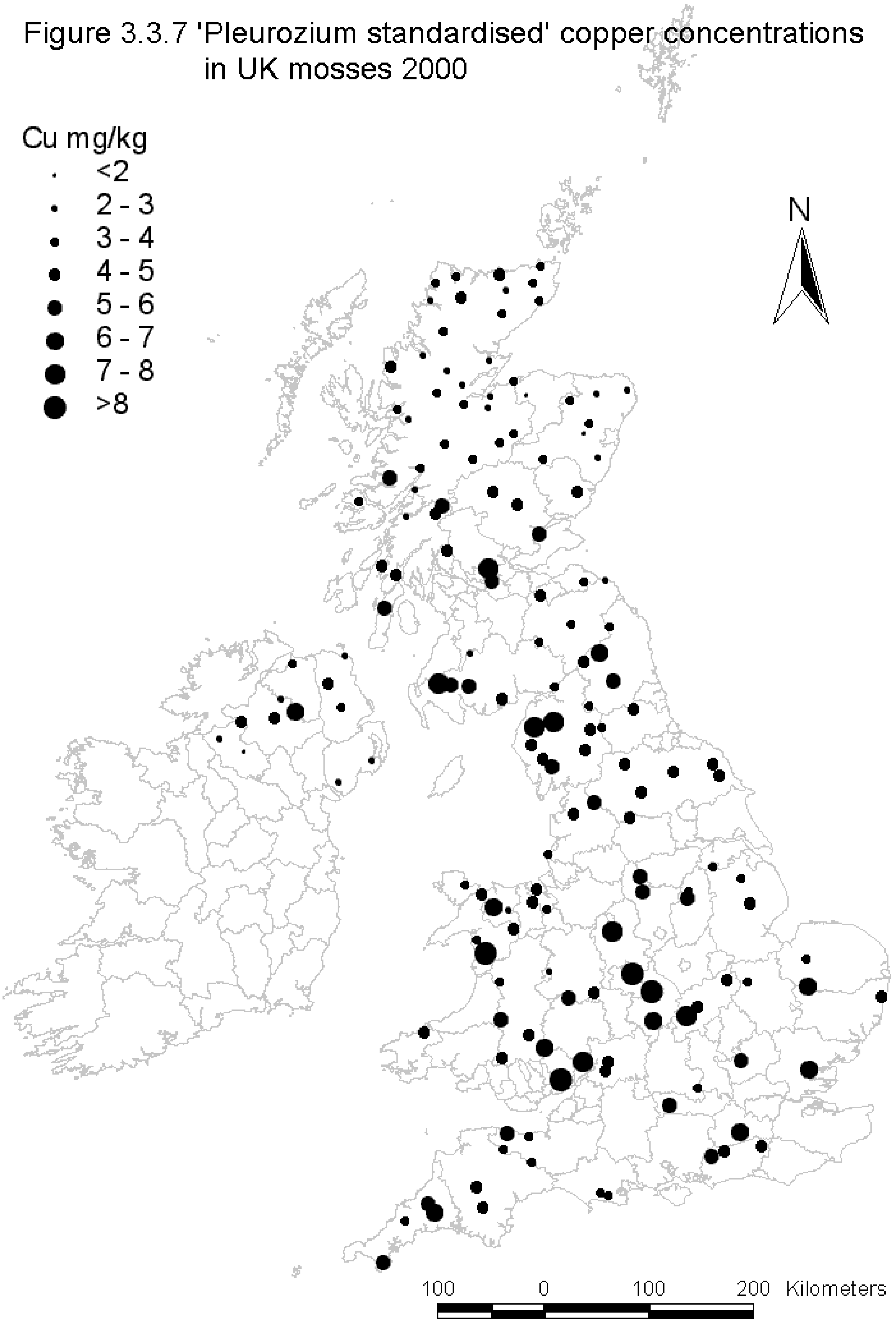


Figure 3.3.7 'Pleurozium standardised' copper concentrations in UK mosses 2000



Lead (figure 3.3.8)

Background values of Pb in the 1995 European survey were less than 5 mg kg^{-1} and these were found in northern Scandinavia and Iceland (Rühling and Steinnes 1998). Although no sites recorded concentrations as low as 5 mg kg^{-1} in the U.K., the large majority of sites have concentrations in the range 5-10 mg kg^{-1}. Concentrations in Scotland, Northern Ireland and Wales are generally lower than in the more densely populated south and central England presumably reflecting the combustion of leaded petrol which was still in use over the period of growth sampled in the year 2000 moss survey. There are a few isolated anomalies, some of which probably relate to contemporary emission sources, for example in the vicinity of the Bristol Channel, whilst others, such as in north Wales and central northern England are close to historic mine sites.

Zinc (figure 3.3.9)

Zinc is present in *Hylocomium* and *Pleurozium*, and possibly other moss species, at baseline concentrations of 20 to 30 mg kg^{-1} even in pristine areas (Ross 1990; Berg et al., 1995) where deposition rates are probably too low to account for the accumulated metal (Rühling and Steinnes 1998). It is thought that the metal is an essential nutrient which is recycled internally in order to sustain concentrations in the growing tissue (Rühling and Steinnes 1998). The majority of sites in the UK fall within, or very close to, these baseline values, leaving a cluster of sites in central England and south Wales with concentrations exceeding 50 mg kg^{-1}. The majority of these probably reflect local emission sources related to metal-based industries and processes. It is not clear why the sites near Stranraer and in the central Highlands of Scotland should have concentrations exceeding 50 mg kg^{-1}. This may be due to local emissions or sources of contamination. In coastal areas, and especially in Scotland, large concentrations of seasalt cations may reduce the uptake of Zn by the mosses (Gjengedal and Steinnes 1990).

Cadmium (figure 3.3.10)

The 1995 European moss survey indicates that background Cd concentrations in remote areas of Scandinavia are below 0.1 mg kg^{-1} (Rühling and Steinnes 1998). For most of northern Scotland and Northern Ireland, Cd concentrations are close to this background value, whilst at the majority of sites in southern Scotland, Wales and England, Cd concentrations fall in the range 0.1 – 0.2 mg kg^{-1}. Particularly large anomalies are associated with the region around the Severn estuary, presumably reflecting emissions from the Avonmouth smelter, whilst those in the Heads of the Valleys area of south Wales may be due to contemporary emissions from the industrial zone along the south Wales coast or wind-blown dust from historic coal mining and metal smelting in the Welsh valleys. The anomaly in north Wales is almost certainly from windblown dust as the site is within the Gwydir Forest mining district which contained active metalliferous mines in the last century. Similarly, the high concentration site in the north Pennines is across the valley from historic mine workings and may be affected by this local contamination source. Other sites with relatively large concentrations will reflect a mixture of local sources from incinerators, fossil fuel combustion and industrial emissions, particularly metal processing in the more industrialised parts of the midlands and northern England.

Figure 3.3.8 'Pleurozium standardised' lead concentrations in UK mosses 2000

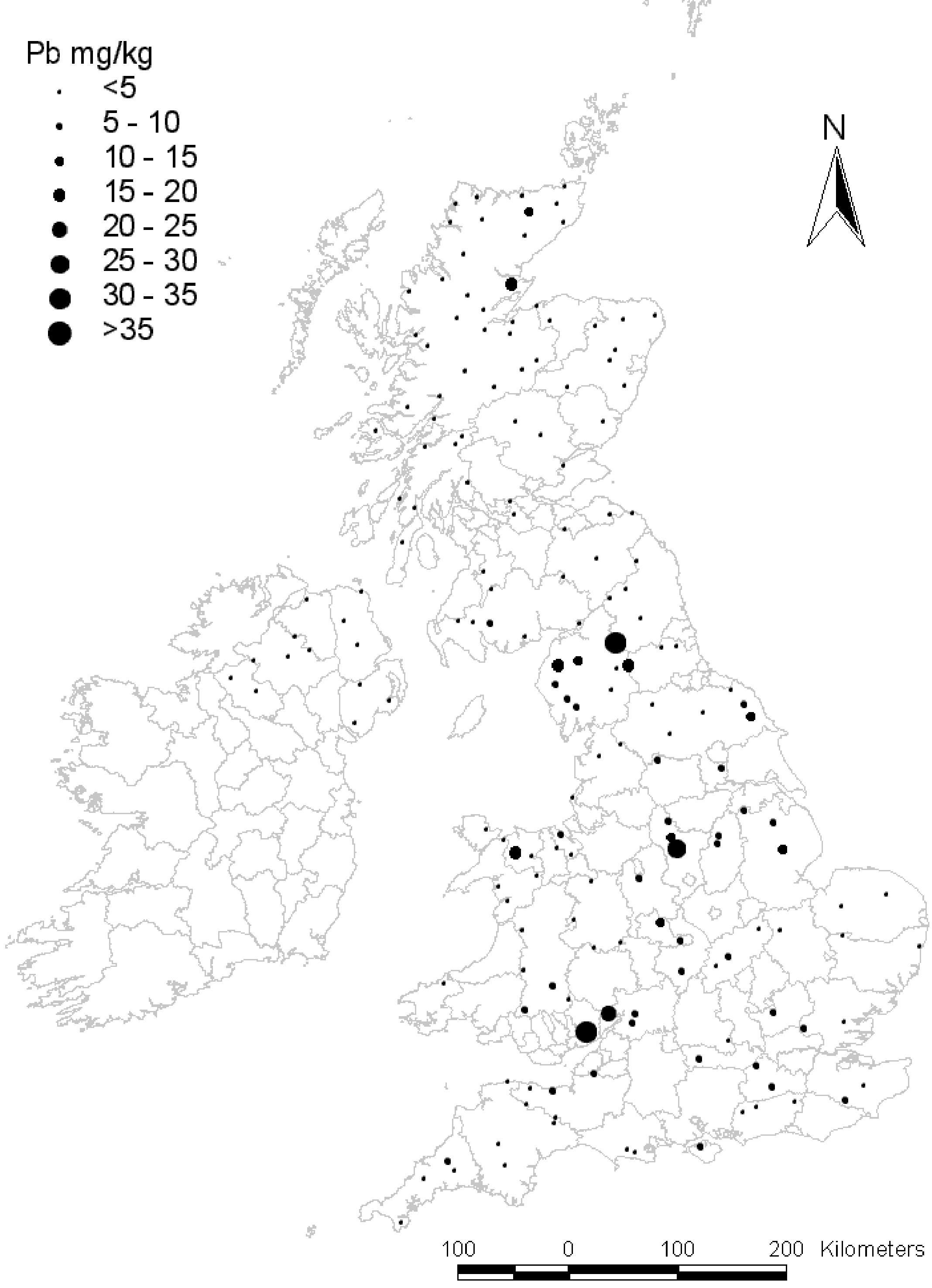


Figure 3.3.9 'Pleurozium standardised' zinc concentrations in UK mosses 2000

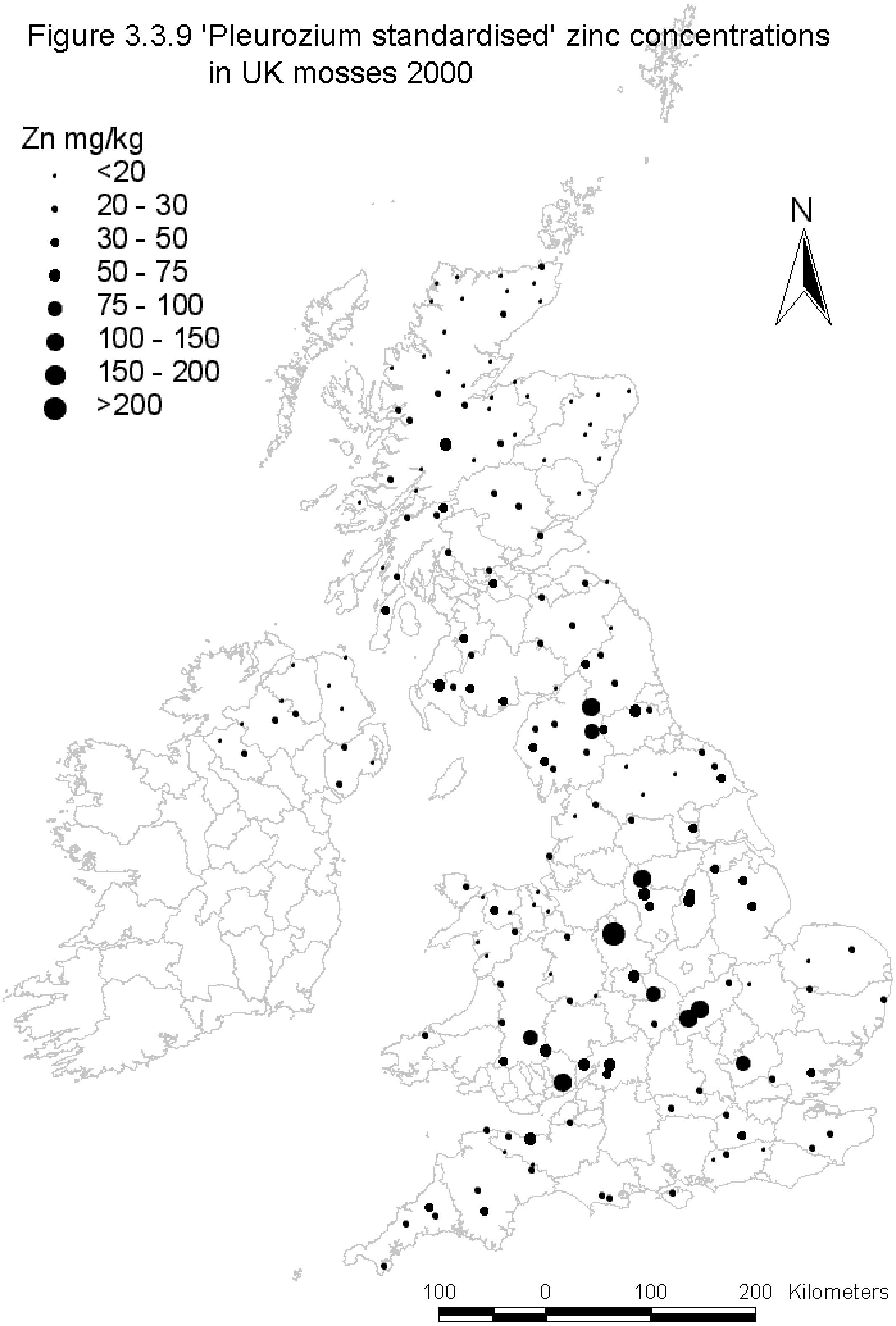
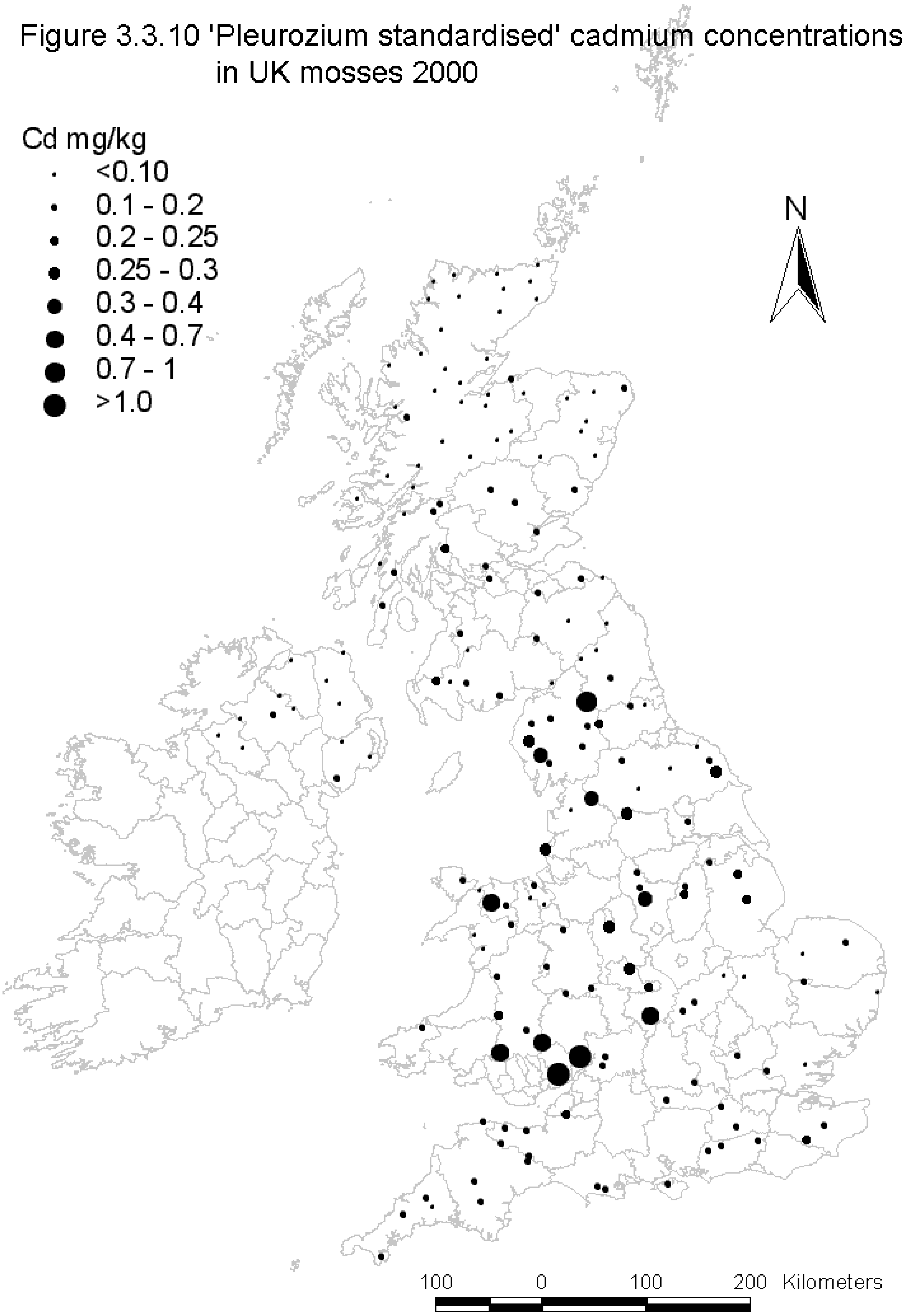


Figure 3.3.10 'Pleurozium standardised' cadmium concentrations in UK mosses 2000



Vanadium (figure 3.3.11)

The main sources of V are coal and oil combustion, although the metal is used in special steel alloys. Consequently, the main local sources are associated with centres of population and industrial areas. Background concentrations in northern Scandinavia measured in the 1995 European survey are below 2 mg kg^{-1} (Rühling and Steinnes 1998) and concentrations across much of the U.K. are at, or below, this value. Many of the larger concentrations are found in south Wales and central and southern England probably reflecting local emission sources from oil refineries such as Fawley near Southampton and from power stations. Emissions from Barrow in Furness and Workington may be sufficient to influence the cluster of relatively large concentrations in the Cumbrian sites. The larger values at some of the remote Scottish sites are not readily explained, although the site near Fort William may be influenced by emissions from the local paper mill and aluminium works.

Chromium (figure 3.3.12)

The main sources of Cr are industrial, in particular iron and steel processing. Background concentrations in rural areas from the 1995 European survey were less than 2 mg kg^{-1} (Rühling and Steinnes 1998). Apart from a cluster of points in northern and central / southern England and two sites in Scotland, the majority of sites are at or below this background threshold value. Large concentrations in the Midlands, northern England, south Wales and the Severn Estuary probably all represent local emission sources. The high concentration site in south-west Scotland is not readily explained, although the large concentrations at the site in northern Cumbria may be influenced by emissions from Workington.

Nickel (figure 3.3.13)

As for Cr, the background concentration of Ni from the 1995 European survey was 2 mg kg^{-1} with values of less than 1 mg kg^{-1} over much of central Scandinavia and north west Scotland (Rühling and Steinnes 1998). Over much of the UK, Ni concentrations in the mosses are in the range 0-2 mg kg^{-1}, although several sites exceed this amount presumably due to the influence of local emission sources. The main source of Ni is oil and coal combustion, plus industrial emissions from steel and alloy processing which would account for sites in South Wales, the Midlands and northern England having larger concentrations. Some of the more enriched sites in Scotland are not readily explained, although local emissions in Fort William may affect the site near that town. Dust from historic mining and smelting may be responsible for the larger concentrations at the site in the far south-west of England.

Figure 3.3.11 'Pleurozium standardised' vanadium concentrations in UK mosses 2000

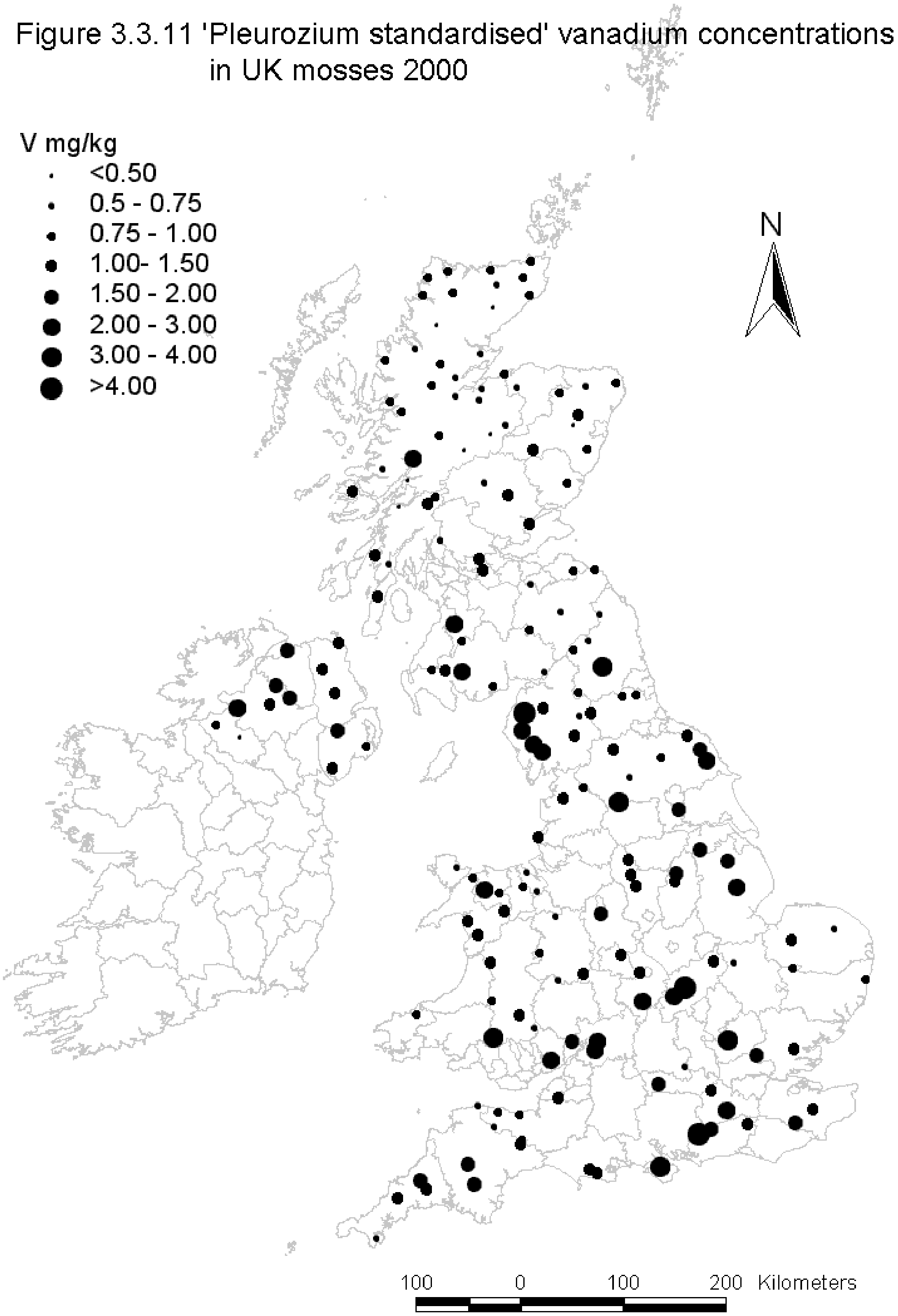


Figure 3.3.12 'Pleurozium standardised' chromium concentrations in UK mosses 2000

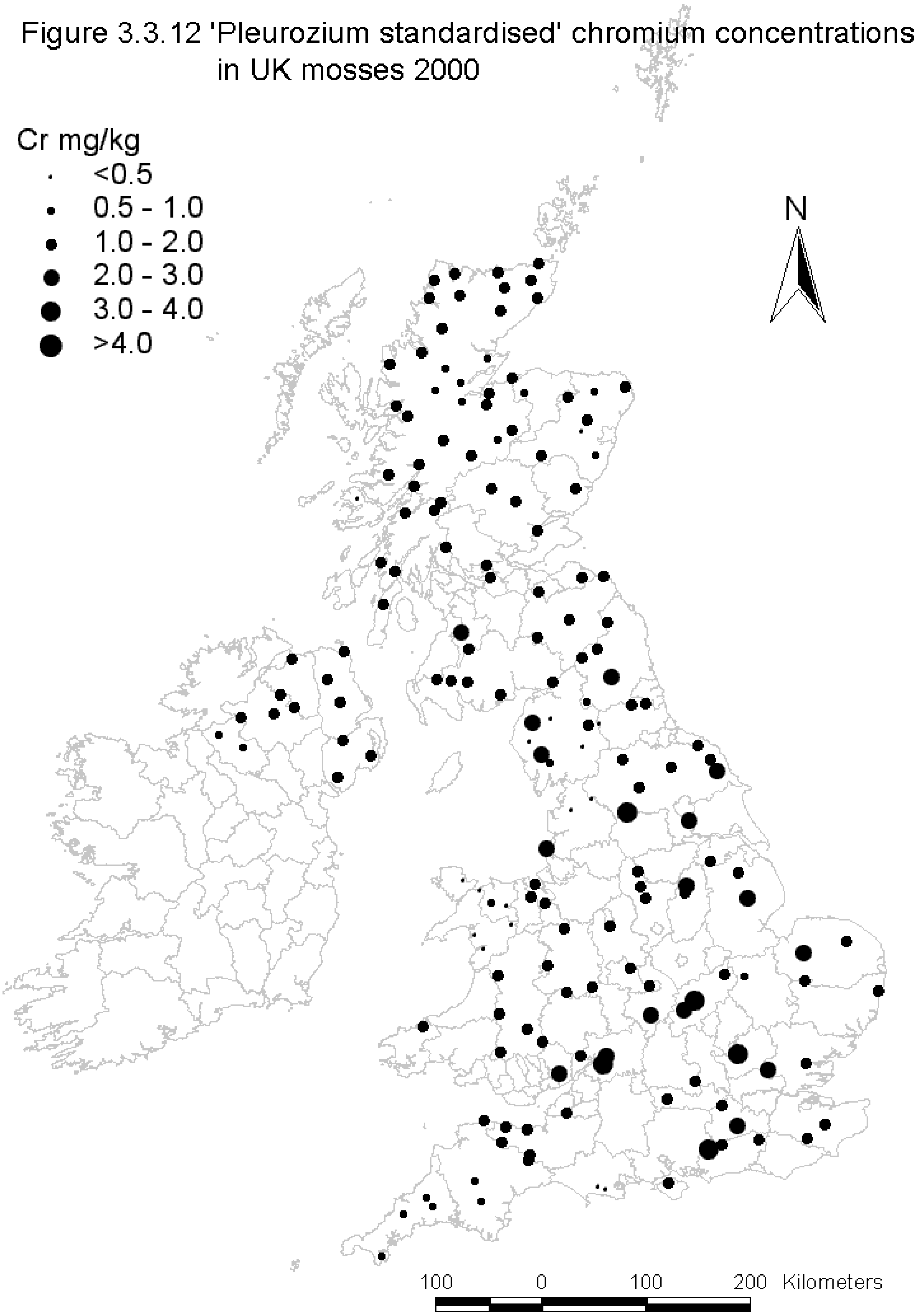
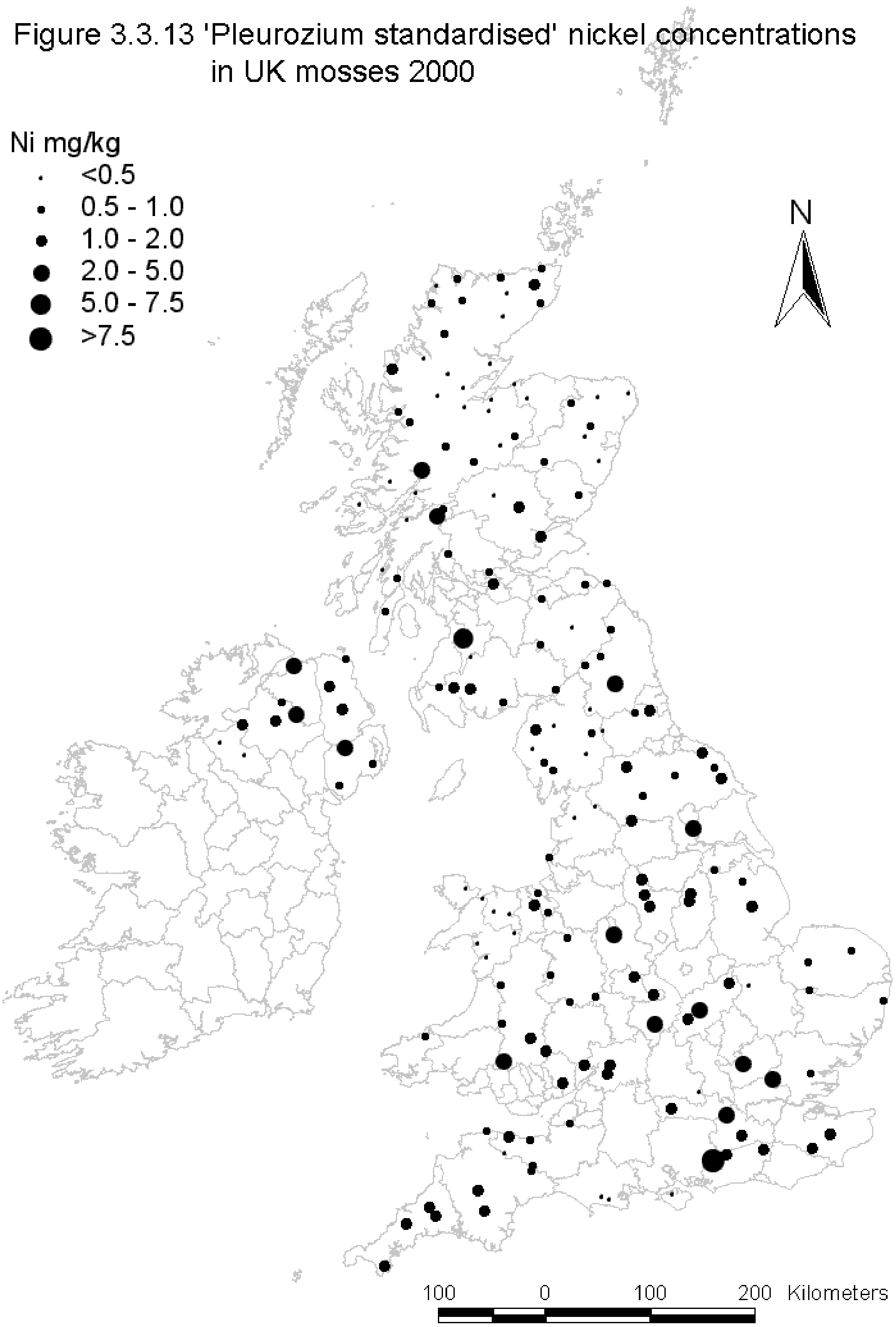


Figure 3.3.13 'Pleurozium standardised' nickel concentrations in UK mosses 2000



Multiple metal patterns

High concentrations of several metals are associated in these maps with industrial areas, such as South Wales. However, other instances of particular sites exhibiting high concentrations for particular combinations of metals occur outside such areas. For example, at Rivock Edge on Rombalds Moor in West Yorkshire, high concentrations of As, V, Cr, Cd, Ca and K coincide to suggest a site of local enrichment; this could reflect the impact of atmospheric transport of emissions from the Bradford conurbation or could be the result of local mineralisation and/or workings. The same could be true of Stedham Common, West Sussex, which also exhibits elevated levels of As, Cr, V and Ni in a rural area. Other sites show different combinations of metals; for example, the elevated concentrations of Pb, Cd and Zn at a site on the Cumbria/Northumberland border strongly suggest an impact of local mining activity.

3.4 Comparison of moss metal concentrations 1996/97 to 2000

Table 3.10 Comparison between 1996/97 moss concentrations and corrected 2000 moss concentrations of cadmium, copper, lead and zinc.

Hylocomium splendens N=40	cadmium	copper	lead	zinc
1995 log conc. (log mg kg^{-1})	-0.90	0.68	0.67	1.48
1995 concentration (mg kg^{-1})	0.12	4.84	4.63	30.43
2000 log conc. (log mg kg^{-1})	-1.27	0.46	0.16	1.13
2000 concentration (mg kg^{-1})	0.05	2.91	1.46	13.38
Correlation coefficient	0.355	-0.054	0.437	-0.188
Correlation significance	0.024	0.739	0.005	0.245
t-statistic	4.95	5.02	8.53	5.03
Significance	<0.001	<0.001	<0.001	<0.001

Pleurozium schreberi N=35	cadmium	copper	lead	zinc
1995 log conc. (log mg kg^{-1})	-0.63	0.76	0.98	1.57
1995 concentration (mg kg^{-1})	0.23	5.82	9.62	36.99
2000 log conc. (log mg kg^{-1})	-0.90	0.61	0.56	1.36
2000 concentration (mg kg^{-1})	0.12	4.04	3.67	22.69
Correlation coefficient	0.578	0.091	0.428	0.379
Correlation significance	0.0003	0.601	0.010	0.025
t-statistic	6.00	4.96	7.05	5.92
Significance	<0.001	<0.001	<0.001	<0.001

Table 3.10 shows a comparison between 1996/97 data for cadmium, copper, lead and zinc, and the same data for 2000, corrected by the bias shown in Table 2.3. The comparisons are paired between the same sites for both surveys. For all metals, and in both moss species, concentrations are significantly lower in 2000. The reduction in concentration in *Pleurozium* was generally rather smaller than it was in *Hylocomium*, but this may reflect the distribution of sampling locations rather than any innate species difference. The reduction in concentration of lead (68% in *Hylocomium* and 62% in *Pleurozium*) was greater than that of the other metals (58/48% for cadmium, 40/31% for copper and 56/39% for zinc). However, for metals such as copper and zinc which appear to have a significant moss content at background deposition (see Section 4. 2), the percentage reduction in deposition may be greater than the percentage reduction in moss content would imply.

Figures 3.4.1 and 3.4.2, in which data for the same site in the two surveys are plotted together, show the differences between metals and moss species in more detail. Generally the reduction in metal content between the surveys is demonstrated in all graphs, apart from the *Pleurozium schreberi* copper graph. Several outliers do exist to complicate the picture, however. Outliers are present in both sets of moss samples, and could be related to sites experiencing heavy historic contamination which is slow to decrease and can impact upon the moss samples as wind-blown material, as discussed in section 3.3. The impact of wind-blown material is proportional to the intensity and duration of wind events and can lead to wide variation around the average. Where terrestrial sources of contamination exist, their spatial heterogeneity is greater than that of atmospheric deposition; this could also explain the significant increases in concentration of some outliers, as the impact of not sampling exactly the same physical location becomes more significant at these sites.

The correlation coefficients between data in the two surveys (Table 3.10) also suggest differences between metals in the mechanisms responsible for this reduction, presumably reflecting different sources for the metals. For copper and zinc concentrations in *Hylocomium splendens*, there is no significant correlation between surveys, indicating a different pattern of metal concentrations between years and differences in the extent of reductions in metal concentrations between sites. The significant background moss concentrations of these metals due to their nutrient function is another further factor which may weaken the impact of changes in metal deposition between the two surveys. Cadmium and lead concentrations, however, show significant correlations between surveys and therefore more consistent reductions in metal pollution throughout the U.K.. These patterns in the correlation coefficients are reflected also in the *Pleurozium schreberi* concentrations, but also include a significant correlation for zinc.

Figure 3.4.1 Scatter plots of 1995 and 2000 *Hylocomium splendens* metal concentrations with 1:1 line

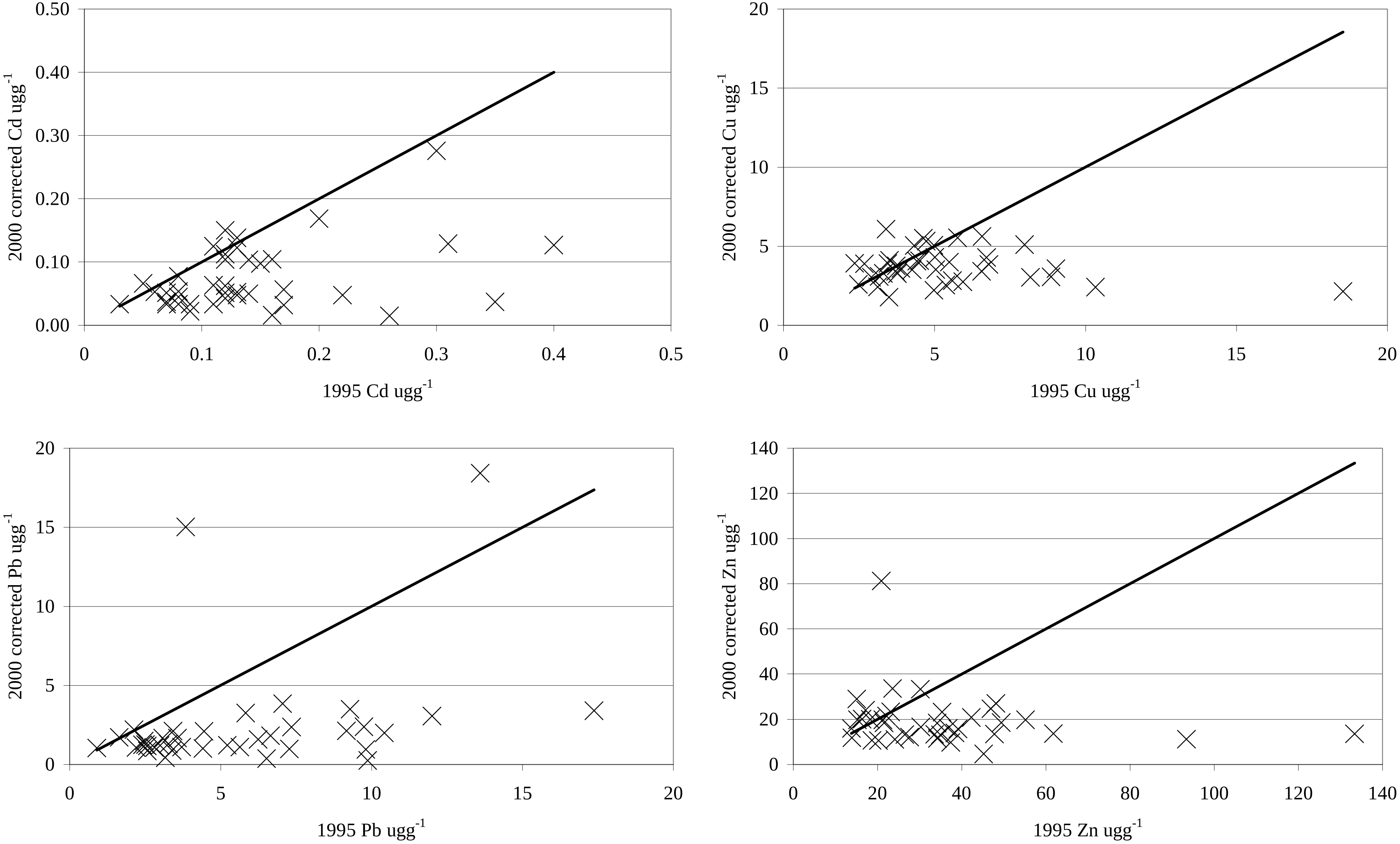
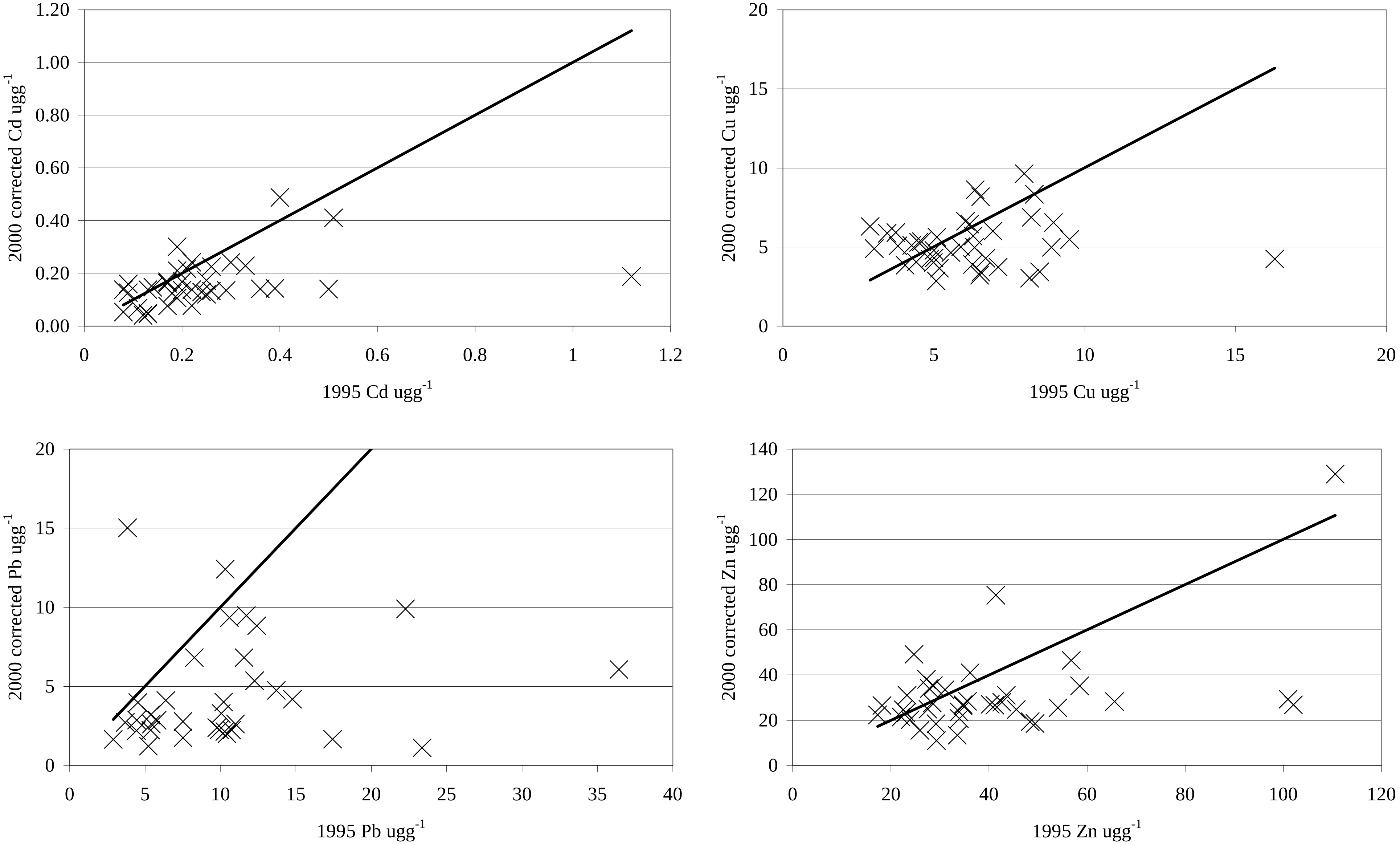


Figure 3.4.2 Scatter plots of 1995 and 2000 *Pleurozium schreberi* metal concentrations with 1:1 line



3.5 Sea salt deposition impact on metal concentration

Table 3.11. Simple regression of four metal concentrations with sodium and magnesium concentrations in mosses from the UK 2000 survey

Pleurozium schreberi (n=14)		
regression equation	R^2 (%)	significance
Cd & Mg	8.8	not significant
Cd = 0.168 - 0.000534*Na	37.6	<0.05
Cu & Mg	0.0	not significant
Cu = 5.41 - 0.0123*Na	28.1	<0.10
Pb = 4.76 - 0.00208*Mg	31.4	<0.05
Pb = 4.89 - 0.0166*Na	51.7	<0.01
Zn & Mg	8.7	not significant
Zn = 30.9 - 0.0797*Na	28.2	<0.10

Hylocomium splendens (n=41)		
regression equation	R^2 (%)	significance
Cd & Mg	3.2	not significant
Cd = 0.0863 - 0.000137*Na	14.6	<0.05
Cu = 0.427 + 0.00225*Mg	21.4	<0.01
Cu & Na	2.7	not significant
Pb & Mg	0.4	not significant
Pb & Na	0.5	not significant
Zn & Mg	3.2	not significant
Zn & Na	0.1	not significant

Research has suggested that high concentrations of sea salt base cations, such as sodium and magnesium, can suppress the uptake of metals from the atmosphere by mosses through competition for active sites (Gjengedal and Steinnes 1990; Berg and Steinnes 1997). With the current data in the U.K., it is not possible to quantify the effect of sea salt deposition on heavy metal uptake by the mosses. This requires either detailed comparison with metal deposition determined from bulk or aerosol collectors (Berg and Steinnes 1997) or laboratory exposure experiments (Gjengedal and Steinnes 1990). The limited number of sites and concerns over the quality of the bulk deposition data in the U.K. (cf. Section 4.2) make such a field analysis impossible.

To examine this theory using the current survey data, an alternative approach was adopted of testing the relationship between sea salt and metal concentrations in the mosses. This concentrated in a region with little spatial variation in metal concentrations. Sites determined by the FRAME-HM deposition model (Nemitz et al, 2001b) to have low deposition of cadmium, copper, lead and zinc were chosen from northern Scotland with a wide range of sodium and magnesium concentrations, as shown in Figures 3.3.1 and 3.3.3. Sodium and magnesium show a highly significant positive intercorrelation, so simple regression between base cation and metal concentrations were used to test whether the relationships differed between metals and moss species.

Cadmium concentrations showed a significant negative correlation with sodium concentration (but not magnesium) for both *H.splendens* and *P.schreberi*, although the relationship was stronger in the latter. Copper demonstrated a significant negative correlation with sodium concentration for *P.schreberi*, yet a positive regression with magnesium for *H.splendens*. Regressions of lead and zinc on sodium were not significant evident for *H.splendens*, yet *P.schreberi* lead was negatively correlated with both sodium and magnesium, and zinc with sodium.

These results suggest that sea salt, and sodium in particular, may have a significant effect in reducing metal concentrations in *Pleurozium schreberi* but not in *Hylocomium splendens*. The reason for this species difference is unclear and needs further investigation under controlled experimental conditions.

4. Deposition Estimates from 2000 Moss Survey

4.1 Introduction

As explained in the Introduction to the main final report, the research supported by DETR under this contract formed part of a wider research programme under the Environmental Diagnostics Programme of the Natural Environment Research Council (NERC). Complementary research under this programme, which was co-ordinated by Prof. Ashmore, was funded by NERC and by the Environment Agency (EA).

A major component of the NERC-funded component of the programme was research to improve the estimates of metal deposition within the U.K.; this research was led by the Centre for Ecology and Hydrology (Edinburgh) and also involved the University of Birmingham and UMIST. This research was also partly supported by EA. These estimates of deposition were used in the critical load assessments described in the main final report of this contract. Because of the limited number of sites at which metal deposition is monitored in the U.K., the data on moss concentrations provides a crucial contribution to this aim of improving our understanding of patterns of metal deposition across the country. This work has involved the four metals (lead, copper, cadmium and zinc) for which critical loads assessments were made. In principle, deposition maps could be derived for the other metals in the moss survey using the same method. However, as is clear from the explanation of the method below, this would require data for physical parameters which are not available from the NERC-funded component of the research programme, which was focussed only on the four key metals.

Four estimates were derived of the deposition field of the metals Pb, Cd, Cu and Zn, using three independent approaches:

1) Deposition maps of Pb, Cd, Cu and Zn were computed from the metal concentrations in moss sampled during the U.K. Moss Survey 1996/97 and the Moss Survey 2000 (using the data described in Section 3). The data were standardised for *Pleurozium schreberi* and the analytical conditions of the 1996/97 survey.

2) Deposition maps for England and Wales were derived using data from a deposition network, operated by the University of Reading over the period 1995-98, using a deposition collector in the shape of an inverted frisbee at 30 mainly agricultural sites (Alloway *et al.*, 1998). This network was supported by MAFF.

3) A further estimate of the deposition field was obtained using an atmospheric transport and deposition model and spatially disaggregated emission inventories.

The research under items (2) and (3) was supported by the NERC/EA component of the research programme. The quantification of the deposition rates of the metals, needed for all three approaches, was, where possible, derived from measurement data, rather than theoretical predictions, and chosen to be representative for U.K. conditions. Process measurements made under the NERC-funded component of the research were specifically designed to address these questions and included:

- simultaneous measurements of wet-only deposition and air concentrations ($PM_{2.5}$, PM_{10} and TSP) of trace metals at a Scottish moorland site (Nemitz *et al.*, 1998),

- micrometeorological measurements of the size-dependent particle deposition velocity (V_d) to UK moorland vegetation and re-analysis of data from measurements over arable crops and forest (Nemitz *et al*., 2001a; Gallagher *et al*., 2001),
- measurements of typical heavy metal size-distributions at three rural and semi-urban locations in the UK (Allen *et al*., 2001).

This section of the report describes the estimates of deposition of Pb, Cu, Cd and Zn derived from the 2000 moss survey. Section 5 draws together these estimates with those from the 1996/97 survey data and from the other two methods, and considers the overall consistency of estimates of U.K. deposition fields made using the three methods.

4.2 Calculation of deposition maps from the surveys of concentrations in moss

4.2.1 The relationship between metal concentrations in moss and bulk deposition

Often the interpretation of moss surveys is confined to the derivation of relative spatial patterns in concentration. A few calibration studies have been carried out to investigate the linear relationship between metal concentrations in moss and bulk deposition (wet deposition & some dry deposition collected by standard bulk deposition collector) (e.g. Ross, 1990; Berg and Steinnes, 1997).

The measurements presented by Berg and Steinnes (1997) included one moss sample, obtained at the most maritime site ‘Lista’, with a lower concentration / deposition ratio compared to other more inland Norwegian sites. It was therefore possible that the Scandinavian calibration would underestimate the deposition in the maritime climate of the U.K., due to metal leaching caused by an increased ion input (Berg and Steinnes, 1997). The data analysis reported in Section 3.5 shows some evidence of a weak negative correlation between contents of sodium and of cadmium and lead in *Pleurozium*, which supports this suggestion. Thus a U.K. comparison between moss concentrations and bulk deposition was advisable. Unfortunately, direct U.K. deposition measurements with standard deposition samplers are very sparse. Table 4.1 summarises the few calibration data that are available for the U.K. and the relationship with the metal concentrations in moss at the closest sampling site (distance is indicated in Table 4.1).

Whilst the measurements of bulk Pb deposition are consistent across the country, the NETCEN data from Chilton, Styrrup and Wraymires tend to indicate larger values for Cd and also for Cu and Zn than those obtained by other groups. A comparison of relationships between concentration in moss and bulk deposition is shown in Fig. 4.1, comparing the U.K. data with the measurements of Berg and Steinnes (1997) and the linear relationship of Ross (1990). Although some of the UK measurements are consistent with relationships observed elsewhere, many deposition values appear to be too large, including those of the NETCEN sites. The fact that the deposition at Wraymires exceeds the value measured 7 miles away at Cockley Beck by a factor of 13 for Cu and by a factor of 3 for Zn sheds severe doubt on the quality of current U.K. deposition measurements, and is probably the consequence of nearby sources or contamination.

Table 4.1. Summary of deposition measurements used for the calibration of the moss surveys

Site name	Years	OS grid reference	Distance [km]	Bulk deposition [g ha^{-1} yr^{-1}]				Moss concentration [mg kg^{-1}]			
				Cd	Pb	Cu	Zn	Cd	Pb	Cu	Zn
Auchencorth Moss[a]	1995-99	NT221562	0	0.35	17	58	220	0.12	2.2	5.0	29
Chilton[b]	1996-98	SU468861	15	0.84	12	41	140	0.20	6.2	5.1	26
Styrrup[b]	1996-98	SK561906	7	2.0	26	46	250	0.15	5.8	3.6	31
Wraymires[b]	1996-98	SD362974	7	2.6	33	151	180	0.16	8.0	5.8	22
Cockley Beck[c]	1998	NY247015	0	0.60	24	12	72	0.39	7.2	4.2	39
Great Dun Fell[c]	1998	NY702295	0	0.17	10	6.4	28	0.20	3.2	4.1	75
Lochnagar[d]	1997-98	NO252859	0	2.2	16	33	292	0.11	4.2	4.3	20

a) Nemitz *et al.* (1998); b) Baker (1999); c) Lawlor *et al.* (unpublished data); d) Neil Rose (unpublished data)

Since many of the non-NETCEN measurements are broadly in line with the measurements by Berg and Steinnes (1997), the measurements of these authors were used to derive calibrations. The Pb calibration for 2000 was found to be consistently below the relationship by Berg and Steinnes (1997), and therefore an alternative calibration, derived from the U.K. data, was also explored for the 2000 moss survey. If lead deposition has fallen significantly over this period, then it is also possible that the bulk deposition measurements, which are only available up to 1998, are overestimates for the period reflected by the 2000 moss survey, i.e. 1999 to 2000.

For the two essential elements, Cu and Zn, there is, as was mentioned in Section 3.3, a significant concentration in the moss at background levels of deposition. Thus the intercept of the relationships in Figure 4.1 is very important for the estimate of deposition, especially in background areas. For Zn, the intercept of the regression line was reduced to limit the number of negative deposition values. Nevertheless, two negative values of deposition were predicted from the moss data; these were set to a small value (2 g ha^{-1} yr^{-1}).
This results in the following calibrations (grey lines in Fig. 1) which were used to estimate bulk deposition:

Cd in PS [mg kg^{-1}] = 0.032 + 0.42 Cd dep [g ha^{-1} yr^{-1}]

Pb in PS [mg kg^{-1}] = 0.378 + 0.56 Pb dep [g ha^{-1} yr^{-1}]

Pb in PS [mg kg^{-1}] = -0.189 + 0.247 Pb dep [g ha^{-1} yr^{-1}] as an alternative formulation for 2000 (1)

Cu in PS [mg kg^{-1}] = 1.984 + 0.348 Cu dep [g ha^{-1} yr^{-1}]

Zn in PS [mg kg^{-1}] = 10.00 + 0.743 Zn dep [g ha^{-1} yr^{-1}]

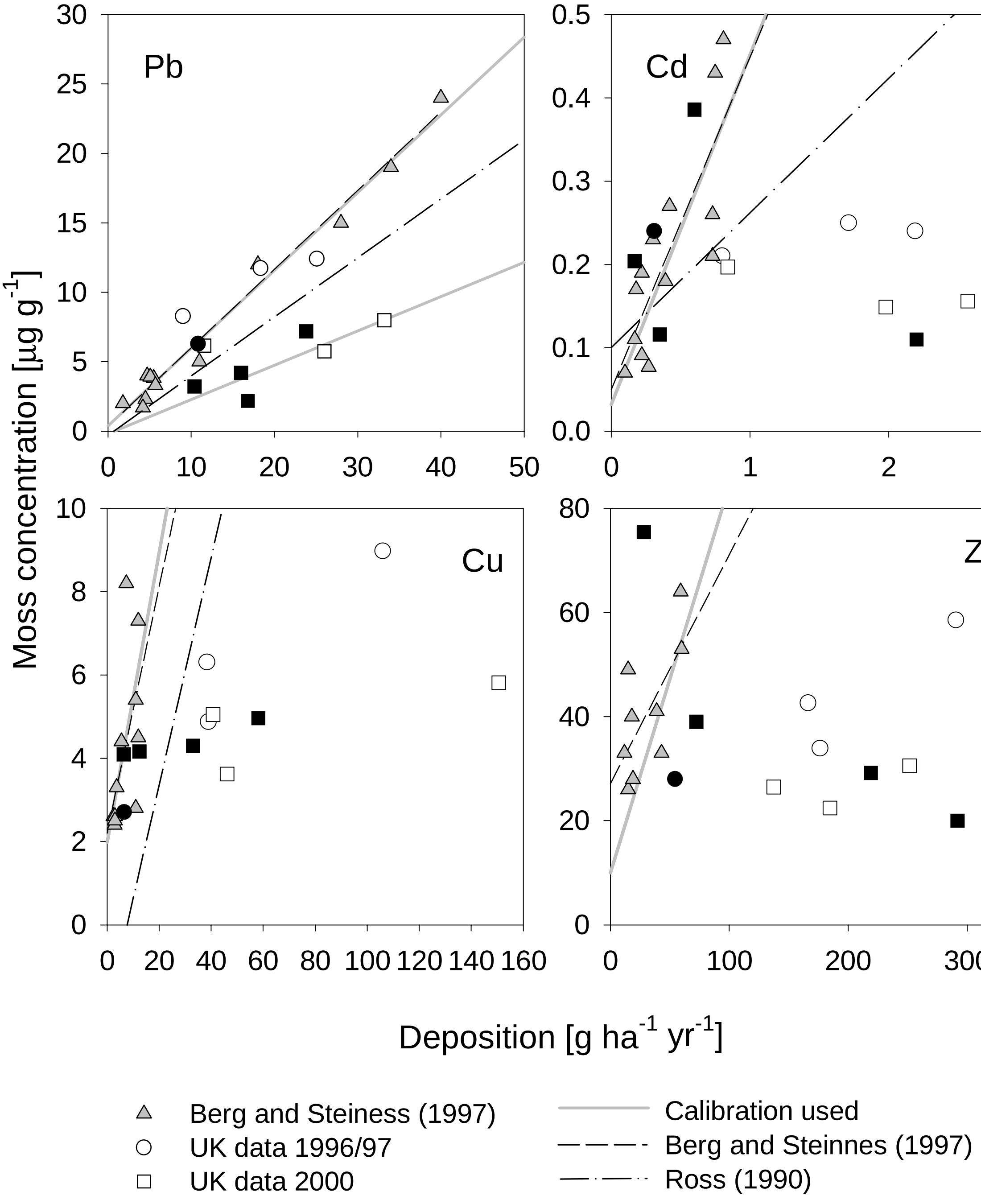


Figure 4.1. Regressions between heavy metal concentrations in moss samples and bulk deposition. The NETCEN measurements (open symbols) are contrasted with the other UK measurements (filled symbols). Two large points have been removed from the Cu and Zn datasets of Berg and Steinnes (1997).

4.2.2 The inferential model

This calibration allows bulk deposition at the moss sampling sites to be estimated. At its simplest, the UK deposition field may be derived by direct interpolation of these deposition values (cf. Fig. 4.5b). However, this does not account for the detailed structure of the effects of the rainfall field and orographic enhancement on wet deposition, the effect of wind speed and land cover on dry deposition or cloud water deposition. By contrast, the air concentration field is expected to be less variable and less sensitive to altitude effects than the deposition field. In order to derive the air concentration at the sampling sites, a link between concentration and deposition is required, similar to an inferential model, in which the deposition is estimated from the concentration field.

Deposition and air concentration are related through the parameterisations of dry, wet and occult (cloud water) deposition. The wet deposition velocity (V_w) [mm s^{-1}] is parameterised through the scavenging ratio (w_w), the ratio of the concentration in rain water (χ_r) and air (χ_a), where both concentrations are in g kg^{-1} (e.g. Gatz, 1975). The values used for w_w are 900 for Cd, 200 for Pb, 2200 for Cu and 800 for Zn and these were derived from a compilation of UK and non-UK measurements (Fig. 4.2).

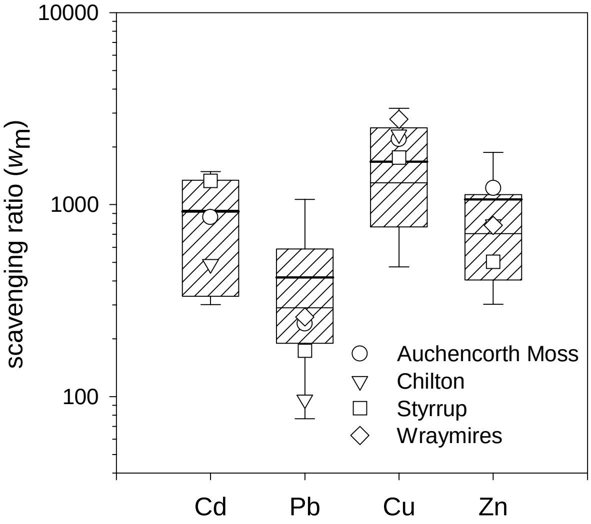


Figure 4.2. Ranges of mass-based scavenging ratios compared with UK measurements (datapoints are from Nemitz *et al*., 1998, and Baker *et al*., 1999).

At high altitudes rain water concentration is enhanced due to orographic effects. By analogy with the treatment of sulphur in the UK modelling approach (e.g. Dore *et al*., 1992), the effect is taken into account assuming that the concentration is doubled in the additional rainfall which is due to orographic effects. The rainfall field which would be expected at sea level (v_{sl}) is calculated according to Smith and Fowler (in press):

$$V_{wet} = w_m \, 802.6 \times [2 \times (v - v_{sl}) + v_{sl}] \times 10^{-8} / c \qquad (2)$$

where the constant c (0.315 g ng^{-1} m^2 ha^{-1} s yr^{-1}) converts the deposition from ng m^{-2} s^{-1} into g ha^{-1} yr^{-1}.

Dry deposition is derived as the product of χ_a with a dry deposition velocity (V_d). Individual parameterisations of V_d as a function of particle size were derived from micrometeorological measurements for UK moorland vegetation as well as for crops and forests (Fig. 4.3). These were weighted by typical size-distributions of the different metals, measured across the UK (Fig. 4.3), to obtain parameterisations of metal V_d which are linear in the friction velocity (u_*), with coefficients of proportionality listed in Table 4.2:

$$V_{dry} = 1 / (R_a(z) + 1/V_d)\ 307.484\ \text{ha m}^{-2}\ \text{s yr}^{-1} = 1 / (R_a + (\alpha\, u_*)^{-1}) \qquad (3)$$

where R_a is the aerodynamic resistance, which for neutral stratification may be calculated as

$$R_a(z) = \ln^2(z/z_0)/(0.168\ u(z)) \qquad (4)$$

Here the land cover dependent roughness length (z_0) was set to 15 mm for grass and moorland, 0.1 m for crops and 0.75 m for forests. $u(z)$ is the wind speed at the height (z) for which the concentration is to be determined (3 m).

Table 4.2. Coefficients of proportionality (α) used to calculate the particle dry deposition velocity (V_d) in Eq. (2).

Land cover class	Cd	Pb	Cu	Zn
Grass / Moorland	0.0068	0.0065	0.017	0.012
Crops	0.012	0.012	0.025	0.020
Forests / Urban	0.11	0.10	0.35	0.23

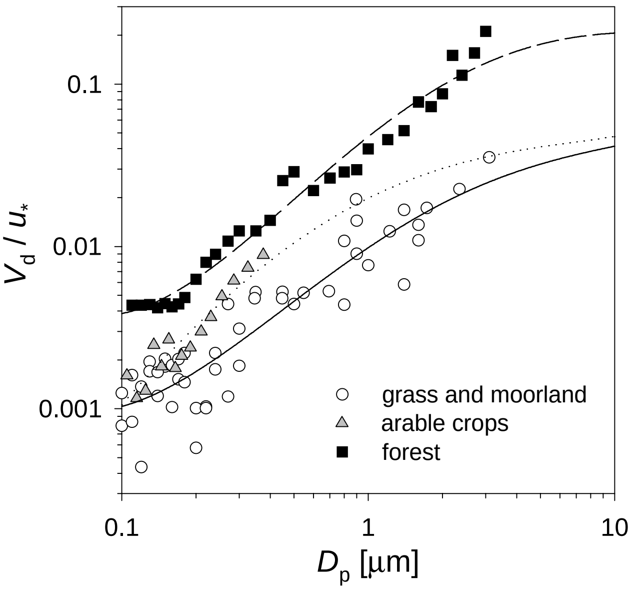


Figure 4.3. Parameterizations of the dry deposition velocity (V_d) as a function of particle diameter (D_p) for grass/moorland, arable crops and forest, derived from measurement data of Nemitz *et al*. (2001a), Joutsenoja *et al*., (1992) and Gallagher *et al*. (1997), respectively.

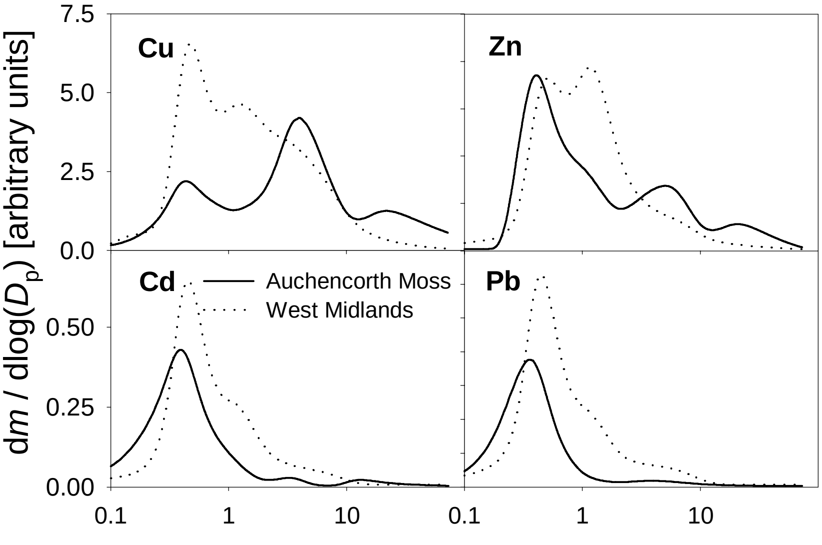


Figure 4.4. Averaged metal size distributions measured at Auchencorth Moss (Scotland) and two sites in the West Midlands (from Allen *et al*., 2001).

Cloud water concentrations of heavy metals are significantly enhanced compared with rainwater. The few simultaneous measurements available indicate wide ranges of enhancement factors (E) of 0.4 to 155 for Pb, 2 to 18 for Cd, 5 to 62 for Cu and 1.6 to 15 for Zn (Wilkinson *et al.*, 1997; Herckes, 1999). In the absence of more precise values we have here used average of the means of these two studies, resulting in 13 for Cd, 7 for Pb, 16 for Cu and 10 for Zn. The deposition velocity due to occult deposition may be calculated as:

$$V_{\mathrm{cloud}} = t_{\mathrm{cloud}} / (8760 \text{ hrs yr}^{-1})\, E\, w_{\mathrm{v}}\, R_{\mathrm{a}}^{-1}(z)\, \chi_{\mathrm{w}} \qquad (5)$$

where t_{cloud} is the number of hours of cloud presence per year and χ_{w} is the average liquid water content (assumed to be 0.2 g m^{-3}). With these parameterisations the total deposition flux (F_{d}) in g ha yr^{-1} is therefore given by

$$F_{\mathrm{d}} = c\,(V_{\mathrm{wet}} + V_{\mathrm{dry}} + V_{\mathrm{cloud}})\,\chi_{\mathrm{a}} \qquad (6)$$

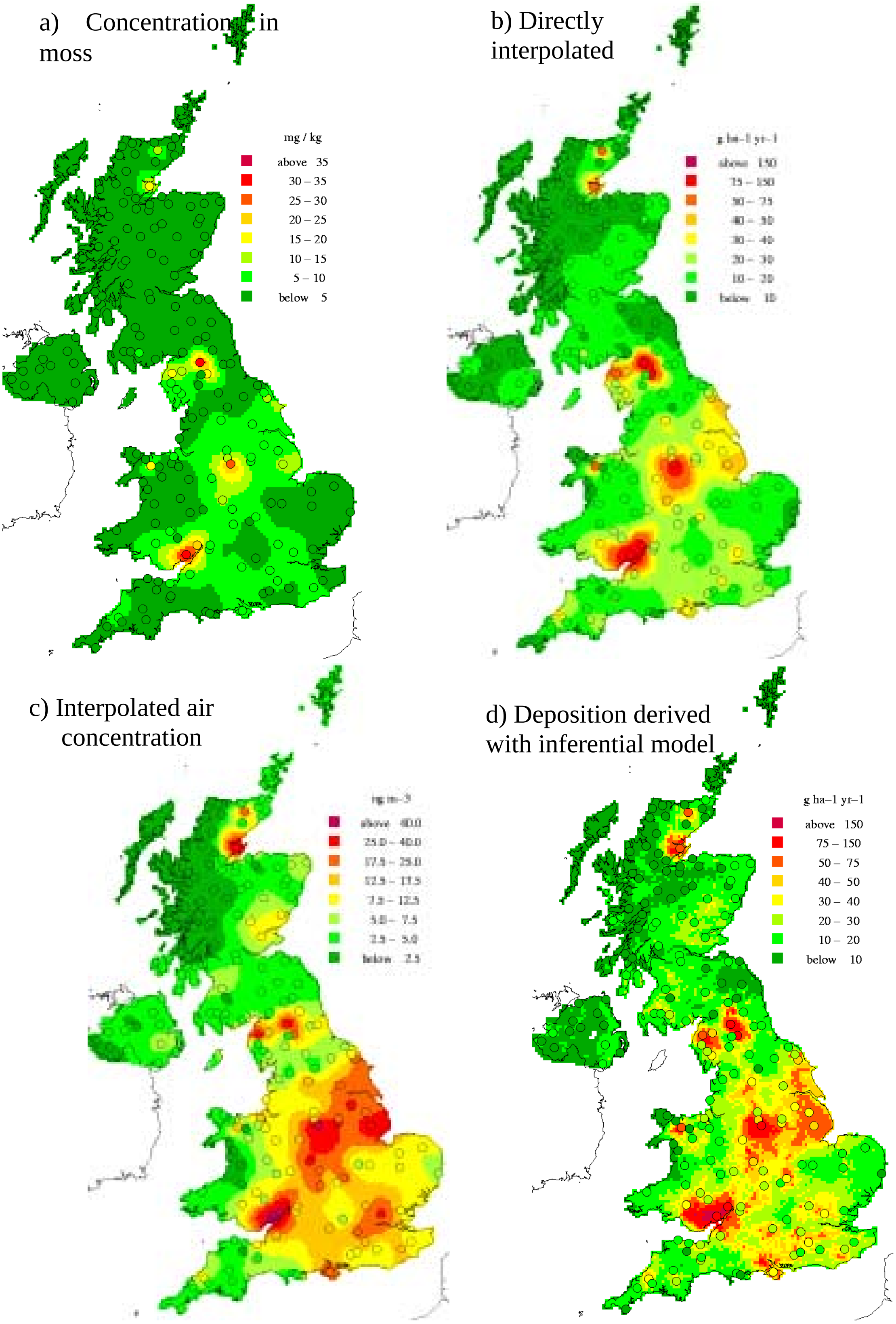
requiring maps of u, t_{cloud}, v, v_{base} and land cover.

The deposition field is derived in a four-step process:
1. The metal concentrations at the measurement sites are converted into bulk deposition using the relationship derived in the previous section.
2. Using the relationship of Eq. (6), the air concentration at the measurement sites is estimated.
3. The air concentration field is interpolated.
4. From the air concentration field, the deposition field is calculated re-applying Eq. (6).

Figure 4.5 shows that using this procedure, the deposition values at the measurement sites are conserved, while more structure in the deposition field is introduced. In particular, deposition is enhanced in the sensitive upland areas, due to increased rainfall, orographically enhanced rain water deposition and cloud deposition. Since the inferential model is applied in both directions, some uncertainties in the parameterisations of w, V_{d} and E are compensated for. However, they do influence the spatial patterns and the air concentration field derived from the measurements.

4.3 Deposition maps for 2000

Fig. 4.6 shows the deposition fields for all four metals, derived using the same methodology which was illustrated in Fig. 4.5 for lead; hence, Fig 4.5d corresponds to Fig. 4.6b. The maps for Cu and Zn show less evidence of clear spatial gradients across the country than do those of Cd and Pb, for which higher rates of deposition are associated with areas such as the Midlands and South Wales, and the lowest rates are found in Scotland and Northern Ireland. Some isolated hot-spots of deposition, such as that in northern Scotland for lead, reflect individual moss sampling sites with unusually high concentrations.



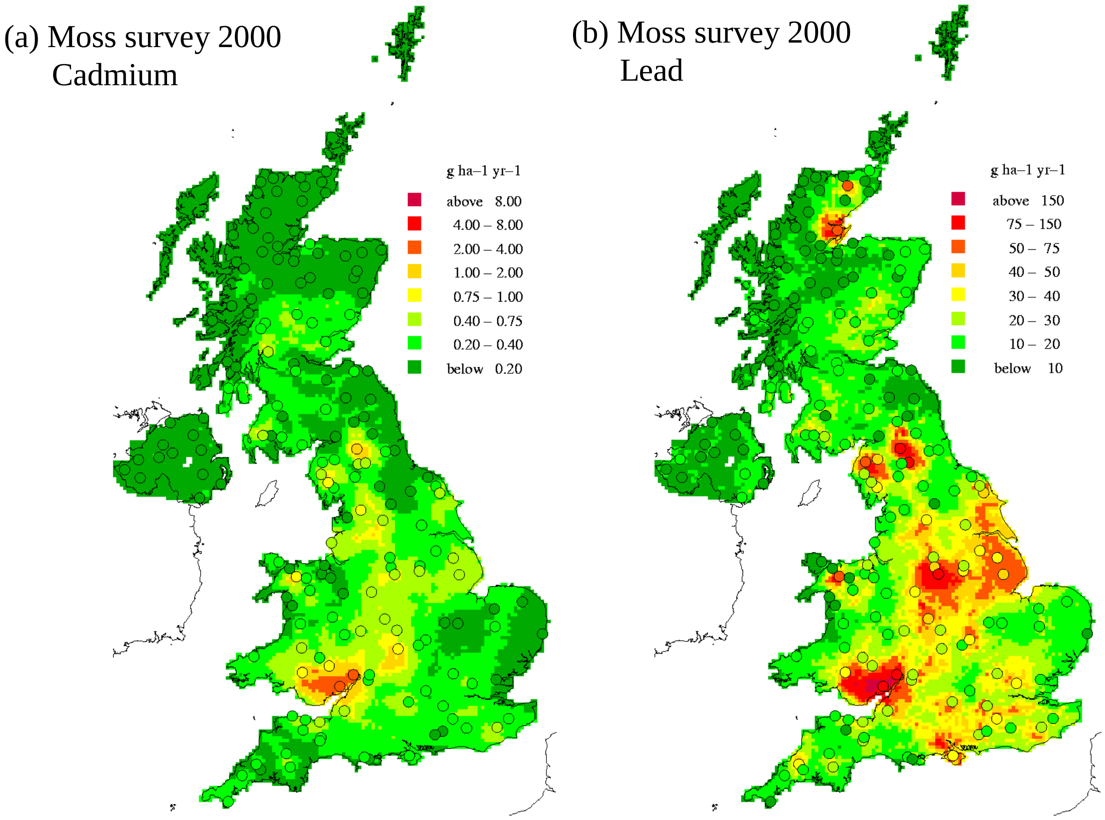
a) Concentration in moss

b) Directly interpolated

c) Interpolated air concentration

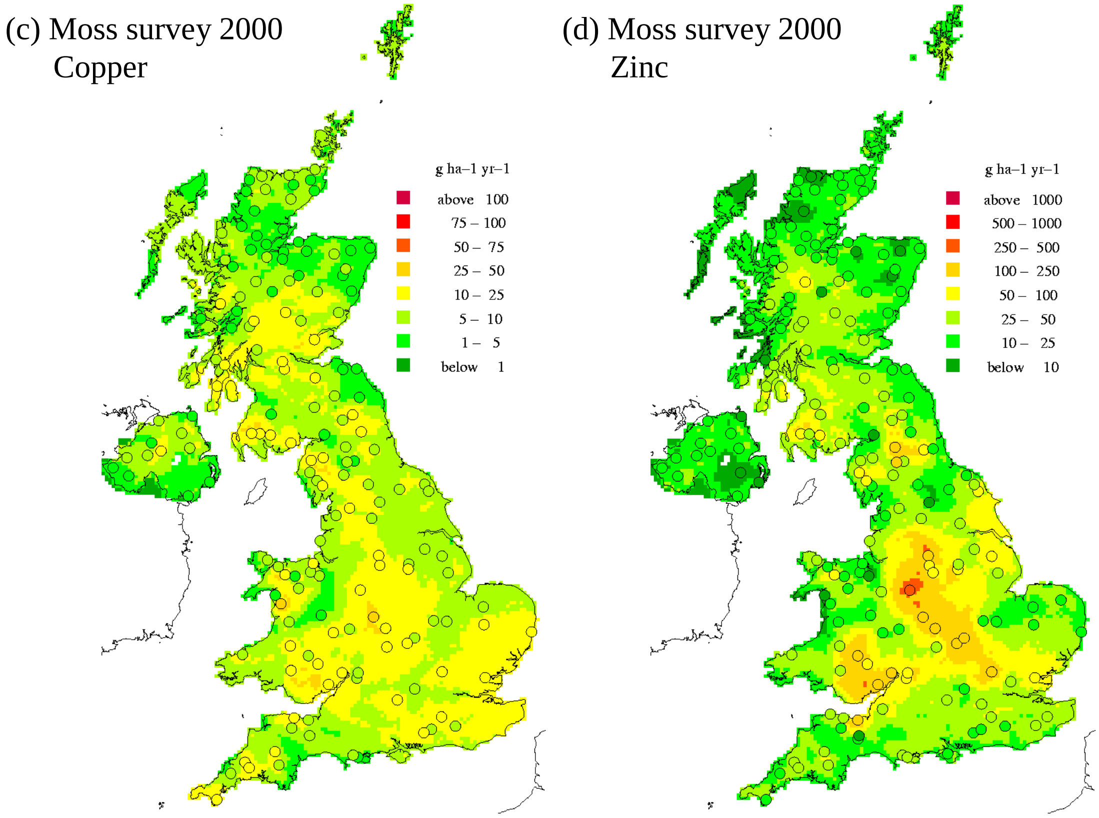
d) Deposition derived with inferential model

Figure 4.5. Example of how the deposition field of Pb is derived from the concentrations in moss from the 2000 survey, illustrating the four-step process (a) ⇨ (b): Calculation of deposition at sample sites; (b)⇨(c). Inverse inferential calculation of air concentrations at sample sites; (c) Interpolation of air concentration field; (c) ⇨(d): Inferential modelling of the deposition field.



(a) Moss survey 2000 Cadmium

(b) Moss survey 2000 Lead



(c) Moss survey 2000 Copper

(d) Moss survey 2000 Zinc

Figure 4.6 Deposition fields of cadmium, lead, copper and zinc derived from the 2000 UK moss survey

5. Comparison of Deposition Estimates

5.1 Introduction

This section of the report compares the estimates of deposition in the UK derived from the 2000 moss survey with those from two other methods. It also considers the deposition fields derived from the 1996/7 survey. The methodologies are first described, then comparisons made and finally conclusions are drawn about the reliability of current estimates of UK deposition.

5.2 Analysis of the frisbee network data

A network of ca. 30 sites covering mainly agricultural lowland sites in England and Wales was operated by the University of Reading from 1995 to 1998 (Alloway *et al.*, 1998). This network was based on an inverted frisbee type dust deposition gauge (e.g. Hall *et al.*, 1993). Originally, the aerodynamic properties of this gauge were designed to maximise the capture of dust and snow and, while this leads to a high capture efficiency for precipitation, it also potentially results in a high capture efficiency for metal containing aerosol particles, such as large locally re-suspended soil particles. While the dry deposition velocity for moss is expected to equal that for moorland / grassland, here V_d for arable crops was used to describe the dry collection efficiency of the frisbee collectors.

As with the moss survey data, the deposition data were not interpolated directly, but the inferential model was used and the interpolation was applied to the concentration field. This results in the same steps as for the moss (e.g. Section 4.2 and Figure 4.5), starting with the deposition at the individual sites (Stage 2).

5.3 The atmospheric transport and deposition model FRAME-HM

As described in more detail by Nemitz *et al.* (2001b), the atmospheric transport model (ATM) used for this study was a stochastic multi-layer Lagrangian straight-line trajectory model, developed on the basis of the Fine Resolution Ammonia Exchange (FRAME) model (Singles *et al.*, 1998). This model (FRAME-HM) calculates concentration and deposition fields for 72 wind directions, using wind speeds averaged for each wind direction. Local parameters such as boundary layer height, atmospheric stability and turbulence are calculated dependent on the time of day. For this purpose, trajectories are started at four times, at 00:00, 06:00, 12:00 and 18:00 hrs GMT. The resulting concentration and deposition fields are averaged, weighted by the average wind direction frequency for the UK. The disadvantages of this Lagrangian approach compared with most Eulerian models is the confinement to straight line trajectories, while the advantages include multi-layering and mass conservation.

Since the model does not simulate lateral dispersion for metals which are emitted from individual strong point sources, the simulated deposition fields show streaks across the country. For this reason, the 5 km output was block-averaged to obtain a smoothed deposition field at a 10 km resolution.

Official gridded U.K. emissions figures of Cd, Pb, Cu and Zn are compiled as part of the National Atmospheric Emissions Inventory (NAEI; Goodwin *et al.*, 2000) and these were used to model the deposition of metals originating from UK sources. Deposition of material emitted outside the U.K. was estimated in two different ways: for Cd and Pb EMEP provide the deposition maps of modified model scenarios, which omit the UK emissions. The results of these model runs (on the 50 km EMEP grid) were added to the deposition of the UK sources to provide the field of total deposition. For Cu and Zn, which are not treated by the CLRTAP, the European Lagrangian straight-line trajectory model TERN (ApSimon *et al.*, 1994) was run for each of the 72 wind directions to generate boundary concentrations for the nested run of the UK model. The TERN runs used the European emissions compiled for 1990 by Berdowski *et al.* (1997), which were re-scaled for 1998 by the factors listed in Table 5.1 to account for industrial restructuring of the Eastern European countries, for improvements in pollution abatement technology and for the introduction of unleaded petrol.

Table 5.1. Estimated scaling factors to estimate emissions for 1998 from the European emission inventory by Berdowski *et al.* (1997).

Metal	Western Europe	Eastern Europe
Cd	0.50	0.60
Pb	0.35	0.60
Cu	0.60	0.70
Zn	0.75	0.80

The two methods were compared for Cd and Pb, indicating that the deposition of non-U.K. sources predicted by EMEP exceeds that predicted with the TERN model by 30 % for Pb and by a factor of 3 for Cd (Nemitz *et al.*, 2001b). The NAEI inventory was also contrasted with deposition maps based on an alternative emission estimate by CEH (Nemitz *et al*., 1999).

5.4 Deposition budgets for the U.K. and England/Wales

The total deposition for the U.K. derived with the different methods is summarised in Table 5.2. Since the frisbee network data was confined to England and Wales the equivalent comparison is also shown for this area for reasons of comparability. Table 5.3 compares the average of U.K. measurements of bulk deposition with the predicted deposition averaged over these sites. For Pb the agreement between the different methods is best, with the measurements implying somewhat larger deposition than predicted by the ATMs based on current emission inventories. Using the Scandinavian calibration for both surveys, a significant decrease was found between the two moss surveys, which is consistent with the gradual introduction of lead substitutes in petrol during this period, and with the decrease in moss concentrations which has been found between 1996/7 and 2000 (cf. Section 3). The application of the calibration that was derived from the U.K. data for the 2000 survey implies an increase in the deposition, which is in contradiction to the decrease in the air concentrations and emissions over this period. As mentioned before, this calibration was biased towards measurements for 1998, while little of the bulk deposition data for 1999 and 2000 is currently available. Whether the large reduction between the surveys of >50% reflects the change in the emissions estimates and deposition data remains to be seen when these data become available over the next two years.

For 1996/7, the predicted Pb deposition at the measurement sites was about 50 % larger than measured deposition (Table 5.3). About half of this discrepancy may be explained by the increased capture efficiency of natural vegetation for dry and cloud deposition, compared with bulk collectors. The deposition derived from the frisbee network data was about three times higher than that derived from the moss survey.

For Cd, the moss surveys agree quantitatively well with the deposition predicted by the AMS and the emission inventories. However, a 6 times larger value was derived from the frisbee network. As discussed in more detail below, the frisbee collector network may over-estimate the deposition. However, for Cd, with a mass median diameter of less than 1 µm, it is less likely that the frisbee collectors were greatly influenced by locally re-suspended large particles, the main positive artefact expected for this collector type.

For Cu and Zn, unexpectedly high deposition values were measured in the frisbee network, with the estimated deposition to England and Wales alone exceeding UK emissions by a factor of 20 for Cu and a factor of 5 for Zn. Compared with the average of all available bulk deposition data, the frisbee values appear to be only a factor of two too large. Therefore, the bulk deposition measurements, including the NETCEN measurement sites, also imply that the UK deposition of Cu and Zn exceeds the estimated emission by a factor of 3 to 10. If, in analogy with sulphate, 30 % of the UK emissions are assumed to be deposited to the UK, the emissions would have to be underestimated by a factor of 10 to 30.

Naturally, the deposition estimates derived from the moss data are much closer to the average selectively calculated over those bulk deposition measurements that agree with the Scandinavian measurements (Fig. 4.1). The deposition estimates derived with the ATM are, however, smaller by a factor of 4 to 6 (for Cu) and 2 to 3 (for Zn) than even these selected measurements, indicating that the current emission inventories significantly underestimate the true emissions.

Table 5.2. Summary of the total emission and deposition for the UK as well as England and Wales only derived by the three methods [t yr^{-1}]. Also included are the EMEP model results for 1998 (Ilyin *et al.*, 2000).

	United Kingdom				England & Wales			
	Cd	Pb	Cu	Zn	Cd	Pb	Cu	Zn
Emissions								
NAEI								
1995	15.7	1648	83.6	1207				
1998	13.0	1033	58.8	1047				
CEH								
1997	18.8	1087	88.9	796				
Deposition								
Moss surveys								
1996/97	13.0	587	340	1382	9.3	427	229	1023
2000	9.8	245	254	1131	7.7	208	173	860
2000 (alternative calibration)		659				518		
Frisbee network								
Total deposition	-	-	-	-	55.7	1473	1320	5552
Soluble fraction only	-	-	-	-	33.5	1052		
EMEP model 1998	7.9	478	-	-				
CEH model FRAME-HM								
Using CEH emissions 1997	11.0	567	59.3	435	9.1	446	53.5	389
Using NAEI 1998	7.5	292	15.2	499	6.2	229	12.6	437

Table 5.3. Comparison of measured deposition values (g ha^{-1} yr^{-1}) with the averages over the predicted estimates for these sites.

	Cd	Pb	Cu	Zn
Measurements				
1996/97	0.91	16.3	33.8	131
1998/99	0.36	19.7	52.4	169
*Selected measurements**				
1998/99	0.38	17.1	9.4	50.3
Predictions				
Moss 1996/97	0.56	25.1	14.3	41.0
Moss 2000	0.46	11.7	9.4	45.0
Moss 2000 (UK calibration)		29.3		
Frisbee network (total)	2.2	53.0	91.3	304
Frisbee network (soluble)	1.9	46.1		
FRAME-HM (CEH 1997)	0.48	27.4	2.8	20.3
FRAME-HM (NAEI 1998)	0.29	12.1	0.76	22.2

*** Measurements include those at Auchencorth Moss, Cockley Beck and Great Dun Fell (cf Table 4.1).**

5.5 Comparison of the deposition fields

The spatial pattern of the deposition derived from the moss surveys 1996/97 and 2000, the frisbee network and the FRAME-HM model are presented in Figs. 5.5.1 to 5.5.4. When interpreting the two moss surveys, it is important to note that the sampling density was significantly lower in 1996/7, especially towards the south and east of the country, which means that individual site anomalies have a stronger influence on the deposition field. It is important also to note than no samples were taken in Northern Ireland in 1996/97; this means that these estimates of deposition are obtained only by interpolation from neighbouring countries.

Common to all metals and methods is the predictions of large deposition in south Wales, most probably originating from the Pb-Zn smelter at Avonmouth, near Bristol. Of the measurement-derived estimates, the moss survey 2000 best predicts the spatial pattern of the deposition around London, while the other networks have too few sample sites in this region.

For Cd, the spatial pattern between the estimates is very similar, even if the total magnitude differs. The main difference is that the elevated levels of deposition in northern England in the moss survey and ATM maps are not found in the frisbee map. There appears to have been a reduction in Cd deposition between 1996/97 and 2000, particularly in Scotland.

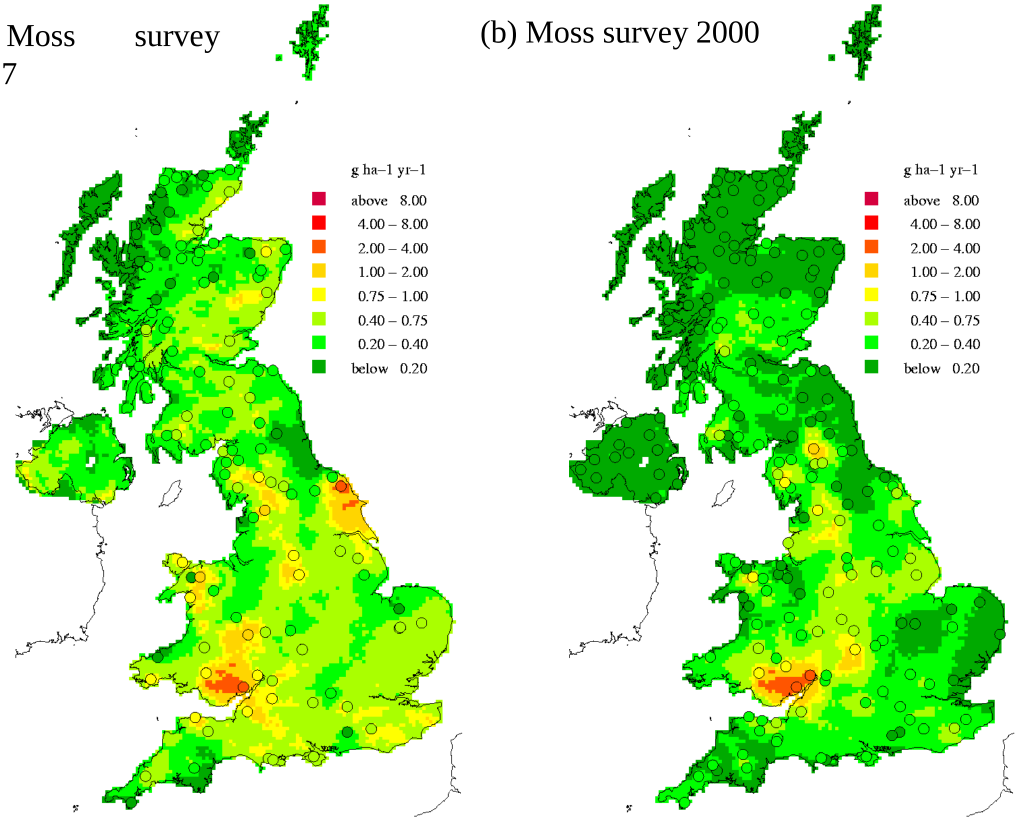
For Pb, as for Cd, there was broad agreement in the spatial patterns revealed by the moss survey and the ATM, although the moss surveys also indicated large deposition in the far south-east of the country, in the North Pennines and in the industrial Midlands. The large deposition in the Scottish Cairngorm mountains derived from the moss survey 1996/97 is an artefact caused by a combination of large cloud deposition and one large sampling point. The deposition levels derived from the frisbee data were much higher, and showed less spatial contrast.

While the ATM predicts elevated levels of Cu deposition only around major cities, the frisbee and moss data suggest a broader distribution of elevated deposition. All measurement derived deposition fields indicate larger deposition in the North Pennines and also in Cumbria, which is not reproduced in the other metals. Areas of large Cu deposition were derived from the moss survey 1996/97 for areas of montane Scotland are likely to be, as for lead, an artefact..

For Zn, as for Cu, there is a strong contrast between the ATM, which predicts elevated deposition only in limited areas close to emission sources, and the broader patterns of elevated deposition across England and Wales indicated by the measurement networks. As for the other metals, the deposition levels based on the frisbee data are substantially higher than those based on the moss survey.

(a) Moss survey 1996/97

(b) Moss survey 2000



(c) Frisbee network

(d) Atmospheric transport

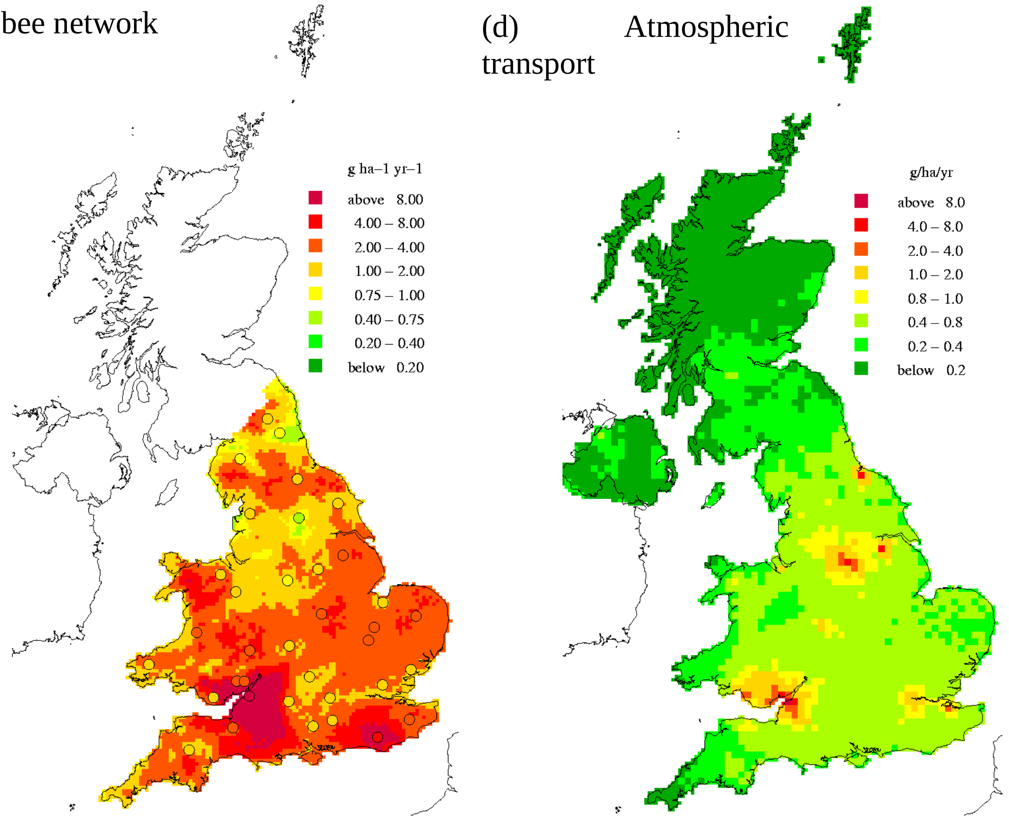
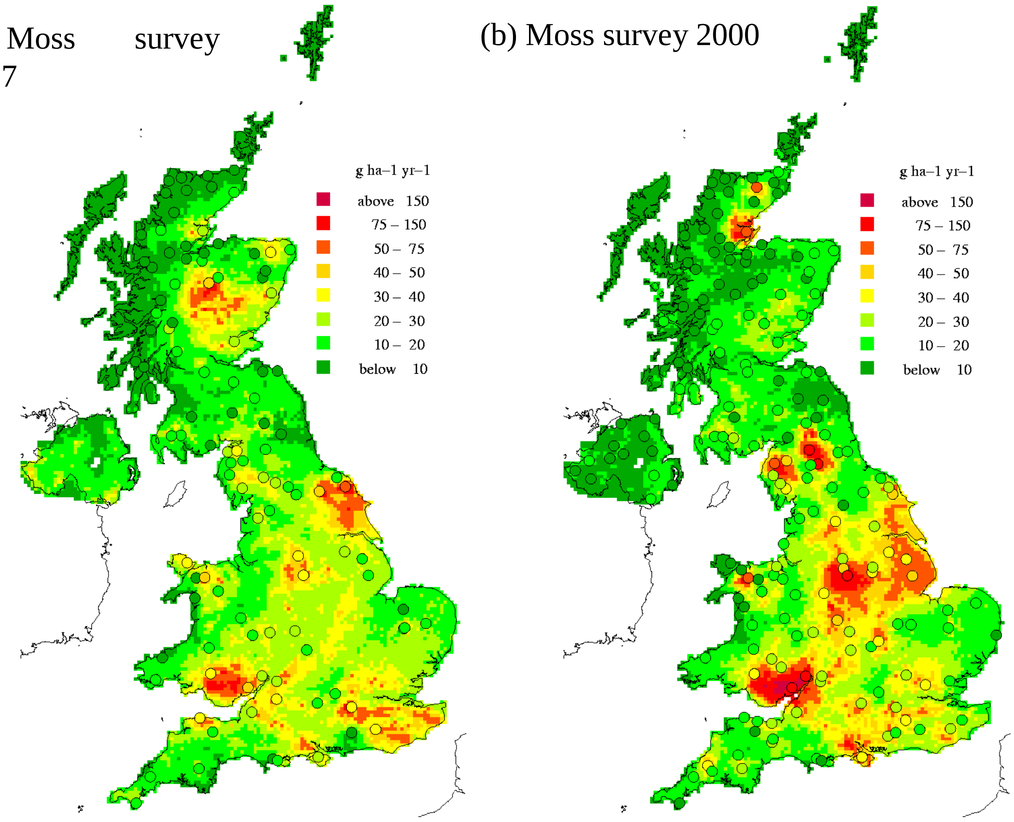


Figure 5.5.1. Deposition fields of cadmium

(a) Moss survey 1996/97

(b) Moss survey 2000



(c) Frisbee network

(d) Atmospheric transport

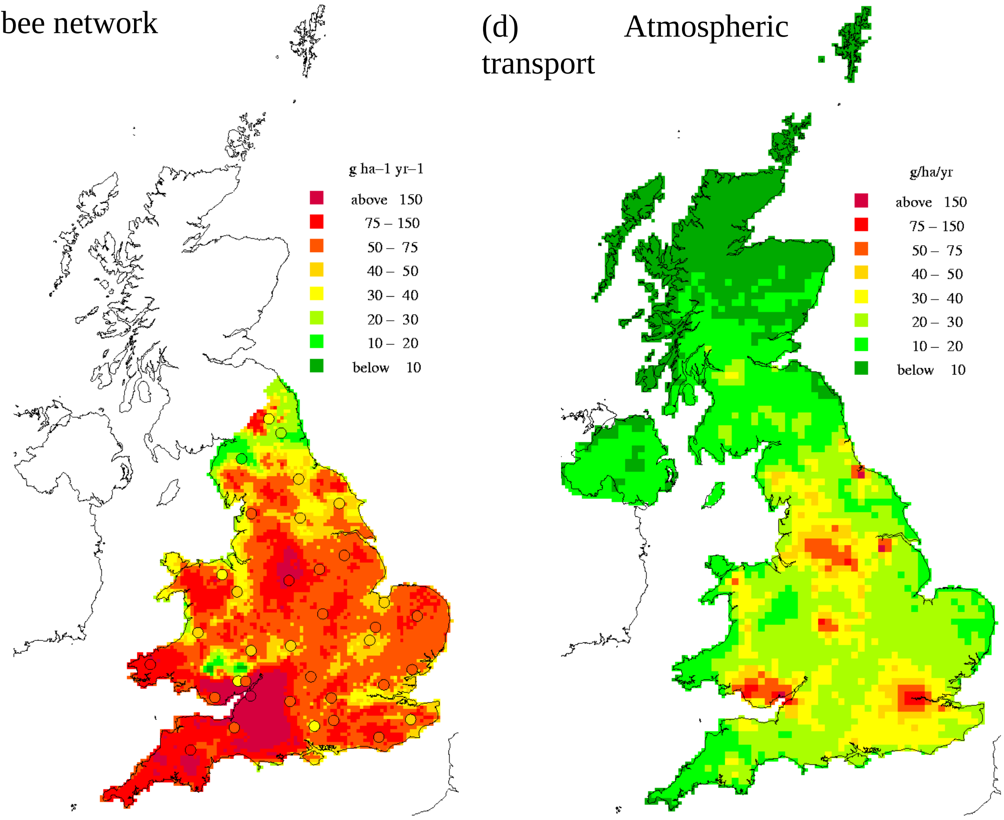
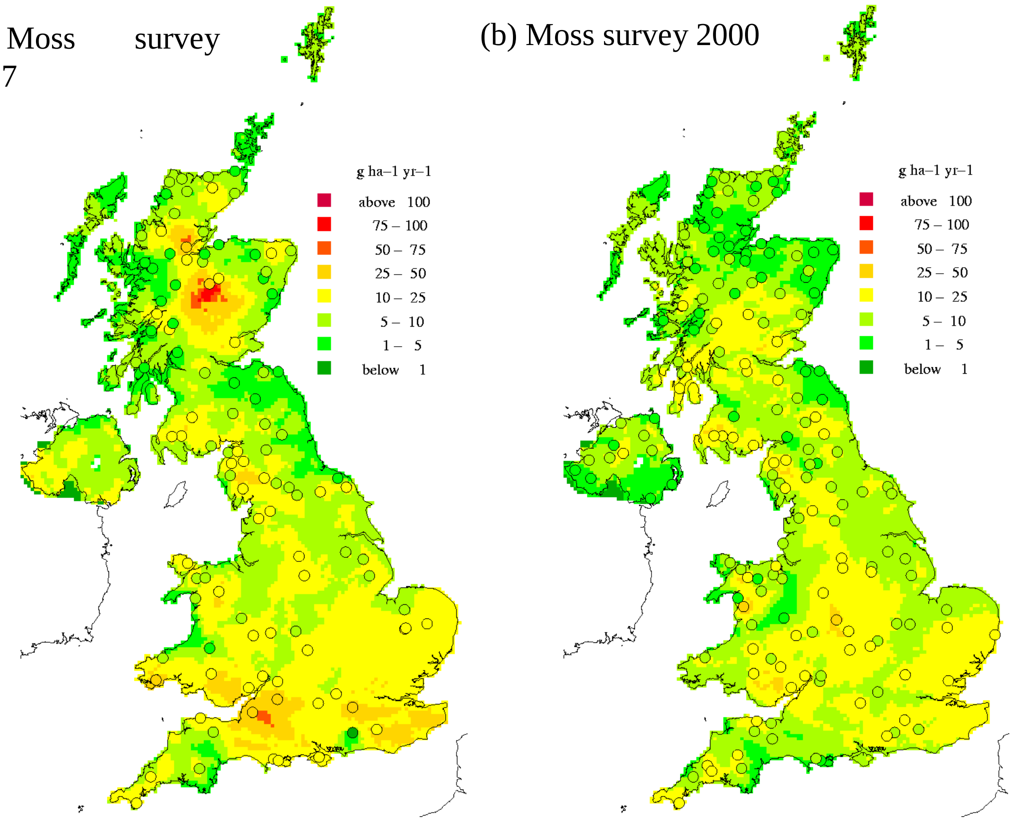


Figure 5.5.2. Deposition fields of lead

(a) Moss survey 1996/97

(b) Moss survey 2000



(c) Frisbee network

(d) Atmospheric transport

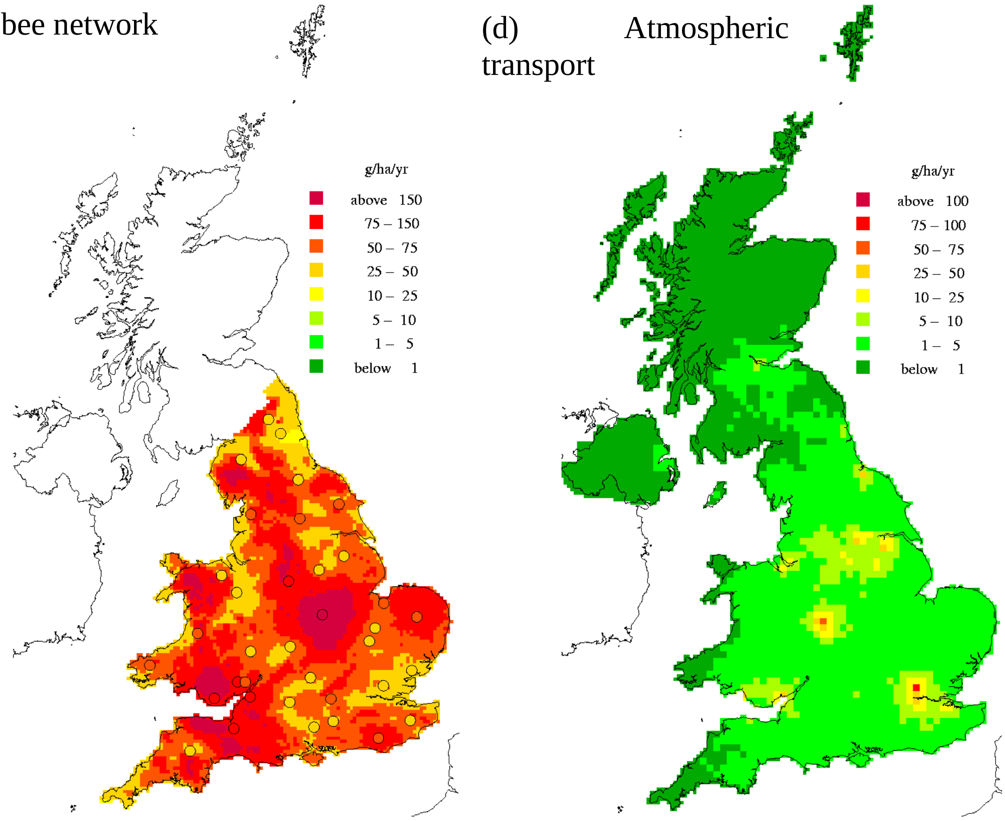
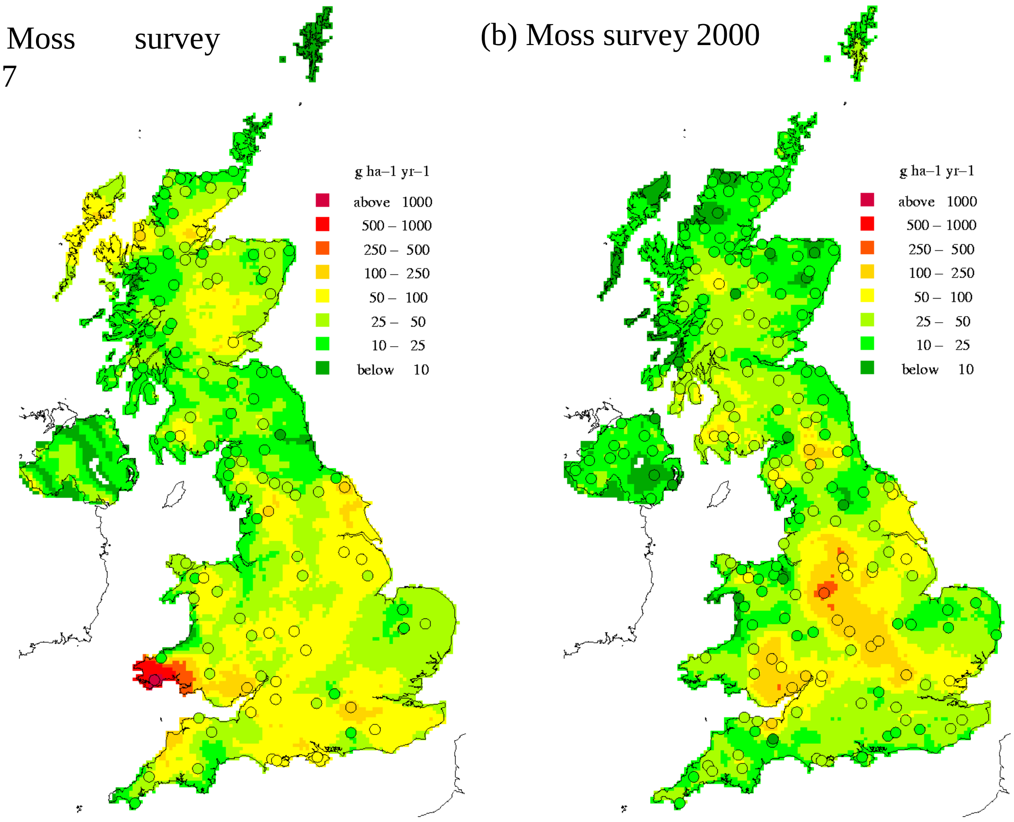
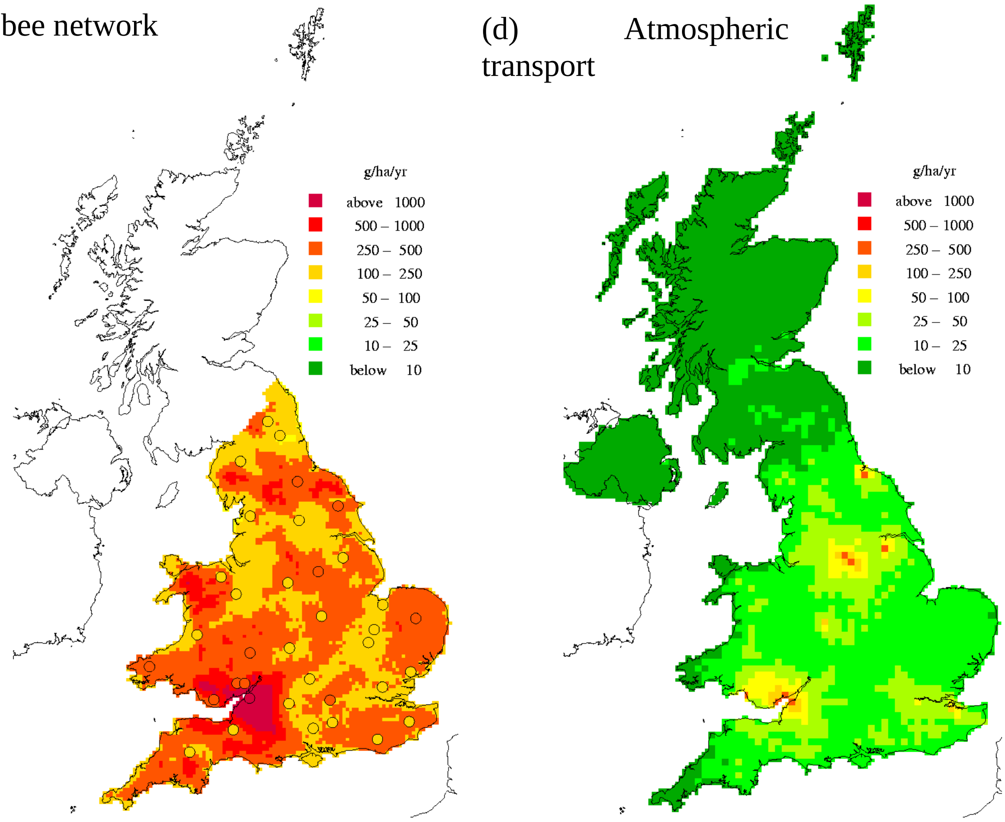


Figure 5.5.3 Deposition fields of copper



(a) Moss survey 1996/97

(b) Moss survey 2000



(c) Frisbee network

(d) Atmospheric transport

Figure 5.5.4 Deposition fields of zinc

5.6 Discussion of uncertainties of the approaches

5.6.1 Interpretation of the moss survey data

The deposition calculated from the moss survey data is very sensitive to the calibration. The number of bulk deposition measurements in the U.K. is currently too limited to derive U.K. specific calibrations. In addition, there is a large inconsistency between the bulk deposition measurements (Fig. 4.1). Instead, Scandinavian calibrations were used to interpret the UK moss survey. Due to the maritime climate and the possibility of metal leaching following high ion inputs (e.g. Berg and Steinnes, 1997), it is possible that this calibration results in underestimates of the deposition. If the higher U.K. bulk deposition measurements are used for the calibration, for example by using the linear relationship for Cu derived from the 1996/97 data and for Zn, derived from the 2000 data (Fig. 4.1), the total deposition is 1574 g Cu ha^{-1} yr^{-1} and 3855 g Zn ha^{-1} yr^{-1}, consistent with the results of the frisbee network.

There are two possible explanations for the discrepancy amongst the bulk deposition measurements: either the analytical procedure used for some measurements sites is insufficient to fully digest the metals, or some sites are affected by local sources (including locally re-suspended material) or contamination during handling and analysis. NETCEN limited their analysis to the soluble fraction in the deposits (Baker 1999), which should be easy to digest at all sites, and still produced some of the largest values. Deposition is therefore more likely to be overestimated at some sites than underestimated at other sites.

For Cu and Zn there is a high intercept of the calibration and a much poorer correlation (e.g. Berg and Steinnes, 1997). This is most likely the reason for the relatively high Cu and Zn deposition derived from the moss survey data in remote areas such as Scotland. The reasons for the high intercept are not entirely clear. This may partly reflect metals originating from soils, but a more likely explanation is that these metals originate from the atmosphere but are recycled internally to meet the nutrient requirements in the actively growing sections of the moss. There is a need for research to determine how these mosses process Cu and Zn.

5.6.2 Frisbee collector network

At a remote Scottish moorland site, 37 % of Cu and 16 % Zn were found to be contained in particles with a diameter larger than 10 μm, and this fraction may be significantly larger in agricultural areas with bare arable land and ploughing activities. Metals may also be derived from windblown fertilisers and animal feed supplements. Since the frisbee collectors were designed to capture dust it is therefore possible that locally re-suspended dust periodically dominated the deposition to the collectors.

Most of the insoluble fraction of the deposited metals (defined as particulates with a diameter of 0.43 μm or more) is more likely to have originated from dry deposition than from wet deposition. Therefore the total deposition to England and Wales was also derived from the soluble fraction in the collectors only (Table 5.2), nearly halving the deposition of Pb. Further analysis of the frisbee data, in relation to metal contents in local soils, proximity to agricultural land and agricultural management, would be required to quantify the contribution of locally re-suspended material to the deposition measurements.

5.6.3 Atmospheric transport and deposition modelling

The ATM modelling approach relies on an accurate estimate of the emissions, which for Cd and Pb are estimated to be accurate within 25 %, while the accuracy for Cu and Zn is more in the region of 50 %. Both the NAEI and the CEH inventory use the emission values supplied by the operators of Part A industrial processes to the Emission Inventory (formerly Inventory of Sources and Releases, ISR) of the Environment Agency of England and Wales, and these two estimates are therefore not fully independent. Bearing in mind the uncertainties in the deposition measurements, the comparison with the modelled deposition values, even with the lowest values measured, nevertheless implies that emissions are underestimated by a factor of 4 to 6 for Cu and 2 to 3 for Zn. In support of this hypothesis first direct flux measurements above the city of Edinburgh indicate emission densities as large as 0.25 kg ha^{-1} yr^{-1} for Cu and 5.3 kg ha^{-1} yr^{-1} for Zn, also an order of magnitude larger than predicted by the NAEI (Nemitz *et al.*, 2001c). The exact quantification of the emissions from deposition measurements, however, relies on the correct parameterisation of the deposition rates in FRAME-HM.

6. Conclusions

6.1 Moss survey

- The U.K. survey of metals in mosses has been completed with the analysis of 250 moss samples from 175 sites across the U.K. with Northern Ireland sampled for the first time. Four species of moss (*Pleurozium schreberi, Hylocomium splendens, Hypnum cupressiforme* and *Rhytidiadelphus squarrosus*) were sampled in order to extend the areal coverage beyond that of the 1995 survey. Samples were analysed for calcium, potassium, magnesium, sodium, arsenic, cadmium, chromium, copper, nickel, lead, selenium, vanadium and zinc.

- Intercalibration between moss species at more than 60 sites where more than one moss was sampled enabled a '*Pleurozium* standardised' measure of element concentrations in mosses across the U.K. to be calculated and mapped.

- The majority of '*Pleurozium* standardised' moss concentrations of arsenic, chromium, nickel and vanadium are at, or below, background values. Large concentrations in the Midlands, northern England, south Wales and the Severn Estuary probably all represent local emission sources.

- '*Pleurozium* standardised' moss concentrations of copper show relatively little structure although concentrations in north and central Scotland are generally much lower than in England and Wales. Clusters of high concentrations probably reflect contemporary emissions or historic mining activities.

- '*Pleurozium* standardised' moss concentrations of lead in Scotland, Northern Ireland and Wales are generally lower than in the more densely populated south and central England presumably reflecting the combustion of leaded petrol.

- Most sites fall within, or very close to, '*Pleurozium* standardised' zinc baseline values, leaving a cluster of sites in central England and south Wales with large anomalies probably reflecting local emission sources.

- '*Pleurozium* standardised' moss concentrations of cadmium are close to background for most of northern Scotland and Northern Ireland, whilst large anomalies are associated with current and historical metal processing industries.

- Comparison of results with matched sites and moss species from the 1995 survey show significant reductions in concentrations of cadmium, copper, lead and zinc in the 2000 survey for both *Pleurozium schreberi* and *Hylocomium splendens*.

- Higher concentrations of sodium were found to be associated with lower concentrations of cadmium, copper, lead and zinc in *Pleurozium schreberi*, but this effect is much less clear in *Hylocomium splendens*.

- The limited comparisons which are possible with U.K. bulk deposition data suggest that Scandinavian calibration relationships are applicable in the U.K.. However, the significant concentrations of Cu and Zn at background deposition mean that the relationships need to be adjusted to avoid the prediction of negative deposition.

- The moss calibration for Pb appears to have changed between the two surveys. This is most likely due to the bulk deposition measurement data being weighted towards 1998 (little of the 2000 data are currently available), when Pb emissions were larger.

6.2 Deposition estimates

- The UK deposition estimates for Pb agree within 50 %.

- For Cu and Zn (and to some extent also for Cd), there are two groups of estimates: the interpretation of the moss survey (using Scandinavian calibrations), the atmospheric transport modelling (ATM) and some of the bulk deposition measurements. These all predict much smaller deposition values compared to those measured with the frisbee collector network and some of the bulk deposition collectors, including those operated by NETCEN. The estimates of the deposition follow the order: model results (consistent with emission estimates) < moss data < low bulk measurements << high bulk measurements < frisbee network.

- For Cd and Pb, the deposition estimates using the moss survey data and the ATM are very similar.

- For Cu and Zn, the lowest deposition estimates were derived from the emission estimates using the atmospheric transport model, indicating that emissions may be underestimated by a factor of 4 to 6 for Cu and by a factor of 2 to 3 for Zn.

- Currently, the deposition estimate derived from the Moss Survey 2000, using the Scandinavian calibration, appears to be the best basis for estimate of national deposition patterns, and should be used for the calculation of critical load exceedances. Although U.K. bulk deposition measurements are not alone adequate to derive U.K.-specific calibrations, the use of selected bulk deposition measurements is consistent with the Scandinavian relationships, lending further support to this approach.

- Although large particles do not contribute to long-range transport, the large deposition collected by the frisbees and some of the bulk deposition collectors raises the question of whether local cycling of earth-crust material should be considered in the calculation of critical loads exceedances for Cu and Zn.

7. Acknowledgements

This work was funded by the U.K. Department of Environment Transport and the Regions (DETR), the Scottish Executive, the National Assembly of Wales and the Department of the Environment in Northern Ireland through the project EPG 1/3/144. The work on deposition was supported by the UK Natural Environment Research Council, and the Environment Agency, within the Environmental Diagnostics Programme under grant GST/03/1709.

We would also like to acknowledge the contribution made by Mike Bambrick and Alistair Headley to the field sampling programme for the moss survey and to Dave Norris (CEH Bangor) for providing the moss survey maps. Site owners are thanked for providing permission to sample and access to sites. Alan Lawlor (CEH Windermere), Colin Neal (CEH Wallingford) and Neil Rose (University College London) are also thanked for the provision of .deposition chemistry data.

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10. Appendices

Appendix 1. Site selection and sampling protocols

Summary criteria for selection of moss sample sites.

Sites to be:
- At least 100m from main roads, villages and industries.
- At least 50m from smaller roads and single houses.
- At least 3m from nearest trees.

Sites must avoid:
- Pronounced canopy drip from trees, shrubs and large herbs.
- Drip from power lines, fences etc., need to be at least 4m away.
- Old quarry sites and mines.

No samples to be taken adjacent to running water.

For the 2000 survey, the majority of samples were collected from clearings, rides and path edges amongst woodlands. However, where this was impossible, then samples were collected from heathland grassy areas near to shrubs or mixed in with Heather (*Calluna vulgaris*) but avoiding canopy drip from shrubs or large herbs.

Protocol for moss sampling

- One composite sample per sampling point collected within an area of about 50 x 50m. The composite sample to consist only of one moss species and to be made up of 5 to 10 sub-samples.
- Approximately 1 litre of sample per site is required (in practice 2 small sealable bags per site)
- No smoking whilst sampling.
- Plastic gloves (pre-washed with de-ionised water) used whilst picking the moss, N.B. do not use vinyl examination gloves if powdered with talcum.
- Samples to be collected in plastic bags which must be sealed/tied securely and then placed within another bag which is also sealed/tied. Sample bags must be clearly labelled with site, moss species and date.
- Where more than one species of moss is present, composite samples of each species should be collected separately to provide data for inter-calibration.
- All of the samples from each day to be placed into a bin liner and tied.
- On return to Bangor or to overnight accommodation, samples should be put in a ‘Jiffy’ bag and posted to the laboratory for chemical analysis.

Appendix 2. Analytical results of metal concentrations (mgkg^{-1}) in moss

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
NS 477 172	Belston Loch	71	HC	160	1331	1947	3127	3.57	3.10	5.67	4.60	49.0	0.325	0.434	0.172	5.67
ST 491 575	Black Down	32	HC	55.6	781	2116	1909	1.57	1.70	1.22	5.24	38.2	0.253	0.365	0.426	11.5
SX 162 772	Bodmin Moor	4a	HC	300	1053	2662	1413	1.59	<1.52	<3.95	4.67	21.6	0.846	0.502	0.124	15.7
SE 492 884	Boltby Forest	107	HC	153	583	1963	1896	0.942	1.98	1.12	2.75	22.6	0.174	0.392	0.113	3.45
TG 175 218	Buxton Heath, nr Hevingham	31	HC	141	987	2614	2117	0.739	1.91	1.08	4.30	20.5	0.259	<0.179	0.0937	2.63
SU 980 649	Chobham Common	29	HC	84.5	1303	2972	3447	1.90	2.14	3.73	7.18	29.5	0.337	0.223	0.159	10.0
SH 503 817	Cors Goch	78	HC	221	1068	2675	4982	0.937	0.561	<0.448	3.38	28.4	0.263	0.288	0.146	1.95
SE 191 691	Dallow Moor		HC	47.1	922	2377	3311	1.46	2.22	1.02	3.79	20.3	0.229	0.415	0.089	5.81
NJ 681 202	E. Bennachie Forest	171	HC	125	881	1733	2015	0.720	1.49	0.817	3.67	16.1	0.0883	0.265	0.0700	1.72
SS 868 287	East Anstey Common	9a	HC	101	663	1525	2071	1.44	1.24	1.01	2.78	21.0	0.252	0.308	0.146	8.04
SE 022 958	East Bolton Moor (Greets Hill)	115a	HC	233	959	1234	2635	1.86	2.18	2.04	5.05	21.9	0.191	0.495	0.116	8.49
TQ 421 989	Epping Forest	21	HC	39.5	886	3792	3110	2.29	3.01	2.56	8.00	33.3	0.630	0.676	0.298	14.3
NY 650 100	Great Asby Scar	121	HC	230	866	1483	1644	0.870	0.219	<0.539	3.06	16.4	0.113	0.290	0.0700	3.16
SJ 190 767	Greenfield Valley, nr Holywell	11	HC	243	871	2894	2816	2.14	2.19	2.90	7.01	22.8	0.590	0.340	0.216	32.8
TQ 969 459	Hothfield Common	15	HC	92.7	1350	2041	2448	1.61	1.84	2.07	5.29	28.7	0.266	0.340	0.189	6.07
NZ 752 095	Lealholm Moor, nr Danby	118	HC	228	933	2499	2792	1.47	1.96	2.27	4.27	23.8	0.301	0.447	0.065	4.32
ST 123 125	Lickham Common	19	HC	184	1153	3110	2759	1.81	1.79	0.941	4.25	23.7	0.438	0.373	0.135	7.06
SW 739 208	Lizard	206	HC	235	1457	1913	2196	0.953	<1.52	<3.95	4.46	18.1	0.109	0.314	0.0833	2.42
SH 767 597	Llyn Bodgynydd	80	HC	191	910	1213	1932	0.920	<0.212	<0.448	3.43	20.2	0.0867	0.363	0.130	6.25
SS 705 498	Lynton	12	HC	180	1649	2911	2551	0.728	1.27	0.942	2.58	27.5	0.193	0.264	0.227	3.24
SE 871 959	May Moss, Lockton High Moor	116	HC	410	925	1423	1771	2.01	2.13	1.50	5.96	31.4	0.285	0.827	0.177	6.96
SJ 152 639	Moel Fammau Country Park	9	HC	58.0	662	1332	2474	0.938	1.59	0.906	3.35	12.9	0.165	0.368	0.0667	4.27
324500 357600	NI Site 2A	2a	HC	357	1367	3730	2408	2.31	1.55	2.43	6.40	17.9	0.230	0.332	0.0633	4.28
SK 194 738	nr Stoney Middleton	11	HC	72.4	590	2132	2630	1.77	1.93	2.48	6.52	47.9	0.321	0.619	0.460	24.1
SZ 472 900	Parkhurst Forest	20a	HC	716	1063	2614	1962	4.58	1.23	<0.448	4.14	17.8	1.01	0.349	0.142	15.2
TQ 797 329	Parsonage Wood, nr Benenden	16	HC	105	1257	3654	4646	2.17	2.24	2.28	5.29	28.5	0.508	0.314	0.336	11.2
NT 887 268	Plantation by Trowupburn	5	HC	229	839	1966	1278	0.730	1.66	1.02	2.92	11.6	0.157	0.244	0.128	2.19
SE 073 446	Rivock Edge, Rombalds Moor		HC	81.3	633	1905	1082	1.56	1.91	1.46	4.01	23.3	0.229	0.487	0.153	12.0
NK 048 520	Rora Moss	201	HC	248	1295	2303	1301	0.321	0.129	<0.0287	0.868	7.36	<0.0341	<0.115	0.0723	2.13
SK 868 984	Scotton Common	103a	HC	139	578	1976	3083	1.48	2.20	1.91	6.01	40.0	0.651	0.629	0.217	9.20
SE 656 372	Skipwith Common	7	HC	70.9	867	2625	2635	2.20	2.71	2.46	5.47	53.5	0.699	0.990	0.183	10.7
SU 460 710	Snelsmore Common	30	HC	132	660	1868	2373	1.24	1.68	1.12	4.79	43.5	0.173	0.253	0.194	6.32
SK 250 630	Stanton Edge	95	HC	53.9	608	2192	2683	1.37	1.85	2.29	6.34	74.7	0.303	0.530	0.620	50.8
ST 118 409	Staple Plain	13	HC	65.0	842	3061	1754	0.886	1.57	1.08	4.60	43.4	0.328	0.230	0.533	10.1
SU 858 217	Stedham Common	21	HC	43.5	1010	1681	2371	4.55	2.71	1.50	3.66	15.0	2.15	0.305	0.0977	3.82
NZ 250 498	Waldridge Fell	135	HC	148	1058	3036	2009	0.918	1.75	1.34	4.20	15.9	0.161	0.237	0.0507	3.19
SJ 284 580	Waun-y-Llyn Country Park	10	HC	165	888	2036	2336	1.10	1.86	1.25	3.93	25.7	0.273	0.268	0.154	12.5

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
SJ 472 343	Wem Moss, nr Northwood		HC	90.7	890	1661	1985	0.700	1.81	0.807	4.10	27.7	0.236	0.290	0.0940	3.22
NJ 758 503	Wood of Delgaty	172	HC	223	965	1825	2019	0.815	0.891	0.225	3.47	13.6	0.102	0.187	0.0400	2.14
ND 152 544	Achlachan Moss	24	HS	188	1272	1220	1395	0.692	1.25	1.22	3.06	16.8	0.116	0.336	0.0467	1.76
NT 221 562	Auchencorth Moss	6	HS	89.6	876	2905	1116	0.842	1.28	1.01	6.30	23.0	0.0633	0.311	0.0957	3.41
SX 616 931	Belstone near Okehampton		HS	333	1114	2246	1685	1.99	<1.52	<3.95	4.35	25.3	1.01	0.617	0.129	4.65
NJ 514 461	Bin Forest	173	HS	155	1079	2398	1819	0.602	1.41	0.764	3.46	15.1	0.0633	0.177	0.0480	0.910
NH 495 577	Blackmuir Wood	176	HS	279	1083	2501	1974	0.436	0.668	0.120	1.90	12.8	0.0450	<0.153	0.0573	0.990
NH 491 382	Boblainy Forest, Invermoriston Moor	167	HS	225	1013	1605	1193	0.494	0.859	0.436	3.18	22.0	0.0533	0.284	0.0453	0.982
SN 828 886	Carreg Wen, Plynlimon		HS	221	1315	2955	1543	1.05	1.64	0.560	3.34	19.0	0.146	0.577	0.204	2.10
NS 558 015	Carsphairn Forest	129a	HS	187	914	2852	2006	0.800	1.67	1.60	5.05	37.3	0.203	0.322	0.400	1.52
NJ 640 104	Corrennie Forest		HS	179	741	1636	1140	0.566	0.912	0.361	1.58	10.0	<0.0171	0.194	0.0512	1.90
SH 971 390	Cors Y Sarnau	81	HS	160	1162	2749	1412	1.19	<0.222	<0.667	4.53	19.7	0.138	0.402	0.102	3.48
NO 005 422	Craigvinean Forest	3	HS	118	966	2699	1871	1.17	1.56	1.17	3.77	17.2	0.215	0.751	0.103	3.79
NH 970 610	Culbin	174	HS	190	1140	2001	1495	0.615	1.06	0.142	2.91	15.2	0.0942	<0.153	0.113	1.06
NH 744 460	Culloden Forest	175	HS	239	1268	2011	1362	0.586	0.966	0.335	2.15	15.7	0.0467	<0.115	0.0288	0.795
SX 675 730	Dart Valley	6	HS	232	1102	2263	1756	1.97	<1.52	<3.95	4.91	23.3	0.254	0.494	0.0940	3.15
NC 182 374	Duartmore Forest	188	HS	232	1332	1640	1657	0.706	1.20	0.632	2.75	10.1	0.0900	0.399	0.0300	0.937
NT 639 690	Dunbar Comon	148a	HS	175	888	3878	951	0.345	1.30	0.265	3.60	22.1	0.0267	0.181	0.153	1.09
NH 113 847	Dundonnell Forest	178	HS	194	1303	1597	1560	0.516	1.21	0.487	2.72	12.5	0.0833	0.436	0.0407	0.876
ND 219 701	Dunnet Forest	183	HS	501	1419	1217	2182	0.864	1.47	0.533	3.34	22.7	0.245	0.342	0.0567	1.99
NJ 681 202	E. Bennachie Forest	171	HS	146	929	1919	1268	0.937	1.45	0.638	3.19	13.2	0.100	0.277	0.0477	1.91
SS 868 287	East Anstey Common	9a	HS	233	1183	3526	1664	0.512	1.11	0.420	4.71	20.4	0.0800	<0.232	0.235	2.19
SE 022 958	East Bolton Moor (Greets Hill)	115a	HS	93.6	869	3431	2620	1.70	2.06	1.47	4.49	29.7	0.441	0.444	0.250	13.3
NY 140 140	Ennerdale Forest	123a	HS	373	1346	2352	1693	2.25	<0.222	<0.667	4.07	18.4	0.604	0.770	0.124	3.97
NT 209 117	Ettrick Water	131	HS	103	1114	2690	1243	0.746	1.49	0.761	3.54	18.7	0.149	0.404	0.111	2.94
NM 960 315	Fearnoch Forest	155	HS	247	1258	2959	859	0.197	1.09	0.178	2.30	18.9	<0.0277	0.290	0.0433	0.384
NO 769 870	Fetteresso Forest	160a	HS	128	966	2257	1134	1.15	1.21	0.313	3.03	25.6	0.0893	0.250	0.115	3.07
NN 088 782	Fort William (Copach Hill)	165	HS	214	1149	2269	1700	2.90	1.46	2.08	3.48	11.2	0.119	0.342	0.0467	1.13
NH 343 703	Glascarnoch Dam	23	HS	278	1404	1805	1967	0.653	0.797	<0.0287	2.36	12.1	<0.0341	0.136	0.0100	0.801
NN 232 333	Glen Orchy	156	HS	181	1274	2125	1847	1.03	1.62	3.49	4.99	31.6	0.102	0.701	0.136	2.76
SW 950 605	Goss Moor	2	HS	281	1070	3436	2750	1.17	<1.52	<3.95	3.41	18.7	0.221	0.281	0.117	2.14
NY 915 750	Gunnerton Crag	137	HS	175	1379	4794	5978	2.76	1.96	1.94	6.36	14.6	0.320	0.422	0.0573	25.9
NG 980 238	Inverinate Forest	166	HS	145	1353	1771	1925	0.799	1.50	0.979	2.70	27.4	0.0700	0.545	0.0937	1.51
TF 225 627	Kirkby Moor	92	HS	35.5	499	1855	3922	2.67	2.15	1.51	4.75	36.8	1.03	0.374	0.256	11.6
NC 417 600	Laid	185	HS	403	1442	1606	1700	0.669	1.27	0.673	3.63	12.5	0.0867	0.503	0.0467	1.54
NC 854 255	Loch Ascaig	57	HS	220	1271	2002	2019	0.428	1.08	0.357	3.49	11.4	0.0333	<0.123	0.0200	1.29
NJ 092 472	Loch Dallas	61	HS	185	1134	2555	1900	0.454	0.674	0.266	1.92	10.5	0.0567	<0.153	0.0383	0.757
NC 230 546	Loch Inchard	187	HS	457	1389	1664	1286	0.631	1.24	0.258	3.12	9.18	0.0400	0.354	0.0143	0.962

Grid Ref	**Location**	**No.**	**Species**	**Na**	**Mg**	**K**	**Ca**	**V**	**Cr**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Cd**	**Pb**
NN 775 548	Loch Kinardochy	64	HS	246	1553	3505	1859	0.310	1.22	0.514	6.33	34.3	0.0400	0.315	0.115	1.30
NS 341 985	Loch Lomond	145a	HS	185	1301	3349	1419	0.566	1.40	0.824	5.28	32.8	0.0667	0.401	0.248	2.14
NC 491 404	Loch Meadie	186	HS	353	1401	1187	1850	0.669	1.39	0.738	4.48	10.9	0.0667	0.513	0.0200	1.08
NR 743 437	Loch na Naich	69	HS	267	1475	3405	1758	0.810	1.26	0.675	5.63	30.3	0.0393	0.487	0.0983	1.60
NH 327 014	Loch Oich	164	HS	286	1419	2224	1818	0.796	1.07	0.743	3.65	76.9	0.109	0.355	0.0700	1.43
NO 252 859	Lochnagar	67	HS	107	1045	2768	1875	0.894	1.17	0.525	3.92	16.9	0.0600	0.386	0.0700	2.87
NH 728 352	Meall Mor	168	HS	175	1266	2600	1515	0.503	0.988	0.125	2.45	17.3	0.0517	0.119	0.0383	0.858
SJ 152 639	Moel Fammau Country Park	9	HS	124	998	3526	2536	1.08	2.09	0.959	3.98	26.7	0.343	0.308	0.0867	5.36
NO 574 546	Montreathmont Forest	4	HS	109	1291	3044	3549	2.30	3.40	2.13	3.93	23.3	0.588	0.429	0.121	3.57
NH 740 803	Morangie Forest	180	HS	245	1310	2783	2425	0.324	0.381	<0.0287	1.96	10.6	<0.0341	<0.115	0.0133	16.6
SN 847 526	Nant Irfon	55a	HS	244	889	2682	1061	0.756	1.33	0.715	5.10	19.5	0.101	0.334	0.102	2.80
TF 755 113	Narborough railway line	89a	HS	94.5	766	3198	4649	1.04	2.15	0.734	3.36	14.8	0.334	0.349	0.0800	2.90
353300 345500	NI Site 1	1	HS	282	1140	2041	2176	0.644	1.10	0.608	1.83	8.03	0.0333	0.138	0.0267	1.39
261000 396700	NI Site 14	14	HS	302	1033	1485	1189	2.31	1.23	1.05	3.65	21.6	0.159	0.438	0.0933	3.12
322800 321900	NI Site 15	15	HS	235	854	1416	1213	1.70	1.31	0.989	3.75	17.0	0.110	0.344	0.0800	2.71
318900 393800	NI Site 16A	16a	HS	252	916	2806	960	1.11	1.08	1.12	3.80	16.0	0.102	<0.153	0.0477	1.71
206500 354500	NI Site 17	17	HS	252	1193	1474	2194	0.828	0.868	0.367	1.93	8.89	0.0267	0.273	0.0367	1.39
318700 442200	NI Site 4	4	HS	283	970	1549	1152	1.38	1.38	0.637	2.66	13.8	0.0597	0.294	0.0483	2.03
269000 430700	NI Site 5	5	HS	382	1247	1809	1124	2.38	1.42	1.91	2.74	10.2	0.0200	0.156	0.0340	1.35
256500 577500	NI Site 7	7	HS	366	1188	1669	1885	1.49	1.75	1.30	5.28	22.0	0.152	0.450	0.0833	1.82
230900 344200	NI Site 8	8	HS	439	1039	2545	1357	1.06	1.53	0.788	3.65	39.8	0.262	0.398	0.0373	1.32
225900 371300	NI Site 9	9	HS	225	1118	1821	2500	0.857	0.806	0.485	2.74	9.86	0.0467	0.251	0.0500	1.72
NC 306 079	nr Cnoc Chaornaidh	179	HS	152	1327	1520	1570	0.618	1.25	0.541	2.26	11.4	0.0767	0.367	0.0300	0.961
NR 857 757	nr Erines (Dunardry Forest)	204a	HS	298	1540	3979	1651	0.439	1.20	0.717	5.40	31.9	0.0477	0.503	0.0943	0.776
NC 815 745	Nr Kerrydale	189	HS	314	1523	1535	1911	0.644	1.25	1.46	4.88	12.9	0.0967	0.462	0.0300	1.17
NN 042 567	nr South Ballachulish	192	HS	294	1460	3388	1223	0.141	0.964	0.142	2.14	12.9	<0.0277	0.266	0.0300	0.340
NG 864 339	nr Stromeferry	190	HS	172	1253	1509	1398	0.825	1.21	0.725	3.46	18.7	0.0940	0.413	0.0600	1.51
SN 857 153	Ogof Ffynnon Ddu	50	HS	200	832	2061	2465	3.01	1.75	3.83	4.67	43.6	0.518	0.653	0.504	7.24
SP 302 508	Oxhouse Farm		HS	103	1119	2825	6665	2.47	2.61	2.40	7.42	31.5	0.553	0.359	0.500	5.92
SN 126 395	Pengelli Forest	193	HS	250	1034	3077	1543	0.794	1.26	0.655	4.34	16.7	0.155	0.196	0.0647	1.47
NO 209 139	Pitmedden Forest	151	HS	149	1388	5110	2430	1.45	2.02	1.42	6.97	25.4	0.235	0.499	0.156	3.58
NN 296 417	Rannoch Moor, Loch Tulla	157a	HS	231	1398	3576	1777	0.157	1.06	0.189	2.96	17.6	<0.0277	0.252	0.0367	0.388
NK 048 520	Rora Moss	201	HS	294	1068	2175	1097	0.878	1.03	0.0578	2.50	17.4	0.0650	0.193	0.0885	1.92
ND 208 380	Rumster Forest	182	HS	201	1121	1560	1432	0.760	1.26	0.685	3.12	14.9	0.130	0.224	0.0333	1.64
NM 500 456	Salen Forest, Mull		HS	273	1361	1616	1312	1.10	<0.212	<0.448	3.10	10.1	0.106	0.570	0.0422	1.98
NY 160 320	Setmurthy Common	124	HS	254	1082	2198	2487	1.17	<0.222	<0.667	3.24	17.9	0.244	0.361	0.0783	2.32
NH 254 493	Strathconon Forest	177	HS	254	1404	1809	1671	0.745	0.912	0.421	2.91	19.0	0.0786	0.490	0.0333	1.33
NC 830 615	Strathy Forest	184	HS	359	1579	1656	1862	0.859	1.38	0.609	4.73	10.5	0.112	0.384	0.0300	1.14

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
NM 973 678	Strontian	9	HS	315	1750	3569	1285	0.457	1.29	0.445	5.89	28.1	0.0393	0.503	0.0700	1.05
NR 727 838	Taynish NNR	203a	HS	261	1234	3409	1718	0.600	1.18	0.388	4.84	28.1	0.0600	0.249	0.0567	1.47
NH 973 102	The Queen's Forest		HS	175	773	1793	1749	0.542	1.08	0.594	3.03	17.6	0.0367	0.193	0.0485	1.80
SU 7200 8784	Warburg Reserve	36	HS	142	614	4050	3214	0.562	1.54	0.453	3.81	20.3	0.338	0.233	0.125	2.15
NY 681 520	Williamston	133	HS	113	916	2007	2460	0.884	0.605	<0.448	3.83	195	0.249	0.315	1.10	32.8
NC 893 473	Woodcock Hill	181	HS	242	1262	1839	1515	0.375	1.22	0.415	2.69	12.7	0.0633	0.315	0.0433	13.6
SH 665 718	Aber Falls	79	PS	240	1068	3530	1447	0.805	<0.222	<0.667	4.26	19.1	0.101	0.233	0.0618	2.00
TQ 125 455	Abinger Common (Leith Hill)	28a	PS	126	913	4691	2840	2.79	2.34	1.48	6.37	36.2	0.588	0.236	0.188	7.39
SD 297 108	Ainsdale sand dunes NNR	37	PS	218	1363	2955	2512	1.01	2.06	0.706	3.45	27.7	0.311	0.359	0.303	3.94
NT 221 562	Auchencorth Moss	6	PS	128	736	2249	720	0.749	1.52	0.507	4.96	29.2	0.0467	0.229	0.116	2.17
SX 616 931	Belstone near Okehampton		PS	413	1391	3276	2033	1.98	<1.52	<3.95	4.85	30.0	1.34	0.499	0.172	4.61
SX 162 772	Bodmin Moor	4a	PS	373	1111	3456	1630	1.84	<1.52	<3.95	5.41	33.6	0.395	0.515	0.116	9.25
TL 765 843	Brandon Park	66	PS	262	1057	5641	2584	0.900	1.83	0.880	6.10	23.5	0.320	0.419	0.121	2.97
NS 558 015	Carsphairn Forest	129a	PS	124	1123	2756	1016	0.960	1.19	0.471	2.86	29.4	0.0467	0.402	0.0700	2.02
SK 632 756	Clumber Park (new)		PS	116	779	3487	2008	1.59	2.47	1.41	3.62	30.5	0.270	0.542	0.149	5.75
NY 247 015	Cockley Beck		PS	129	1348	4442	2107	2.11	2.10	0.778	4.16	39.0	0.531	0.631	0.386	7.18
SH 619 289	Coed Crafnant	76	PS	232	1387	2519	1680	1.17	0.220	<0.448	3.24	12.3	0.114	0.364	0.0830	1.79
SY 864 848	Coombe Heath	17	PS	176	1149	2556	2477	1.11	0.509	<0.448	3.05	26.8	0.100	0.241	0.110	2.01
NJ 640 104	Corrennie Forest		PS	192	1179	2855	1246	0.456	0.484	0.186	1.78	9.44	<0.0171	<0.115	0.0525	1.63
NO 005 422	Craigvinean Forest	3	PS	79.8	989	2520	1951	1.40	1.74	1.47	4.51	24.3	0.182	0.348	0.132	4.57
NX 388 720	Cree-Wood (Grey Mare's Tail)	127	PS	108	1133	3231	1819	1.18	1.49	1.57	5.10	28.7	0.197	0.375	0.0767	2.66
NX 854 582	Dalbeaty Forest (Townwood)	125	PS	146	1064	3044	1623	0.834	1.47	0.640	4.99	36.0	0.0863	0.332	0.134	2.36
SE 191 691	Dallow Moor		PS	163	726	2852	1855	0.671	1.77	0.593	4.47	12.5	0.152	0.288	0.0750	2.05
SX 675 730	Dart Valley	6	PS	224	1250	3073	2078	1.86	<1.52	<3.95	4.08	30.9	0.188	0.458	0.164	4.99
NT 845 699	Dowlaw Dean	149	PS	155	1144	3599	1782	0.846	1.44	0.628	2.96	18.7	0.0700	0.218	0.0600	1.92
NT 639 690	Dunbar Comon	148a	PS	132	866	3088	948	0.964	1.39	0.577	3.04	20.4	0.152	0.334	0.123	2.34
SS 868 287	East Anstey Common	9a	PS	174	923	2716	1538	0.606	1.09	0.391	3.41	17.5	0.0533	<0.232	0.125	1.93
SE 022 958	East Bolton Moor (Greets Hill)	115a	PS	158	1585	3013	2402	1.10	1.79	1.50	4.64	19.5	0.190	0.320	0.112	3.92
NY 140 140	Ennerdale Forest	123a	PS	414	1318	2333	3133	2.31	<0.222	<0.667	4.73	46.5	0.837	0.879	0.273	6.15
NO 769 870	Fetteresso Forest	160a	PS	158	890	2703	955	0.802	1.02	0.145	2.24	18.6	0.0840	0.223	0.0667	2.29
SD 535 490	Forest of Bowland, nr Oakenclough	109	PS	157	869	2829	1644	1.20	0.433	<0.448	4.42	14.7	0.165	0.304	0.0692	3.77
SO 627 121	Forest of Dean	46	PS	181	997	3839	2174	1.87	1.70	1.57	7.66	71.4	0.488	0.469	1.15	24.9
SD 740 600	Gisburn Forest	113a	PS	165	1010	4007	2872	0.990	<0.222	<0.667	5.73	27.7	0.122	0.333	0.372	3.62
NY 650 100	Great Asby Scar	121	PS	188	1113	2580	2148	1.09	0.291	<0.448	4.42	25.0	0.155	0.348	0.128	4.29
SD 331 938	Grizedale Forest	112	PS	168	1126	2639	1659	2.32	0.828	0.721	5.81	22.5	0.454	0.651	0.156	7.98
NY 915 750	Gunnerton Crag	137	PS	132	1305	4159	5875	3.71	2.17	2.20	5.25	21.2	0.371	0.346	0.115	3.60
SS 895 447	Horner Wood NNR	12	PS	174	1226	4026	2093	0.784	1.54	1.10	5.11	26.3	0.180	0.182	0.167	3.46
NH 833 022	Inshriach Forest	163	PS	180	1044	2435	1726	0.342	0.916	0.443	3.77	25.2	0.0900	<0.123	0.0422	1.00

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
NT 785 006	Kielder (Redesdale Forest)	132	PS	262	1274	5209	2908	0.654	1.50	0.952	6.97	27.9	0.0937	<0.182	0.104	2.02
NY 634 926	Kielder Forest	132	PS	134	1151	3513	2561	0.803	1.67	0.840	4.50	33.4	0.196	0.226	0.0967	2.60
NS 728 808	Kilsyth	70a	PS	98.2	977	3134	1025	1.36	1.44	0.772	7.26	21.6	0.0500	0.586	0.116	3.23
NC 417 600	Laid	185	PS	271	2038	2188	2396	0.425	1.31	0.447	2.86	7.64	0.0800	0.267	0.0250	0.881
TF 133 877	Linwood Warren	93	PS	60.5	663	3051	1170	1.59	1.74	0.928	3.57	44.0	0.285	0.420	0.208	8.44
SW 739 208	Lizard	206	PS	311	1682	2637	2017	0.733	<1.52	<3.95	5.88	23.3	0.113	0.159	0.125	2.04
SH 917 574	Llyn Aled	27	PS	214	1198	3510	1328	0.980	<0.212	<0.448	2.94	17.7	0.0898	0.298	0.133	2.01
SH 767 597	Llyn Bodgynydd	80	PS	189	1248	1534	2637	2.65	0.800	<0.448	6.20	39.0	0.221	0.917	0.415	15.7
SH 705 160	Llyn Gwernan	29	PS	150	1242	3088	1866	1.36	0.389	<0.448	9.70	17.2	0.162	0.384	0.0767	1.99
NC 854 255	Loch Ascaig	57	PS	184	1432	2234	1666	0.382	1.22	0.464	3.53	22.7	0.0600	0.282	0.0727	1.60
NJ 092 472	Loch Dallas	61	PS	180	1287	3431	2140	0.667	0.832	0.120	1.79	12.1	0.0592	<0.153	0.0773	0.924
NX 546 700	Loch Grannoch	74	PS	92.1	1193	2717	1819	2.06	1.56	1.20	5.69	39.8	0.167	0.493	0.150	5.29
NN 775 548	Loch Kinardochy	64	PS	157	1440	3063	1438	0.630	1.24	0.399	5.00	27.5	0.0433	0.350	0.169	2.45
NS 341 985	Loch Lomond	145a	PS	97.1	1203	3614	1198	0.701	1.30	0.504	4.34	29.4	0.0733	0.414	0.112	1.57
NR 743 437	Loch na Naich	69	PS	189	1235	2913	1638	1.14	1.43	0.676	5.56	35.3	0.0733	0.451	0.120	2.56
NN 575 863	Lochan na Doire Uaine	66	PS	130	1226	2471	1735	0.458	1.19	0.776	3.04	13.8	0.0550	0.184	0.0317	1.04
NO 252 859	Lochnagar	67	PS	99.1	967	2202	1719	1.09	1.38	0.621	3.73	16.4	0.0733	0.502	0.0900	3.70
SE 871 959	May Moss, Lockton High Moor	116	PS	487	1082	1991	2139	1.53	2.02	0.992	4.46	25.4	0.251	0.691	0.171	5.47
NX 263 720	Meadow Hill (nr Blood Moss)	128	PS	117	1117	2270	1323	0.990	1.29	0.666	7.47	52.3	0.0733	0.541	0.220	3.83
SJ 152 639	Moel Fammau Country Park	9	PS	125	1000	4233	2326	0.775	1.63	1.04	4.19	19.8	0.168	0.331	0.0960	3.64
NO 574 546	Montreathmont Forest	4	PS	107	972	2491	1738	1.00	1.88	0.806	4.42	19.9	0.195	0.526	0.141	3.45
SO 495 724	Mortimer Forest	72	PS	259	951	4456	1577	0.576	1.08	0.877	5.33	23.5	0.110	0.158	0.127	2.37
SO 263 253	Mynydd Ddu Forest	29	PS	134	1091	4396	1805	0.717	1.24	1.11	6.06	58.2	0.159	0.278	0.417	4.85
SN 847 526	Nant Irfon	55a	PS	142	1109	2811	1037	0.780	1.32	0.745	5.21	26.8	0.0800	0.359	0.219	2.51
305000 415100	NI Site 10	10	PS	228	1254	1775	1398	1.48	1.54	1.11	4.05	14.9	0.0420	0.285	0.0563	1.56
261000 396700	NI Site 14	14	PS	277	1119	2307	935	1.91	1.28	0.756	2.90	18.2	0.0433	0.428	0.0800	2.26
322800 321900	NI Site 15	15	PS	249	1195	2308	1356	1.32	1.31	0.752	2.85	20.2	0.0800	0.335	0.112	2.41
318700 442200	NI Site 4	4	PS	318	1032	2353	1859	1.08	1.56	0.685	2.62	13.8	0.0433	0.180	0.0870	1.53
269000 430700	NI Site 5	5	PS	398	1300	2604	1359	1.85	1.57	2.08	3.89	18.6	0.0640	0.257	0.0467	1.36
276200 385800	NI Site 6	6	PS	312	1265	2685	1909	1.56	1.88	2.10	6.11	20.9	0.0733	0.224	0.0933	1.60
230900 344200	NI Site 8	8	PS	405	1122	3593	1154	0.383	0.647	0.158	1.44	20.4	<0.0171	<0.123	0.0390	0.688
225900 371300	NI Site 9	9	PS	286	1327	1510	2244	2.06	1.94	1.40	4.57	16.6	0.197	0.681	0.0597	2.75
NC 306 079	nr Cnoc Chaornaidh	179	PS	194	1716	2084	1534	0.448	1.19	0.693	3.02	9.70	0.0600	0.307	0.0417	0.920
SE 930 856	nr Wykeham Forest	18	PS	89.4	724	2962	2523	2.21	2.44	1.20	4.74	49.2	0.400	0.680	0.261	10.1
SN 857 153	Ogof Ffynnon Ddu	50	PS	130	761	2510	2052	3.05	1.86	3.96	4.86	38.8	0.507	0.697	0.442	8.93
SN 126 395	Pengelli Forest	193	PS	275	1430	4752	2023	0.895	1.32	0.830	4.52	25.1	0.113	0.203	0.144	2.46
NT 887 268	Plantation by Trowupburn	5	PS	199	1037	3884	1347	0.533	1.50	0.609	3.03	17.6	0.110	0.328	0.0975	1.76
NN 296 417	Rannoch Moor, Loch Tulla	157a	PS	143	1378	1996	1798	0.907	1.59	0.896	5.59	32.3	0.102	0.667	0.123	2.89

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
SE 073 446	Rivock Edge, Rombalds Moor		PS	137	1154	5215	6530	3.37	3.68	1.55	4.41	29.1	3.30	0.390	0.268	7.84
SK 871 984	Scotton Common	103a	PS	76.4	665	3417	1875	1.53	1.73	0.92	3.77	33.3	0.237	0.510	0.117	8.56
NY 160 320	Setmurthy Common		PS	103	1233	3159	7680	5.72	2.80	1.55	7.40	26.2	4.49	0.686	0.190	18.1
SK 623 682	Sherwood Forest Country Park	14	PS	54.8	812	3242	2314	1.40	1.76	1.25	5.04	62.8	0.218	0.455	0.233	8.73
NY 358 708	Silverhill Wood	2	PS	158	1143	2487	1608	0.659	1.83	0.555	3.08	14.2	0.161	0.270	0.0500	1.41
NY 702 295	Sink Beck		PS	84.2	1072	3859	1805	0.653	1.88	0.712	4.09	75.5	0.307	0.232	0.204	3.21
SU 460 710	Snelsmore Common	30	PS	74.5	783	3331	1724	1.52	1.72	1.09	5.05	26.5	0.336	0.289	0.197	6.16
SO 312 988	Stapeley Hill	73	PS	100	728	3019	1354	0.894	1.43	0.810	2.53	19.6	0.117	<0.123	0.147	3.72
SU 858 217	Stedham Common	21	PS	195	925	1703	1719	8.25	3.63	8.04	5.19	18.9	4.29	0.412	0.116	4.77
SP 100 960	Sutton Park	71	PS	63.1	709	3715	2251	1.49	1.51	2.00	10.0	73.1	0.289	0.216	0.287	11.4
SY 793 878	Tadnoll Barrow, nr Moreton	15	PS	134	1104	2130	2225	1.17	0.438	<0.448	3.45	24.1	0.111	0.250	0.123	2.58
NR 727 838	Taynish NNR	203a	PS	367	1598	3400	1786	1.17	1.30	0.136	4.70	10.4	0.0933	0.315	0.0370	1.49
NY 810 311	Teesdale NNR	120	PS	114	893	2864	1338	1.45	<0.222	<0.667	3.24	31.7	0.251	0.478	0.218	19.7
NY 236 283	The Dodd	122	PS	295	1328	3222	1823	1.25	<0.222	<0.667	7.26	25.5	2.57	0.346	0.152	11.2
SP 278 789	Tile Hill Wood	70	PS	251	1054	3946	2579	1.18	1.65	1.28	8.37	80.9	0.233	0.161	0.228	6.46
TM 481 737	Walberswick	35	PS	152	1408	5483	1898	0.761	1.21	0.807	4.96	20.1	0.281	0.295	0.0700	1.97
SJ 284 580	Waun-y-Llyn Country Park	10	PS	69.7	987	3444	2382	0.707	1.59	0.613	3.32	11.2	0.195	0.218	0.098	4.35
ST 421 944	Wentwood Forest	48a	PS	167	825	2871	2360	2.82	2.63	1.83	8.56	122	0.503	0.652	1.20	34.5
NJ 758 503	Wood of Delgaty	172	PS	228	1134	2854	1396	0.537	0.742	<0.101	2.13	10.1	0.0583	0.166	0.0583	2.50
SO 738 779	Wyre Forest	57a	PS	90.1	665	2349	1849	1.12	1.25	0.915	4.12	18.4	0.171	0.124	0.204	4.83
SH 503 817	Cors Goch	78	PS	356	1760	4067	3515	0.689	0.235	<0.448	3.31	25.5	0.201	0.218	0.130	1.50
SK 178 885	Abbey Brook	102	RS	299	938	4229	2210	1.48	1.99	1.84	5.99	74.8	0.230	0.538	0.360	10.7
NT 221 562	Auchencorth Moss	6	RS	108	926	3204	1096	0.701	1.45	0.447	3.91	24.5	0.0280	0.196	0.132	2.41
NT 512 291	Blackpool Moss	140	RS	339	1335	6230	1567	0.381	1.40	0.515	4.47	27.4	0.0453	<0.109	0.0767	0.806
SE 492 884	Boltby Forest	107	RS	155	955	3446	2122	0.826	1.92	0.799	4.80	21.9	0.145	0.390	0.114	3.24
SO 118 376	Brechfa Pool	36	RS	213	1035	4851	2431	1.53	1.99	1.87	5.09	53.6	0.514	0.269	0.251	7.43
SN 828 886	Carreg Wen, Plynlimon		RS	139	1336	3294	1598	1.15	1.72	0.559	3.90	17.9	0.170	0.445	0.375	2.50
NY 247 015	Cockley Beck		RS	328	1314	4008	2015	1.41	1.68	0.777	5.74	33.9	0.335	0.385	0.172	6.30
SE 191 691	Dallow Moor		RS	71.5	1151	3751	1749	4.35	4.80	2.95	6.20	23.7	0.958	0.519	0.116	23.8
TL 782 046	Danbury Common	20	RS	198	1416	7791	2550	1.26	2.10	0.870	7.02	35.7	0.302	0.301	0.101	4.68
NT 845 699	Dowlaw Dean	149	RS	266	1162	4238	1650	0.531	1.38	0.565	5.00	22.5	0.0667	0.182	0.0700	1.82
SJ 902 366	Downs Bank	12	RS	112	966	4348	4721	2.14	2.14	2.78	8.72	112	1.10	0.344	0.571	13.1
NT 639 690	Dunbar Comon	148a	RS	180	1208	4110	1198	0.524	1.37	0.517	3.88	25.1	0.0400	0.229	0.0970	1.17
SS 868 287	East Anstey Common	9a	RS	157	593	2670	2287	3.19	1.63	1.49	6.15	31.5	0.829	0.530	0.313	24.6
SU 975 269	Ebernoe Common	22a	RS	80.1	1151	3675	1520	1.88	2.09	1.08	4.75	24.0	0.272	0.323	0.148	5.02
SP 607 565	Everdon Stubbs		RS	189	1408	6710	2654	3.13	2.49	1.88	8.36	63.5	1.40	0.248	0.206	5.27
NO 769 870	Fetteresso Forest	160a	RS	134	973	2723	1189	0.905	1.04	0.183	2.68	21.2	0.0950	0.269	0.128	2.79
TF 005 903	Glapthorn Cow Pasture		RS	264	904	6485	2904	1.47	2.14	1.48	4.69	24.3	0.327	0.213	0.0700	2.47

Grid Ref	Location	No.	Species	Na	Mg	K	Ca	V	Cr	Ni	Cu	Zn	As	Se	Cd	Pb
NS 757 693	Glenmavis	146a	RS	116	1147	3638	1809	1.13	1.95	1.40	6.16	29.4	0.144	0.276	0.180	3.15
SX 225 688	Golitha Falls	200	RS	350	1242	3369	1709	1.61	<1.52	<3.95	7.37	25.0	0.675	0.441	0.0903	4.28
SJ 190 767	Greenfield Valley, nr Holywell	11	RS	507	1148	6264	1941	0.574	1.72	0.816	5.78	20.7	0.245	<0.202	0.141	9.60
NY 915 750	Gunnerton Crag	137	RS	463	1471	5301	6700	4.99	2.24	2.33	6.59	18.3	0.329	0.412	0.0850	11.6
SP 717 643	Harlestone Heath	34	RS	74.1	798	3306	2124	6.19	4.34	2.17	5.42	60.7	2.44	0.410	0.187	13.3
TF 203 893	Holme Fen	38	RS	228	1032	4914	2488	0.503	0.873	0.184	4.21	21.7	0.135	<0.115	0.0600	2.58
NT 785 006	Kielder (Redesdale Forest)	132	RS	359	1452	7210	2081	0.675	1.62	0.940	8.50	27.4	0.140	0.387	0.136	1.56
SJ 152 639	Moel Fammau Country Park	9	RS	151	1268	4267	3024	0.850	1.80	1.18	4.86	35.5	0.216	0.253	0.112	5.92
NO 574 546	Montreathmont Forest	4	RS	160	1321	3992	3559	2.20	3.43	2.17	4.07	22.0	0.582	0.384	0.138	2.94
SO 263 253	Mynydd Ddu Forest	29	RS	230	984	5500	1585	0.581	1.33	1.10	5.55	41.5	0.113	0.182	0.240	2.77
NZ 112 484	nr Castleside (Rabbitbank Wood)	134	RS	276	1222	5492	2372	0.735	1.69	0.837	5.18	41.0	0.265	0.287	0.185	3.85
SK 194 750	nr Stoney Middleton	11	RS	168	581	2652	2098	1.10	1.63	1.58	6.06	41.6	0.238	0.383	0.278	19.1
SO 868 120	Painswick Beacon	45	RS	96.0	955	5550	7120	2.85	3.01	1.26	5.23	42.7	1.88	0.306	0.385	9.65
NT 887 268	Plantation by Trowupburn	5	RS	237	1173	4342	2335	0.641	1.72	0.954	3.90	20.6	0.135	0.303	0.110	1.97
SO 850 038	Rodborough Common	34a	RS	176	1135	4854	5451	3.35	3.53	1.35	5.18	31.9	3.06	0.349	0.341	7.74
TL 132 135	Rothhamsted	29	RS	187	789	3298	3913	4.76	3.88	3.21	6.21	51.2	1.02	0.319	0.247	8.19
NY 358 708	Silverhill Wood	2	RS	216	978	2942	1572	0.601	1.84	0.790	4.03	18.2	0.148	0.206	0.0760	1.73
NY 702 295	Sink Beck		RS	77.0	1436	6206	2118	0.764	1.61	0.686	4.40	27.1	0.215	0.249	0.297	4.24
ST 118 409	Staple Plain	13	RS	150	973	4331	2319	0.813	1.57	0.804	4.52	48.2	0.213	0.287	0.404	7.39
SP 278 789	Tile Hill Wood	70	RS	228	942	4651	2303	1.32	1.46	1.04	7.71	48.2	0.437	0.296	0.177	8.62
TQ 334 316	Wakehurst Place, nr Balcombe	23	RS	186	1245	4616	3816	1.64	2.04	1.33	5.18	22.7	0.448	0.293	0.218	5.13
SJ 284 580	Waun-y-Llyn Country Park	10	RS	217	1149	4043	2188	0.742	1.81	0.801	3.46	23.5	0.156	0.221	0.140	6.11
ST 136 173	Wellington Memorial		RS	119	603	3368	3467	0.891	1.31	0.629	4.38	19.4	0.225	<0.232	0.177	3.78